Project risk planning in high-tech new product development

Planificación de Riesgos en Proyectos para el Desarrollo de Nuevos Productos de Alta Tecnología

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Abstract

Purpose – The purpose of this paper is to present the implementation and testing of a modified project risk management framework that integrates PMI's framework with Monte Carlo simulation to improve the effectiveness in high-tech new product development (NPD) projects.

Design/methodology/approach – The modified framework considers three bodies of knowledge: project management, risk management, and Monte Carlo simulation to produce an enhance project risk management framework. Its application is shown through a case study.

Findings – Using the integrated framework in a recent case study project and prior NPD projects measures (as benchmarks), it was shown that it could help to enhance risk responses caused by task durations and costs' uncertainties. The framework proved to be better than segregated generic best practices and was key in providing insight to the issue of early project risk assessment.

Research limitations/implications – More experimental replications are required for enhancement effectiveness assertions of the framework, through the application of the framework to similar case studies. Furthermore, this could improve its reliability and soundness.

Practical implications – Future directions for research could include case and empirical studies that include hypothesis's testing, and the integration of optimization procedure for improved NPD project's planning and execution.

Originality/value – This paper outlines a way to close the gap of project risks management planning in NPD's initiatives. It was motivated by a relatively new tendency in exploring integrated frameworks to deal with complex project risks issues.

Keywords Project management, Risk management, New product development, CLADEA-2015

Paper type Research paper

Resumen Estructurado

Propósito – La investigación presenta la implementación y demostración de un esquema modificado de gestión de riesgos para proyectos que integra el esquema propuesto por el Project Management Institute (PMI) con la simulación Monte Carlo para mejorar la eficacia de proyectos de desarrollo de nuevos productos (DNP) de alta tecnología.

Diseño/metodología/enfoque – El esquema modificado considera tres áreas de conocimiento: gestión de proyectos, gestión de riesgos y simulación Monte Carlo, para producir un mejor esquema de gestión de riesgos del proyecto. Su aplicación se demuestra a través de un estudio de caso.

Resultados – Utilizando el esquema integrado en un reciente estudio de caso de un proyecto y previos proyectos de DNP como puntos de referencia, se demostró que el esquema podría ayudar a mejorar las estrategias de respuestas a los riesgos causados por la incertidumbre en la duración de las tareas y costos asociado a estos proyectos. El esquema ha demostrado ser más eficiente que aquellos propuestos como mejores prácticas genéricas, proporcionando un claro entendimiento sobre el tema de la evaluación de riesgos en la fase inicial de proyectos DNP.
Limitaciones/implicaciones – Se requieren más repeticiones experimentales para mejorar la eficacia de las afirmaciones del esquema, a través de su aplicación a estudios de casos similares. Por otra parte, esto podría mejorar su confiabilidad y estabilidad.
Implicaciones prácticas – Futuras investigaciones podrían incluir estudios de casos y estudios empíricos que incluyan pruebas de hipótesis e integración de procedimientos de optimización para mejorar la planificación y ejecución de proyectos de DNP.
Originalidad/valor – El estudio describe una forma de cerrar la brecha en la planificación de gestión de riesgos de proyecto en la industria. Fue motivada por una relativamente nueva tendencia en la investigación de esquemas integrados para hacer frente a asuntos de riesgos en proyectos complejos.
Palabras Claves Gestión de proyectos, Gestión de riesgos, Simulación Monte Carlo, Desarrollo de nuevos productos, CLADEA-2015
Tipo de papel Trabajo de investigación

1. Introduction

During the last two decades, there has been an increasing number of published research on risk management in high-tech product development projects (Hobday, 2000). They showed numerous risk complexities presented in software design and system engineering projects, and in high-tech multi-project programs (Cohen *et al.*, 2014; Gil and Tether, 2011; Midler and Silberzahn, 2008; Söderlund, 2004; Van Der Merwe, 1997). In these projects, risks are caused by uncertain elements within the tasks, tasks' interdependencies, and the project's structure. They manifest in events such as deviations in tasks' durations, cost overruns, and inadequate resources allocations, and could be exacerbated by either internal or external sources (Ferns, 1991; Pellegrinelli, 1997).

