Methodology for the integrated management of technical and managerial risks related to the product design process

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Abstract: Product development (PD) projects which, if not managed adequately, can have a negative impact on the business. Typical risks related to the product development process (PDP) are: inappropriate definition of the design problem, changes in customer needs, delays in the delivery of results and costs being higher than envisioned. Some of these risks are related to product design, others to project management. In this context, this article presents a methodology for the integrated management of technical and managerial risks, with the focus on the identification, analysis and treatment of the product design risks. Risk identification makes it possible to establish and to characterize the technical and managerial risks. The integrated analysis of these risks allows the project team to identify and analyze the influence of the technical risks on the managerial risks of scope, time, costs and quality. Finally, the risk treatment aims to aid the project team in the definition of specific actions to deal with the risks identified and analyzed. In this way, it is possible to better understand the context in which the project is inserted in terms of risks and manage them in a pro-active way.

Keywords: risk management, technical and managerial risks, product design process.

1. Introduction

Product development projects are rarely executed as planned (ULRICH; EPPINGER, 1995; VARGAS, 2002). This is partly due to the existence of risks that can adversely affect the progress of the project, if they are not appropriately managed. Typical risks associated with the product design process are: inappropriate definition of the design problem, changes in customer needs, lack of knowledge for the execution of the activities, delays in the delivery of results, costs being higher than envisioned, among others. Some of these risks are related to product design, others to project management (PM). The risks related to product design arise from the uncertainties associated with the inputs, methods, project team and outputs of these process activities. In this article such risks are called technical risks.

The risks related to project management arise from the uncertainties associates with the scope, time, costs, communication and quality among other project management elements. These risks here are called managerial risks.

Since the number of identified risks related to the product design process can be high, it is necessary to analyze them in order to highlight those that present the most relevant characteristics. Moreover, the influence of one risk on others can be significant in the product design process because of the interdependence between the activities.

Thus, risk analysis must deal with the influence of one risk on the others in order to investigate, for instance, the effect of the technical risks on the managerial ones. In this way, it is possible to identify the technical and managerial risks which most influence the project. These risks must then be treated through actions, in order to reduce their probability of occurrence and their impact until levels acceptable for the project are achieved.

In this context, this article presents a methodology for the integrated management of technical and managerial risks, with the focus on the identification, analysis and treatment of these risks, in relation to the product design process.

The present methodology seeks to better understand the project context in terms of risks in order to refine the project plan, considering the integrated management of technical and managerial risks associated with the product design process.

2. Methodology for the integrated management of technical and managerial risks related to the product design process

The integrated planning of technical and managerial risks is carried out in the project planning phase, as represented in Figure 1, being constituted of the phases of identification, integrated analysis and treatment of the technical and

