# Strategic decision-making in NPD projects according to risk: application to satellites integration and test projects

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# STRATEGIC DECISION-MAKING IN NPD PROJECTS ACCORDING TO RISK: APPLICATION TO SATELLITES INTEGRATION AND TEST PROJECTS

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**ABSTRACT:** *the project management team has to respect contractual commitments, in terms of deadlines and budgets, that are often two antagonistic objectives. At the same time, the market becomes more and more demanding as far as costs and delays are concerned while expecting a high quality level. Then, the project management team has to continuously consider innovation and a risk management strategy in order to determine the best balance between benefits and risks. Based on the principles of a synchronized process between risk management and project management, and on the concepts of risk scenario, we propose a decision-making tool to help the project manager choose the best way to improve project practices while controlling the level of risks. As a finding, the project manager would be able to evaluate and compare different innovations or development strategies according to potential risks and risk treatment strategies. Finally, a case study in the aerospace industry and specifically on satellite integration and tests is developed to validate this approach.*

**KEYWORDS:** *Decision support system, Project planning, Project variant, Risk management, Scenarios, Treatment strategy.*

## 1 INTRODUCTION

In the current context of market globalisation, and in order to increase their competitiveness, companies have to offer innovative products. They also have to change their ways of production to improve their profitability and reactivity. More and more companies use project management tools and methods for managing their innovations, to ensure a better product quality, better deadlines and lower costs. In this context, a particular attention is paid to project management methods by decision-makers and academics. Every project type faces risks, whatever the size or topic concerned. Nevertheless, the more innovative the project, or if the technology area is poorly known, the more uncertain and risky the project. Professional organisations as well as standards bodies have produced guides and books on project management and good practices for several years ((ISO10006 1997), (IPMA 1999), (PMBoK 2009) etc.). These reference framework documents present the process required for management. Turner proposes a review of progress on the global project management body of knowledge (Turner 2000). He states that, even if the internal breakdowns may not be always appropriate, the guide to the PMBoK contains the core elements used by all project managers. The following dimensions are systematically mentioned in the reference framework documents: integration, scope, time, cost, quality, human resources, communication, risk and procurement management. In a context of project and especially on a competitive market, the manager has to make practices evolve to increase the reactivity and profitability. He has to take risks into consideration in two main situations. Firstly, when facing a risk situation, the manager has to choose a strategy which keeps the project on budget and on time. Secondly, he has to evaluate different development strategies when choosing between exclusive technological innovation on product. Therefore risks have to be correctly evaluated and the strategies correctly chosen to obtain a realistic estimate (cost/duration) of the project.

This paper is specifically interested in approaches that take risks into account in managing project. These approaches aim to anticipate potential phenomena and to measure their possible consequences on the project life or objectives. They lead the manager to choose the risk treatment strategies appropriate to the project. In the first section, we present a literature survey on risk management methodologies, which shows the diversity of the existing approaches; some are dedicated to specific domains while others are generic. We illustrate the evaluation problem of the influence of risk on project schedule. In the second section we describe our methodology, that deals with the complexity of choosing development strategies and/or treatment strategies in a technological innovation context facing potential risks. Finally a case study from the aerospace industry is detailed, we discuss the results obtained and present our conclusions to this research work.

## 2 LITERATURE REVIEW

### 2.1 Dealing with project risk management

In the literature, the risk management methodologies refer to a standard process presenting the well-known steps: risk identification, risk evaluation and quantification, risk mitigation for treatment and/or impact minimization and risk monitoring ((BSI 2000), (ISO31000 2009), PMI). Tixier et al. propose a classification of sixty two existing approaches (Tixier et al. 2002). They sort methods as being deterministic and/or probabilistic, but also qualitative or quantitative. In a project context corresponding to this work, a risk occurence may introduce in a project: (1) the modification of existing tasks related to the risks influence on duration or cost. (2) the modification of the project structure by treatment strategies (treatment actions are represented by new tasks in the planning). This therefore impacts the project planning: cost and duration. The specificities of the project context are: the notion of uniqueness (there is no recurrence in the projects), the notion of limited horizon (there are different milestones and contractual commitments), and the notion of a multi-expertise environment (numerous actors with different skills, perceptions and points of view working together). Several academic research works propose methods to complement the different phases of the previously presented global approaches, such as the optimisation of different criteria during the schedule or after the identification phase. As an example, Kilic et al. propose an approach to solve a bi-objective optimisation problem where the makespan (or project duration) and the total cost both have to be minimized. Different preventive strategies are possible for each risk and a multi-objective genetic algorithm is used to generate a set of pareto optimal solutions (Kiliç et al. 2008). Van de Vonder et al. are interested in generating robust projects by inserting buffers in the project schedule. Using heuristics, their approach aims to minimize project duration and maximize project robustness, which are antagonistic objectives. Depending on the project characteristics, this strategy can be an interesting way to increase solution stability (Van de Vonder et al. 2005). In parallel to these global approaches, several authors propose methodologies to manage the risk in projects. Gourc et al. propose a reading grid of the risk management approaches as follows (Gourc 2006): the symptomatic approach and the analytic approach. The first group of approaches, called risk-uncertainty, is associated with approaches where project risk management is transformed into project uncertainty management (Ward and Chapman 2003). This approach is supported by different software tools such as @Risk ®, Pertmaster ®, Crystal Ball ®etc. These software solutions use the Monte Carlo simulation method (Kalos and Whitlock 2008) to assess the duration, cost etc., of a project in relation to uncertainties. The second approach family considers risk as an event that can affect the achievement of the project objectives (Carter et al. 1996). According to ISO/IEC Guide 73, "Risk can be defined as the combination of the probability of an event and its consequences" (ISO-Guide73 2002). Software tools such as Riskman, RiskProject ®etc. implement this type of approach. Risk is described as an event, which has occurrence characteristics (potentiality to occur) and consequence characteristics on the project objectives (impact in the event of occurrence). Nguyen et al. propose Prorisk which can model and evaluate the impact of risks on the project cost and the schedule cost (Nguyen et al. 2010). They define the concepts of risk scenario, treatment scenario and project scenario. This project management approach uses synchronized processes of project schedule and risk management (Pingaud and Gourc 2003).

