RISK MANAGEMENT AND POST PROJECT EVALUATION PROCESSES FOR RESEARCH AND DEVELOPMENT PROJECTS

by
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Submitted to the Graduate School of Engineering and Natural Sciences
in partial fulfillment of
the requirements for the degree of
Master of Science

Sabancı University
Spring 2002

RISK MANAGEMENT AND POST PROJECT EVALUATION PROCESSES FOR RESEARCH AND DEVELOPMENT PROJECTS

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ACKNOWLEDGEMENTS

I would like to thank my adviser Prof. Gündüz Ulusoy for his patience, encouragement and considerable time he has spent during the thesis process. I have been very fortunate to have Prof. Ulusoy as my thesis adviser throughout my study at Sabancı University. He devoted considerable time, motivation and energy to me. His discussions, verifications and contributions hopefully made this thesis readable and valuable.

I would like to thank graduate committee members of my thesis, Prof. Ünver Çınar and Dr. Bülent Çatay for their constructive criticism and suggestions on this final work.

I would also like to thank İffet İyigün Meydanlı, Yasemin Kaya İleri, Fatma Komut Sedef and Melda Polat from the R&D department where I have worked on my thesis for nine months. Their contributions and helpful comments enabled me to study efficiently throughout my study.

I also wish to acknowledge all the faculty members, graduate students and other individuals who have contributed to me during the period of my study at Sabancı University. I would like to present my special thanks to my friends Demet Teker, Öykü Oflezer and İsmail Çapar for their help and motivation.

I'm grateful to my family and all my friends for their continuous encouragement and trust.

Finally, I'm grateful to my beloved husband, Emre Merdan Fayda M.D., for his constant love and encouragement, thank you…

ABSTRACT

Project risk management has become a popular subject in the last decade, in parallel with the developments in the field of project management to adopt to the uncertain and changing environment.

Risk management is the systematic process of identifying, analyzing, and responding to project risk. Successful project risk management will greatly improve the probability of project success. It is necessary to learn from risk management activities, for obtaining improvements in the project management process.

The post project evaluation process consists of activities performed by a project team at the end of the project to gather information on what worked well and what did not, so that future projects can benefit from that learning. It aims to find out best practices and documenting “lessons learned”.

Risks are the major part of post project evaluations and vice versa. Learning points are easily identified upon risk issues and the risk management process outcomes may provide insights into the weaknesses in the project management processes. Post project evaluation helps in building a knowledge database on possible risks to be used in risk management process. Historical databases may help to manage the risk checklists, create information for estimations and response strategies.

Ninety-three R&D projects in an R&D Center of a leading manufacturer in Turkey, were analysed to identify the factors that may affect the project performance and to form a risk checklist as an input to the proposed risk management process for the R&D Center. Then, a risk management process and a post project evaluation process

have been designed for the establishment of risk management and organizational learning in the R&D Center.

Quantitative risk analysis techniques are not employed in the proposed process. To demonstrate the use of quantitative risk analysis, a mathematical formulation for the expected value of the total project cost has been described, and a hypothetical example has been modelled and simulated using @Risk, a commercial risk analysis software.

ÖZET

Son yıllarda proje risk yönetimi konusunun popularitesi, belirsiz ve değişken ortama uyum sağlamak amacıyla yaşanan gelişmelere paralel olarak artmaktadır.

Risk yönetimi, proje risklerinin sistematik olarak teşhisi, analizi ve yanıtlanması sürecidir. Başarılı bir risk yönetimi süreci, belirsizliklerin olumsuz etkilerini yumuşatarak proje performansını geliştirecektir. Risk yönetimi faaliyetlerinden proje yönetimi sürecini geliştirmek amacıyla faydalanabilmek için öğrenmeyi sağlamak gereklidir.

Proje sonrası değerlendirme süreci, gelecekteki projelerin öğrenmekle yarar sağlayacağı, iyi yapılan uygulamalar ve gelişmeye açık alanlar hakkında bilgi toplamak üzere bir ekip tarafından proje sonunda yapılan faaliyetlerdir. Projedeki iyi uygulamaları tespit etmek ve öğrenilenleri yazılı hale getirmeyi hedefler.

Riskler, proje sonrası değerlendirmeleri için önemli birer inceleme alanıdır. Öğrenme alanları, riskler ve risk yönetimi süreci çıktıları üzerinden kolaylıkla tespit edilerek proje yönetimi sürecindeki zayıflıklara ışık tutar. Proje sonrası değerlendirme süreci de, riskler konusunda bir bilgi bankasının oluşmasına yardımcı olur. Böylelikle geçmiş verilerin bulunduğu veritabanları kullanılarak risk kontrol listeleri oluşturulabilir, risk analizi için gerekli tahminlerin daha kolay yapılabilmesi sağlanır ve yanıt stratejileri geliştirilmesi kolaylaştırılmış olur.

Bu çalışma kapsamında, Türkiye'de önde gelen bir endüstriyel firmanın Ar-Ge Merkezi'nde yapılmış 93 proje, proje performansını etkilediği düşünülen faktörleri belirlemek ve tasarlanan risk yönetimi sürecine girdi teşkil eden Risk Kontrol Listesi'ni oluşturabilmek amacıyla analiz edilmiştir. Ar-Ge Merkezi'nde risk yönetimi

uygulamaları ve kurumsal öğrenmeyi tesis edebilmek amacıyla risk yönetimi ve proje sonrası değerlendirme süreçleri tasarlanarak firmaya önerilmiştir.

Kantitatif risk analizi teknikleri, önerilen süreçte yer almamaktadır. Kantitatif risk analizinin kullanımını gösterebilmek amacıyla proje maliyetinin beklenen değerini hesaplayan matematiksel bir formülasyon geliştirilmiş ve kurgusal bir örnek proje, @Risk ticarî yazılımı ile modellenerek simüle edilmiştir.

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1. INTRODUCTION

The 1950s and 1960s were years of mass production. During the 1970s, in an attempt to differentiate themselves, companies strove for quality by imposing uniformity and by restricting their product range. In the 1980s, the emphasis shifted to variety. In the 1990s, customers want novelty. Product development times and market windows are shrinking, requiring new products to be introduced quickly and effectively. Rapidly changing technology, fierce competitive markets, and a powerful environmental lobby have all encouraged companies to change their management systems. In this new environment, all managers must manage change through projects and project management (Turner, 1993; Burke, 2000).

The purpose of projects is given by the definition of projects: to deliver beneficial change, by undertaking a unique scope of work, using a novel organization. The change caused by a project will have value only if it meets certain cost and time requirements. Because the organization is novel and the work is done over a limited time, its management is transient. Similarly, because the work is unique, it involves a level of risk, and the expected benefits from doing the project outweigh the risks. Since it can cost more to eliminate those risks rather than the potential damage they might cause, it is more effective to manage them than to eliminate them. Project management, therefore, involves the management of risk. It then has to be subjected to a disciplined regular review and investigative procedure known as risk management. The essential purpose of risk management is to improve project performance defined as meeting the expectations of those involved in the project (effectiveness) without unnecessary expenditure of effort (efficiency), in other words, meeting its schedule and cost objectives while obtaining the defined specifications and satisfying the customer.

When it comes to maintaining the consistency of the performance, there is negligence in project management. It is essential to learn from project successes and failures, both at the technical and the process levels. It is essential to find out the factors that made the management successful, that had a positive impact on the performance, and it is important to codify, disseminate, and improve upon those management practices. Learning will enable us to improve systematically and continuously the management of projects. Therefore, post project evaluation systems geared to learning will provide support to improve the projects' performance.

2. SCOPE OF THE THESIS

This study has been accomplished to serve as a Master of Science thesis at Sabancı University Engineering and Natural Sciences Faculty Industrial Engineering Graduate Program, and as a process improvement project in the Research and Development Center of a leading manufacturer in Turkey.

It is very important to prevent valuable information escape, especially in the Research and Development (R&D) departments where the information is created by adding building blocks of past experience. This company captures most of the technical information by technical reports, but the management side of the projects needs to be realized by means of organizational learning. For this reason, this project has been defined to develop a systematic process to evaluate projects after their completions.

The objective of the project has been defined initially as the development of a post project evaluation system, an analysis of past projects accomplished in the R&D Center, and the design of a database structure which can be used in project planning and monitoring with the help of the parameters found as analysis results. During the initial phase of the project, risk management issues emerged as the main focus point in post project evaluation for organizational learning. Since there is no defined risk management process in the R&D Center, it would be hard to capture the data about the risk issues in the future projects. Therefore, it has been decided to design a risk management system as well. So, the objective of the project is reformulated to be the analysis of the current system and the design of risk management and post project evaluation systems, to fulfil the need for improving project management and organizational learning.

At the beginning of the project, a literature review was conducted. Then, the data of the projects executed and finished during 1994-2001 in the R&D Center were collected. After the verification of the data, analyses explained in chapter 4 have been executed. The systems analysis and design of the new processes with their necessary tools follow these analyses. Because risk management is integrated into the planning phase of the projects, in the flow of the thesis, it is explained before the post project evaluation system, which is integrated into the closeout phase.

3. RELATED LITERATURE

3.1. Project Risk Management[1] Literature

3.1.1. What Is Risk?

3.1.1.1. Definition

"Risk is exposure to the possibility of economic or financial loss or gain, physical damage or injury, or delay, as a consequence of the uncertainty associated with pursuing a particular course of action" (Cooper and Chapman, 1987).

The subject, of risk as a project management issue, first appeared in Project Management Institute's (PMI) 1987 edition of Project Management Body Of Knowledge (PMBOK). For the most of the part, risk has been interpreted as being unsure about project risk duration and / or costs, but uncertainty plagues all aspects of the work on projects and is present in all stages of project life-cycles (Meredith and Mantel, 2000).

Project risk is an uncertain event or condition that, if it occurs, has a positive or negative effect on a project objective (PMBOK®Guide, 2000). It is also a measure of the probability and consequence of not achieving a defined project goal (Kerzner, 2001). A risk has a cause and, if it occurs, a consequence. Project risk includes both threats to the project's objectives and opportunities to improve on those objectives. It has its origins in the uncertainty that is present in all projects. Known risks are those that have been identified and analyzed, and it may be possible to plan for them. Unknown risks cannot be managed, although project managers may address them by applying a general contingency based on past experience with similar projects.

3.1.1.2.Classification

It is possible to classify risks based on different aspects. A broad classification can be made as:

Internal Risks: Risks that are under the control of the project team like resource assignments, cost estimates, etc.

External Risks: Risks that remain out of the project team's control like government decisions, changes in technology or market, etc.

The PMI explain risk categories as (Kerzner, 2001):

External-unpredictable: Government regulations, natural hazards and acts of God.

External-predictable: Cost of money, borrowing rates, raw material availability.

Internal (non-technical): Labor stoppages, cash flow problems, safety issues, and health and benefit plans.

Technical: Changes in technology, changes in the state of the art, design issues, operations/maintenance issues.

Legal: Licenses, patent rights, lawsuits, subcontractor performance, contractual failure.

Another breakdown structure for risks can be as follows (Chapman,2001):

Environment- Changes in legislation, public enquiry, inflation, and changes in rates of exchange.

Industry- Change in end value in market, increase in competition, change in demand, cost of raw materials, availability of raw materials, innovation by competitor, etc.

Client – Client representative does not allow adequate time to the project; changes in client representative; responsibilities of the client team ill defined; inadequate project management controls; incorrect balance of resources and expertise; responsibilities of team ill defined; project objectives ill defined; project objectives changed mid design; timing of availability of funds does not match cashflow forecasts; client does not accept change control procedure, etc.

Project – Poor team communication, changes in core team, incompatibility of professional staff, inadequate resource allocation due to low fee, late cost checks on design, lack of change control, etc.

In addition to the classifications above, many different approaches and classifications can be found in the literature (Kerzner, 2001; Ansell and Wharton, 1992;

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[1] From now on, the terms risk management and project risk management are used synonymously.

Webb, 1994; Royer, 2000; Elkington and Smallman, 2002; Lester, 2000; Miller and Lessard, 2001).

3.1.1.3. Sources of risk

Many of the really serious project risks are late realisations of unmanaged risks from earlier project stages. A situation where the objectives of a project change imprecisely during the project without proper recognition of the new situation implied is particularly risky (Chapman and Ward, 1997).

The need for analysis is particularly apparent when projects involve large capital outlays; unbalanced cash flows, requiring a large proportion of the total investment before any returns are obtained; significant new technology; unusual legal, insurance or contractual arrangements, important political, economic or financial parameters; sensitive environmental or safety issues; stringent regulatory or licensing requirements (Cooper and Chapman, 1987).

Inherent in all risky situations are three identifiable determinants: *lack of control, lack of information, and lack of time.* If we had complete control over the situation, we could determine the best outcome and there would be no risk. But events are uncontrollable for a variety of reasons. These can be determined by nature, caused by other people or caused by lack of suitable resources. In order to control a risky situation, we need information on which to base our control actions. In other words, we will have lack of control whenever we lack information or time.

If we had complete information about which event will occur, we could select the best alternative based on this knowledge and again there would be no risk. Lack of experience, information possessed by other parties, uncertainty, and lack of time can be counted as reasons for lack of information. Sometimes information can be available to be acquired from experts in some situations but there are problems like reliability and cost.

Again, if we had unlimited time to choose an alternative, we could wait until the outcome of the uncertain event was resolved and then choose the best alternative after the fact. This scenario also involves no risk. But this is not possible in the real life (MacCrimmon and Wehrung, 1986).

3.1.2. What Is Risk Management?

3.1.2.1. Definition and purpose

With projects, the luxury of ignoring the risks cannot be permitted. Because the projects are inherently unique and often incorporate new techniques and procedures, they are risk prone and risk has to be considered from the start. It then has to be subjected to a disciplined regular review and investigative procedure known as risk management (Lester, 2000).

Risk management is the systematic process of identifying, analyzing, and responding to project risk. It includes maximizing the probability and consequences of positive events and minimizing the probability and consequences of adverse events to project objectives (PMBOK®Guide, 2000).

Risk management process is used to identify and handle the risks on their project, by project teams. It covers the needs of the project team to proactively manage their project (http://www.dir.state.tx.us/eod/qa/risk.htm).

The aim of devoting attention to risk management is to achieve better and more reliable outcomes from projects and business activities. To do this, it is necessary to understand where the major risks lie and the priority they deserve in amongst all the other demands on your resources and establish realistic budgets, targets, and contingencies for commercial contracts and internal performance agreements (Grey, 1999). The essential purpose of risk management is to improve project performance via systematic identification, appraisal, and management of project-related risk (Chapman and Ward, 1997).

3.1.2.2. The risk management process

There are different approaches to risk management process in the literature. But the main steps including risk assessment, risk response development and risk monitoring and control are common in most cases (PMBOK®Guide, 2000; Murray, 1998; Kuver, 2000; Chapman and Ward, 1997; Webb, 1994; Ward, 1999; Raz and Michael, 2001; Royer, 2000; http://www.dir.state.tx.us/eod/qa/risk.htm).