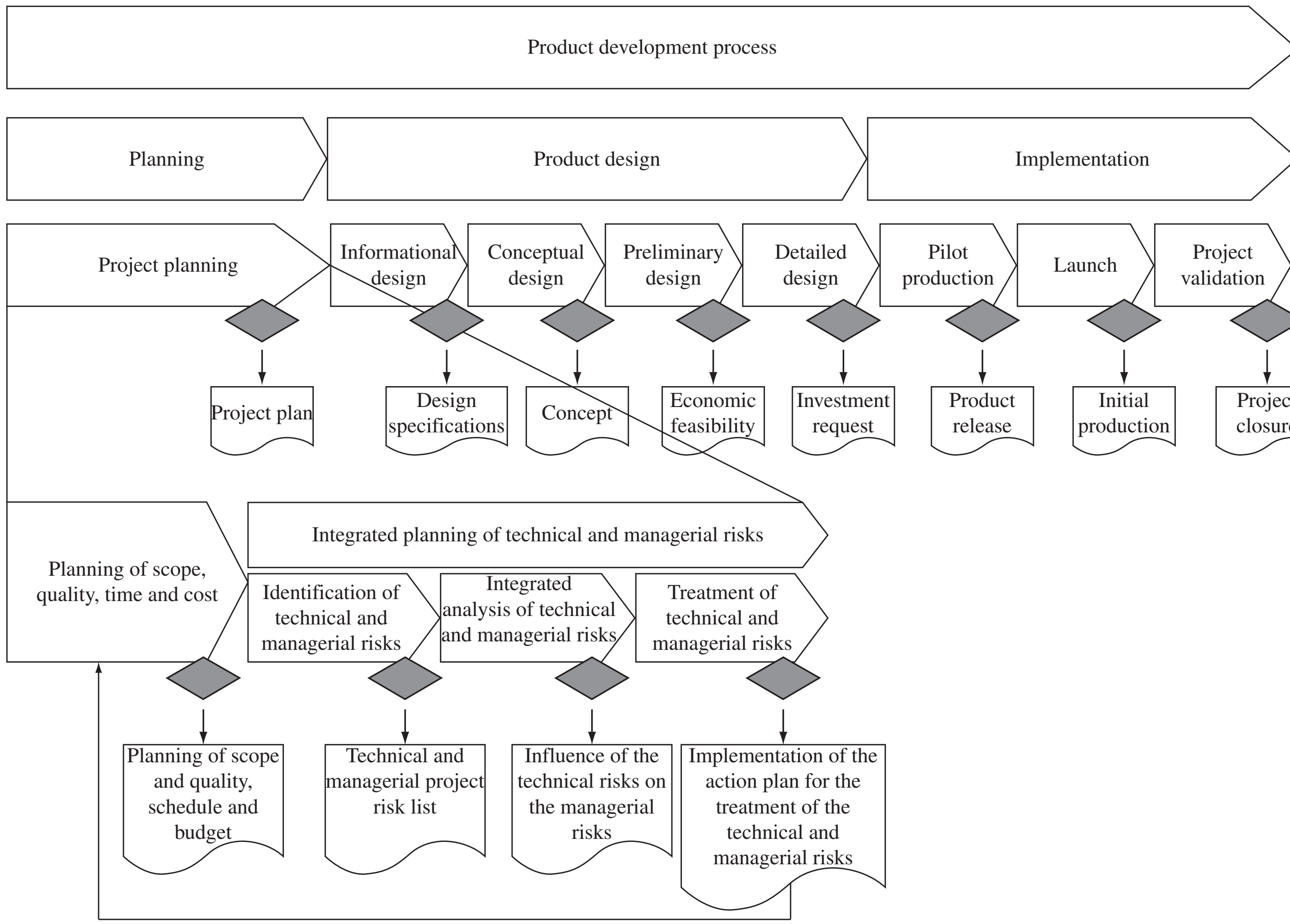


Figure 1. Scope of the methodology for the integrated management of technical and managerial risks related to the product design process (GRUBISIC, 2009).

managerial risks. Each phase of the methodology comprises activities, methods and tools, which are detailed below.

2.1. Phase 1 – Identification and characterization of technical and managerial risks

In general terms, risk is an undesirable event with four main basic characteristics: a definition, probability of occurrence, cause and impact, as defined in Table 1. As will be seen, other elements are proposed to characterize a risk such as the estimated date of its occurrence, root cause, domains involved, impact severity, risk relative weight, and others. In this article, these elements are dealt with as complementary risk elements.

The risk definition allows the project team to understand the risk event and the project context in terms of its associated risks. The determination of the probability of occurrence and impact allows the project team to define the risk severity and, thus, identify the project priority risks. Finally, the identification of the causes aids the definition of actions to be taken during the risk treatment phase, since they reveal the risk origin.

Table 1. Basic elements of risk definition.

Elements	Definition
Risk definition	Describes an undesirable event related to the product design process and project planning.
Probability of occurrence	Indicates the probability of the risk occurring in the project.
Cause	Describes the origin of the risk.
Impact	Refers to the negative effect generated by the risk on the project objectives and the product design activities.

Considering the risk definition described in Table 1, the present methodology phase consists of the identification of the technical and managerial risks, from the categories defined in Tables 2 and 3, respectively. Moreover, in this phase each risk identified is characterized by basic and complementary elements.

Table 2. Technical risk categories related to the product design process.

Technical risk categories	Definition
Input risks	Risks arising from the input information to be transformed by the product design activities.
Domain risks	Risks relating to the project team (e.g. technical specialists) and the product clients/customers in terms of knowledge domains required in the product design activities.
Mechanism risks	Risks derived from the methods, tools and other resources to be used in the execution of the activity.
Output risks	Risks arising from the output information or physical objects to be transformed by the product design activities (deliveries).

Table 3. Risk management categories.

Risk management categories	Definition
Scope risks	Risks related to the product and project scope.
Time risks	Risks associated with the product design process and the project schedule.
Cost risks	Risks related to the project costs.
Quality risks	Risks associated with the desired quality of the result.

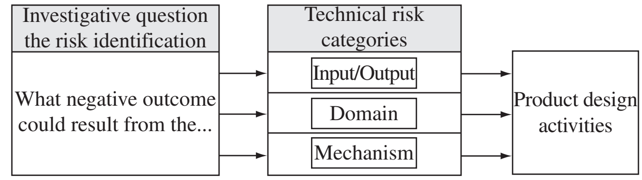


Figure 2. Formularization of investigative questions for the technical risk identification.

Table 4. Examples of investigative questions and technical risks.

Investigative questions for the technical risk identification	Technical risks
What negative outcome could result from the activity "Identifying the client/customer needs", in terms of information availability?	Non consideration of important project customers.
What negative outcome could result from the activity "Establishing the product functional structure"?	Non consideration of basic functions in the product functional structure.
What negative outcome could result from the activity "Developing the product initial layout"?	Inappropriate CAD tools.
What negative outcome could result from the activity "Submitting the prototype to approval"?	Lack of norms for the prototype test.

The activities proposed for the identification and characterization phase of technical and managerial risks will now be presented.

2.1.1. Activity 1.1. – Identifying technical and managerial risks

The objective of this activity is to identify the technical and managerial risks which may arise in the product design process and in the project management, based on the risk categories defined in Tables 2 and 3, respectively.

To aid in the technical risk identification, a set of investigative questions is proposed, as presented in Figure 2. These questions seek to stimulate the project team to think about the possible product design risks, considering the inputs, domains, mechanisms and outputs of this process, that is, the risk categories defined in Table 2. Table 4 gives examples of investigative questions and technical risks.

Besides these questions, a technical risk base (GRUBISIC, 2009) with the typical technical risks associated with the main product design activities is proposed. These risks were obtained by the application of the investigative questions proposed in the main product design activities. The risk base must be employed as a complement to the risks identified by the investigative questions. The project team must use the risk base as a checklist to verify, for each product design activity, the relevance of each potential risk.

For the identification of the scope, time, cost and quality managerial risks a structure for the investigative questions similar to that of the questions suggested for the technical risks is also proposed. Once again, the objective of these questions is to stimulate the project team to think about the possible risks, in this case, the managerial risks. Beyond these questions, a risk base (GRUBISIC, 2009) with typical managerial risks that could arise during the project is proposed.

The risks highlighted from the investigative questions and from the risk bases will form the technical and managerial project risk list.

2.1.2. Activity 1.2. – Characterizing the technical and managerial risks

In this activity, the technical and managerial risks identified are detailed and registered in order to promote the project team's understanding of these risks. For this, the following elements must be specified for each risk: definition, cause, impact, responsibility, estimated date of occurrence, domains involved and the risk code. The risk characteristics will be the input for the risk analysis and treatment phases. To register this information, both Technical and Managerial Risk Identity Forms are proposed. These forms will complement the project documentation.