### 2.2 The decision process in project risk management

In the project management literature, two themes are well-known for their reference to the innovation and then for the omnipresence of risk: the project management of new product development (NPD) at an operational level and the portfolio management of NPD at a tactical level. A first definition of portfolio management is given in 1999 (Cooper et al. 1999): a dynamic decision-making process that allows the project lists to be always updated. In this process, new projects are evaluated, selected and sorted. Past projects can be accelerated, stopped or put on standby and resource assignments can be changed. The portfolio management practices, are then described as leading to high satisfaction levels, helping to choose several projects into a set of possible ones. The decision and the choice are mainly difficult due to the omnipresence of the evaluation of the balance benefits versus risks. The objectives of the portfolio practices are to construct a balanced portfolio in innovative project, between risk and profitability. One of the problem is to be able to evaluate and compare several possible portfolio with a global risk indicator. Risks are also intrinsic in new product development (NPD) in all industries (Kwak and LaPlace 2005). Thus firms need to take initiatives to reduce risks that are related with NPD. The risk management framework should integrates the three most important risk factors that affect NPD performance: technology, marketing, and organization (Doering and Parayre 2000). However, in such an innovation context, it remains difficult to acquire knowledge about the sources of uncertainty to decide the way of reducing the risk of failure of the project or resulting product and manage efficiently NPD risk (Crawford and Benedetto 2006). In NPD management, decision-makers have to choose exclusively one orientation as strategy development according with a global risk level tolerance. As an answer, decision trees (DT) are regularly used in the literature on decision (Chiu et al. 2006). DT is a structure that represents decision problems with exclusive and competing solutions. It permits to find optimal solution to short time dynamic decision problems (Clemen 1997). Based on decision variables, decision trees allows to choose one way and to react inside this way in front of event. To increase the efficiency of innovative projects two main ways are possible: modifying the product, modifying the project structures and then practices. Both of these perspectives lead to modifications of the risk level and it is difficult to evaluate the balance between risks and benefits. If the first way requires specific and technical skills to reduce per example conception risks, there is not any tools helping the project manager to evaluate the project risk level when integrating the studied variants of project and its consequences on (1) the planning of the project, (2) the risks and its associated treatment strategies.

As observed in this literature review, little account is taken of risk and the strategies to deal with it regarding their repercussions on planning. The ability to present the project manager with a range of alternative risk treatments when faced with a risk situation, and the further ability to provide information on the consequences on decision criteria such as project cost and duration should improve the decision-making process. Therefore, is a need of methodological tools helping measuring the repercussion on the risk level of modification on the project structure. In this work, we make the link between project planning, project management and risk management. To our knowledge, few methods are able to do that. They mainly apply risk management to an object, but the repercussions on planning are rarely modelled. Among the most closely-related approaches, RISKMAN examines the notion of risk as an event that can affect the project. PRAM mixes qualitative and quantitative elements by transforming events into uncertainties impacting the tasks (Ward and Chapman 2003), and the ARAMIS method allows the notion of the scenario to be highlighted. The risk becomes one or several uncertainties that are taken into account in tasks as a cost or delay range. It is reflected in the global project by the means of delay distribution or total project cost distribution. By taking into account the fact that well-managed technology risk leads to better NPD performance (Mu et al. 2009), our objective is to propose a complete framework helping decision-makers to decide innovation and risk prevention strategy. This tool should facilitate the decision-making process by making the link between project management and risk management and by analysing the consequences of a risk, as an event, in a project. It should permit the evaluation of consequences of the change in practices on project management, particularly on the deadline and cost dimensions. In addition, this environment will be useful for managers, in order to measure the project global risk level, by taking into account the different possible scenarios, as well as helping choose the most suitable risk strategies.

## 3 MODEL

Taking decisions in the choice of modifications to improve an existing project is a multicriteria problem. When the project manager makes the decision, the number of criteria used to evaluate the proposal is often reduced to the main ones: the cost, which is a sensitive and finite resource and the delay, which traditionally is a matter of contractual commitment. However, when different possible modifications are identified to improve the performance of a project, the repercussion on the risks are rarely anticipated in the classical approach. The project manager has to consider the profitability of the new solution, but also the consequences of the modified risks.