Companies planning new product development (NPD) projects, often underestimate these complexities and their potential consequences on their objectives. These projects face a wide variety of risks, hindered in very different ways, among various levels (Zacharias *et al.*, 2008). Their lengthy relative durations, high costs, and the unbalanced requirement of resources makes the risk management process a necessity. On the market side, most new products that reach their targeted marketplace could have a relatively short time-span left based on patent protection expiration, low entry barriers, and substitutes' strengths, creating additional pressures and uncertainties. Therefore, a thorough risk management exercise is needed to prepare for the effects that stemmed from these complexities.

Recent studies have tackled the issue from several angles. For example, setbacks caused by inappropriate dependencies' assumptions and lack of coordination among task's elements have Foster research in the understanding of the role of contracts' on the project's outcomes (Martinelli *et al.*, 2014). The result has been an increase in the number of improved project risk management frameworks that integrate current best practices to tackle these and other project risk management issues.

This paper considers the integration of three bodies of knowledge (project management, risk management, and Monte Carlo simulation) to produce a modified project risk management analytical framework, suitable for NPD projects. It is centered on the risk management framework proposed by the Project Management Institute (PMI) linked to a Monte Carlo simulation procedure for risk assessment to analyzed

NPD project's task elements uncertainties (Elmaallam and Kriouile, 2011; Project Management Institute, 2013). For the purpose of illustration, a case study of an NPD project conducted during 2012-2014 was used. For confidentiality, the name of the company is not revealed and will be referred as "The Company." It contributes to the discussion of improving NPD project management, introducing a framework that considers stochastics behaviors within the tasks' elements and among their dependencies. The presented study might also stimulate and facilitate the progress of such cross-disciplinary best practices discussions.

2. Theoretical background
2.1 Risks
In general, a risk refers to a possible future event that could impact the successful completion of at least one intended objectives. This definition applies to either project and process based initiatives. Most authors in risk management recognized that there is a distinction between the uncertainty and risk, and have provided definitions of both based on a cause-and-effect behavior (Bellos *et al.*, 2004). In the academic literature, risks definitions emphasized stakeholders' attitude toward risk (Chapman and Ward, 1996; Turner and Müller, 2005). Furthermore, professional associations have their particular interpretations that take into account the primary activities of their affiliates. Due to these discrepancies, there is no accepted definition of the term "risk." Therefore, in this study it was: used PMI's risk definition ("[…] an uncertain event or condition that if occurs, has a positive or negative effect on one or more project objectives such as […]"); assumed a distinction of cause-and-effect; and included two other terms, event and issue, to appropriate address numerous concerns during risk's assessment, as have been done by other authors (Mousavi and Gigerenzer, 2014; Rasmussen, 2013; Saunders *et al.*, 2015).

Considering risk as a part of a cause-and-effect process, a cause is related to at least a task element's uncertainty, such as duration, cost, quality inadequacy, resource availability, or task dependencies. In this process view, the risk is the concern that something would not be met or done (or something that could be a lost), and the effect is the consequence. For example, inadvertently a supplier over sighted the quality of a product (the cause); consequently, the production unit that received this product (e.g. parts, components, or services) had to use defectives products (the risk), resulting in a shortfall in the production unit's productivity (the effect). While in this example the discussion only considered one cause and one effect, in reality, a risk might be the product of various causes and generate many effects (see Figure 1).

PMI distinguished between a risk and an issue. The simple distinction is that the former has not happened yet. The latter has already happened and might be the result of an unidentified risk, thus should be addressed at once. In the author's experience, for all practical purposes, an identified high-impact risk should be considered an "issue" if it has a high probability of occurrence. Whatever the case may be, to be a successful project manager, risks have to be proactively planned. This proactive approach

Figure 1.
Cause-and-effect
risk's process

embraces three critical issues: first, it is impossible to account for all risks; second, it is not feasible to respond to all identified risks; and third, risks tend to decrease and impacts to increase as the project progresses (Yeo and Ren, 2009).