2.1.3. Activity 1.3. – Revising and emitting the project risk list

This activity consists of revising the risks identified and their characteristics. This revision seeks to verify the consistency of the information registered for each risk and the existence of similar risks that can be synthesized into only one. The technical risks are then listed according to the following categories: input, domain, mechanism and output, associated with the informational design phase. The same procedure is applied to the risks related to the other phases: conceptual, preliminary and detailed design. The order for the managerial risk list is scope, time, cost and quality risks. With this information, the following phase consists of the integrated analysis of the identified risks.

2.2. Phase 2 – Integrated technical and managerial risk analysis

The objective of this phase is to analyze in an integrated way the technical and managerial risks, that is, to define the interaction between them, the output being the accumulated effect of the technical risks on the managerial risks of scope, time, cost and quality.

Thus, the integrated technical and managerial risk analysis allows us to know how the risks related to the product design activities can affect the probability of occurrence of the managerial risks of scope, time, cost and quality. Furthermore, through the integrated risk analysis it is possible to identify the technical and managerial risks which have the greatest influence on the project.

In this phase, firstly the technical and managerial risks are prioritized. Secondly, the relationships between the prioritized risks are defined and represented. Thirdly, the joint probability of the risk is defined and, finally, the joint analysis of the priority risks is also defined.

2.2.1. Activity 2.1. – Prioritizing the technical and managerial risks

The number of identified risks in product development projects can be high, given the innumerable uncertainties. Therefore, since risks have different characteristics, it is necessary to identify the project priority risks. To this aim, the calculation of the risk importance weighting, based on the risk elements presented in Table 5, is proposed.

The first characteristic (Figure 3) which must be defined is the probability of occurrence for each technical and managerial risk identified. This value must be attributed by the people associated with the risk domains, mainly by the person responsible for the risk defined on its Identity Form. A debate on the analyzed risk, consulting of previous projects, analysis of context and the project plan are recommended, in order to weight the opinions and establish the percentage probability of occurrence of the risk (0 to 100).

For the second characteristic, the project team must allocate one value to the severity of each impact of the identified risks, according to the following scale: 0.1/0.3/0.5/0.7/0.9. In qualitative terms, the values correspond, respectively, to the following: very low, low, medium, high and very high (PMI, 2000).

Considering that generally risks involve more than one impact, the average severity (arithmetic mean) of the impact of each risk needs to be calculated (characteristic 2),

Table 5. Scale for the average severity of the impacts (PMI, 2000).

Interval	Severity of the total impact
[0.1;0.3)	Very low
[0.3;0.5)	Low
[0.5;0.7)	Medium
[0.7;0.9)	High
≥0.9	Very high

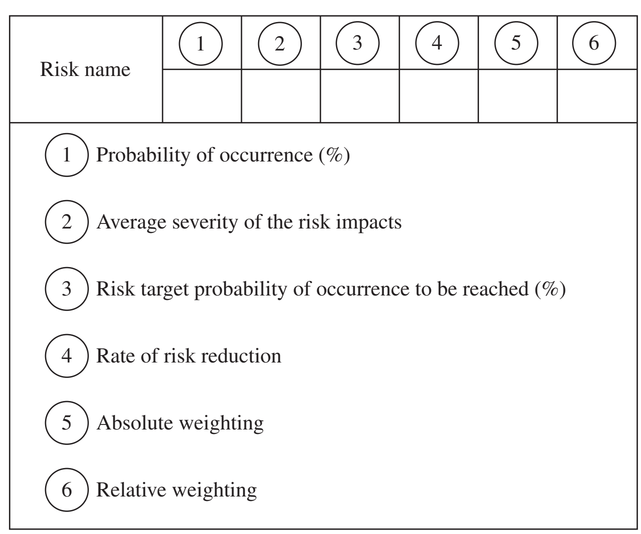


Figure 3. Elements for the calculation of the risk importance weighting.

Figure 3. These average values must then be classified according to the scale proposed by PMI (2000), Table 5.

Next, the risk target probability of occurrence to be reached must be defined (characteristic 3). This characteristic involves defining the risk tolerance, that is, the maximum value that the project team can accept for the risk probability of occurrence.

For example, let's imagine that the probability of occurrence of the risk "Project delay of 30 days" was defined as 90%. However, the maximum acceptable delay for the project is one week. In this case, the risk probability of occurrence defined initially must be reduced to a much lower value, for example, 10%. To reach this probability, the level of effort in terms of action for the risk treatment will be considerable.

Ideally, all risks should have probabilities of occurrence close to zero, in which case the project would be executed in an environment predominated by certainties. Some risks can be reduced to zero through actions that eliminate them but, unfortunately, not all risks can be managed by this type of action.

In this regard, the project team must define the target probability of occurrence to be reached within the interval of 0 to 100. Values close to zero mean that the project team desires that the risk is eliminated, in these cases the project manager must not economize efforts to eliminate such risks. Values approaching 1 mean that the risk matters little to the project, it is a negligible risk, in the project team's opinion.

Based on the definition of risk probability of occurrence and the target probability of occurrence to be reached, it is possible to calculate the rate of risk reduction (characteristic 4) which is the division of the former by the latter.

The rate of risk reduction indicates the degree to which its probability of occurrence has to be reduced in order to reach an acceptable level, that is, it indicates how much the project team members have to work to reduce the risk.

Finally, based on the four risk characteristics defined previously, the absolute weighting (characteristic 5) and the relative weighting (characteristic 6) for each risk are calculated. The risk absolute weighting is obtained by the multiplication of the average severity of its impact by its rate of reduction. For the calculation of each risk relative weighting (pi), it is necessary to divide the risk absolute weighting by the sum of all technical and managerial risk absolute weightings.