An overview of the major processes given in PMBOK can be described as in Table 3.1:

Table 3.1 An overview of the major processes in risk management

<table>
<tr><th colspan="3">Step</th><th>Statement</th></tr>
<tr><td rowspan="4">Risk Assessment</td><td colspan="2">Risk Management Planning</td><td>deciding how to approach and plan the risk management activities for a project.</td></tr>
<tr><td colspan="2">Risk Identification</td><td>determining which risks might affect the project and documenting their characteristics.</td></tr>
<tr><td rowspan="2">Risk Analysis</td><td>Qualitative Risk Analysis</td><td>performing a qualitative analysis of risks and conditions to prioritize their effects on project objectives.</td></tr>
<tr><td>Quantitative Risk Analysis</td><td>measuring the probability and consequences of risks and estimating their implications for project objectives.</td></tr>
<tr><td colspan="3">Risk Response Development</td><td>developing procedures and techniques to enhance opportunities and reduce threats to the project's objectives.</td></tr>
<tr><td colspan="3">Risk Monitoring and Control</td><td>monitoring residual risks[2], identifying new risks, executing risk reduction plans, and evaluating their effectiveness throughout the project life cycle.</td></tr>
</table>

The implementation of the risk management process does not need to be a big formal deal. In fact, on small projects, it may be determined that the best process calls for an agenda item called risk to be added to daily team meetings. The important thing here is to put some structure into managing risk. While the biggest benefit of risk management occurs during the initial project planning phase, it is important to continue to process throughout the entire project life cycle (Kuver, 2000).

[2] Residual risks are those that remain after avoidance, transfer, or mitigation responses have been taken.

3.1.2.2.1. Risk assessment

Risk assessment is the problem definition stage of risk management, the stage that identifies, analyzes, and quantifies program issues in terms of probability and consequences, and possibly other considerations (e.g. the time to impact). It is often a difficult and time-consuming part of the risk management process. Despite its complexity, risk assessment is one of the most important phases of the risk management process because the calibre and quality of assessments can have a large impact on program outcomes (Kerzner, 2001).

A complete risk assessment process consists of the following parts (Vose, 2000):

1. Identification of the risk that is to be analysed and potentially controlled.
2. A qualitative description of the risk: why it might happen, those things that would make it more or less likely to occur or make the subsequent impact larger or smaller, what one might do to reduce the risk efficiently, etc.
3. A semi-quantitative or quantitative analysis of the risk and the associated risk management options that are available in order to determine the optimal strategy for controlling that risk.
4. Implementing the approved risk management strategy.
5. Communicating the decision and its basis to the various stakeholders. The risk communication stage may also include considerable communication with the stakeholders at each stage in the whole process. Keeping stakeholders informed of why and how a risk assessment is being done and seeking their comments at each stage goes some way to ensuring that there will be acceptance of the final decision.

These steps can be grouped as main components of assessment, identification, and analysis, which are performed sequentially with identification being the first step (Kerzner, 2001; Conrow and Shishido, 1997).

3.1.2.2.1.1. Risk identification

Risk identification is the process by which the perception of a potential problem is translated into recorded information (Murray, 1998). Risk identification is generally done as part of a feasibility study, at the beginning of the active project work, and at each new phase of a large project. The process of identification is assisted by use of risk checklists that capture indicators of commonly encountered risks (http://www.dir.state.tx.us/eod/qa/risk.htm).

Risks can be identified by two major techniques: experience-based and brainstorming-based risk assessment. The impact of unmitigated risks encountered in past projects are imprinted indelibly in the psyche of the project manager and will be remembered in future projects. Why isn't this knowledge resource more readily available to the new project manager? Specific techniques in risk identification can include the formulation of checklists based on experience of earlier projects; the new project can then be examined against the list and an opinion formed about each point raised. Nevertheless, even if organizational culture minimizes the importance of project closure reviews, project managers should take it upon themselves to document their risk management experiences during the projects and proactively share them with other project managers. This experience can form the beginning of a project risk checklist to aid in examining potential project risks and prior mitigation and contingency plans (Royer, 2000; Webb, 1994).

The first step of risk identification is understanding what the project objectives are, which are commonly time, cost, and quality. The second step is the selection of the core design team or principal designers from the project team who are to participate in the identification and assessment of the risks facing the project. The third step in assessing risk involves identifying as exhaustively as practicable the risks associated with each activity and documenting what is involved (Chapman, 2001).

Records of previous project results can be used as objective sources to identify risks. These may include current performance data; organized lessons learned that describe problems and their resolutions. Experiences based upon knowledgeable experts can be gained by interviews as subjective sources to identify risks (Kerzner, 2001; PMBOK®Guide, 2000).

Common tools and techniques for risk identification are checklists, brainstorming, periodic risk reporting, experienced judgement, risk indicator scales, probability-impact calculations, probabilistic modelling, documentation reviews, information gathering techniques (brainstorming, Delphi, interviewing, SWOT analysis), diagramming techniques (cause-and-effect diagrams, system or process flowcharts, influence diagrams). (Grey, 1999; PMBOK® Guide, 2000; Raz and Michael, 2001; Royer, 2000).

3.1.2.2.1.2. Risk analysis

The principal contribution of risk analysis is to focus the decision-maker's attention on understanding the nature and extent of the uncertainty associated with some variables used in a decision-making process (Meredith and Mantel, 2000).

The identified risks are analyzed to establish the risk severity and project exposure for each risk and to determine which risk items are the most important ones to address. Impact and likelihood are combined within the risk matrix to provide a measurement of risk severity. Risk exposure is defined as the product of the likelihood that the risk will occur and the magnitude of the consequences of its occurrence. Adding to the complexity of the analysis is the need not only to anticipate unintended eventualities and determine appropriate responses, but also to contemplate unintended outcomes from the responses. Clearly there is no limit to the potential depth of the analysis in contingency planning and risk reduction. In most cases, though, attacking the most significant of the risk items will maximize the project opportunity (Wharton, 1992; http://www.dir.state.tx.us/eod/qa/risk.htm).

Risk analysis can provide benefits including (Cooper and Chapman, 1987):

- Better and more definite perceptions of risks, their effects on the project, and their interactions.
- Better contingency planning and selection of responses to those risks, which do occur, and more flexible assessment of the appropriate mix of ways of dealing with risk impacts.
- Feedback into the design and planning process in terms of ways of preventing or avoiding risks.
- Feed forward into the construction and operation of the project in terms of ways of mitigating the impacts of those risks, which do arise, in the form of response selection and contingency planning.
- Following from these aspects, an overall reduction in project risk exposure.
- Sensitivity testing of the assumptions in the project development scenario.
- Documentation and integration of corporate knowledge which usually remains the preserve of individual minds.

- Insight, knowledge, and confidence for better decision making and improved risk management.

Qualitative risk analysis

Following risk identification, qualitative risk analysis enables an organization to estimate the probability of a risk event occurring, and the potential impact of the risk on the program. Qualitative risk analysis is the process of assessing the impact and likelihood of identified risks. This process prioritizes risks according to their potential effect on project objectives. Without this assessment, a project manager can waste time on risks that may be of little importance to the project, or fail to give sufficient attention to significant risks. More significant risks will be subjected to quantitative assessment of their impact on program cost, schedule, and performance (Murray, 1998; PMBOK®Guide, 2000; Graves, 2000).

Risk probability and risk consequences may be described in qualitative terms such as very high, high, moderate, low, and very low. Risk probability is the likelihood that a risk will occur. Risk consequence is the effect on project objectives if the risk event occurs.

A matrix may be constructed that assigns risks ratings to risks or conditions based on combining probability and impact scales (An example for this matrix can be seen in Table 3.2). Risks with high severity (high probability and high impact) are likely to require further analysis including quantification.

Table 3.2 A risk matrix (Royer, 2000)

Likelihood \ Impact	Low	Moderate	High
High	2	2	3
Moderate	1	1	2
Low	0	1	2

3 mitigation strategy and detailed contingency plan
2 mitigation strategy and outlined contingency plan
1 mitigation strategy
0 treat as a project assumption

Assessing risk probability may be difficult because expert judgement is used, often without benefit of historical data (PMBOK®Guide, 2000; Graves, 2000).

Quantitative risk analysis

The quantitative risk analysis process aims to analyze numerically the probability of each risk and its consequence on project objectives, as well as the extent of overall project risk. This process uses quantitative techniques to:

- Determine the probability of achieving a specific project objective.
- Quantify the risk exposure for the project and determine the size of cost and schedule contingency reserves that may be needed.
- Identify risks requiring the most attention by quantifying their relative contribution to project risk.
- Identify realistic and achievable cost, schedule, or scope targets.

This process uses techniques such as sensitivity analysis, probability analysis, Monte Carlo simulation, and decision analysis (Cooper and Chapman, 1987).

Quantitative risk analysis generally follows qualitative risk analysis. It requires risk identification. The qualitative and quantitative risk analysis processes can be used separately or together.

When estimating impacts, however, it is often necessary to have a set of response decision rules in order to arrive at consistent quantification. This will depend very much on the orientation of the particular project, i.e., whether it is primarily scope, quality, time or cost driven (Wideman, 1992).

Perhaps the most contentious aspect of risk analysis is the estimation of probability distribution, due to the scarcity of relevant data. Information on prior, similar completed projects, studies of similar projects by risk specialists and risk databases that may be available from industry or proprietary sources and expert judgement from the experts in the organization or from others outside the organization provide valuable input for quantitative analysis (PMBOK®Guide, 2000).

Tools and techniques that can be used in quantitative analysis are interviewing, sensitivity analysis, decision tree analysis, and simulation.

Interviewing techniques are used to quantify the probability and consequences of risks on project objectives. The information needed depends upon the type of probability distributions that will be used. For instance, information would be gathered on the optimistic (low), pessimistic (high), and the most likely scenarios if triangular distribution is used. Continuous probability distributions are usually used in quantitative risk analysis. Distributions represent either the probability or the consequences of the project component. Common distribution types include the uniform, normal, triangular, beta, and log normal. These distributions' structure and the information needed to shape them are easily understood and the estimations can be made easily. Therefore, they are widely used.

Sensitivity analysis helps to determine which risks have the most potential impact on the project. It examines the extent to which the uncertainty of each project element affects the objective being examined when all other uncertain elements are held at their baseline values. It can be performed as a part of simulation study.

Decision tree analysis describes a decision under consideration and the implications of choosing one or another of the available alternatives. It incorporates probabilities of risks and the costs or rewards of each logical path of events and future decisions. An example of a decision tree analysis can be seen in Figure 3.1. In this example, it is assumed that the response strategies decrease the probability of occurrence for the risks. Further examples can be found in Dey (2002).

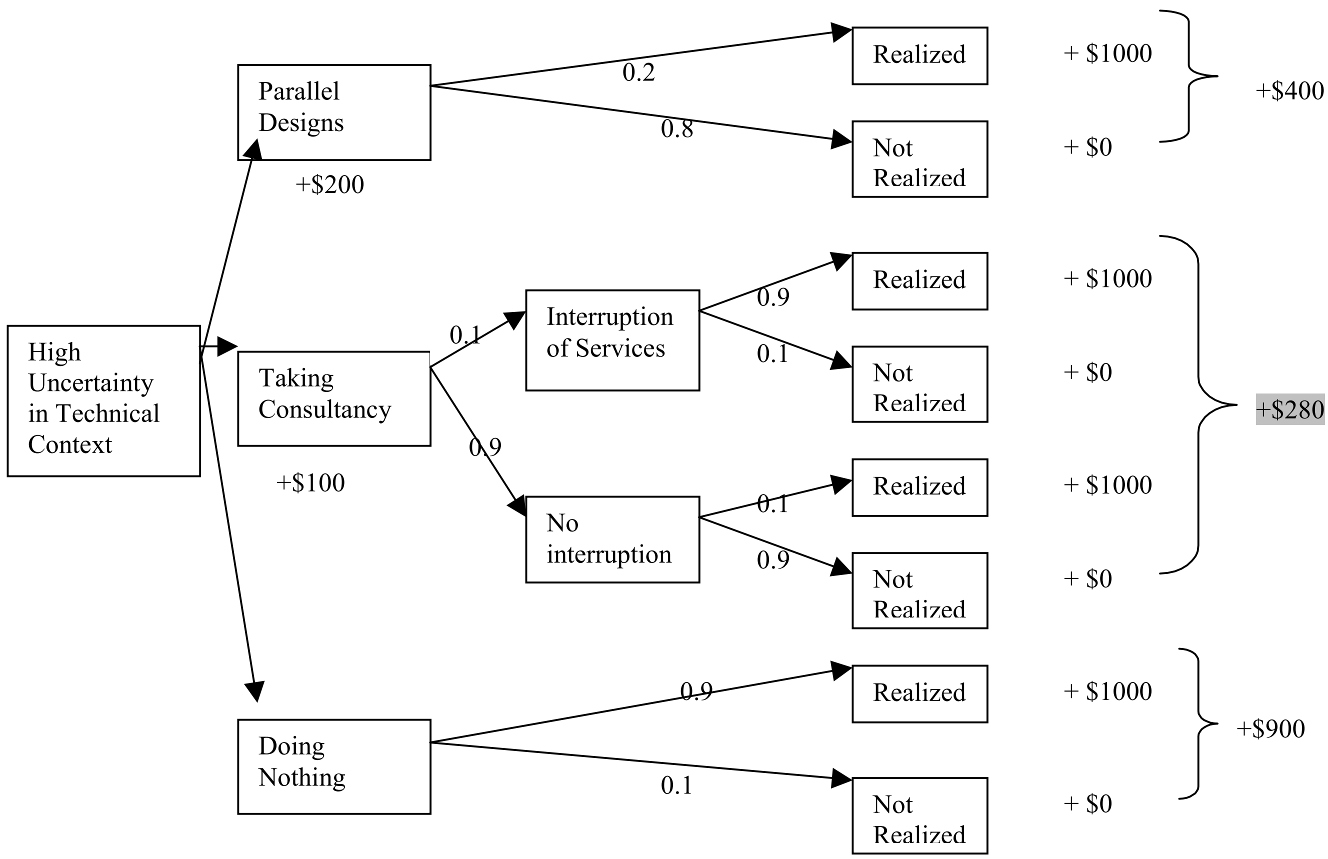

Figure 3-1 Decision tree analysis

A project simulation uses a model that translates the uncertainties specified at a detailed level into their potential impact on objectives that are expressed at the level of the total project. Project simulations are typically performed using the Monte Carlo technique.