2.2 Frameworks
Most risk management frameworks suggest sequential processes to assess, planning, and control hazards. The goal of these frameworks is to provide a set of guidelines based on best practices in the identification, categorization, and prioritization of risks. At this stage, most frameworks recommend using quantitative approaches to understanding further troubling risks. Once these processes has been completed, risk response strategies are recommended based on the likelihood (probability) and severity of consequences (impact) of the risk, some cost-benefit company policy, or some trade-off between risk response requirements and risk potential outcomes (de Carvalho *et al.*, 2015; Guzman and Asgari, 2014). In most cases, these frameworks endorse using quantitative approaches in risk assessment to support the selection of risk response strategies (Guled *et al.*, 2012).

During the last decade, most risk management frameworks has been developed based on ISO 31000:2009 principles and guidelines (D'Ignazio *et al.*, 2011; Preda, 2013; Raydugin, 2012; Wiboonrat, 2011). This standard was published as a generic framework to safeguards a consistent approach to risk management, providing principles, framework, and a process for managing risk in processes and projects, as shown in Figure 2.

Table I shows several studies that have used project risk management frameworks based on ISO 31000:2009. As can be seen, some studies used all processes recommended by the standard (marked with an X). They confirm the lack of consensus regarding what methods should be utilized in a project risk management framework: only risk identification, risk analysis, and risk evaluation were utilized in all studies, and most centered on issues related to durations, costs, and tasks' dependencies.

Risk management in projects has received a distinctive consideration by PMI. It is an integrative sequential process that accompanies a project in its initiation, planning, execution, control, and closure processes: Figure 3 shows the interaction perspective of
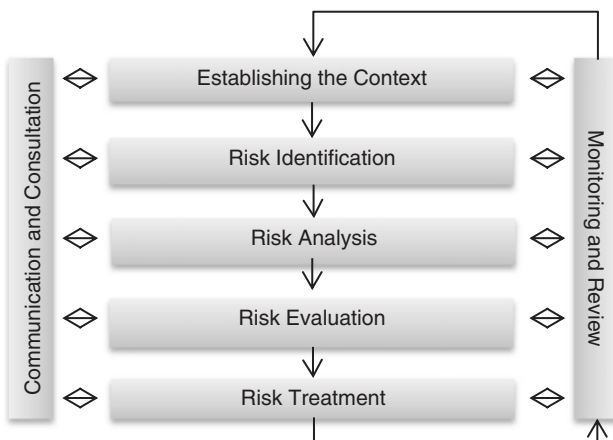
Source: ISO 31000:2009 risk management principles and guidelines

Sample studies	Communication and consultation	Establishing the context	Risk identification	Risk analysis	Risk evaluation	Risk response strategies	Monitoring and review
Oehmen *et al.* (2014)	X	X	X	X	X	X	X
Gangadharan *et al.* (2013)			X	X	X	X	
Perano (2012)	X	X	X	X	X		X
Löhr and Khushnood (2012)	X		X	X	X	X	X
Olechowski *et al.* (2012)			X	X	X		X
Arnold (2013)	X	X	X	X	X	X	
Yashin and Semenov (2013)		X	X	X	X	X	X
Maria-Sanchez (2012)	X		X	X	X	X	