It should be observed that the attribution of values for the probabilities and impact severity, depends strongly on the knowledge and experience of project team members and the debates among them. If the evaluations are unreliable, this can compromise the quality of the other risk analysis activities. Thus, all possible effort must be dedicated to the evaluation of the technical and managerial risks, in order to obtain results coherent with the project reality.

After the calculation of each risk relative weighting, the values are ranked to show the order of importance. For the cases that present the same relative weighting value, the risks need to be classified according to their date of occurrence, defined on their Identity Forms. At the end, a list of the technical and managerial risks by priority order is obtained.

Considering the risk priority order, the number of technical and managerial risks which will be considered the most important for the project is defined, that is, those risks that need to receive more attention during the project execution.

This information is extremely useful, mainly, in projects that present a high number of risks and little time to manage them. Moreover, the risk treatment phase will be directed to the definition of actions to deal with these risks.

In order to aid the project team in the definition of the project priority risk number, Table 6 presents some aspects to be considered.

During the planning phase, the project team compiles the first list of priority risks. Throughout the project execution, the characteristics of these risks must be revised and updated. Therefore, it is worth emphasizing that the number of risks to be prioritized can change in each risk revision.

2.2.2. Activity 2.2. – Defining the relationships between the priority risks

This activity consists of identifying the relationships between the priority risks, establishing relations of cause

Table 6. Aspects to be considered in the definition of the project priority risk number.

Aspects	Definition
Project Priority	In the case of priority projects, the team must select the greatest number of risks to be prioritized. In this way, the project exposure to risks is reduced and its objectives tend to be reached more easily.
Time availability for RM	The project team must evaluate the time available to manage the risks. The greater the time available to manage them, the higher the number of the risks which can be considered as priority.
Risk relative weighting	Risks with high relative weighting and whose values are very far from others must be considered as priority.
Type of project to be developed	Creative and innovative projects, generally, are associated with a great number of risks. In order to conclude the project successfully, in these cases, a greater number of priority risks must be defined.

and effect. This involves identifying the interaction between the priority risks and the intensity of each interaction. Later, this information will be considered in the joint analysis of the technical and managerial risks.

For this activity, the use of the matrix of co-relation between risks, illustrated in Figure 4 is proposed. This matrix is composed of two fields. Field I serves to register the project priority risks defined in the previous activity. Field II is dedicated to the identification and evaluation of the relationships between the risks.

In Field I of the co-relation matrix (Figure 4), the project manager must first list the names of the priority technical risks (Rn), and their respective codes and priority numbers. The same procedure must then be performed for the priority managerial risks (Rn'). Since in this case, the influence of the technical risks on the managerial ones will be identified, in Field I the technical risks must be listed first followed by the managerial risks.

Next, the identification of the relationships between the priority risks in Field II of the co-relation matrix, as indicated by the acronym grRiRn, is initiated.

For this, Table 7 gives some guidelines in order to aid the project team in the identification of cases where one risk can negatively affect another.

This analysis is applied from the first to the last risk listed in Field I of the co-relation matrix. Thus, at the end the influence of each technical risk on each managerial risk is obtained.

After the relationships between risks are identified, their intensity must be defined according to an appropriate scale. Field II of the co-relation matrix, Figure 4, is designed for the representation of these values.

The original scales used in the roof of the house of quality, on which this method is based, express positive and negative relationships between the requirements.

Since this article deals with the relations of cause and effect between risks and these are defined as negative events, the scale used herein is summarized to include the null (inexistent) and negative relationships only, as indicated in Figure 4.

When there is no relation between two risks, it means that this relationship is null. When a relationship between two risks exists, it can be classified as a weak, medium or strong negative relationship.

As a result of this activity, the co-relation matrix, with the relationship between the technical and managerial priority

Table 7. Guidelines for the identification of the relationships between risks.

Nº	Guidelines
1	Verify the elements "input" and "control" of the PRODIP Model (BACK et al., 2008). These elements indicate whether one activity has a relation with another. Consequently, a risk in a certain activity is likely to influence a risk in another related activity.
2	Verify, in the project schedule, the activity sequences, since a risk in one activity can influence a risk in another, when there is an association between the two.
3	The causes and impacts, defined on the Technical and Managerial Identity Forms, can be used in the identification of the relationships between the risks.
4	The experience of the project team, the PDP model of the company, the judgment of specialists and analogies with previous and similar projects must be considered for the identification of the relationships between the risks.