### 3.1 Hypothesis

The model we propose is based on three main hypotheses:
- the risk integration to the project management takes into account the deadlines and the cost criteria. The considered impacts (modification or suppression of an existing task or the insertion of a new task for example) influence the project total duration and cost.
- tasks duration are independent of resources and no resource constraints are imposed. The required resources are supposed to be always available and no particular skill are required.
- another hypothesis used for this model is that, when the decision of treatment strategy and project structure has to be made, the tasks list and the risks list are known and are not supposed to vary, during the project. Every characteristic relative to the risks are supposed to be known since approaches such as the Delphi method (Dalkey and Helmer 1963) or RIR (Benaben et al. 2004) could previously be applied helping this identification. This research work's objective is not to develop a tool facilitating the data-

gathering that may be costly in time and effort with a realistic number of tasks.
At any time, the objectives of the model are (1) to analyse the possible scenarios, (2) to evaluate the global risk level, i.e. the global risk level represents the chance, for the project, to satisfy commitments, (3) to select the best treatment strategies.

### 3.2 Data

$PV^v$ $(v = 0,...,V)$ is a Project Variant associated to a development strategy of a project, $V$ being the number of possible variants and $PV^0$ is the Project Reference that is improved by the added modifications.
Each $PV^v$ is described by its tasks $T_t^v(t = 1...T^v)$, $T^v$ being the number of project tasks of the project variant $PV^v$. The planning process gives an initial planning $PVi^v$ that does not integrate any risks. A project variant is also described by its set $E_R^v$ of identified risks $R_i^v(i = 0...n^v)$, $n^v$ being the number of identified risks in $PV^v$. Each $R_i^v$ is characterized via the risks management process. A risk $R_i^v$ is also characterized by its period of occurrence, i.e. the tasks during which the risk can occur. Its probability $proba(R_i^v)$ is the probability that the event related to $R_i^v$ occurs and its impacts in costs $CI(R_i^v)$ and/or on delay $DI(R_i^v)$ on a task that can be different of the period of occurrence. These probability and impact are also called *initial probability* and *initial impact*. The fact that the task is running in a graceful degradation is taken into consideration by the initial impact.
A risk scenario $ScR_s^v$ corresponds to the combination of the risks occurring during a project variant $PV^v$. A project variant presenting $n^v$ risks leads to $2^{n^v}$ risks scenarios. Then $ScR_s^v(s = 1,...,2^{n^v})$ is a possible achievement with $k$ risks $(0 \leq k \leq n)$ and the total number of risk scenarios, presenting $k$ of the $n$ identified risks, is equal to $\frac{n!}{k!(n-k)!}$. Its probability is $proba(ScR_s^v)$ (the probability that the events related to this risk scenario occur and that the other risks do not occur).

$$proba\left(ScR_s^v\right) = \prod_{i=1}^{n} \left\{ \begin{array}{cc} proba\left(R_i\right) & if\left(R_i \in ScR\right) \\ 1 - proba\left(R_i\right) & if\left(R_i \notin ScR\right) \end{array} \right.$$

Each risk can be treated in various ways that can be preventive, corrective or a combination of several actions. A risk $R_i^v$ can be associated to one or more treatment strategies $StT_{ij}^v(j = 1...m^v)$, $m^v$ being the number of identified strategies for $R_i^v$. A treatment strategy $StT_{ij}^v$ groups a set of treatment actions $A_{ij\alpha}(\alpha = 1...a)$ to avoid or reduce the risk $R_i^v$, $a$ being the number of identified treatment actions. A treatment action can be materialized by a task to achieve and introduces three types of modifications to the WBS:
- addition of a new task, which generates a new action to realize;
- suppression of a task from the initial schedule. The risk is reduced by suppressing a task from the schedule;
- modification of an existing task.
A treatment strategy is a preventive strategy if it contains at least a preventive treatment action. Otherwise, it is a corrective strategy. If the strategy consists in running no action at all, it is noted as being an empty set such as $\emptyset$.

Finally, several treatment strategies are possible for each risk $R_i^v$. The definition of these strategies can lead to the appearance of treatment actions common to several risks. The set of all the identified $StT_{ij}^v$ for a risk $R_i^v$ is written $StR_i^v$. Then $StR_i^v = \{\emptyset, StT_{i1}^v, .., StT_{ij}^v, .., StT_{im}^v\}$ and $Card(StR_i{}^v) = m^v + 1$.
A treatment scenario $ScT_d^v(d = 1...D^v)$ corresponds to a combination of the treatment strategies chosen to deal with the different risks of a project variant. The set of treatment scenarios is given by: $E_{ScT}^v = \prod_{i=1}^{n} StR_i^v$. For each $PV^v$, $E_{ScT}^v$ may contain a set of preventive treatment scenarios $E_{ScT_{prev}}^v$ and corrective treatment scenarios $E_{ScT_{correc}}^v$.