Table I.
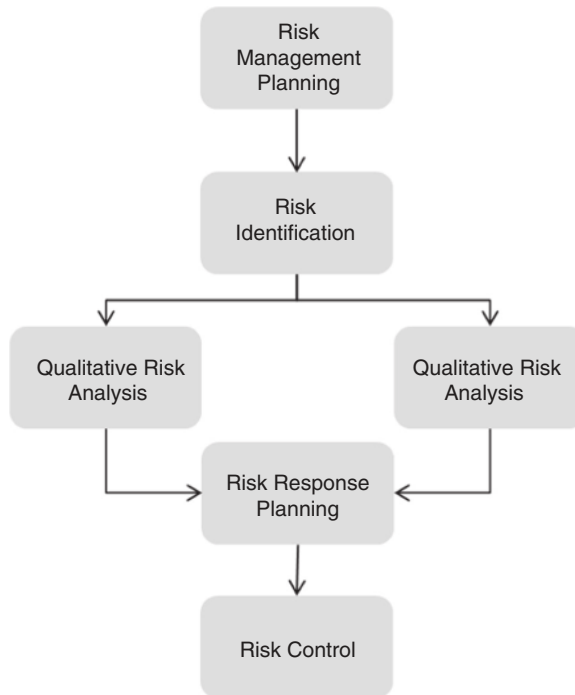ISO 31000:2009 processes in project risk management

Figure 3.
PMI's PMBOK® risk management area of knowledge

these processes. Pekkinen and Aaltonen (2015), Sanz and Bernad Silva (2014), and Too and Weaver (2014) have discussed in detail its implementation. Many formal project risk management frameworks are extensions of PMI's (Carbone and Tippett, 2004; Herroelen, 2014).

Some companies used ad hoc frameworks based on an array of standards, norms, or references, including those shown in the following Table II. Most of these frameworks

Code and name	Publisher	Scope
ISO 28000:2007 – supply chain security management system	International Organization for Standardization	Supply chain
ISO 31000:2009 – risk management (principles and guidelines)	International Organization for Standardization	General (non-specific)
ISO 22301:2012 – societal security business continuity management system	International Organization for Standardization	Business continuity
BSI 259999 and 31100	British Standards Institution (BSI)	Business continuity
Supply chain management framework	Association of Operations Management (APICS)	Supply chain
COSO	Committee of Sponsoring Organizations of the Treadway Commission	Enterprise
ASIS/BSI BCM.01:2010 business continuity management systems: requirements with guidance for use	ASIS and BSI for North America	Business continuity

were developed for business continuity management, supply chain risk management, or enterprise risk management. Therefore, they focus on the organization's primary interest risk management scope and where their operations are more vulnerable. They can be applied to both small and large scale operations, with convenient levels of data requirements.

2.3 Risk identification and categorization

The risk identification process consists of identifying, profiling, and categorizing the potential risk events of the project and their consequences. Methods used in the identification of risks include brainstorming, cause-and-effect (Ishikawa), risk registers of completed projects, and several forms of expert opinion studies. The final selection of a particular identification method will rest on stipulated company policies, project member's expertise, and project's requirements. Once a risk has been identified, it is classified in a designated category for further consideration, accountability, and prioritization.

Although there is no consensus on the subject of project risk categories, some companies use generic categories contingent on the risk origin: internal and external. Because internal risks are based on decisions made by the company they can be better controlled, and in most cases are entrenched within and among project tasks' elements. External risks are caused by external factors like political risks, natural disasters, human factors, and breakdowns in the supply chain, among others. Nevertheless, there is a tendency to view risks in a hierarchical structure depending on the risks sources (Hillson, 2003).

PMI recommends using a risk breakdown structure (RBS) as a categorization scheme. Other PMI's categorizations are based on the work-breakdown-structure (WBS) while others combine the RBS with the WBS and the organizational breakdown structure. Keizer and Vos (2003) suggested the use of the following categories: technology, market, finance, and organization. Financial risks are related to cash flow, commercial viability, inflation, foreign exchange, and insurable resources. Market risks are associated with the customers and potential actions of competitors. Those related to

product design and development, intellectual property, completion time, quality and performance are technical risks, and those related to political instability, attitude of the government toward particular type of projects are organizational (or political) risks. Organization risks are related internal processes, the project team, co-development with external parties, and supply and distribution.

2.4 Risk analysis
Most risk analysis methods fall into two generic categories: quantitative or qualitative. Current practices use a mix of quantitative and qualitative methods and models, but at aggregate level subjective methods are preferred to estimate total risks. Quantitative risk methods are predominantly used when:

- it is essential to improve accuracy of the probability or impact of a risk;
- developing a probability-based performance standards, as is the case when organizations must objectively show that a proposed activity can meet a specified performance standard; and
- regulations, competitiveness goals, legal and compliance constraints, and internal issues require more rigorous measures (Cagliano *et al.*, 2015).