3.1.2.2.2. Risk response development

To truly take risk management off the shelf and deliver bottom-line impact, responses must be developed to the threats represented by the identified risks. Risk response development is the process of developing options and determining actions to enhance opportunities and reduce threats to the project's objectives. Risk responses must be appropriate to the severity of the risk, cost effective in meeting the challenge, timely to be successful, realistic within the project context, agreed upon by all parties involved, and owned by a responsible person (PMBOK®Guide, 2000; Murray, 1998).

Risks may be handled a number of different ways. Alternatives include (Elkington and Smallman, 2002; PMBOK®Guide, 2000; Royer, 2000; Murray, 1998; Lester, 2000; http://www.dir.state.tx.us/eod/qa/risk.htm):

- *Avoidance:* Changing the project plan to eliminate the risk or condition or to protect the project objectives from its impact. Some risk events that arise early in the project can be dealt with by clarifying requirements, obtaining information, improving communication, or acquiring expertise.
- *Transference:* Seeking to shift the consequence of a risk to a third party together with ownership of the response. Transferring the risk simply gives another party responsibility for its management, it doesn't eliminate it. If a customer or partner is better able to handle the risk, this is probably the most effective approach.
- *Mitigation:* Mitigation seeks to reduce the probability and / or consequences of an adverse risk to an acceptable threshold. Taking early action to reduce the probability of a risk's occurring or its impact on the project is more effective than trying to repair the consequences after it has occurred. Risk mitigation may take the form of implementing a new course of action that will reduce the problem- e.g., adopting less complex processes, conducting more seismic or

engineering tests, or choosing a more stable seller. It may involve changing conditions so that the probability of the risk occurring is reduced, – e.g., adding resources or time to the schedule. It may require prototype development to reduce the risk of scaling up from a bench-scale model.

- *Acceptance:* This technique indicates that the project team has decided not to change the project plan to deal with a risk or is unable to identify any other suitable response strategy. Active acceptance may include developing a contingency plan to execute, should a risk occur. Passive acceptance requires no action, leaving the project team to deal with the risks as they occur. Acceptance is appropriate when the cost of mitigating exceeds the exposure and the exposure is acceptable.

A contingency plan is applied to identified risks that arise during the project. Developing a contingency plan in advance can greatly reduce the cost of an action should the risk occur. Risk triggers, such as missing intermediate milestones, should be defined and tracked. A fallback plan is developed if the risk has a high impact, or if the selected strategy may not be fully effective (PMBOK®Guide, 2000; Royer, 2000; Murray, 1998; Lester, 2000; http://www.dir.state.tx.us/eod/qa/risk.htm).

Hillson (2002) suggested that opportunities should be managed as well as risks. Extending the risk process to manage opportunities is possible by maximising the probability and positive impacts of these uncertainties. In this approach, avoidance strategy becomes “exploit” to make the opportunity definitely happen, transfer strategy becomes “share”, mitigation strategy becomes “enhance”, and acceptance strategy becomes “ignore”. But this is not the subject of this study and given here only to point out different approaches in risk management and response strategies.

The risk response plan should include some or all of the following (PMBOK ® Guide, 2000):

- Identified risks, their descriptions, the areas of the project affected, their causes, and how they may effect project objectives.
- Risk owners and assigned responsibilities.
- Results from the qualitative and quantitative risk analysis processes.
- Agreed responses including avoidance, transference, mitigation or acceptance for each risk in the risk response plan.

- The level of residual risk expected to be remaining after the strategy is implemented.
- Specific actions to implement the chosen response strategy.
- Budget and times for responses.
- Contingency plans and fallback plans.

After developing mitigation and contingency strategies for the risks, it becomes the responsibility of the project manager and the assigned accountable person to provide continuous monitoring and risk status evaluation. For effective monitoring, a success measurement for the mitigation strategy and a triggering event that identifies when the contingency plan must be invoked needs to be identified (Royer, 2000).

3.1.2.2.3. Risk monitoring and control

Risk monitoring and control is the process of keeping track of the identified risks, monitoring residual risks and identifying new risks, ensuring the execution of risk plans and evaluating their effectiveness in reducing risk. Risk monitoring and control is an ongoing process for the life of the project.

The purpose of risk monitoring is to ensure that mitigation actions are keeping the risks under control and monitor indicators to know when to invoke contingency plans. Risk control may involve choosing alternative strategies, implementing a contingency plan, taking corrective action or replanning the project.

Risk monitoring and control can be executed by project risk response audits or periodic risk reviews. Project managers regularly review and update the status for each risk to ensure risks are under control, revise the mitigation action or get approval to proceed with the associated contingency plan, update and publish the current top risk list, and prepare a risk status report for use in project reviews. Tools and techniques for risk monitoring and control can be one or more of the following:

Project risk response audits: Risk auditors examine and document the effectiveness of the risk response in avoiding, transferring, or mitigating risk occurrence as well as the effectiveness of the risk owner.

Periodic project risk reviews: Project risk reviews should be regularly scheduled. Project risk should be an agenda item at all team meetings. Risk ratings and prioritization may change during the life of the project. Any changes may require additional qualitative or quantitative analysis.

Earned value analysis: Earned value is used for monitoring overall project performance against a baseline plan. This analysis involves calculating three key values for each activity. The planned value is the approved cost estimate planned to be spent on the activity during a given period. The actual cost is the total of costs incurred in accomplishing work on the activity during a given period. The earned value is the value of the work actually completed. Results from an earned value analysis may indicate potential deviation of the project at completion from cost and schedule targets.

Technical performance measurement: Technical performance measurement compares technical accomplishments during project execution to the project plan's schedule of technical achievement. Deviation, such as not demonstrating functionality as planned at a milestone, can imply a risk to achieving the project's scope.

Additional risk response planning: If a risk emerges that was not anticipated in the risk response plan, or its impact on objectives is greater than expected, the planned response may not be adequate. It will be necessary to perform additional response planning to control the risk.

At the end of the phase, risk exposures for the risks to the project are at or below the level agreed as acceptable for this project. When the risks are no longer considered a threat, the risk owner closes the risk with a lessons learned analysis. This introduces the risk documentation phase in accordance with the post project evaluation. These lessons should be recorded in the risk database for retrieval as needed. This approach enables an organization to gain multiple payback for its risk management activities and can act as a catalyst for continuous organizational improvement (PMBOK® Guide, 2000; Wideman, 1992; Murray, 1998; http://www.dir.state.tx.us/eod/qa/risk.htm).

3.1.2.3. Benefits of risk management

The experiences of many organisations suggest a risk management approach to provide many benefits, which may prove far more important in long term (Cooper and Chapman, 1987). Systematic risk management provides better control of uncertainty. It forces to concentrate on actions to control the risk and assess the cost benefit of such actions. Risk management clarifies the objectives and refines the project brief. When setting the project objectives, systematic risk management helps to recognise the importance of any constraints and to assess their impacts on the project.

Risk management process entails the early prioritization of risks. It can be ensured that the limited resources are concentrated on the major risks to achieve maximum effect. It helps to reduce the cost of risk by clarifying and making the risks explicit. A systematic approach which focuses on risk issues at an early stage is more likely to have high cost benefit and is therefore recommended from inception, through successive project phases, to completion and beyond. (Cooper and Chapman, 1987; Chapman and Ward, 1997; http://www.dir.state.tx.us/eod/qa/risk.htm).

3.1.2.4. Drawbacks in risk management

Probabilistic approaches are used in risk management and these include the following limitations (Pender, 2001):

- Probability theory is based on the assumption of randomness, whereas projects deal with consciously planned human actions that are generally not random.
- Projects are unique by definition. This reduces the relevance and reliability of statistical aggregates derived from probability-based analysis.
- Probability theory assumes future states are known and definable, however uncertainty and ignorance are inevitable on projects. Especially with regard to human actions, the future is fundamentally unknowable.
- Because uncertainty and ignorance exist, temporal aspects of the flow of knowledge are important in project planning. Probability theory is based on a two-period (the present and the future) model that ignores the flow of knowledge over time. At time period one, analysis of future states and their probability distributions lead to a rational plan of action that maximises expected positive outcomes. The plan is then implemented and the predicted consequences of the plan are realised at time period two. This model falsely implies that the role of a project manager is limited to analysis and planning.
- Project parameters and outcomes must be communicated to others and the imprecision of our language is not encompassed in probability theory.

Risks cannot be easily identified in most cases. The causes and the impacts of a risk can be easily confused with the risk itself (Hillson, 2000). For example, problems in the integration of a system can be a risk, caused from the use of new hardware (cause) and causing an increase in the project cost (impact). This brings a difficulty to the estimation of likelihood (probability) and impacts. Some unimportant risks may appear to be serious in risk analysis and vice versa. This can cause waste of effort and resources on secondary risks and missing important points.

Mitigation strategies can introduce risks of their own. For example, adopting a fast-track schedule that may be overrun is a risk taken to achieve an earlier completion date.

Both risk mitigation strategies and contingency plans cost time, money, and resources to develop and implement. In addition, project sponsors often do not want to spend the time for detailed risk mitigation planning. Consequently, it may be more appropriate to set an overall risk mitigation budget as a percentage of the overall projected costs, rather than by detail costing for each identified risk's mitigation strategy and contingency plan. Industry experience suggests a 5 % contingency budget for identifying and tracking risks (Royer, 2000).

In a study of Ho and Pike (1992), respondents were asked to list the barriers they have experienced through their risk management activities. Common problems according to their frequency are listed as follows:

- Managers' understanding of techniques (69%).
- Obtaining input estimates (62 %).
- Time involvements (60.8%).
- Cost-justification of techniques (57 %).
- Human / organizational resistance (56 %).
- Trade-off between risk and return (56 %).
- Understanding output of analysis (55%).

3.2. Post Project Evaluation Literature

3.2.1. What Is Post Project Evaluation?

The post project evaluation process consists of activities performed by a project team at the end of the project's life cycle to gather information on what worked well and what did not, so that future projects can benefit from that learning. It aims to find out best practices and documenting "lessons learned". Lessons learned can be determined especially while discussing the problematic areas and their reasons, or while developing improvement suggestions. By this way, lessons of the project will be transformed into explicit knowledge from tacit knowledge and can be used later on future projects.

3.2.1.1. Project performance evaluation

During post project evaluation, the project is compared with its baseline plan and then, its performance is examined against accepted success criteria.

Project success is probably the most frequently discussed topic in the field of project management, yet it is the least agreed upon. Most commonly, a project can be considered successful if (http://www.gov.tas.au/projman/pmirp/pm4_11.htm):

- outcomes are realised;
- project outputs are delivered on time and to the agreed quality;
- costs are within those budgeted and;
- the requirements of all stakeholders are met.

Obviously, project outcomes must please the customer, but they should also bring value to the organization (Shenar *et al*., 1997).

3.2.1.1.1. Characteristics of successful projects (success factors)

It is important to distinguish between success criteria (the measures by which success-failure of a project or business will be judged) and success factors (those inputs to the management system that lead directly or indirectly to the success of the project or business).

In several studies, the common idea upon the success of R&D projects is that, it depends on numerous factors and it is necessary to take them up in a multi-dimensional format. Some of those factors in these studies are found to be common (Balachandra and Friar, 1997; Griffin and Page, 1993; Griffin, 1997; Cooper and Kleinschmidt, 1995; Shenar *et al*., 2002).

Balanchandra and Friar (1997) undertook an extensive review of the germane literature to find whether a general agreement exists about the factors leading to success or failure in new product development and R&D projects. Their findings for the common factors of success in R&D projects are high-level management support, probability of technical success, market existence, availability of raw materials, need to lower cost, timing, commitment of project staff.

Most of the studies support that; "Projects; managed by cross-functional, experienced, and qualified teams, involved customer and suppliers, had systematic monitoring and control mechanisms and well defined and managed product development processes are more likely to obtain successful outcomes." (Dwyer and Mellor, 1991; Maidique and Zirger, 1985; Griffin, 1997; Cooper and Kleinschmidt, 1995; Souder and Jenssen, 1999; Gaynor, 1996).

In fact, De Wit (1988) and other authors distinguish between project success (measure against the overall objectives of the project) and project management success (measured against the traditional measures of performance against cost, time, and quality). Project success involves project management success, but project impact and consistency of this success as well (Cooke and Davies, 2002).

Pinto and Slevin (1987) generated critical success factors that can be crucial to successful project implementation as project mission, top management support, project schedule/plan, client consultation, personnel issues, technical tasks, client acceptance, monitoring and feedback, communication and trouble-shooting.

3.2.1.1.2. Characteristics of failed projects

Any product that is ultimately successful may have been dependent upon a whole series of previous failures (Lewis, 2001). Especially in projects, involving high technological innovation, it is hard to find examples of success, which did not depend on past failures. Success in the development of new technologies is a matter of learning, what eventually makes most techniques possible is the object lessons learned from past failures (Maidique and Zirger, 1985). For this reason, it is important to concentrate on the reasons of failure as well as success to catch learning possibilities and beneficial points for future projects. There are some common characteristics of failed projects, such as (Meredith and Mantel, 2000):

- Problems with organizing project team.
- Weak project leadership.
- Communication problems.
- Conflict and resolution.
- Insufficient upper management involvement.
- Difficulties in defining work in sufficient detail.

In the study by Payzın *et al.*(1998), some of the factors that affect the new product development projects negatively in the Turkish electronics industry, are lack of qualified personnel, uncertain demand, financial problems, high innovation costs, high risks, lack of management support and venture capital, etc.

In addition to the issues mentioned above, inadequate risk analysis and incorrect assumptions regarding risk analysis are also found as failure factors for information system projects in a study of Yeo (2002).

3.2.1.2. Lessons learned

In order to provide learning-based improvement in project management, organizations need an understanding that the investment in learning can pay off, and that there needs to be two outputs from every project: the project itself and the post project assessment of what was learned (Cooper *et al.*, 2002).

After the evaluation of the project against company's success criteria, there will be a decision to distinguish whether it is "best practice" or not. If it is, lessons learned should be repeated, otherwise, they should not. In most cases, failures can be more instructive than successes.

Case studies can be written from best practices, important points from successful projects can be collected in booklets, lessons learned can be captured in a database and then, similar future projects can benefit from them (Gulliver, 1987; Garvin, 1993; Duarte and Synder, 1997).

Documentation of lessons learned is essential for dissemination. A database consisting of past project data is beneficial to learn what types of problems are unique, what types are characteristic or systemic, how often do they occur, what has been done to deal with them, things well done by chance and should be repeated (Busby, 1999).

3.2.2. How Can Post Project Evaluation Be Executed?

Post project evaluations mostly refer to the "analyze" step of the problem solving cycle and are usually done after project closures (Lientz and Rea, 1995).

It is possible to distinguish various approaches in different studies, according to the variety of the post project evaluation activities; but there are mainly two approaches systematically applicable to post project evaluation. One of them is the evaluation of the project by project team (as performed by many USA firms). The second is the evaluation executed by a department or group established to conduct post project reviews (as performed, e.g. by British Petroleum). The first approach has the advantages of being performed in a relatively short time, with less cost, and ease. But it has the disadvantage of being subjective and superficial. The second approach is more in-depth and objective. But it has the disadvantage of being costly and time-consuming, and therefore is recommended only for large-scale projects.