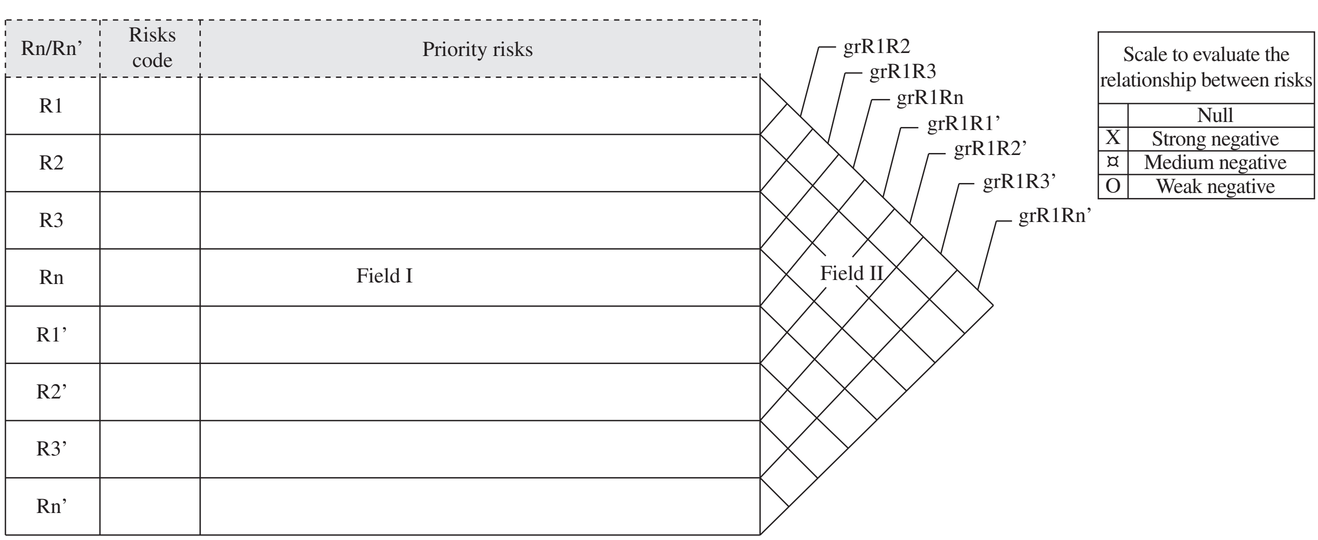


Figure 4. Matrix of co-relation between risks.

risks and their intensities defined is obtained. Figure 5 gives an example of a co-relation matrix considering two technical risks and three managerial risks.

Considering the guidelines presented in Table 7 for the definition of the risk relationships of Figure 5 it was defined that:

- R1 (Clients/customers express their needs in terms of solutions and not in terms of necessities) influences strongly R5 (Product representation in terms of solution and not in terms of functionalities), since the output of the activity related to R1 is the base for the execution of the activity related to R5;
- R1 influences moderately R2' (Project delay), since the existence of R1 can lead to extra time being required to obtain the customer needs expressed in appropriated terms; and
- R2' and R3' (Non attendance of product scope) have a weak relationship, that is, the risk R2' (Project delay) can compromise slightly the product scope. R3' tends to be strongly influenced by the risks more closely related to the activities of definition and conception of the product.

Through the example of Figure 5, it is possible to observe that the establishment of the relationships between the risks in the co-relation matrix depends strongly on the project team's knowledge regarding the company PDP. Thus, it is necessary to know the influence between the different pieces of project information, such as the influence of establishing adequately, or not, the design requirement list on the product global function, the product function structure, the solution principles, the product behavior model, the engineering descriptions for the manufacture, etc.

2.2.3. Activity 2.3. – Representing graphically the relationships between the priority risks

This activity consists of representing graphically the relationships between the project priority risks, producing a relationship network. This graphical representation will be used, later in the joint analysis of the technical and managerial risks.

For this, the use of arrows is proposed, as indicated in Table 8. The strong relationships are represented by a continuous arrow, the medium relationships by a dashed arrow and the weak relationships by a dotted arrow. The arrows leave from the risk that is causing the effect, and arrive in the affected risk, representing the relation of cause and effect between risks.

For example, Figure 6 shows the representation of the relationships of four risks with R3', as the result of the example of Figure 5 and the scale proposed in Table 8.

Thus, as in the co-relation matrix, Figure 5, it was defined that R1 has a strong effect on R3', the direction of the relationship between these two risks will be from R1 to R3', and will be represented by a continuous arrow. This indicates that R1 is the cause (origin) and R3' the effect (destination), as shown in Figure 6. The same analysis must be applied to the other three risks in relation to R3'.

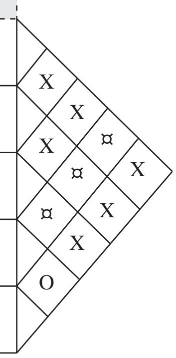
The relations shown in Figure 6 can have another risk as the central risk. The selection of a particular risk as the central risk depends on the interest in knowing the influence of certain risks on another. In this article, the risks considered as central are the managerial risks of scope, time, cost and quality. Thus, these risks must be placed in the last line of the co-relation matrix proposed.

As will be seen, the different types of arrows used to represent graphically the relationships between risks will aid in the definition of the joint probabilities between risks and in the joint analysis of the risks through the Bayesian network.

2.2.4. Activity 2.4. – Defining the joint (or conditional) probabilities of the priority risks

Based on the definition and representation of the relationships between risks, in this activity the joint

Rn/Rn'	Risk code	Priority risks
R1	RPP-I-E01	Clients/customers express their needs in terms of solutions and not in terms of necessities
R2	RPP-I-S01	Design specifications that do not reflect the market needs
R5	RPP-C-M01	Product representation in terms of solution and not in terms of functionalities
R2'	RPG-T-01	Project delay
R3'	RGP-E'-01	Non attendance of product scope



Scale to evaluate the relationship between risks	
	Null
X	Strong negative
¤	Medium negative
O	Weak negative

Figure 5. Example of co-relation matrix for the definition of relationships between risks.

Table 8. Scale for graphical representation of the relationships between risks (GRUBISIC, 2009).

Scale for graphical representation of the relationships between risks	
Strong negative	——→
Medium negative	- - - →
Weak negative	········→

Table 9. Scale for the conversion of the type of relationship into joint probability.

Types of relationship	P(B|A)	
Null	Null	0%
Weak negative	Low	0% < X ≤ 25%
Medium negative	Medium	25% < X ≤ 50%
Strong negative	High	50% < X <100%

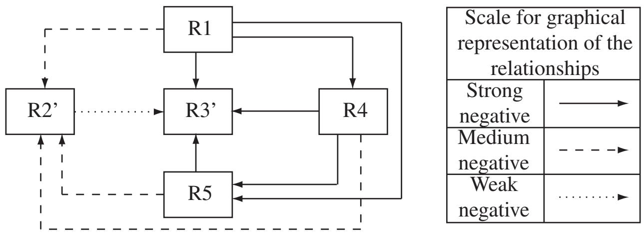


Figure 6. Representation of the relationships between risks with risk R3' as the central risk. Source: Adapted of Grubisic and Ogliari (2007).

probabilities of the risks are defined. To determine the joint probability of A given B, P(A|B), according to Bayes' theorem[i] it is necessary to define the probability of B given A, P(B|A), and the marginal probabilities P (A) and P (B).