Most quantitative methods (e.g. Monte Carlo simulation, cost risk analysis, decision analysis, value at risk method, earned value analysis, and network analysis) are based on proven scientific theories. Therefore, have been traditionally preferred over qualitative risk techniques (e.g. brainstorming, Delphi method, and scenario analysis), when accurateness is imperative.

After risk analysis, through quantitative and qualitative methods, risk are scaled based on the perceive impact and probability. This binomial is used for risk prioritizing, usually shown using a visual aid like heat-maps or impact-and-probability matrices.

2.5 Response strategies
Once risks have been assessed and prioritized, cost-efficient response strategies are considered. Risk response strategies are expected to lessen adverse risks effects or increase positive risks, in the most effective and practical way. Figure 4 shows the generic strategies suggested by PMI for positive (opportunities) and negative (threats) risks. The particular action requires for responding to a risk will depend upon its nature. Contingent response strategies are those developed to be used in a predefined situation on a particular event, and fallback plans, frequently known as secondary plans, are those response actions that would only be delivered in case that the primary response strategy was ineffective.
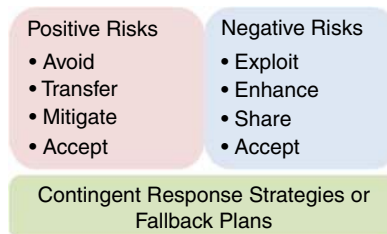
Figure 4.
PMI's generic strategies

In most projects, the preferred generic strategy for high-probability and high-impact risks is avoidance. Risks with low probability and low impact are dealt with mitigation strategies or are not thoughtfully planned for (acceptance strategy). In the latter, if the risk occurs, administrative and budget reserves are often used to confront it. Furthermore, it is often the case to make trade-offs between the cost of implementing a risk response strategy's and the cost of living with it. As shown in Figure 5, response intensity (assigned resources, processes, and budget) should be suitable for each risk, and any deviation from this adequacy could result in a disproportionate risk response.

Concisely, risk prioritization has to be done before a response strategy is chosen. Risk analysts may establish a function for determining a risk level. Traditionally, to determine a risk level, risk analysts use two risk measures: risk probability, and risk impact, as shown below. The response level is an index presenting the intensity of risk response that should be used. Within a simple view, it can determine a response level as the following equation. It should be noted that a negative risk/response level refers to a threat while a risk/response level of a positive value refers to an opportunity:

$$\text{Risk level} = \text{risk probability} \times \text{risk impact}$$

$$= f(\text{risk measures; risk classes weighted factors})$$

$$\text{Total normalized cost} = \frac{\text{response probability} \times \text{response impact}}{\text{intensity of risk response}}$$

Once the total risk response strategy cost has been normalized, its prioritization might change, as illustrated in Figure 6.

3. Methodology

The study presents the application of a modified PMI's project risk management framework to a case study. The framework is instrumental in providing insight to the issue of early medium-high probability and impact risks assessments (see Figure 7). Monte Carlo simulation was used to understand or confirm the impact of risks thought to have the greatest impact on the main project's objectives.
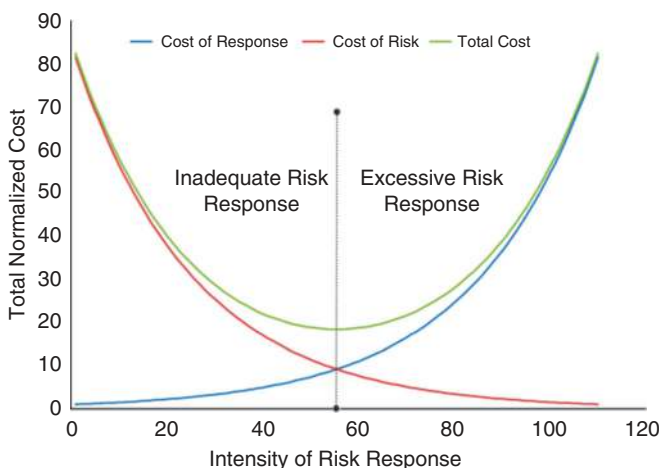

Figure 5.
Cost of risk and
cost of response's
trade-off

The attention was drawn to the case because of the complex nature of NPD projects. The framework provided a useful tool used by project stakeholders to understand better the myriad of risks that can impact an NPD project. This framework uses both qualitative and quantitative techniques, providing a robust framework.