3.2.2.1. Steps of the post project evaluation process

The steps of the post project evaluation process differ between users, according to their structures. But, it is possible to generalize some main steps referring to different studies (Gulliver, 1987; http://www.dir.state.tx.us/eod/qa/evaluate/index.htm; Corbin, 2001; http://marssociety.ca/projects/templates/MS/Post_Project_Evaluation.doc; Turner, 1993):

1. *Data Collection:* This is the step where data about the project to be evaluated are collected. These data (important points for the success and management of the project) provide input for the performance evaluation and learning in the next steps.
2. *Evaluation:* This is the step where the project is evaluated against success criteria, risks, and different applications. Thus, a general picture of the project is taken for future projects' benefit.
3. *Establishing Lessons Learned:* In this step, different applications in the project and their advantages-disadvantages are examined after evaluation; and lessons for future projects can be obtained from them. Especially, problem solution techniques and their results are important learning areas.
4. *Verification:* This is the step where data and/or evaluation results' correctness and sufficiency are examined. This can be done before the evaluation.
5. *Documentation:* This is the step where evaluation results are documented as case studies or reports.
6. *Information dissemination:* This is the step where the results and lessons learned are disseminated for future use.

3.2.2.2. Scope of the post project evaluation

It is important to appreciate that there are at least three separate dimensions, which may be covered by any such study of the project. Each may have equal importance to its final outcome and success. The first consideration relates to the "technical objectives" of the project as represented by its scope and quality parameters. The second dimension of the project relates to the "business management objectives" as represented by its time and cost parameters. The third dimension, which is more difficult to grasp and to state explicitly, has to do with "stakeholder satisfaction and their collective perception of the success of the project". Therefore, a complete project evaluation should take all these considerations into account and try to distinguish the factors affecting them (Wideman, 1991). Post project evaluation should also focus on some other issues, affecting these main subjects, like project risks and risk management activities, human resources, and communications (Wideman, 1991; Maylor, 1999; http://www.maxwideman.com; http://www.dir.state.tx.us/eod/qa/evaluate/index.htm; http://marssociety.ca/projects/templates/MS/Post_Project_Evaluation.doc; Corbin, 2001).

Information about communication frequencies between the project team members, changes in specifications and the way these were managed in the course of the project, active roles of the team members, what worked or did not work about the team's communication, moral, and motivation of project team, what worked or did not work about how responsibilities were distributed, whether the project team had the right skill mix, the project team's understanding of the responsibilities, the working relationships with outside groups, vendors or other team members; would be beneficial to discuss (http://www.dir.state.tx.us/eod/qa/evaluate/index.htm; Hameri and Nihtilä, 1998; http://marssociety.ca/projects/templates/MS/Post_Project_Evaluation.doc).

New methods, materials, technology or processes used, lessons learned that could be used in the future, project planning techniques (found most useful on the project), any improvement ideas, anything that would be done differently if repeated, risks responded effectively or ineffectively, suggestions upon what went right or wrong can provide valuable input to process improvement activities and project planning phases (Hameri and Nihtilä, 1998; Lientz and Rea, 1995; http://www.dir.state.tx.us/eod/qa/evaluate/index.htm; EUREKA Booklet, 1992; Maylor, 1999; http://marssociety.ca/projects/templates/MS/Post_Project_Evaluation.doc).

Satisfaction and the opinion of the customer upon the project outcomes is an important issue for post project evaluation process. Performance of the project and new project scopes can be obtained from this information (Garvin, 1993).

Project leaders should pay attention to documentation and share the way s/he managed the difficulties in the course of the project with other project leaders. If past experiences are to be used, data must be collected but also validated, structured, and made available for easy re-use. All this has to be done at a time when most of the project team members have already been transferred to other activities. The motivation to look back and put extra effort into transferring the best practices and passing an information about the possible pitfalls to other parts of the organization, is often minimal (Hameri and Nihtilä, 1998).

In brief, subjects to be dealt within a post project evaluation process can be described as follows (Ward, 2000; Kniestedt and Hager, 2000; Chiesa *et al.*, 1996; http://www.dir.state.tx.us/eod/qa/evaluate/index.htm; Hameri and Nihtilä, 1998; http://marssociety.ca/projects/templates/MS/Post_Project_Evaluation.doc; Wideman, 1991; Lientz and Rea, 1995; Meredith and Mantel, 2000; Wheelwright and Clark, 1992):

- Basic Project Information

Project name, customer's name, start-finish dates, type of the project, subject of the project, a brief summary of the project, etc.

- Project Management Process

Project management techniques, things done better from other projects, conflicts and conflict resolution techniques, change requests and their reasons, information about risk management used.

- Performance

Achievement of schedule and cost objectives, quality of the project outcomes (achievement of the technical objectives), achievement of other objectives (social benefit, knowledge creation etc.), new findings of the project and technical benefits, satisfaction of the customer, etc.

- Lessons Learned

The reasons that prevent a project to reach its objectives; project participants' and stakeholders' opinion about key things that were done right on the project and key things that were done wrong and should be changed; potential uses of new technology; suggestions for improvement and other items of potential benefit to other projects.

- Teamwork Evaluation

Communication between the team and third parties, active roles of the team members, what worked and did not work about the team's communication, team motivation, what worked and did not work about how responsibilities were distributed, whether the project team had the right skill mix, cross-functional approach, etc.

- Customer Information

Customer satisfaction, information about the implementation of the project outcomes, change requests and their reasons, communication issues, customer involvement, new project requests, etc.

3.2.2.3. Post project evaluation report

Post project evaluation reports serve many purposes: they summarize findings, provide checklists of “do”s and “do not”s, and describe important processes and events (Garvin, 1993).

A sample report content for post project evaluation can be described as (Lientz and Rea, 1995):

1. Purpose and scope of evaluation (approach in doing the review).
2. Review of the system (review of the system that resulted from the project).
3. Project summary (highlights of what happened in the project).
4. Findings (specific findings related to the review).
5. Conclusions and recommendations.

3.2.2.4. Roles and responsibilities

The responsibility of post project evaluation can be given to project members, to project support office, to consultants, or to a special department according to the defined process structure.

The principal responsibility rests with the evaluation team and consultants in the processes conducted by a special department. Project leader and project teams are responsible to transfer their knowledge during interviews with evaluation team or by preparing reports. The evaluation team is responsible with the determination of main discussion points and lessons learned (Whitten, 2000; Murphy, 1997). Project support offices can play a role as a facilitator in the process (Whitten, 1999a; Murphy, 1997).

In some cases, post project evaluation sessions are established and it is expected that technical personnel, management, sales team, and if possible, customers participate in these sessions (Chiesa, 1996).

Generally, role players in the post project evaluation processes include the project team, project office, stakeholders, and the users of project outcomes (http://www.dir.state.tx.us/eod/qa/evaluate/index.htm).

3.2.3. Benefits of Post Project Evaluation

It is very important to prevent valuable information escape, especially in the R&D departments where the information is created by adding building blocks of past experience and in the environments that are faced with high personnel turnovers. Post project evaluation is a beneficial tool to provide learning from past experiences and capturing this kind of information.

In the most basic terms, a learning history is a written narrative of a company's recent set of critical episodes: a corporate change event, a new initiative, a widespread innovation, a successful product launch, or even a traumatic event such as a major reduction in the work force. Systematic properties of projects like the resource-time usage, frequently encountered risks and their effects provide help to the planning phases of future projects. Information gathered from post project evaluation provide input to risk management, especially in identifying risks and developing response strategies (Royer, 2000).

It is observed that learning histories have several positive effects. People who believe their opinions were ignored in the past come to feel that those opinions have been validated when they see them in the document. Learning histories seem to be particularly effective at raising issues that people would like to talk about but have not had the courage to discuss openly during the course of the project. They are also successful at transferring knowledge from one part of a company to another and building a body of generalizable knowledge about management- about what works and what does not (Kleiner and Roth, 1998). Referring to history also identifies what types of problems are unique and what types are characteristic or systemic (Busby, 1999).

Post project evaluations take a large view to examine the rationale for the project; examine the strategic fit of the project into the overall organizational strategy; offer insight to the success or failure of a particular project as well as a composite of lessons learned from a review of all the projects in the organization's portfolio or capital projects (Clelland, 1994).

Post project evaluation provides feedback to the project team about their own performances. Therefore, training needs, strengths and weaknesses, clues as to where to use which resources can be determined by this way (Maylor, 1999).

3.2.4. Drawbacks in Post Project Evaluation

The reality is, however, that those post project evaluations are often curtailed and sometimes fall into complete disuse. Even when they are enthusiastically conducted, their outcomes are poorly disseminated. The reasons for this neglect include (Busby, 1999):

- They take time. This is especially a problem in project-oriented firms since project managers want to minimize costs allocated to their projects (particularly toward the end), and the beneficiaries of post project evaluations are future projects, not current ones.
- Reviews (evaluations) involve looking back over events that project participants are likely to feel cynical or embarrassed about. Looking forward to new work is more appealing.
- Maintaining social relationships typically matters more to most people than accurate diagnoses of isolated events. People can be reluctant to engage in activity that might lead to blame, criticism, or recrimination.
- Many people think that experience is a necessary and sufficient teacher in its own right. According to this point of view, if you have an experience you will necessarily learn from it, and if you have not had the experience you will not learn from someone else, who has. This is generally not so, but many people believe it is and are predisposed against post project evaluations.

With respect to the factors above, post project evaluations are often neglected. In addition, in some cases they are regarded as witch-hunts. Post project evaluation might be employed to achieve a political goal through the project using past events as the means. Another reason for avoiding post project learning is that people pretend they are too busy on other projects to learn, because they don't wish to face unpleasant facts. At project closure, project team is often overworked, under stress and evaluation will be easily neglected because it offers extra work. In these circumstances, reviews cannot be executed efficiently and there will be no "learning". Therefore, it might not be worth to conduct a post project evaluation under these conditions (Lientz and Rea, 1995; Garvin, 1993).

Even in organizations, where the post project evaluations are enthusiastically conducted, there still are also some factors that keep these organizations from learning and implementing change (Lientz and Rea, 1995; Busby, 1999):

- What should be done with the findings of the review? In many situations, it is not understood and told how the findings of the evaluation will be used.
- People who are assigned to new work and other projects have to accept the tools and methods of the new project, there is a reluctance to criticise them. To overcome this, reviews should have started before the project is totally completed and has finished while the information is still fresh.
- On large projects that have spanned several years, there are memory problems. It is possible to conduct periodic project reviews and to motivate project members for documenting the points they think as important.
- The tendency to seek the fault outside may cause not to diagnose the real reasons behind the failures and therefore, important lessons will be lost.
- Overspecificity may cause learning to be less effective than it should be, by drowning in details.

3.3. Risk Management and Post Project Evaluation

Successful project risk management will greatly improve the probability of project success. Identifying project risks and assumptions, documenting them, and including them in the overall project plan and processes is a justifiable activity. At project closure, the project risks and responding experiences should be integrated into the organisation's project management knowledge repository. In future projects, this knowledge base can serve as the starting point for risk identification and analysis. New and experienced project managers can use these past real-world experiences to reduce worry and burden and increase the likelihood of success.

The best guide to a company's future lies in its past; unless some very major organisational change has taken place, things tend to proceed in the same way as previously. An examination of previous projects including an assessment of similarities, differences, time scales, costs, failures, and successes can lead to a more realistic view of each new proposal. Therefore, the best point to start to the quantification and prioritization of risks is the analysis of historical data, particularly if similar projects have been undertaken in the past (Webb, 1994).

To sum up, risks are the major part of post project evaluations and vice versa. Learning points are easily identified upon risk issues and the risk management process outcomes may provide insights into the weaknesses in the project management processes. Post project evaluation helps in building a knowledge database on possible risks to be used in risk management process. Historical databases may help to manage the risk checklists, create information for estimations and response strategies.

4. ANALYSIS OF THE PAST PROJECTS

4.1. Data Collection and Evaluation Methodology

Ninety-three R&D projects (including 56 technology development, 22 new product development, 15 supportive) that have been executed between 1994 and 2001 in the R&D Center, have been analyzed to determine the factors that affect project performance. A further expectation from this study has been to find out a risk checklist to systematise the risk identification.

To address the concerns noted above, most of the projects have been collected from the database by using the project management software used in the R&D Center. The project data include the project number and name, actual and baseline start and finish dates, actual and baseline duration, actual and baseline labour units, name of the project leader and the number of team members, where baseline values correspond to planned values.

Closure conditions and the reasons of deviations that will lead to the risk checklist have been gathered from project documents. The experience of project leader has been calculated as the duration between the project start date and the project leader's starting date of employment in this company. Number of the disciplines participating in the project has been calculated by counting the different working discipline families, whom the team members belong to. Different science disciplines are grouped under families in the organizational structure of the R&D Center.

It was intended to analyze data concerning project cost, origin of the project idea, and customer satisfaction, but the data were neither reliable, nor available due to the current database structure.

Also, there was not a proper definition of project performance. Thus, for being able to formulate the hypotheses about the factors that can affect the project performance, project performance has been defined as:

The amount of deviation from the project duration and manpower usage are calculated with the Expression 4.1:

$$\text{Deviation} = | \text{Baseline} - \text{Actual} | / \text{Baseline}. \qquad (4.1)$$

With these data, the following hypotheses have been tested:

H1: Project duration has a positive impact on the project performance.

H2: Amount of labour units used has a positive impact on the project performance.

H3: The experience of the project leader has a positive impact on the project performance.

H4: The size of project teams has a positive impact on the project performance.

H5: Multi-functional approach to project team formation has a positive impact on the project performance.

To test these hypotheses, *t-test*s and one-way ANOVA have been used with a level of significance α=95%. The results are shown in Table 4.1 and Table 4.2.

<u>H1: Project duration has a positive impact on the project performance.</u>

H1.1: Duration deviation of the projects that lasted less than 2 years (Group 1), are less than that of the projects that lasted 2 years and more (Group 2). Thus,

H_0: $\mu_2-\mu_1 \geq 0$ versus H_A: $\mu_2-\mu_1<0$.

First, equality of the variances should be tested to determine which *t-test* to use. For this test, H_0: $\sigma_2^2=\sigma_1^2$ versus H_A: $\sigma_2^2 \neq \sigma_1^2$.

The test statistics is $s_2^2 / s_1^2 \sim F(N_2-1, N_1-1)$.

Here, the test statistics $F=10.1$, with $df1=54$, $df2=37$.

The p-value is p=0.00.

Since the p-value is smaller than 0.05, the equality hypothesis (H_0), will be rejected. Therefore, two-sample *t-test* assuming unequal variances can be used (Table 4.1).