Thus, based on the results of Field II of the co-relation matrix, Figure 4, a conversion scale is proposed to transform the types of relationships into joint probabilities. Table 9 presents this scale of conversion.

Table 9 presents some bands of values of joint probabilities. The project team must define a value inside these bands considering the results of the relationships defined in Field II of the co-relation matrix (Figure 4).

Therefore, when the relationship between two risks is defined as strong negative in the co-relation matrix, it implies that the probability of risk B given the probability of risk A will be high. The same applies to the relationships defined as low and medium negative.

For example, in Figure 5, risk R1 (Clients/customers express their needs in terms of solutions and not in terms of necessities) influences strongly R5 (Product representation in terms of solution and not in terms of functionalities). This implies that the R5 probability of occurrence given the R1 probability of occurrence is high, that is, it is inside the interval (50,100), according to Table 9.

Thus, the P(B|A) will be known and, with the P(A) and P(B) defined previously, Bayes' theorem will be satisfied. As will be seen, the results obtained in this activity will be used in the calculation of the probability of the managerial risk given the probability of other risks.

2.2.5. Activity 2.5. – The joint analysis of the priority risks

This activity consists of calculating the probability of occurrence of the managerial risks, given the probability of occurrence of the technical risks, considering all the relationships previously established.

Thus, the value of the effect of the technical risks on the managerial risks, in terms of probability of occurrence is defined. This information will guide the team in the treatment of the risks that most influence the managerial risks, increasing the chances of the project being concluded as planned.

For the calculation of the joint analysis of the risks the use of a Bayesian network is considered. Firstly, the joint probabilities of the risks defined in activity 2.4 are inserted in the network obtained in activity 2.3. Then, Bayes' theorem is applied to the network.

Figure 7 gives an example of a joint analysis. Since there are two managerial risks, R2' and R3' in this example, it is possible to produce two Bayesian networks, each with a different central managerial risk. Each Bayesian network will have all the relationships that affect the central managerial risk, and the relationships between the other risks.

Figure 7 illustrates the Bayesian network for the risk "Non attendance of product scope", R3'. To produce this network all risks that affect R3' (R1-R3'; R4-R3'; R5-R3'; R2'-R3') and the relationships between them (R1-R4; R1-R5; R1-R2'; R4-R2'; R4-R5; R5-R2') were considered. The intensity of the relationships between the risks is represented by the arrows and the joint probabilities, as defined in activity 2.3 and Table 9, respectively.

Figure 7 must be read from each risk toward the center, starting from R1, then from R2', R4 and R5, following the direction of the arrows. Thus, it is possible to see the influence of a risk on the others, particularly on R3'.

Based on Bayes' theorem, the accumulated effect of R1, R2', R4 and R5 on R3', that is, the probability of occurrence of this risk, given the probability of occurrence of the others, is calculated. The equation for the calculation of this probability is (Equation 1):

[i]Bayes'theorem: P(A|B) = (P(B|A).P(A))/P(B) (JENSEN, 2001).

$$P(R3'|R1,R2',R4,R5) = \frac{P(R1|R3').P(R2'|R3').P(R4|R3').P(R5|R3').P(R3')}{P(R1).P(R2').P(R4).P(R5)} \quad (1)$$

It was defined, hypothetically, that P(R1), P(R2'), P(R4), P(R5) and P(R3') assume the following values: 60, 60, 70, 20 and 50%, respectively. Based on Table 9, the values of P(R3'|R1), P(R3'|R2'), P(R3'|R4) and P(R3'|R5) were defined, hypothetically, as 80, 20, 70 and 95%, respectively. Having defined these values, through Bayes' theorem the probabilities of P(R1|R3'), P(R2'|R3'), P(R4|R3') and P(R5|R3') are determined as, respectively, 96, 24, 98 and 38%. Substituting the previous values in Equation (1), the probability of R3' (Non attendance of product scope) given R1, R2', R4 and R5 is obtained as 85.12%, which is considered high.

This example shows that the influence of one risk on the others is significant, making it possible to analyze the level of project vulnerability in relation to the managerial risks. Initially, the probability of occurrence of R3' was defined as 50%. After the consideration of the influence of the technical and managerial risks, on the risk "Non attendance of product scope", this probability became 85.12%, an expressive increase. According to the values of the joint probabilities of Equation 1, it is also possible to conclude that R1 and R4 are the risks that most influence R3'. In this case, in order to assure that the product scope is satisfied, the project team must pay more attention to these risks.

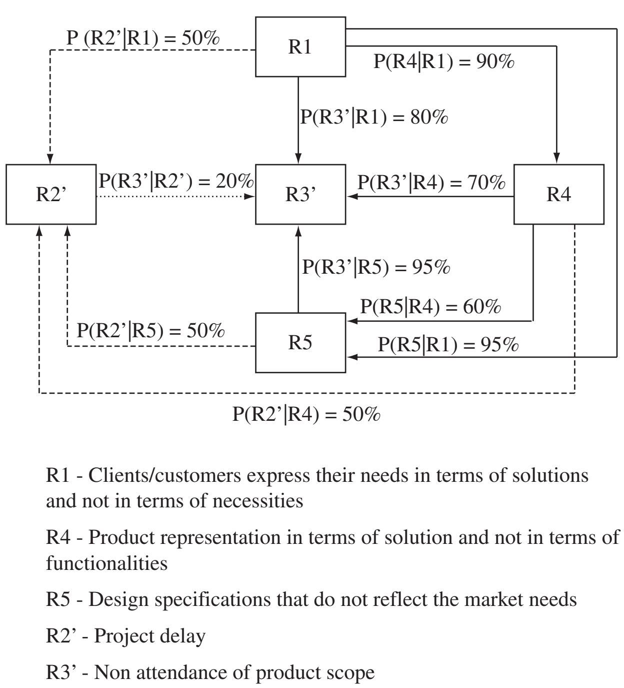


Figure 7. Bayesian network for the central managerial risk "Non attendance of product scope".