In the study, data were collected from several sources, to understand different aspects of the project at hand. Publicly available documents were reviewed for background information on the events leading up to the decision to venture into The Company's industry and its activities since its establishment. Supporting records provided includes historical data and records of similar project performances over the past decade: in-depth, detailed data on nine projects including risk assessments, categorization, references, and recommendations. Finally, brief semi-structured interviews were conducted with some stakeholders seeking feedback on their experiences with the risk assessment process.
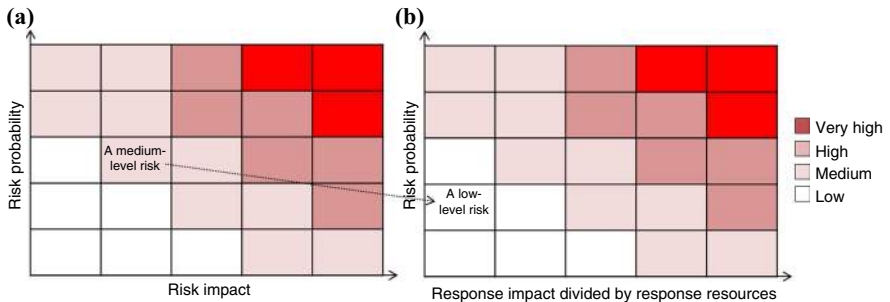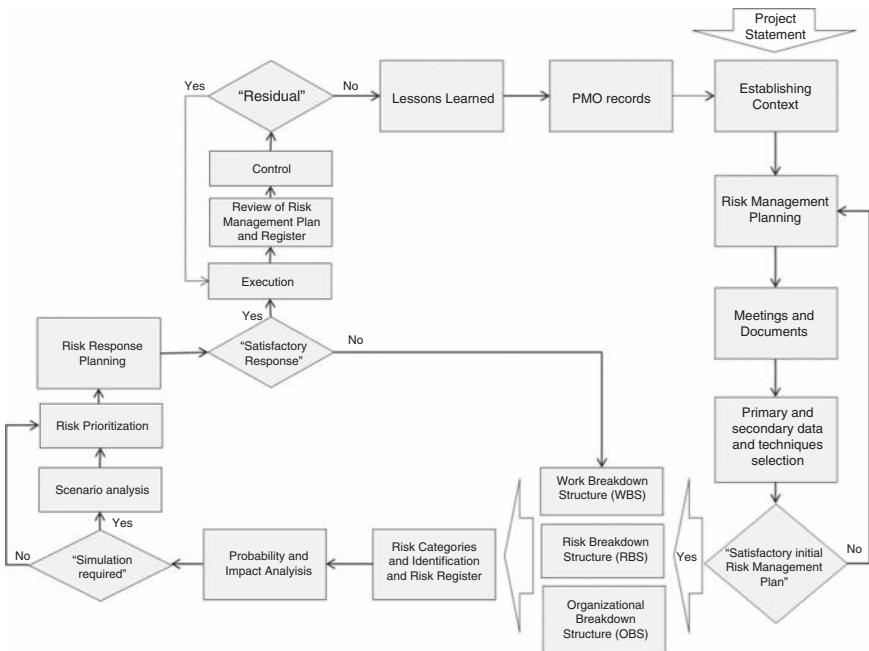