As it can be seen from Table 4.1, p-value is smaller than 0.05 and therefore, H_0: $\mu_2-\mu_1 \geq 0$ is rejected. Schedule performance is better in the projects, whose duration is 2 years or more.

Table 4.1 Results of *t-tests*

Hyp.	Groups	No. of Observations	Mean	Variance	*T statistics*	*P (T<=t)*	T_{crit}
H1.1	< 2 years	55	0.91	1.9	3.1	0.001	1.06
	≥ 2 years	38	0.29	0.18			
H1.2	< 2 years	55	0.39	0.08	2.13	0.01	1.66
	≥ 2 years	38	0.26	0.11			
H2.1	< 6 man-months	47	1.07	2.12	3.757	0.0002	1.68
	≥ 6 man-months	46	0.25	0.11			
H2.2.	< 6 man-months	47	0.45	0.13	3.57	0.0003	1.66
	≥ 6 man-months	46	0.23	0.042			
H3.2	< 4 years	54	0.63	0.65	1.92	0.03	1.66
	≥ 4 years	37	0.37	0.22			
H3.4	< 4 years	54	0.32	0.07	0.41	0.34	1.66
	≥ 4 years	37	0.30	0.06			
H5.2	1 and 2 disc.	42	0.88	1.30	1.7	0.04	1.66
	3 and more disc.	51	0.48	1.22			

Table 4.2 Results of one-way ANOVA

Hyp.	Groups	No of Observations	Mean	Variance	*F Value*	*P Value*	F_{crit}
H3.1	Group 1	33	0.58	0.51	1.23	0.30	2.71
	Group 2	21	0.73	0.90			
	Group 3	19	0.35	0.15			
	Group 4	18	0.41	0.31			
H3.3	Group 1	33	0.29	0.07	0.65	0.59	2.71
	Group 2	21	0.36	0.08			
	Group 3	19	0.26	0.04			
	Group 4	18	0.33	0.08			
H4.1	Group 1	20	1.38	3.78	4.49	0.005	2.71
	Group 2	23	0.72	0.86			
	Group 3	24	0.35	0.21			
	Group 4	26	0.34	0.27			
H4.2	Group 1	20	0.52	0.19	4.02	0.009	2.71
	Group 2	23	0.36	0.08			
	Group 3	24	0.25	0.05			
	Group 4	26	0.25	0.04			
H5.1	Group 1	42	0.88	1.3	2.21	0.11	3.097
	Group 2	28	0.66	2.1			
	Group 3	23	0.27	0.1			
H5.3	Group 1	42	0.43	0.14	4.03	0.02	3.097
	Group 2	28	0.31	0.07			
	Group 3	23	0.21	0.03			

H1.2: Manpower deviation of the projects that lasted less than 2 years (Group 1), are less than that of the projects that lasted 2 years and more (Group 2). Thus,

H_0: $\mu_2-\mu_1 \geq 0$ versus H_A: $\mu_2-\mu_1<0$.

First, equality of the variances is tested to determine which *t-test* employ. For this test, H_0: $\sigma_2^2=\sigma_1^2$ versus H_A: $\sigma_2^2 \neq \sigma_1^2$.

Here, the test statistics $F=1.42$, with $df1=37$, $df2=54$.

The *p*-value is p=0.12.

The *p*-value is greater than 0.05 and there is no evidence to accept that the variances are not equal. Therefore, two-sample *t-test* assuming equal variances can be used (Table 4.1).

Again, *p*-value is smaller than 0.05 and therefore, H_0: μ_2-$\mu_1 \geq 0$ is rejected. Manpower usage performance is better in the projects that lasted 2 years and more.

H2: Amount of labor units used, has a positive impact on the project performance.

H2.1: Duration deviation of the projects that employed less than 6 man-month labour units (Group 1) are less than that of the projects that employed more than 6 man-months (Group 2). Thus,

H_0: μ_2-$\mu_1 \geq 0$ versus H_A: μ_2-$\mu_1 < 0$.

Again, equality of the variances is tested to determine which *t-test* to employ. For this test, H_0: $\sigma_2^2=\sigma_1^2$ versus H_A: $\sigma_2^2 \neq \sigma_1^2$.

Here, the test statistics $F=20.33$ with $df1=46$, $df2=45$.

The *p*-value is $p=0.00$.

The *p*-value is sufficiently small to reject the equality hypothesis and therefore, two-sample *t-test* assuming unequal variances can be used (Table 4.1).

The *p*-value is sufficiently small and therefore, H_0: μ_2-$\mu_1 \geq 0$ is rejected. Schedule performance is better in the projects that employed 6 man-months/or more manpower.

H2.2: Manpower deviation of the projects that employed less than 6 man-month labour units (Group 1) are less than that of the projects that employed more than 6 man-months (Group 2). Thus,

H_0: μ_2-$\mu_1 \geq 0$ versus H_A: μ_2-$\mu_1 < 0$.

First, equality of the variances is tested to determine which *t-test* to employ. For this test, H_0: $\sigma_2^2=\sigma_1^2$ versus H_A: $\sigma_2^2 \neq \sigma_1^2$.

$F= 3.08$ with $df1=46$, $df2=45$ and $p=0.00$.

The *p*-value is sufficiently small to reject the H_0 and therefore, two-sample *t-test* assuming unequal variances can be used (Table 4.1).

The *p*-value is sufficiently small for the *t-test* and therefore, H_0: μ_2-$\mu_1 \geq 0$ is rejected. Manpower usage performance is better in the projects that have employed 6 man-months/or more labour units.

H3: The experience of the project leader has a positive impact on the project performance.

Group 1: Experience of the project leader < 2 years

Group 2: Experience of the project leader ≥ 2 years and < 4 years

Group 3: Experience of the project leader ≥ 4 years and < 6 years

Group 4: Experience of the project leader ≥ 6 years

One-way ANOVA has been employed under the null hypothesis

H_0: $\mu_1=\mu_2=\mu_3=\mu_4=\mu$ *versus* H_A: $\mu_1\neq\mu_2\neq\mu_3\neq\mu_4\neq\mu$,

where μ represents the mean duration deviation of the group.

The results of this analysis are reported under H3.1 in Table 4.2. The *p*-value is greater than 0.05 and therefore, we cannot reject H_0: $\mu_1=\mu_2=\mu_3=\mu_4=\mu$.

By this grouping, the project leader's experience has no significant effect on the schedule performance. This result is in accordance with the study by Rubin and Seelig (1967). They report that project manager's experience has no direct relevance or influence on project success but the high priority given to larger projects does have an influence on project success. In the study by Coulliard (1995), the most experienced project managers are generally assigned to the riskier projects. As project risk increases; establishing goals clearly, communication and handling problems become more difficult. It is possible that, these facts have led to the result of irrelevance of experience to project performance.

The mean experience of the projects' leaders was about 4 years. Then, a new hypothesis "Projects executed by above-mean experienced project leaders are more likely to have less duration deviation" has been tested.

H_0: $\mu_2-\mu_1\geq 0$ versus H_A: $\mu_2-\mu_1<0$.

First, equality of the variances is tested to determine which *t-test* to employ. For this test, H_0: $\sigma_2^2=\sigma_1^2$ versus H_A: $\sigma_2^2\neq\sigma_1^2$.

Here, $F=2.87$, with $df1=53$, $df2=36$ and p=0.00.

The *p*-value is sufficiently small to reject the H_0. Therefore, two-sample *t-test* assuming unequal variances can be used.

The results for this *t-test* are reported under H3.2 in Table 4.1. The *p*-value is sufficiently small and we can reject H_0: $\mu_2-\mu_1\geq 0$. It is found that schedule performance is better in the projects directed by project leaders with more than 4-years-experience.

One-way ANOVA has been employed under the null hypothesis

H_0: $\mu_1=\mu_2=\mu_3=\mu_4=\mu$ versus H_A: $\mu_1\neq\mu_2\neq\mu_3\neq\mu_4\neq\mu$,

where μ represents the mean manpower deviation of the group.

The results of this analysis are reported under H3.3 in Table 4.2. The *p*-value is bigger than 0.05 and therefore, we cannot reject H_0: $\mu_1=\mu_2=\mu_3=\mu_4=\mu$.

The hypothesis "Projects executed by above-mean experienced project leaders are more likely to have less manpower deviation" has been tested.

H_0: $\mu_2-\mu_1\geq 0$ versus H_A: $\mu_2-\mu_1<0$.

First, equality of the variances is tested to determine which *t-test* to employ. For this test, H_0: $\sigma_2^2=\sigma_1^2$ versus H_A: $\sigma_2^2\neq\sigma_1^2$.

Here, $F=1.21$, with $df1=53$, $df2=36$ and $p=0.26$.

According to the *p*-value, H_0 cannot be rejected and the *t-test* assuming equal variances is employed. The results of the *t-test* are reported under H3.4 in Table 4.1. According to the *p*-value, we cannot reject the H_0: $\mu_2-\mu_1\geq 0$.

There isn't a significant finding about the impact of the project leader's experience on manpower deviations neither by ANOVA, nor by *t-test*.

H4: The size of project teams has a positive impact on the project performance.

Group 1: Number of the team members < 4 persons

Group 2: Number of the team members ≥ 4 persons and < 6 persons

Group 3: Number of the team members ≥ 6 persons and < 10 persons

Group 4: Number of the team members ≥ 10 persons

One-way ANOVA has been executed under the null hypothesis:

H_0: $\mu_1=\mu_2=\mu_3=\mu_4=\mu$ versus H_A: $\mu_1\neq\mu_2\neq\mu_3\neq\mu_4\neq\mu$,

where μ represents the mean duration deviation of the group.

The results of this analysis are reported under H4.1 in Table 4.2. The *p*-value is sufficiently small and therefore, H_0: $\mu_1=\mu_2=\mu_3=\mu_4=\mu$ is rejected.

One-way ANOVA has been employed under the null hypothesis:

H_0: $\mu_1=\mu_2=\mu_3=\mu_4=\mu$ versus H_A: $\mu_1\neq\mu_2\neq\mu_3\neq\mu_4\neq\mu$,

where μ represents the mean manpower deviation of the group.

The results of this analysis are reported under H4.2 in Table 4.2. The *p*-value is sufficiently small and therefore, H_0: $\mu_1=\mu_2=\mu_3=\mu_4=\mu$ is rejected.

Schedule and manpower usage performances are better in projects with relatively larger project teams.

<u>H5: Multi-functional approach has a positive impact on the project performance.</u>

Group 1: Number of the different disciplines contributing to the project: 1 and 2 disciplines.

Group 2: Number of the different disciplines contributing to the project: 3 and 4 disciplines.

Group 3: Number of the different disciplines contributing to the project: 5 and more disciplines.

One-way ANOVA has been executed under the null hypothesis:

$H_0: \mu_1=\mu_2=\mu_3=\mu$ versus $H_A: \mu_1\neq\mu_2\neq\mu_3\neq\mu$,

where μ represents the mean duration deviation of the group.

The results of this analysis are reported under H5.1 in Table 4.2. Since the p-value is bigger than 0.05, we cannot reject the $H_0: \mu_1=\mu_2=\mu_3=\mu$.

According to the results, there is no significant relation between the number of disciplines contributing, and the schedule performance. But the sample size of 1 and 2 disciplines were large and the number of the disciplines were tested again with two samples, group 1 including 1 and 2 disciplines, and group 2 including 3 and more disciplines.

$H_0: \mu_2-\mu_1\geq 0$ versus $H_A: \mu_2-\mu_1<0$.

First, equality of the variances is tested again to determine which *t-test* to employ. For this test, $H_0: \sigma_2^2=\sigma_1^2$ versus $H_A: \sigma_2^2\neq\sigma_1^2$.

Here, $F=1.06$ with $df1=41$, $df2=50$ and p=0.41.

The p-value is greater than 0.05 and there is no evidence reject H_0. Therefore, two-sample *t-test* assuming equal variances has been executed. The results of this test are reported under H5.2 in Table 4.1. The p-value is sufficiently small and therefore, $H_0: \mu_2-\mu_1\geq 0$ is rejected.

Projects with project teams consisting of 3 or more disciplines are better in schedule performance.

One-way ANOVA has been executed under the null hypothesis:

$H_0: \mu_1=\mu_2=\mu_3=\mu$ versus $H_A: \mu_1\neq\mu_2\neq\mu_3\neq\mu$,

where μ represents the mean manpower deviation of the group.

The results of this analysis are reported under H5.3 in Table 4.2.

According to the *p*-value, H_0: $\mu_1=\mu_2=\mu_3=\mu$ has been rejected and *t-test* would give a similar result:

Projects consisting of multi-functional project teams are better in manpower usage performance.

4.2. Significant Findings

- Projects with lower duration (<2 years) are more likely to deviate from their baseline duration and baseline manpower requirements.
- Projects using less manpower (<6 man-months) are more likely to deviate from their baseline duration and baseline manpower requirements.
- Projects executed by experienced project leaders (>4 years) are more likely to be successful in following their baseline schedules.
- Projects, which have relatively large project teams, are more likely to be successful in following their baseline schedules and baseline manpower requirements. It is possible to think that this is a result of a synergy between project members who are reducing the delays caused by the others.
- Projects handled with a multi-functional approach are more likely to be successful in following their baseline manpower requirements and projects handled by 3 or more disciplines are better in schedule performance in this R&D Center.

4.3. Inputs for the Risk Checklist

The common problems declared in the project documents as the reasons of deviations are transformed into a risk checklist, which will be explained in the next chapter when reporting on the risk management process.

- Projects are often facing problems about resource management like shortage of resources (both labour and infrastructures) and changes in the project team.
- The distribution of the problems according to the risk categories is as follows:

Resource Management	40%,
Customer Related	20%,
Technical	20%,
External-Predictable	14%,
Non-Technical Internal (Managerial, Project Management)	4 %,
External-Unpredictable	2 %.

The resource management category includes risks caused by resource conflicts, changes in project team and lack of resources, etc.

The definitions related to the customer related (also client), technical, external-predictable, non-technical internal, and external-unpredictable risk categories mentioned above are given in chapter 3.

5. RISK MANAGEMENT PROCESS

5.1. Proposed Risk Management Process

In the proposed risk management process, there are four main activities as described in the related literature (PMBOK®Guide, 2000; Murray, 1998; Kuver, 2000; Chapman and Ward, 1997; Webb, 1994; Ward, 1999; Raz and Michael, 2001; Royer, 2000; http://www.dir.state.tx.us/eod/qa/risk.htm).

I. Risk Identification,

II. Risk Analysis,

III. Risk Response Development,

IV. Risk Monitoring and Control.

In the planning phase, risks are identified, assessed and response strategies are developed. The most powerful contribution of risk assessment comes at the end of the feasibility phase of the innovation process, at the contact gates, or project planning phase. However, a periodical reassessment of potential risks in subsequent phases is still required (Keizer *et al*., 2002).