The $proba(R_i^v \left| StT_{ij}^v \right.)$ is the probability that the event related to $R_i^v$ occurs, knowing that $StT_{ij}^v$ (preventive strategy) has been achieved. This probability, as well as the impacts $CI(R_i^v \left| StT_{ij}^v \right.)$ and $DI(R_i^v \left| StT_{ij}^v \right.)$, is then qualified "reduced probability" and "reduced impact".

A project scenario $ScP_p^v(p = 1...P)$ is defined as being a possible project achievement that is built with a risk scenario and treatment scenario ($ScP_p^v =< Pi^v, ScR_s^v, ScT_d^v >$). The set of project scenarios $ES^v$ is obtained by combining the set of occurring risks (or a risk scenario) and the set of determined treatment actions (or treatment scenario).
$proba\left(ScP_p^v\right)$ is the probability of a given $ScP_p^v$. It takes into account (1) the probability of the occurring risks $(R_i^v \in ScR_s^v)$, (2) the probability that several risks do not occur $(R_i^v \notin ScR_s^v)$, (3) the probability of the occurring risks $(R_i^v \in ScR_s^v)$ knowing that a Treatment strategy is developed $\left(StT_{ij}^v \in ScT_d^v\right)$ (4) the probability that $R_i^v$ does not occur $(R_i^v \notin ScR_s^v)$ knowing that a preventive strategy has been processed and the initial probability has been modified $\left(StT_{ij}^v \in ScT_d^v\right)$.

$$proba\left(ScP_p^v\right) = \prod_{i,j}^{R_i^v \in ScR_s^v, StT_{ij}^v \in ScT_d^v} \left\{ \begin{array}{ll} proba(R_i^v) & (1) \\ 1 - proba(R_i^v) & (2) \\ proba(R_i^v \left| StT_{ij}^v \right.) & (3) \\ 1 - proba(R_i^v \left| StT_{ij}^v \right.) & (4) \end{array} \right.$$

The cost of a project scenario is noted $C\left(ScP_p^v\right)$ in eq.1. It includes the cost of the $T$ tasks that con-

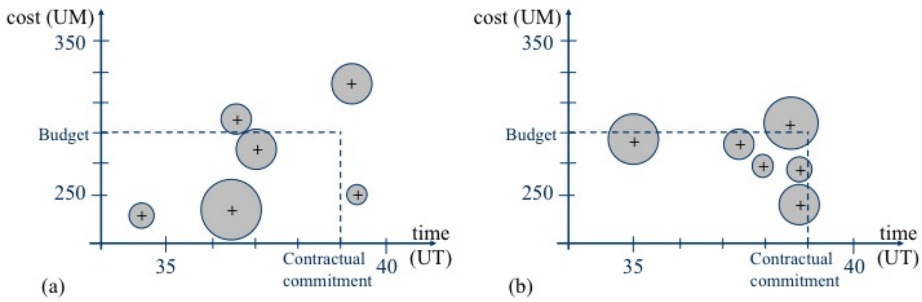


Figure 1: example of two project variants

$$C\left(ScP_p^v\right) = \sum_{t=1}^{T} C\left(T_t^v\right) + \sum_{i,j}^{R_i^v \in ScR_s^v, StT_{ij}^v \in ScT_d^v} \begin{cases} \sum_{R_i^v \in ScR_s^v} \mathrm{GC}^{\text{initial}}\left(R_i^v\right) & \text{(A)} \\ \sum_{R_i^v \in ScR_s^v} \mathrm{GC}^{\text{reduced}}\left(R_i^v\right) \mid StT_{ij}^v & \text{(B)} \\ \sum_{R_i^v \in ScR_s^v} \sum_{StT_{ij}^v \in StR_i^v} C(StT_{ij}^v) & \text{(C)} \end{cases} \quad (1)$$

stitute the initial planning of the project variant, the $ScR_p^v$ and the chosen $ScT_p^v$ and (A) the Global Cost $GC^{initial}\left(R_i^v\right)$ of the occurring risks that are not treated by the treatment strategies. It includes the cost impact that is composed of a fixed part of the total cost (materials, tools, parts etc.) and of an indirect cost that depends on the action duration, through the Delay Impact, and the actors' charge. (B) The reduced global cost impact $\mathrm{GC}^{\text{reduced}}\left(R_i^v\right)$ is obtained taking into account the different strategies $StT_{ij}^v$ applied to treat $R_i^v$ and its reduced repercussions on the project cost and duration. (C) The cost of the treatment strategies $StT_{ij}^v$ that is determined by the cost of the action is composed of a direct cost (materials, tools etc.) and of an indirect cost that depends on the action duration and on the actors.

### 3.3 Objectives

In the project conception phase, project managers have to provide target costs and deadlines. Knowing the different risks, s/he has to estimate the chances of success, as well as of meeting the budget and the contractual commitments. Fig. 1 presents two different project variants (a and b) of a same project. Each project variant could lead to a set of project scenario. For each project scenario, the project duration is represented in x-coordinate and its cost in y-coordinate. The probability of the scenario is represented by the bubble diameter. Therefore, an acceptability zone can be defined, using the budget and deadline thresholds. The choice of the best variant is based on the potential of reaching the promised improvements but also on performance of the improvement itself.
Each project variant is associated with different development strategies. They contain specific risks portfolio that can impact their respective duration and cost and then their respective global risk level differently.The objective of this research work is to give the decision-maker a methodological tool to compare each project regarding its benefits/risks balance.