Thus, applying this theory, the results of the risk analysis tend to be more precise and the actions related to the risk treatment are directed toward the risks that can most compromise the project execution in managerial terms.

The Bayesian analysis must be carried out every time that the joint probability and the project priority risks change. To facilitate the joint analysis, specific software, such Netica can be used. The Netica software uses a bayesian network for the joint analysis. More information about this software can be found at: http://www.norsys.com.

2.3. Phase 3 – Technical and managerial risk treatment

The risk treatment phase consists of the definition of specific actions associated with the following strategies: prevent, mitigate, transfer or accept the project risks. The final objective of this phase is to reduce the probability of occurrence of the risks to acceptable levels, as defined in activity 2.1, and/or reduce their effect on the project. This phase comprises some activities, which are detailed below.

2.3.1. Activity 3.1. – Defining actions for the risk treatment

This activity seeks to guide the project team in the definition of actions for the treatment of the technical and managerial risks that most affect the project in managerial terms, as identified in activity 2.5 and for the treatment of the risk of scope, time, cost and quality.

In the same way as in the risk identification process, the present activity also requires abstract thinking and creativity from the project team for the identification of actions for the risk treatment. Table 10 gives some guidelines in order to aid the identification of actions for the risk treatment.

The identified actions must be registered according to Table 11. The first three columns of Table 11 are used for the risks and the other two to register their respective actions.

2.3.2. Activity 3.2. – Prioritizing the actions for the risk treatment

This activity consists of prioritizing the actions for the risk treatment, in order to highlight the actions that have the most effect on the priority risks. For this, the matrix present in Table 12 is proposed, in which the degree of importance of each action is defined by analyzing the relationship of the actions with all the priority risks. This matrix is based on the first matrix of the QFD method, the house of quality. The first two columns are used, respectively, to register the priority risk number and its relative weighting, defined in activity 2.1. The other columns are for the definition of the degree of importance of the actions for each priority risk.

Initially, for each action, the existence of a relationship with each priority risk is verified. For this, the project team must reflect on whether the implementation of one action can eliminate, mitigate, transfer or accept (actively) the risk. If so, there is a relationship between the action and the risk in question. In these cases, the intensity (Gr) of this relationship must be defined according to the scale proposed in Table 13. The results of this analysis are registered in the column of each action.

Finally, in the last line of the matrix, Table 12, the sum of the products of the relative weighting of each risk multiplied by the degree of importance of the relationship between each action and the risk is calculated. The result obtained will correspond to the order of priority of each action in the project, indicating the implementation order.

Table 14 gives an example of a form for the registering of actions for the treatment of three risks and the application of the matrix (Table 12). The actions defined in Table 14 were obtained from the guidelines given in Table 10. The values of the relative weightings of the three risks and the degree of importance of the actions of these risks were obtained from the activity 2.1 and Table 13, respectively.

Through the procedures presented for the calculation of the degree of importance of the risk actions, it is possible to conclude that action 1.1 is the most relevant for the considered scenario, that is, this action must be implemented first. Subsequently, actions 2.1, 3.1, 1.2 and 2.2 are applied, as shown in Table 15.

Table 10. Guidelines for the identification of actions for the risk treatment.

Nº	Guidelines
1	Define the action strategy to be adopted, the rate of risk reduction, defined in activity 2.1, must be considered since it indicates the effort necessary to reduce the risk to acceptable levels.
2	Analyze the element "cause" of the risk. The project manager and the person responsible for the risk must consider specific actions directed toward the causes. These actions can be of a managerial and/or technical nature.
3	Identify alternative actions that do not require too many resources. Bear in mind that simple actions can reduce or even eliminate the risks.
4	Identify actions based on the best practices of product development in order to improve this process and avoid potential technical risks.
5	Identify actions based on the best practices of project management in order to improve the projects and avoid the potential managerial risks.
6	Involve the sponsors, clients/customers and suppliers in the identification and definition of actions for the risks.
7	Search historical information on past or similar projects and experiences that can aid in the risk treatment phase.

Table 11. Form for register of the actions for the risk treatment.

Nº	Risk code	Risk	Nº	Action
R1			1.n	
-	-	-	-	-
Rn			n.n	

2.3.3. Activity 3.3. – Registering the risk priority action

This activity consists of registering the actions defined and evaluated in activities 3.1 and 3.2, respectively. For this, a structure for the action plan for the risk treatment is proposed in Table 16. The actions evaluated in activity 3.2 must be listed by order of importance in the action plan.

The first blank field serves to register the actions and the following field the person responsible for the action implementation. To define the latter, the project manager must check in Table 14 the risk that originated the action and the person responsible for the risk.

The last field in Table 16 is for the definition of the implementation date of the action, that is, the moment at which the action must be implemented in the project. For this, the project manager must check in the project plan the date allocated to the activity.

The information obtained in this activity will complement the project documentation. Thus, the project manager must update the project plan with the results of the risk treatment in order to improve the estimates of the time, resources and costs.

2.3.4. Activity 3.4. – Implement the action plan for the technical and managerial risk treatment

This activity consists of implementing the actions planned for the risk treatment. For this, based on the literature, Table 17 gives some guidelines in order to aid the project manager in this process.

Table 12. Matrix for the prioritizing of the actions for the risk treatment.