Risk issues, which will be discussed during the closeout phase, were described by means of organisational learning, supported by the post project evaluation process. The flow chart of the proposed risk management process can be seen in Figure 5.1.

To design the risk management process, it was necessary to decide on which techniques to use and how to implement it into the present project management process. Human factor was the main issue to be considered during this design process. The process should be easy to understand and to apply; should be objective; should not depend on people; and its outputs should be reusable.

To provide easiness, complex quantitative techniques have been omitted from this process. To ensure objectiveness, a standardised checklist has been developed and scoring scales have been defined for the analysis phase. A database structure has been designed to support the process and maintain effective usage of information. These decisions will be described in detail later.

I. Risk Identification Phase: In this phase, risks associated with the project will be identified. It is necessary to standardise the risk issues, for not to depend on people and for future use. In the present process, there was a "risk issues" part in the project documents and project leaders were filling it in free format. This approach had two main disadvantages; the detail depends on the project leader and it was not possible to reuse this disorganised information. The Risk Checklist, which has been developed from past project data and R&D management literature, will be used for risk identification in the process.

This Checklist has been prepared at four steps. At first step, problems encountered in the past projects have been determined by analysing historical data from the project documents.

Second, these problems are enriched with the problems reported in the literature, especially for the R&D projects. Then, the risks in this list are classified under main risk categories as technical, resource management, non-technical internal, customer related, external- predictable, and external-unpredictable.

In the third step, overlaps between the risks and uncertainties in the definitions have been omitted and the past projects have been analysed again with the new format to be sure that the checklist covers all problems encountered before.

Finally, the Risk Checklist is tested in a project close to initiation, to determine whether it is comprehensible and sufficient. It is concluded that this checklist is applicable in the R&D Center. It will be beneficial for standardisation and therefore, for future use.

In preparing this checklist, attention is paid for risks to;

- be in accordance with the project structure in the R&D Center,
- be not overlapping or repeating the other risks listed,
- be understandable, in accordance with their titles and not confusing in impact-probability estimations,
- contain all the problems encountered in the past.

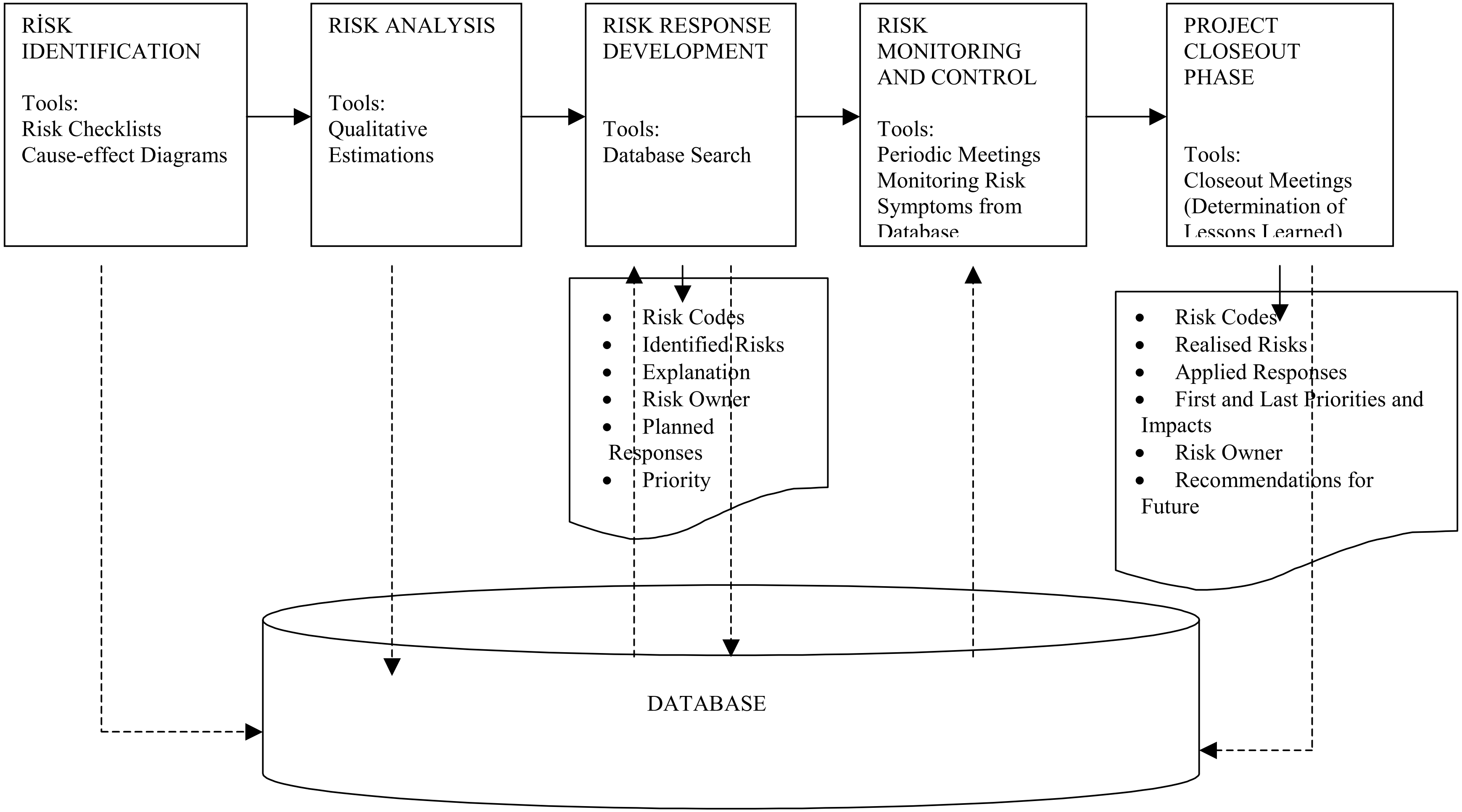

Figure 5-1 The proposed risk management process flow chart

In a recent study of Keizer *et al.* (2002), a reference list with potential risk issues in the innovation process has been developed in similar fashion with this study. Some of these issues were extracted from articles about success factors in product innovation projects, similar to the preparation of the checklist represented in this study. They also used their risk diagnosing methodology (RDM) studies in the last decade in various industrial firms including Unilever. But this is a kind of prospective approach, differing from our retrospective study on the past projects.

The final version of the Risk Checklist can be found in Table 5.1.

Table 5.1 Risk Checklist

Risk Category	Risks	Risk Causes
Technical	Problems arising from the maturity level of the technology used	Use of new-to-the-firm technology
		Use of new-to-the-world technology
	Problems arising from the complexity and uncertainty of the technical content	High uncertainty in technical content
		Difficulty in defining the project scope
	Problems arising from the inadequacy of the technical personnel	Absence of qualified people (person who has the experience and knowledge about the technology)
Resource Management	Problems arising from inadequacy of resources	Inadequacy of labour units for this project because of overloading
		Inadequacy of laboratories / equipment because of overloading
		No experience with the use of the laboratories / equipment
		Equipment breakdown / lack of maintenance
		Reduction in project team size
	Problems arising from the changes in team members	Turnover in project team
Non-technical Internal (Managerial – Project Management)	Problems arising from inadequate communication	Inadequacy of communication with upper management
		Inadequacy of communication within the project team
	Problems arising from the changes in strategy / project priorities	Changing objectives / expectations
	Problems arising from inadequate project experience	Inexperienced project leader
		Lack of teamwork experience in the project team
Customer Related	Problems arising from the uncertainty in the communication with the customer	No previous experience of working together with the customer
		Customer, not respectful to his engagements
	Problems arising from the uncertainty in customer requests	Frequent change requests
		Project, aborted by the customer
	Problems arising from the budget	Payment delays / cash flow irregularities

Table 5.1 Risk Checklist (continued)

Risk Category	Risks	Risk Causes
External-Predictable	Problems encountered in material / service acquisition	No previous experience of working together with the supplier / consultant
		Difficulty in material procurement
		Limited service alternatives
		Interruption of provided services
		Problems in deliveries
	Problems arising from the competitive environment	New technologies developed by competitors
		Changes in standards and regulations
External-Unpredictable	Natural hazards	Earthquake, flood… etc
	Problems arising from economic crises	Economic crises and exchange rate fluctuations affecting the project
	Problems arising from the international relations and legal regulations	Changes in international relations affecting the project
		Legal and bureaucratic obstructions affecting the project

After planning the project activities, risks will be identified, which are related to the project and entered into the database by the project leader with the help of the project team. As a helpful tool, cause-effect diagrams can be used to identify risks. The project team analyses the project and identifies the possible causes of potential problems and their effects. An example of cause-effect diagrams is given in Figures 5.2 and 5.3. The risk identification step is followed by the analysis phase.

II. Risk Analysis Phase: In this phase, identified risks are analysed to determine their severities and then priorities. It is necessary to organise the project risks in a hierarchy. Suppose we try to deal with 20-30 risks in a project. We can cope with this complexity by attacking on the most important, top in hierarchy risks.

For prioritization, only qualitative analysis will be employed in this proposed process, because quantitative methods will make the process even more complex. The risk management concept is new to the firm and easiness of the process will be the main factor for its adoption.

The decision to be made here was the selection of the analysis method. Analytic Hierarchy Process (AHP) and scoring methods were considered as potential methods to be used in the process.