## 4 RESOLUTION APPROACH

### 4.1 Representation of the decision problem

In an industrial context, the modification of a project structure or process is the source of many uncertainties. For this reason, different decisions are made over the different phases of project conception and management in order to reduce and control the risks level. Fig. 2 shows the decisional process of risk management over the time.To reach its objectives, the project management team goes through different phases of decision represented by the decision nodes $D1$ to $D3$ on fig. 2. Its first decision ($D1$) aims to choose a project variant among a list of project variants. The second one ($D2$) is to select the preventive risk treatment strategy. $D1$ and $D2$ are made during the preparation phase of the project. However, $D3$ is made to react when events occur. Decision $D3$ consists in deciding which corrective actions should be carried on facing an undesirable set of events (a risk scenario). These events are represented by the event nodes $E$ (also called chance node) on the decision tree.

### 4.2 The proposed proactive approach

The body of the approach is composed of three phases: (a) the generation of all the possible project scenarios and their evaluations for each variant proposed, (b) the filtration in each project variant of the best project scenarios based on the decision of treat-

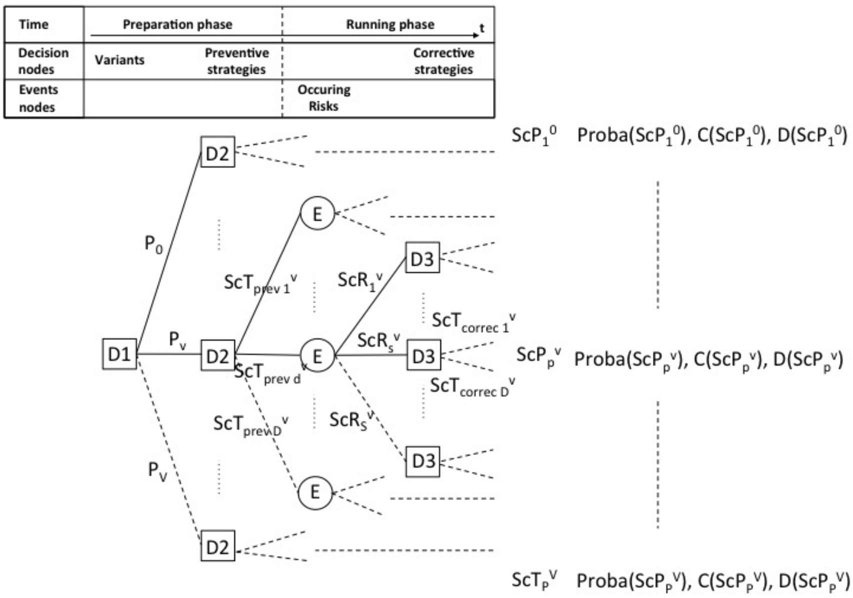


Figure 2: decision tree of the risk project management

ment scenario, (c) the selection of the best project variant following the criteria identified.

In the preparation phase of a project, the technical orientations and the way of managing risks have to be chosen. The approach we propose (Fig. 2) uses data relatives to the project in its classical view: the different tasks planned, the risks, their associated treatment actions. It also uses data relatives to the variants and their modifications: consequences on the tasks and consequently on the risks and treatment strategies. These data are supposed to be collected on the basis of expert knowledge concerned by the project. Therefore, our method includes input data provided by the schedule process (management team) and from the risk management process;

#### 4.2.1 (a) The generation of all the project scenarios for each variants proposed

To evaluate the different possible project scenarios, the management team needs to generate an initial schedule, without integrating the notions of variant, risk and risk treatment. From this initial planning, called *Reference*, for each variant, a planning is realised including the project modifications.

It is then necessary to calculate the different risks and treatment scenarios. These scenarios allow the set of the project scenarios to be constructed. Finally, when the project scenarios are known it is possible to obtain their durations and costs. The approach called ProRisk proposed in (Nguyen et al. 2010) is then used to generate $E_{ScP^v}$. The probability calculation method for each project scenario differs, depending on whether the project scenarios contain, a treatment strategy or not.

For each project scenario, the calculation the probability, the cost and the duration take into account potential modifications induced by the achievement of treatment strategies at the schedule level. Once the initial schedule adapted in accordance with the studied scenario (modified duration, tasks added or removed), the project scenario duration is computed using the PERT method and the earliest starting dates.

#### 4.2.2 (b) The filtration in each project variant of best project scenarios for each preventive treatment scenario

Step (a) of our approach, makes it possible to adopt an opposite way than presented in the classical approach (section 4.1) and then to become proactive. The decisions can be anticipated: $D2$ can be made knowing that for each variant, the best $D3$ and $D1$ can be made knowing the best $D2$.

Two steps consequently compose the filtration phase. $D3$ is the step of filtration of the coherent or pertinent project scenario. The corrective strategies are selected in order to avoid scenarios that would not be possible in the reality, i.e. the scenario where the project is stopped waiting for a corrective action or the scenario presenting a NoGo situation.