Risks	Risk relative weighting	Actions				
		1.1	1.2	1.3	2.1	n.n
R1	p1	Gr1.1 (R1)	Gr1.2 (R1)	Gr1.3 (R1)	Gr2.1(R1)	Grn.n (R1)
-	-	-	-	-	-	-
Ri	pi	Gr1.1(Ri)	Gr2.1 (Ri)	Gr1.3 (Ri)	Gr2.1(Ri)	Grn.n (Ri)
Total:		∑pi.Gr1.i	∑pi.Gr1.n	∑pi.Gr1.n	∑pi.Gr2.i	∑pi.Grn.n

Table 13. Scale for definition of the degree of importance of the actions.

Action degree of importance (Gr)	Values for relationship between the action and risk
Null	0
Low	1
Medium	3
Strong	5

Table 14. Example of actions for technical and managerial risks.

Nº	Risk code	Risk	Nº	Actions
R1	RPP-I-S01	Clients/customers express their needs in terms of solutions	1.1	Improve the questionnaires to be applied in the carrying out of the market research.
			1.2	Involve more the clients/customers of the product in the activities that require information from them, through fortnightly meetings.
R4	RPP-C-M01	Product representation in terms of solution and not in terms of functionalities	2.1	Offer training on design methodology, mainly on functional synthesis methods for the project team.
			2.2	Designate more time for the activity of unfolding of the global function.
R2'	RGP-T-01	Project delay	3.1	Stimulate the communication between the areas involved in the PDP through fortnightly meetings.

Table 15. Example of prioritizing of actions for the risk treatment.

Risk	Risk relative weighting	Actions				
		1.1	**1.2**	**2.1**	**2.2**	**3.1**
R1	0.44	5	5	3	0	3
R4	0.074	3	3	5	5	3
R2'	0.39	5	1	5	0	5
Total:		4.372	2.812	3.64	0.37	3.492

Table 16. Structure of action plan for the risk treatment.

Nº	Action	Person responsible	Date of implementation
1			
2			
n			

Table 17. Guidelines for the implementation of the action plan for the risk treatment.

Nº	Guidelines
1	Integrate the actions for the risk treatment into the project plan. Thus, the project plan will be update in terms of the risks of scope, time, cost and quality, as shown in Figure 1.
2	The person responsible for the risk and the project manager are responsible for the implementation of the action for the risk treatment. Moreover, they are directly responsible for the risk control. The people indirectly responsible for the risk control are the other project members involved with the risks.
3	Define the frequency with which the risks will be controlled based on their estimated date of occurrence and relative weighting and the probability of occurrence of the managerial risk of scope, time, cost quality given the probability of the other risks.
4	In the dates of control, the characteristics of the priority risks must be revised, as well as the results of the implemented actions. The documentation of the project plan be updated.
5	Verify whether the scope, schedule, budget and the project quality have been affected by any risk throughout the project. If so, the project manager must take action to improve the project.
6	After each risk control, the project manager must share the updated information with the project team.

Based on the above guidelines, the implementation of the actions for the risk treatment will be carried out in a pro-active way, that is, before the risk becomes a problem. The implementation of these actions will improve the chances for the project to be executed and concluded as planned.

3. Evaluation of the methodology for the integrated management of technical and managerial risks related to the product design process

The present methodology was submitted to a critical evaluation according to some requisites that had been defined for its development (GRUBISIC, 2009). Also, it was submitted to the evaluation of a company and a group of specialists in PD and PM.

In the company, eight people attended a presentation of 45 (forty-five) minutes, in which the methodology was detailed. At the end, a questionnaire was given to them to fill out and to comment on the methodology. For the group (four) of specialists in PD and PM the questionnaire and the methodology were sent by email. The main results of these evaluations are presented below.

In general, the structure of the methodology was considered clear, objective, complete and consistent. The risk identification phase allows the project team to identify and detail thoroughly the methods, guidelines and forms, according to the risk categories defined in the methodology. The methodology evaluation showed that its phases and activities are integrated into a formal product design process.

According to the evaluation results, the risk analysis phase deals with the objective of joint analysis of the technical and managerial risks through, mainly, a Bayesian network. Thus, it is possible to identify and analyze the influence of the technical risks on the managerial risks of scope, time, costs and quality.

It was verified that the risk treatment phase allows the definition of actions for the risks, based on guidelines. The prioritizing of actions for the risk treatment also highlights the effect of one action on more than one risk, if this is the case. Thus, the number of actions that must be implemented can be reduced, increasing the effectiveness of the risk management.

In the opinion of the appraisers, the methodology could be extended to propose ways to adapt it to different project types. In this case, the solution would define which aspects of the methodology would have to be specified for different project types.

It can thus be concluded that the results of the three types of evaluation, requisites and appraisers (company and specialists) were positive, indicating that the methodology for the integrated management of technical and managerial risks related to the product design process achieved its objective.

4. Conclusions

In this article the three phases that form the methodology for the integrated management of technical and managerial risks related to product design were described.

It can be concluded that the investigative questions and the risks highlighted in the risk identification phase stimulate the project team to reflect on potential risks in the main activities of the product design process and the project risks of scope, time, cost and quality.

The integrated technical and managerial risk analysis allows the project team to identify the project priority risks. Also, it is possible to identify the accumulated effect of the technical risks on the managerial risks of scope, time, cost and quality and, identify the technical risks that have the greatest influence on the project.

In view of this, the results of the analysis are more precise and the actions for the risk treatment are directed toward the risks that can most compromise the project execution in managerial terms.

The activities and the methods of the risk treatment phase seek to stimulate the project team to identify actions for the technical and managerial risks according to the following strategies: prevent, mitigate, transfer or accept.

Moreover, the methodology for the integrated management of technical and managerial risks related to the product design process presents the following benefits: it offers tools to register the information obtained in the methodology phases; improves the project plan in terms of activities, estimates of time and cost and criteria of quality; allows the project team to better understand the nature of the projects and develop a pro-active culture within the company.

5. Acknowledgements

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