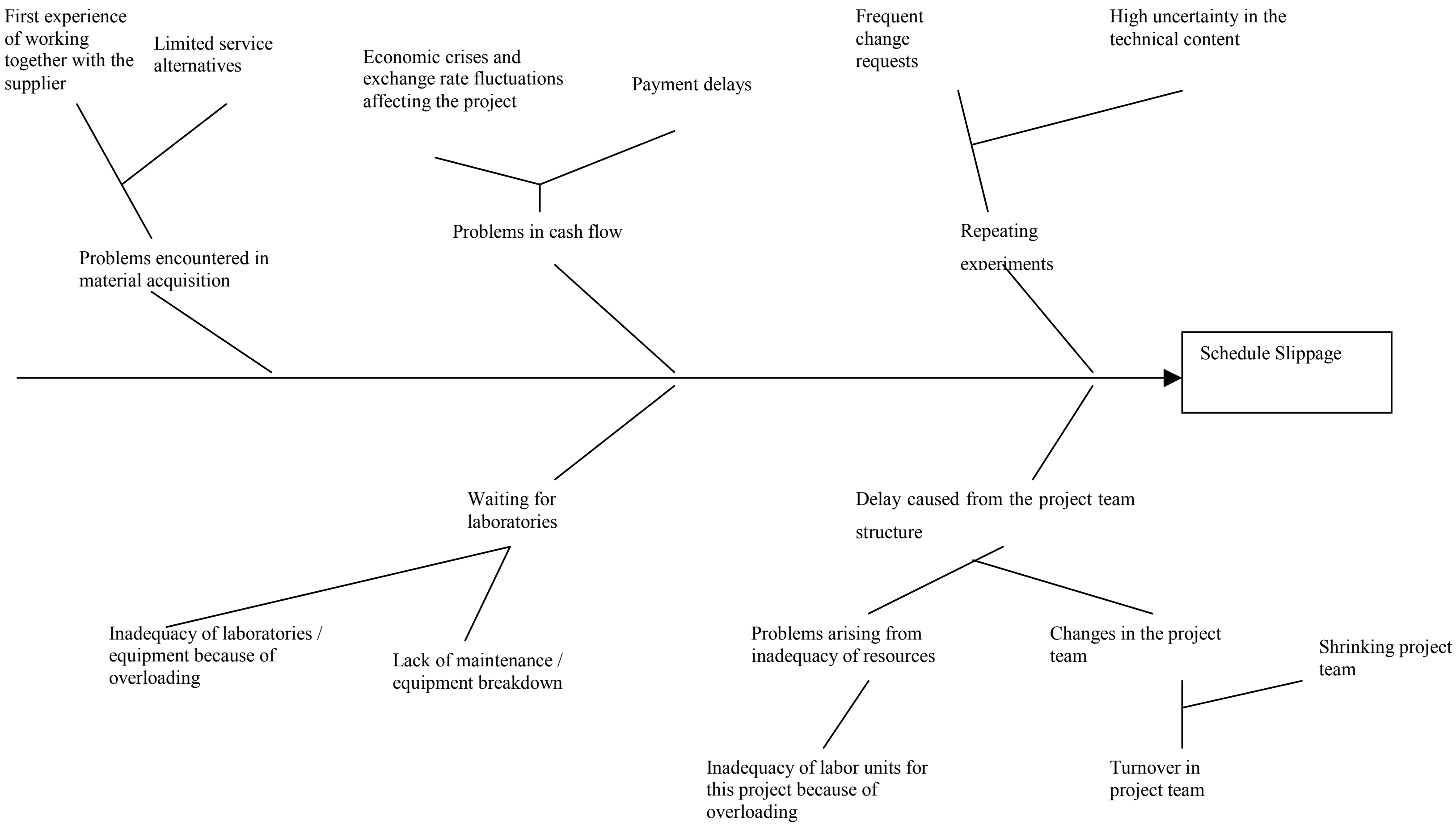

Figure 5.2 Cause-effect diagram-1

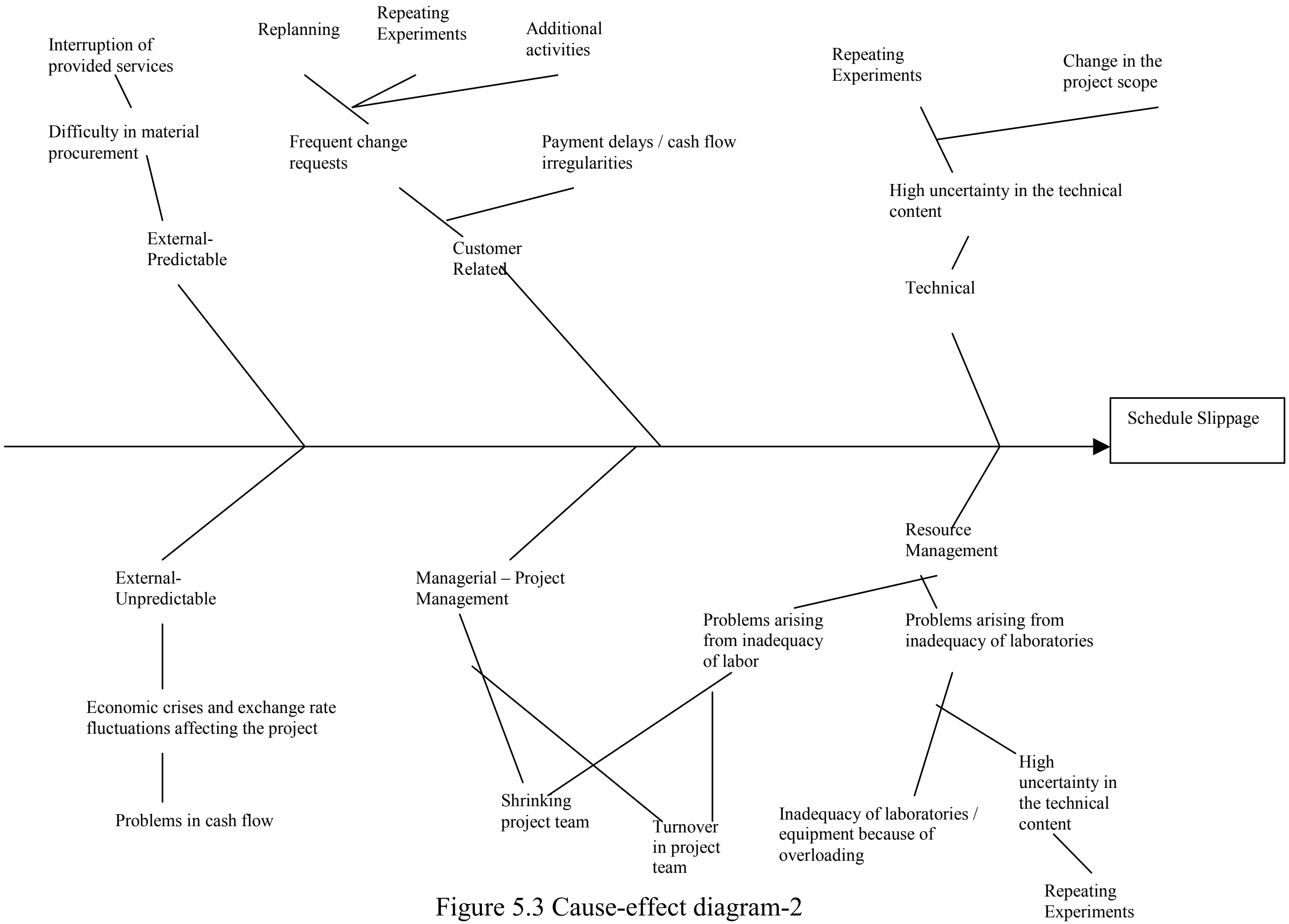

Figure 5.3 Cause-effect diagram-2

The AHP, developed at the Wharton School of Business by Thomas Saaty , allows decision makers to model a complex problem in a hierarchical structure showing the relationships of the goal, objectives (criteria), sub-objectives, and alternatives. AHP is a compensatory decision methodology because alternatives that are deficient with respect to one or more objectives can compensate by their performance with respect to other objectives. AHP is composed of several previously existing but unassociated concepts and techniques such as hierarchical structuring of complexity, pairwise comparisons, redundant judgments, an eigenvector method for deriving weights, and consistency considerations (Forman and Selly, 2001). The AHP starts with the creation of comparison matrices by the decision-maker, moves on to the phase in which relative weights are derived for the various elements. The relative weights of the elements of each level with respect to an element in the adjacent upper level are computed as the components of the normalized eigenvector associated with the largest eigenvalue of their comparison matrix.

With the introduction of its PC implementation, called Expert Choice, the number and diversity of AHP applications have grown rapidly. It can be used in resource allocation, vendor selection, strategic planning, human resources management, and risk assessment (for AHP applications in these areas and others, see e.g., Saaty and Vargas, 2000).

Due to the combination of tangible and intangible information involved in risk assessment, it is hard to show an audit trail that can explain how decisions about risk are made. AHP overcomes the hurdles of managing risk using a unique process that guides decision makers to incorporate all relevant information to advance the company toward its goals. Some major organisations such as Ford, GM, Manhattan Oil, and the U.S. Intelligence Community use AHP method to identify and prioritize risks and mitigation strategies to reduce uncertainty in organisational decision-making. Two different approaches are possible for using AHP in risk assessment. It is possible to prioritize risk factors using the AHP and measure, monitor, control for key risks when planning for the future, considering all projects in a global approach. It is also possible to prioritize a specific project's risks considering both probabilities and impacts (www.expertchoice.com). The major weaknesses of the AHP are suggested as the ambiguous questioning procedure about criteria weights and the strong assumption of a ratio scale for the measurement of the scores (Belton, 1986).

In the proposed process, project-based approach would be used. But it seemed more complex and difficult to apply, because of the culture in the R&D Center. Supporting this idea, in a study of Belton (1986), decision-makers suggested that the single additive weighted value functions (which is used in our model) are more transparent and easily understandable when compared to AHP.

It would also be hard to distinguish between a risk's impact and its probability of occurence. It is possible to overcome this handicap like in the study by Dey (2002). Dey applied AHP in a construction project to determine probabilities and determined the impacts of failure by guess estimations.

Weights, scores on probability and impacts, and matrices combining those factors to determine severities are widely used in project risk management literature (Royer, 2000; Murray, 1998; Chapman, 2001; Pinto, 2002; Graves, 2000; Datta and Mukherjee, 2001; Pyra and Trask, 2002; http://www.dir.state.tx.us/eod/qa/risk.htm; PMBOK®Guide, 2000; Patterson and Neailey, 2002; Wideman, 1992).

The method has the advantage of simplicity that can be viewed as commensurate to the nature of use of expert-opinion elicitation (Ayyub, 2001). Simplicity was considered as the main factor for adoption and therefore, scoring was preferred for risk analysis in the proposed process.

Either using 1-3 or 1-5 scales determines the likelihood and the impact of a single risk. Then, these are combined in a matrix to determine the severity of risks. These severities give the priorization of project risks.

Since it is more applicable in the R&D Center, scoring method is adopted for the remainder of this study.

In the proposed process, generic impact scales given in the study of Graves (2000) and probability scales given in the study of Patterson and Neailey (2002) were decided to be used in priorization. The time scales given in the literature were not valid for the R&D Center. According to the past project data analysed in chapter 4, scales for time impacts had been increased about % 20-30. There were different scales for probabilities (see also Chapman, 2001; Pinto, 2002). We choose this scale because of the structure of the Checklist. Some risks had one or zero probabilities and it seemed better to use this scale to emphasise this situation. These can be found in Table 5.2.

Table 5.2 Scales for probability and impact estimations (Graves, 2000; Patterson and Neailey, 2002)

Probability		**Scale**
Very low probability of risk to happen	(%0-%5)	1
The risk less likely to happen then not	(%6-%20)	2
The risk is just as likely to happen as not	(%21-%50)	3
The risk is more likely to happen than not	(%51-%90)	4
The risk will happen almost definitely	(%91-%100)	5
Quality Impact (Quality: Project end item in accordance with its technical specifications)		
Quality degradation barely noticeable		1
		2
Quality degradation noticeable but acceptable		3
		4
Project end item is effectively unusable		5
Schedule Impact		
Insignificant schedule slippage		1
Overall project slippage <10%		2
Overall project slippage 10-20%		3
Overall project slippage 20-50%		4
Overall project slippage >50%		5
Cost Impact		
Insignificant cost increase		1
<5% cost increase		2
5-10% cost increase		3
10-20% cost increase		4
>20% cost increase		5

Using this 1-5 scale, project leader assigns probabilities and impacts for the identified risks, with the help of the project team. Then, these values are entered to the database and the computer calculates the risk severity. This calculations accomplished using the values from Table 5.2 are represented in Table 5.3.

Table 5.3 Risk severity matrix (Graves, 2000)

Probability (Likelihood)	5	**19**	**14**	**9**	**4**	**1**
	4	**21**	**16**	**11**	**6**	**2** A
	3	**23** C	**18**	**13** B	**8**	**3**
	2	**24**	**20**	**15**	**10**	**5**
	1	**25**	**22**	**17**	**12**	**7**
		1	2	3	4	5
	Overall Impact					

A=High severity, B=Moderate severity, C=Low severity.

It is possible to accept the highest impact among the impacts on time, quality, and cost (Graves, 2000). Here, overall impact will be taken as the integer value of the average (Pinto, 2002). Because, when there are two risks with same probability and same highest impact, they will both have the same severity. But one of them may have the other two impact dimensions as 1, while the other risk has the impacts of those dimensions equal to the highest impact. It is unfair to deal with them in the same manner. The impact dimensions could have their own weights according to the project type. For example, schedule impact in a new product development project would be prior to that of an in-house research project. In the proposed system, there will be an option to change the priorities of time, quality and cost impacts. Then, the expression will be:

$$\textbf{\textit{Overall Impact}} = [a*x + b*y + c*z] \tag{5.1}$$

Under the condition: $(a + b + c) = 1$.

a: *Schedule impact coefficient*

b: *Quality impact coefficient*

c: *Cost impact coefficient*

x: *Value of the time impact in 1-5 scale*

y: *Value of the quality impact in 1-5 scale*

z: *Value of the cost impact in 1-5 scale*

One of the weaknesses of scoring model is its failure to incorporate systematic checks on the consistency of judgements (Belton, 1986). Also, using a scoring model imputes a degree of precision that simply does not exist. A halo effect (if a risk scores high on one criterion, it tends to score high on many of the rest) is also possible for a scoring model (Cooper and Edgett, 1997).

The feasibility of the method was tested in a project close to initiation. The scales and the application were easily understood and approved. As a feedback, the project leader has offered a decision-tree like structure. This quantitative approach (see chapter 3) has been integrated as a voluntary process to be done before completing the project planning phase to determine the response strategies.

Then comes the response development phase, for the risks with high and moderate severity.

III. Risk Response Development: The project leader will define response and contingency plans for the prioritized risks. Strategies that can be used in this phase could rely upon:

Acceptance: Just monitoring the risk without doing anything.

Mitigation: Mitigation seeks to reduce the probability and / or consequences of an adverse risk to an acceptable threshold. For example, there is a risk of shortage in a critical material because of a problem in supplier's delivery. The response strategies (mitigation) can be; signing strict contracts with suppliers to decrease the impact of risk, or working with several suppliers to decrease the probability of risk.

Transfer: Transfer is seeking to shift the consequence of a risk to a third party together with ownership of the response. For example, there is a risk of damage in the laboratories because of the possible earthquakes. The response strategy can be the transfer of the risk's impacts to an assurance company.

Avoidance: Avoidance is to eliminate the risk or condition or to protect the project objectives from its impact. For example, there is a risk of having difficulties in the material procurement. The response strategy can be; avoiding the risk by changing the design and not using that specific material.

In this phase, past project data will provide useful information about what has been done for a specific risk in the previous projects. There will be a search option to see the examples of response and contingency plans used in past projects. After the definition of the risk response plan, a document containing identified risks, severities, response plans, risk symptoms, and risk owners will be prepared and approved by the project sponsor. Then comes the monitoring and control phase.

IV. Risk Monitoring and Control: During the execution of a project, these events are possible from risk point of view:

- Applying a response plan by monitoring risk symptoms.
- Identification of new risks and determination of associated response plans.
- Changes in the response plans.
- Identification of risks that are realised.
- Changes in the severity of risks.

In the proposed process, all these events are entered to the database and then tracked. If there is a need for a change in the project plan, a document containing the planned responses, applied responses, severities of risks at the initiation of the project, the most recent severities of risks and risk owner will be prepared and approved by the project sponsor. Risk monitoring and control is a continuous process.

Project Closeout: By this phase, all the risk-related data would be in the database and ready for future use. In our studies, we determined the possible situations about risks as shown in Table 5.4.

Table 5.4 Potential Risk Situations

Identified		Realised	
Risk	Response	Risk	Response
+	+	+	+
+	+	+	-
+	+	-	+
+	+	-	-
-	-	+	+
-	-	+	-

+ Represent identified or realised risks, planned or applied response strategies

- Represent not identified or not realised risks, not planned or not applied response strategies

Acceptance is a response strategy, which means doing nothing. Therefore, there will definitely be a response strategy for an identified risk. Also, not identified and not realised risks are not of interest for the project.

All these situations can be covered under three titles in the final documents. With the closing documents, identified and realised risks, not identified but realised risks, identified but not realised risks will be separately declared with their applied responses, estimated impact on project objectives at the initial plan, realised impact on project objectives, and recommendations for the future.

5.2. Recommended Tool and its Properties

A database structure has been designed to capture all the information about risks and to support the processes with computer. In the database, projects will be defined by their project identification numbers. All other information related with the project will be transferred from the organisation's project database. Risk checklist will produce a screen on which the project leader can choose related risks. Then the selected risks will be filtered and then, the project leader will enter his/her probability and impact estimations using pop-up screens. After entering the risk owners, risk response plans will be entered as well. This will be the end of the planning phase and project planning documents can be printed for approval, from the database.

During the execution, risk symptoms will be tracked and response plans will be applied according to these symptoms. Applied response activities should be entered into the database. If a risk is realised, it will be checked on the database with the "realization" indicator. When a risk is no more considered as a threat, its "status" will be marked as inactive. If there are some additional risks, which have not been identified during the planning phase but emerged as a risk issue later, or if there are changes in the response plans, these will be identified on the database in a similar fashion to the planning phase. If there are changes in the severity of the risks, these will also be entered into the database by re-estimating their probabilities and impacts.

During the closeout phase, recommendations for future projects will be entered into the database and closing documents will be printed for approval. Also, the record of the project will be locked and most recent information will be transferred from the main database. After that, project data will be available for future use with several search options.

In designing this database structure, the following factors were considered as important:

- capturing all the situations about risks,
- easy to use, user-friendly,
- understandable,
- easy to reach and use data when needed,
- secure enough with defined rights for access.

5.3. Expected Benefits of the Process

The expected benefits of the risk management process are;

- Better understanding of the project.
- Defining more realistic objectives and reduction in change requests.
- Being prepared against uncertainties and reduction in time, money and resource losses.
- Learning from the past projects with the help of the standardisation gained by the Risk Checklist.
- As a result, increasing the project performance.

5.4. Potential Drawbacks

- Response activities cost time, bring cost, and use extra resources.
- It is hard to provide input for estimations.
- It is hard to understand the techniques used in the process (For this reason, quantitative techniques have not been used for now, to simplify this process).
- It is possible to confuse risks with their causes or potential effects.

6. DETERMINING PROJECT DURATION AND COST UNDER RISK: A HYPOTHETICAL EXAMPLE TO THE QUANTITATIVE RISK ANALYSIS

The quantitative risk analysis process aims to analyze numerically the probability of each risk and its consequence on project objectives. It uses techniques such as Monte Carlo simulation to determine the probability of achieving a specific project objective; to quantify the risk exposure for the project, and to determine the size of total project cost; to identify risks requiring the most attention by quantifying their relative contribution to project risk; to identify realistic and achievable cost, schedule or scope targets. Especially in large engineering projects it is essential to determine the project duration and expected cost to overcome uncertainties and penalties. In the proposed process, simplicity was the main issue; project sizes were not that large, the purpose was mainly to establish the awareness in project risks and therefore, quantification did not emerge as an indispensable issue.

In this chapter, the elements of a project scheduling problem are described and the mathematical formulation of the model used in quantitative risk analysis is given. Finally, to give an example to the determination of the project duration and cost under risks, in a quantitative manner, a hypothetical project is formulated to be analysed using simulation.