$D2$ is the second step that composes the filtration phase. It consists in avoiding the worst possible cases (project scenarios) as defined by the Savage's criterion often used in decision-making theory (Petar 1999). Minimizing the maximum criticity (also called in similar context regret) can, when the assessment of each scenario is known, measure the regret that the decision-maker would have if he had preferred an action over another. A measure of the criticity of each project scenario allows evaluate the project scenarios, knowing the filtrations realized in $D3$. The criticity

calculation is obtained as follows:
Each $PV^v$ presents a set of $ScP_p^v$ and each of them can be characterized by a criticity $Cr(ScP_p^v)$. This criticity measure is based on its probability of occurrence $proba(ScP_p^v)$, and a duration and a cost metrics of the project scenario respectively $\alpha_p^v$ and $\beta_p^v$:

$\alpha_p^v = \frac{DI(ScP_p^v)}{max(DI(ScP_p^v))}$ and $\beta_p^v = \frac{CI(ScP_p^v)}{max(CI(ScP_p^v))}$, $(p = 1...P)$ $(v = 0...V)$

then $\alpha_p^v, \beta_p^v \in [0, 1]$

Where $CI(ScP_p^v)$ and $DI(ScP_p^v)$ are respectively the distance between the Cost and Duration Impacts and the budget and delay thresholds defined in the contractual agreement of the project. $max\left(CI(ScP_p^v)\right)$ and $max\left(CI(ScP_p^v)\right.$ the distance of the costly and longest project scenario possible over the project variant with the defined threshold.

The global impact, weighted and normalised, $Impact(ScP_p^v)$ is then obtained through the following formulae:

$$Impact(ScP_p^v) = q \times \alpha_p^v + q' \times \beta_p^v$$

Where $q$ and $q'$ (respecting $q + q' = 1$) are two coefficients that are chosen by the project manager in accordance with the importance of the duration relatively to the cost.

Then, $\forall v$ and $\forall p, Cr(ScP_p^v) = proba(ScP_p^v) \times Impact(ScP_p^v)$

$D2$ consists in choosing which preventive strategy is the most adequate for each variant. The preventive strategies that minimize the maximal criticity are chosen depending on the filtrations realized in $D3$, for each project variant. For each $ScTprev_s^v$, the maximal criticity $Cr_{max}(ScP_p^v/ScTprev_s^v)$ is obtained by the $ScP_p^v$ associated with the given $ScTprev_s^v$ that presents the maximal $Cr(ScP_p^v)$.

Then, $\forall v$, choose $ScTprev_s^v$ that $min$ $Cr_{max}(ScP_p^v/ScTprev_s^v)$

#### *4.2.3 (c) The selection of the best project variant*

The project management team wants to maximize the chance of meeting the commitments that is modelled in fig. 1 by the zone of agreement. To choose the appropriate Project Variant, $D1$ consists in selecting the variant that maximizes the number of possible $ScP_p^v$ in this area knowing $D2$ for each variant. This methodology and tool are flexible. Statistics are therefore available before the project starts, as well as during the project life-cycle, and take into account the current date and the state of the different risks and tasks.

## 5 A SATELLITE DEVELOPMENT PROJECT BASED CASE STUDY

This approach was applied to the case of the Company X, an anonymous satellite constructor. The aerospace industry, characterized by its continuous technological innovation, has been pressured over the last twenty years. Many potentially more or less good ideas have been developed to meet the requirement of the market. The problem of our industrial partner consists in being able to select new technological solutions by taking into account their repercussion on the existing risks that make the decision tricky.

### 5.1 Presentation of a satellite integration and test project

The different numerical data have been modified accordingly without any impact on the scientific logic of our approach. The probabilities and the risks data have initially been characterized by experts referring to their experiences but were slightly modified.

#### *5.1.1 The different steps to integrate and test a satellite*

Each satellite follows numerous steps from the conception to its launching in space. The phase that is handled here is the integration and test phase. Its particularity is to represent about the half of the total time of the conception, i.e. between 9 and 18 months out of the 24 to 36 months necessary to achieve all the steps. An observation satellite is composed of several modules and each of them is tested to valid its behavior. The different tasks presenting a fixed rate that compose the process studied are detailed in table 1 where the duration is in Time Unit (TU) and the costs in Monetary Unit (MU).

| Phases | Description | Duration (TU) | Cost (MU) |
|---|---|---|---|
| T1 | Material integration | 216 | 16.2 |
| T2 | Initial tests for reference | 27 | 2 |
| T3 | EMC tests | 18 | 1.4 |
| T4 | Thermal vacuum test | 27 | 2.2 |
| T5 | Mechanical tests | 12 | 0.9 |
| T6 | Final Tests for reference | 27 | 2 |
| T7 | Flight | - | - |
| | TOTAL | 327 | 24.7 |

Table 1: detail of the planning phases

#### *5.1.2 The inherent risks and their associated treatment strategies*

Different risks have been identified during the project (table 2). Possible treatment strategies characterizes them (table 3). The impacts of the majority of the risks are judged as $\infty$ since the costs and delays will continually increase until an action is decided.