Figure 6.
(a) Risk level and
(b) response level

Figure 7.
Framework for
implementation
projects risk
assessment

4. Case study analysis

4.1 Company setting

The case study concerns a company that needed to expand its production line to compete in a fast-growing high-tech market. Only two companies were servicing the market, with proprietary and patent-protected products, and in 2011 both companies were serving 45 percent of the potential market. The Company had prior experience developing and marketing similar products, but with limited functionalities, which follows its low-cost niche strategy at the time. Each NPD project was structured in four major dependent phases: project administration, technical analysis, the development stage, and commercialization. In most projects, The Company uses these stages as a natural risk category outline. The expectations and project objectives were: that the proposed new product would be able to compete one-on-one with the other companies' products, but at a lower price (using its experience producing low-cost products); complete the project (including commercialization) in less than 1.5 years; overrun costs could not be more than 20 percent of the assigned budget (prior projects had an average overrun of 7 percent); and comply with project's metric baselines. Regarding the latter, these metrics measurements were selected to make some goals clearer, assigned actions, and defined consequences. Some metrics were: percent of requirement deficiencies at qualification testing, number of in-process design changes, number of prototype iterations, percent R&D resources/investment (total of new products plus sustaining and administrative), task completion vs plan, and time-to-market/time-to-volume (Crow, 2001; Vanek *et al.*, 2008).

In the past, The Company risk management process was based on brainstormed lists of risks and response strategies based on the WBS, for each project phase. Each risk was assessed for its probability and impact, and a risk response plan was created. Among other issues, the process lacked an articulate structure and a scoring method for risk prioritization. Fortunately, when the framework was implemented, The Company had institutionalized a more structure risk approach (including risk identification and categorization), as a requirement for ISO 22301 (business continuity) certification. Nevertheless, the project management knew that the scope of the certification focusses more on supply chain management issues (even that some would overlap several project tasks) and was prepared to start digging into risky events and its consequences to the NPD project.

4.2 Risk identification and categorization

The Company was aware of the endemic problem of cost, time-to-market, and tasks' duration escalation on its NPD projects. Cost and duration estimations were complex, and managing the capital development and commercialization of these projects requires the coordination of a multitude of resources: organizational, technical, human, and natural. Being acquainted with these issues, The Company decided to base the risk identification and categorization in the four top-dependent phases mentioned previously.

In the identification process, 32 risks were identified. In all, 13 risks were classified as low-probability/low-impact, and a contingency budget was separated in case a threat materialized: consequently, no specific strategy responses were selected. Eight risks were regular tasks within many of The Company's projects, which were considered "insignificant systematic exposures," and again; no specific strategy responses were selected. In total, 11 tasks have risk's constructs that became the focus of the risk management efforts, which are shown in the following table.

4.3 Risk analysis – Monte Carlo simulation

Table III shows the impact on each of the 11 main risks selected by The Company's project team. These figures were obtained by Monte Carlo simulation performed on the project model using the program @Risk. Historical data were used to estimate the statistical distribution and correlations of all tasks. The observed project's output variables were the NPD project cost and duration. The variation of the output variable with changes in input parameters (the 11 tasks) helped both model validation and interpretation of results. The tornado graph in Figure 8 displays the input risk factors that have the greatest impact on the project's duration. Three other similar analyzes were performed in the other output variables with their corresponding (and pertinent) input variables (accuracy, representativeness, productivity, etc.).

4.4 Risk response strategies

As shown in Figure 8, "inadequate documentation," "product doesn't fit for purpose," and "unreasonable project schedule and budget," have the greatest impact on NPD's

| Category	Task	Risk	Risk elements construct	Probability (1-5)	Impact (1-5)
Administration	Align and confirm marketing strategies	Changing market conditions	Resources	3	4
	Financial assessments	Inadequate metric measures gathering	Duration/accuracy	2	3
	Initial NPD plan	Inadequate documentation	Duration	2	5
	Initial S&OP	Lack of single point accountability	Duration	1	3
Technical	Product prototype process	Product does not fit for purpose	Duration	3	5
	Verify operational capabilities	Inadequate third-party performance	Resources/ productivity	1	3
	Customer product testing	Inadequate test procedure elements	Resources/ representativeness	2	4
Development	Selection of proper customer sample group	Lack of agreed-to user acceptance testing and criteria	Duration/ representativeness	2	3
	Redefine product requirements	Poor production system performance	Duration	2	4
Commercialization	Confirm product specification	Technical limitations of solution reached or exceeded	Duration/accuracy	1	4
	Product capability against competitive response	Unreasonable project schedule and budget	Duration/yield	2	5