For an example, the first risk ($R_1$), express the anomaly observed during the material integration on the satellite (error of wiring, systems presenting de-

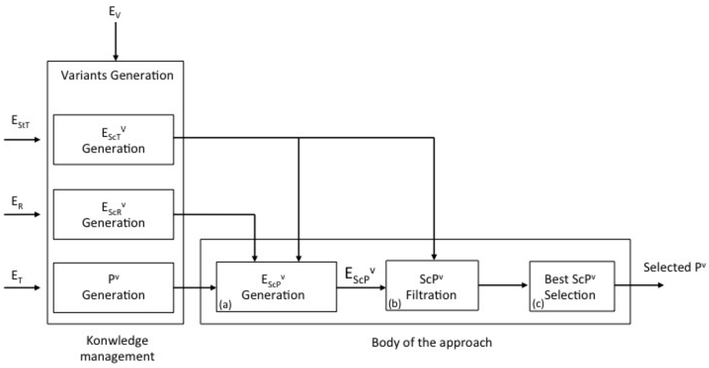


Figure 3: the proposed approach

| Risks | Prob. | Occurence period | Fixe cost impact | Delay impact | Strategies |
|---|---|---|---|---|---|
| $R_1$ | 30% | $T_1$ | $\infty$ | $\infty$ | $StT_{11(p)}$ $StT_{12(c)}$ |
| $R_2$ | 20% | $T_1$ | 10 | 20 | $StT_{21(p)}$ |
| $R_3$ | 25% | $T_2$ | $\infty$ | $\infty$ | $StT_{31(c)}$ |
| $R_4$ | 1% | $T_3$ | $\infty$ | $\infty$ | $StT_{41(c)}$ |
| $R_5$ | 15% | $T_6$ | $\infty$ | $\infty$ | $StT_{51(c)}$ |
| $R_6$ | 6% | $T_6$ | $\infty$ | $\infty$ | $StT_{61(c)}$ |
| $R_7$ | 1% | $T_7$ | $\infty$ | $\infty$ | |

Table 2: risks associated with the project

fault...). $R_1$ is relatively probable since all the failures are recorded. If such a risk occurs, the production is immediately stopped until a strategy is implemented. Then two strategies are possible: a preventive one $StT_{11(p)}$ and a corrective one $StT_{12(c)}$. $StT_{11(p)}$ consists in carefully check critical material at the subcontractor plant by participating to the reviews, auditing etc. If it did not suppress the risks, it reduced its probability of occurrence of 10%. The cost of these actions is estimated to 10 MU for an associated duration that is not located on the critical path. $StT_{12(c)}$ aims to modify the material or the software when problems are observed. Such a strategy costs 5 MU and makes the satellite unavailable for 5 TU. If ($R_1$) occurs even if a preventive strategy has been carried out, it is still possible to develop the corrective strategy. However, only its duration will be pass onto, since the cost will be supported by the suppliers.

| Strategies | Modif. task | Succ. | Dur. (TU) | Total cost (MU) | Reduced probability |
|---|---|---|---|---|---|
| $StT_{11(p)}$ | $T_1$ | $T_2$ | 0 | 30 | 10% |
| $StT_{12(c)}$ | $T_1$ | $T_2$ | 5 | 5 | |
| $StT_{11(p)}$ & $StT_{12(c)}$ | $T_1$ | $T_2$ | 5 | 5 | |
| $StT_{21(p)}$ | $T_1$ | $T_2$ | 5 | 10 | 10% |
| $StT_{31(c)}$ | $T_2$ | $T_3$ | 5 | 2 | |
| $StT_{41(c)}$ | $T_3$ | $T_4$ | 5 | 2 | |
| $StT_{51(c)}$ | $T_6$ | $T_5$ | 5 | 2 | |
| $StT_{61(c)}$ | $T_6$ | $T_5$ | 120 | 12 | |

Table 3: available risk treatment strategies

### 5.2 How to improve the project

In this study, the project management team has to respect contractual commitments. Therefore and in order to improve their practices, different modifications of the structure of their satellite development projects are proposed by experts: the reduction of the tests for references, the suppression of tests for EMC compatibility and the suppression of the final ones. This approach will then be applied to comparatively show the advantage and the risks of each proposition. The phase of the initial tests for reference is composed of global tests and specific ones to each subset of the satellite. However, each equipment is already tested and certified by the retailer. The philosophy of the reduction we propose for theses tests (alternative 1) would then be based on retailers certified equipments. Only then should the global systems be tested, leading to an increase of the failure probability in the phase of final tests for reference (R5). For several years and many projects, the EMC tests did not allow to find major failures. Therefore EMC tests are regularly reduced. Their suppression (alternative 2) would mainly save time, but also increase the possibility of defect during the flight and a failure of the mission. The third proposition consists in planning the mechanical tests before the thermal vacuum test and suppress the final tests (alternative 3). The thermal vacuum will valid the global behaviour of the system and the final reference test could be suppressed. However, the risk of failure during the thermal vacuum test could be more consequent, since the cost of such tests is important. Experts consider that the combination of reduction of the tests for references and suppression of tests for EMC compatibility as potentially pertinent (alternative 4). Table 4 presents such possible alternatives, their consequence on risks and then the different simulations developed in this paper. In this table, NC means No Change (for example the probability may change but not the impact delay) and NoGo means that the project failed since no corrective action was possible once the project launched. As a conclusion, each proposal may significantly improve the project indicators. However, the decrease of the number of trials during the conception phase may lead to an increase of the risks (probability, impacts). To select the project structure that will present the best compromise between efficiency and safety, we propose to analyse the risks impact, focused on costs and delay of such modifications likely to improve the project efficiency.