Table III.
Risk elements identification
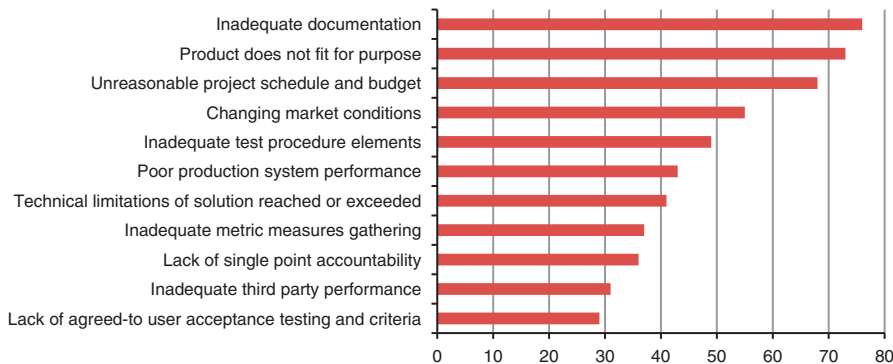
Figure 8.
Risks with the
greatest impact on
project's duration

project duration. On the former, once the causes of this risk were studied, the generic
strategy avoid was chosen. As it happened, this task was delegated mainly to an
"ad hoc" committee composed of personnel that works strictly at the PMO (there were
budget and time control issues behind this decision), triggering a series of difficulties.
Afterward, The Company decided to include this task into the project's team
responsibilities.

"Product doesn't fit for purpose" risk elements were caused by assumptions made at
the beginning of the project that were revised and changed throughout the project
lifetime. If deviations arose, they were managed using administrative (including
technical) reserves, established for this purpose. Suggestions based on changing task
precedences were considered but finally rejected. The impact of "unreasonable project
schedule and budget" was convoluted: squatter actual project schedule could lead to an
increase over the budget (mainly to fast-track several tasks), and vice versa. To prepare
for this task, The Company relies on some procedures: for example, benchmark studies,
actual operation's capabilities, and industry information. The primary concern for The
Company was tying up financial resources by overallocation. The response strategy for
this task's elements was based upon a combination of transfer's risks, using
prearranged excess capacity of third-party companies to buffer any operational
requirement: The Company operates at the expected schedule level and budget. This
strategy implies a contingency reserve in case that risk was triggered. Adequate
response strategies were chosen for other risks elements. All responses costs were
normalized, prior their selection and inclusion in the risk register.

5. Conclusion

Risk management using combined recognized generic frameworks, as PMI's
project risk management, and Monte Carlo simulation provides an effective way for
assessing complex projects' objective outcomes. Such approach leads to an analysis
system where scenarios based on variabilities in task's elements, could trace many
possible consequences: the interaction between cost, schedule, and performance
measures drives the analysis. Risk events are intrinsic in NPD projects, which are based
on some assumptions and estimates that reflect the organization's understanding of the
current situation in the project formulation phase. However, events seldom go according
to plan, so the project must adapt to an ever-changing environment.

The project risk management framework that includes Monte Carlo simulation
provided a systematic process for identifying, analyzing, and responding to project risks.

The modified framework effectiveness was demonstrated through a case study of an NPD project of a high-tech company. The revised framework presented in this study builds upon the existing literature and takes a more analytic approach to risk assessment. Based on similar NPD projects, The Company reduced the uncertainty of the project's duration and cost. Future directions for research could include case studies or empirical studies that could include hypotheses testing, and the integration of optimization procedure for improved NPD project's planning and execution.

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