| Alternatives | Modified Risk | New characteristic Proba/Delay/Cost |
|---|---|---|
| Reference | | |
| 1 | R5 | 30% / NC / NC |
| 2 | R4 transfered to T7 | NC / NoGo |
| 3 | R5 transfered to T4 | R5:15% / 5/ 8 |
| | R6 transfered to T4 | R6:15% / 120 / 48 |
| 4 | R5 | 30% / NC / NC |
| | R4 transfered to T7 | NC / NoGo |

Table 4: repercussion of the modifications

| Variants | Preventive strategies | Nbr ScP | % Pertinents | Criticity max | %Contract respected |
|---|---|---|---|---|---|
| Ref. | ∅ | 972 | 6.5844 | **0.1652** | 31.2500 |
| | StT1 | 1296 | 4.9383 | 0.2409 | 21.8750 |
| | StT2 | 972 | 6.5844 | 0.2107 | 10.9375 |
| | StT1+StT2 | 1296 | 4.9383 | 0.3030 | 0 |
| 1 | ∅ | 972 | 6.5844 | **0.1328** | 35.9375 |
| | StT1 | 1296 | 4.9383 | 0.1947 | 21.8750 |
| | StT2 | 972 | 6.5844 | 0.1703 | 12.5000 |
| | StT1+StT2 | 1296 | 4.9383 | 0.2459 | 0 |
| 2 | ∅ | 648 | 4.9383 | **0.1658** | 34.3750 |
| | StT1 | 864 | 3.7037 | 0.2424 | 25.0000 |
| | StT2 | 648 | 4.9383 | 0.2121 | 12.5000 |
| | StT1+StT2 | 864 | 3.7037 | 0.3057 | 0 |
| 3 | ∅ | 972 | 6.5844 | **0.1399** | 29.6875 |
| | StT1 | 1296 | 4.9383 | 0.1984 | 12.5000 |
| | StT2 | 948 | 6.7511 | 0.1736 | 7.8125 |
| | StT1+StT2 | 1296 | 4.9383 | 0.2441 | 0 |
| 4 | ∅ | 648 | 4.9383 | **0.1319** | **53.1250** |
| | StT1 | 864 | 3.7037 | 0.1945 | 25.0000 |
| | StT2 | 648 | 4.9383 | 0.1702 | 15.6250 |
| | StT1+StT2 | 864 | 3.7037 | 0.2468 | 0 |

Table 5: the results of our approach

### 5.3 Results and discussion

Table 5 presents the results obtained with this approach. The first column shows the different variants introduced in section 5.2. For each variant, the second column gives the possible preventive strategies. For each variant, ∅ means that there is no possible preventive strategy. The third column presents the number of project scenarios containing the previously evoked preventive strategy. The column entitled "% Pertinents" refers to the percentage of pertinent project scenarios. Are considered as non pertinent scenarios, the scenarios in which one or more risks occurred, stopping the project without any corrective strategies despite the presence of possible preventive strategies. We consider that the corrective strategies should have been applied to that case. The next column presents the maximal criticity among the pertinent scenarios. Still, among the pertinent scenarios, the last column shows the percentage of scenarios that respect the contractual commitments (425 TU and 39 MU).

The variant that maximizes the project scenario number in the zone of agreement is presented in bold in the last column of table 5. This result means that by choosing the variant 4 and by applying no preventive treatment strategy, 53% of the pertinent project scenario respects the contractual commitments. Based on these results, the recommendation to the project manager would be simple: choose variant 4 and apply no preventive strategy.

## 6 CONCLUSION

Choose the best strategy in a project structure in the preparation phase of a project is often tricky. Especially when the project should deliver a product presenting technological innovation. If the benefit of such modifications is easy to evaluate, each possible modification of the project structure generates variants with different plannings and different costs and delays but also different risk levels. To estimate the risk level for each project variant, we propose an approach to model and evaluate the impact of risks on the project cost and the schedule cost. This approach uses the synchronized process principle and integrates the repercussion of the project structure modifications on risks and the global risk level. We used the concepts of risk scenario, treatment scenario and project scenario to characterize and evaluate the project variants. We illustrate the principles of our approach illustrated through a case study from the aerospace industry. This methodology analyses the possibles scenarios, evaluates the global risk level and to selects the best treatment scenarios at any time. An estimate of the global risk level of each project variant can be made and gives a vision of the possible scenarios: from the least to the most probable, from the most disastrous to the most optimistic! A software tool has been developed (Java platform). The main perspectives for this research work will be to examine the influence of previously occurring risks on the probability scenarios, but also to integrate human resources constraints in the model, such as the limiting availability that can be shared over several projects or skill, since particular actors can be be assigned/required for specific tasks.

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