6.1. Problem Description

The elements of a project scheduling problem are (Kolisch, 1995; Kolisch and Padman, 2001):

- **Activities:** A project consists of a number of activities, also known as jobs, operations, or tasks.

  - *Modes for an Activity:* In order to complete the project successfully, each activity has to be processed in one of several modes. Each mode represents a distinct way of performing the activity under consideration.
  - *The Duration of the Activity*: Indicates the time taken to complete the activity.
  - *Resource Requirements*: The requirements for resources of various categories.

- **Resources:** Resources utilized by the activities are classified according to categories, types, and value. The category classification includes resources that are renewable, non-renewable, partially renewable and doubly constrained.

  - **Categories:**
    - *Renewable resources* are constrained on a period basis only. That is, regardless of the project length, each renewable resource is available for every single period. Examples are machines, equipment, and manpower.
    - *Non-renewable resources* are limited over the entire planning horizon, with no restrictions within each period. The classic example is the capital budget of a project.
    - *Doubly constrained resources* are limited on a period basis as well as on a planning horizon basis. Budget constraints that limit capital availability for the entire project as well as limiting its consumption over each time period is an example of this type of resource.
    - *Partially renewable resources* limit utilization of resources within a subset of the planning horizon. An example is that of a planning horizon of a month with workers whose weekly working time, not the daily time, is limited by the working contract.

  - **Type:** The type classification further distinguishes each category according to the function of the various resources.

  - **Value:** Finally, each resource type has a value associated with it, representing the available amount.

- **Precedence Relations:** Often technological reasons imply that some activities have to be finished before others can start. This is handled by depicting the project as a directed graph where an activity is represented by a node and the precedence relation between two activities is represented by a directed arc: Activity-on-Node (AON), or where an activity is represented by an arc: Activity-on-Arc (AOA).

- **Objective Functions:** Makespan, total cost, return, profit, quality, etc.

There are additional elements in our model to incorporate risks:

- **Risks Associated with Activities.**
- **Probability and Impact Estimations for Each Risk of Each Activity.**
- **Criticality of a Particular Activity:** Criticality of an activity is defined as the probability of that activity being on the critical path.

6.2. Mathematical Formulation of the Problem

The problem is formulated here as an optimization problem to minimize the expected project cost under risks. It is assumed that the risks are independent and their impacts are additive at the activity level. It is further assumed that all the risks associated with an activity are identified and the risks are static throughout the project life. The problem is represented on an activity-on-node (AON) network with one starting and one ending node.

Expected total cost is a combination of overhead costs, penalty costs, resource usage costs, duration dependent response costs, and duration independent response costs. The overhead cost is taken as a unit fixed cost for simplicity's sake and has been multiplied by the project duration to find its total. Penalty cost is determined by multiplying a fixed cost per unit time with the project delay. In this model, resources are considered only as various levels of manpower. Resource costs are the sum of the resource costs for each activity. To find the resource cost for an activity, cost associated with the type of the resource is multiplied by the number of workers for that type needed for the activity and the expected duration of the activity. Duration dependent response cost represents the variable cost of the response, which increases while the duration increases. Duration independent costs are the costs of responses that are incurred once. Probability of occurrence of risks is assumed as to follow discrete probability distribution (Figure 6.1). For example, decreasing the probability of occurrence of the risk n on activity j from state k' to state k'', where $k'>k''$, has a cost of $C_{jnk''}$. The impact of risk n on activity j at the state k' decreases or stays same at k'' $(I_{jnk'} \geq I_{jnk''})$, and it is assumed to follow continuous probability distribution. Transition from K_{jn} to K_{jn} has a cost of 0 and represents "doing nothing" as a response.

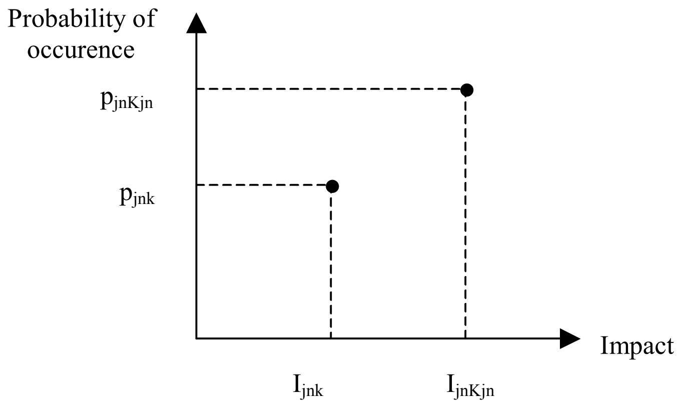

Figure 6.1 The relationship between the probability of occurrence and the impact of a risk

Notation:

$\{J\}$: *Set of activities j;*

$\{P_j\}$: *Set of immediate predecessors of activity j;*

$\{S_j\}$: *Set of immediate successors of activity j;*

$\{N_j\}$: *Set of risks n assigned to activity j;*

$\{L_j\}$: *Set of resource types for activity j;*

d_j: *Duration of activity j with no risks involved;*

C_p: *Unit penalty cost of being late;*

C_o: *Unit cost of overhead;*

T_{plan}: *Due date set for the project;*

p_{jnk}: *Probability of* n^{th} *risk's occurrence, for activity j for state k;*

K_{jn}: *Number of states for the probability of occurrence of risk n on activity j;*

I_{jnk}: *Impact of risk n, if it occurs, for activity j at the state of k;*

C_{lj}: *Unit cost of resource type* l_j*;*

C_{jnk}: *Fixed cost of reducing the probability of occurrence of risk n on activity j from state* K_j *to state* $k \leq K_{jn}$*;*

W_{nklj}: *Number of workers of type* l_j *assigned to activity j for state k of risk n;*

E(TC): Expected total cost;

ST_j: *Start time of activity j (EST: Earliest start time, LST: Latest start time);*

FT_j: *Finish time of activity j (EFT: Earliest finish time, LFT: Latest finish time);*

d_j': *Duration of activity j under risks;*

$x_{jnk} = \begin{cases} 1, & \text{if the the probability of occurrence of risk } n \text{ on activity } j \text{ is reduced from state } K_{jn} \text{ to } k \le K_{jn} \\ 0, & \text{otherwise} \end{cases}$

$y = \begin{cases} EFT_J - T_{plan}, & \text{if } EFT_J > T_{plan} \\ 0, & \text{otherwise} \end{cases}$

$$Min\,E(TC) = y \times C_p + \sum_{j=1}^{J}\sum_{n=1}^{N_j}\sum_{k=1}^{K_{jn}} C_{jnk} \times x_{jnk} + EFT_J \times C_o + \sum_{j=1}^{J}\sum_{l_j=1}^{L_j}\sum_{n=1}^{N_j}\sum_{k=1}^{K_{jn}} W_{nkl_j} \times d'_j \times C_{l_j} \qquad (6.1)$$

$$EST_1 = 0 \qquad (6.2)$$

$$EST_j = \max\{EFT_i \mid i \in P_j\} \qquad j = 2,....,J \qquad (6.3)$$

$$EFT_j = EST_j + d'_j \qquad j = 1,....,J \qquad (6.4)$$

$$EFT_J = LFT_J \qquad (6.5)$$

$$LFT_j = \min\{LST_i \mid i \in S_j\} \qquad j = 1,.....,(J-1) \qquad (6.6)$$

$$LST_j = LFT_j - d'_j \qquad j = 1,.....,J \qquad (6.7)$$

$$d'_j = d_j + \sum_{n=1}^{N_j}\sum_{l_j=1}^{K_{jn}} I_{jnk} \times x_{jnk} \times p_{jnk} \qquad j = 1,......,J \qquad (6.8)$$

$$C_{jnK_{jn}} \equiv 0 \qquad (6.9)$$

$$\sum_{k=1}^{K_{jn}} x_{jnk} = 1 \qquad n = 1,.....,N_j;\ j = 1,.......,J \qquad (6.10)$$

$$x_{jnk} \in \{0,1\} \qquad j = 1,......,J;\ n = 1,.....,N_j;\ k = 1,....K_{jn} \qquad (6.11)$$

This is a zero-one programming model. The expected total cost is given by the Expression 6.1. The objective is to minimize this cost.

The well known critical path formulation for an activity on node representation lies between Expressions 6.2 through 6.7. Forward tracking to calculate early start and finish times for activity j is given in Expressions 6.2, 6.3, and 6.4. Backward tracking to calculate late start and finish times for activity *j* is given in Expressions 6.5, 6.6, and 6.7. Critical path is calculated to determine the project duration (EFT_J).

Expected duration of activities under risk (d_j') are calculated with Expression 6.8. The expected increase in an activity's duration caused by a particular risk is calculated by multiplying the impact of risk *n* at state *k* with its probability of occurrence for the same state. This is also multiplied by x_{jnk} to identify the state. This product is summed over K_j to cover all states and N_j to cover all the risks for an activity. This summation gives the total expected increase in the activity's duration and it is added to d_j to determine d_j'.

If the probability of occurrence of risk n in activity j is not reduced from its initial level K_{jn}, then this means that the probability of occurrence remains the same as a result of doing nothing for mitigation. Therefore, C_{jnKjn}=0, as stated in Expression 6.9.

One and only one level for the probability of occurrence of risk *n* on activity *j* has to be selected (Expression 6.10).

The decision variables x_{jnk}'s can take on only values 0 or 1 (Expression 6.11).

The number of zero-one variables increase with the number of activities, risks and states. For example let us assume a problem including 20 activities with 3 risks associated with each activity, and 3 possible states per risk. Then, there will be 180 zero-one variables to deal with. This might become a difficult problem to solve exactly. Thus, a heuristic solution procedure might be the only feasible way to treat the problem within the mathematical programming realm. Rather than seeking a heuristic solution procedure for the above mathematical programming formulation, a Monte Carlo simulation approach is selected to analyze the problem.

6.3. Problem Representation and Assumptions

Monte Carlo simulation is widely used in quantitative risk analysis. Risk assignments to activities and schedule risk analyses are common in the studies. Since schedule has such a high leverage on project success and can have a high negative effect on costs, the main concern is focused on the schedule (Goodpasture and Hulett, 2000; Dey and Ogunlana, 2001; Finley and Fischer, 1994; Hulett, 1995; Weiler, 1998).

For the quantitative risk analysis, the data needed and the outcomes, which help the decision-maker, can be described as follows:

Planning Phase:

Data needed: Estimations on the probability density functions of identified risks' probabilities of occurrence and their impacts.

Outcomes: Probability density functions of total project duration and total cost with respect to Monte Carlo simulation. Possible scenarios upon project duration and total cost.

Decision: Risk response strategies.

Execution Phase:

Same considerations as the planning phase but this time it is necessary to update the project model for simulation according to the possible modifications as:

- Milestone reviews and go/kill decisions.
- Finished/continuing activities.
- Realised/not realised risks.
- Changes in the probability of occurrence or impact of a risk.
- Addition/removal of activities.
- Addition/removal of risks.
- Resource constraints.
- Replanning needs.

In our hypothetical project, there are 12 activities with 2-5 risks assigned to each of them (see Table 6.1).

Table 6.1 Activities and their identified risks for the hypothetical example

Activities	Duration (days)	No. of Workers	Risks
A1: Feasibility Studies	15	4	Difficulty in defining the project scope
			Changes in standards and regulations
			Changing objectives/expectations
A2: Literature Search	11	1	Absence of qualified people
			Use of new-to-the world technology
A3: Theoretical Studies	10	2	Absence of qualified people
			Changing objectives/expectations
			No working experience with the consultant
A4: Laboratory Set-up	15	2	Limited service alternatives
			Interruption of the services provided
			No experience with the use of the equipment
			Payment delays/cash flow irregularities
A5: Patent Search	7	2	New technologies developed by competitors
			Changes in standards and regulations
A6: Conceptual Design	10	3	High uncertainty in technical content
			Inadequacy of project team's working hours because of overloading
A7: Preparation of Research Report	15	1	Inadequacy of project team's working hours because of overloading
A8: Determination of Design Parameters	15	4	Changes in standards and regulations
			Inadequacy of communication within the project team

Table 6.1 Activities and their identified risks for the hypothetical example (continued)

Activities	Duration (days)	No. of Workers	Risks
A9: Experimental Studies in the Laboratory	25	3	Machine breakdown / lack of maintenance
			No experience with the use of the equipment
			Inadequacy of laboratories because of overloading
			Inadequacy of project team's working hours because of overloading
			High uncertainty in the technical content
A10: Detail Design	13	3	High uncertainty in technical content
			Customer change requests
			Inadequacy of communication within the project team
A11: Optimization	10	2	High uncertainty in technical content
			Inadequacy of project team's working hours because of overloading
			Machine breakdown / lack of maintenance
			Inadequacy of laboratories because of overloading
A12: Final Prototypes and Reports	20	3	Payment delays/cash flow irregularities
			Difficulty in material procurement
			Inadequacy of laboratories because of overloading

The precedence relations are represented on an AON network in Figure 6.2.

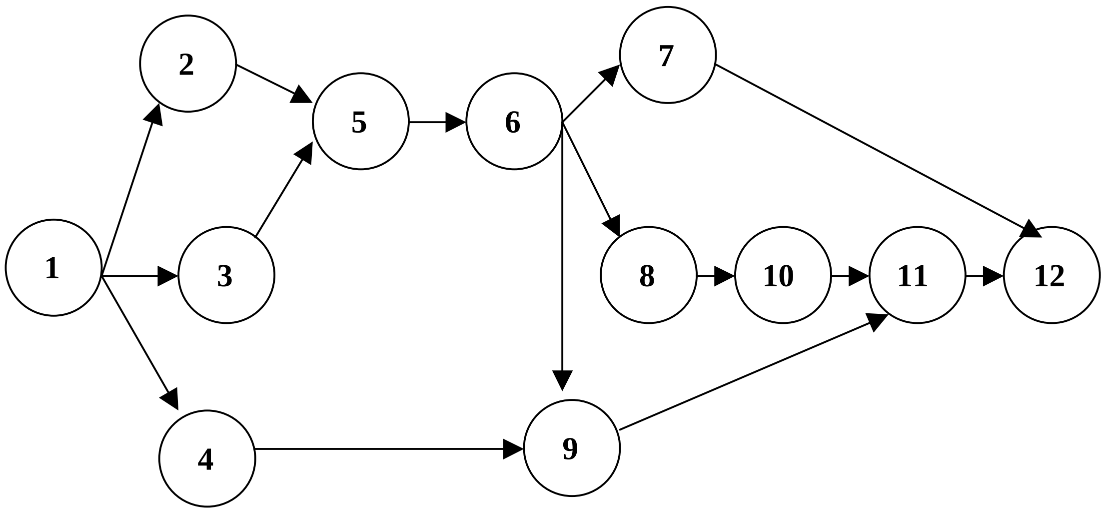

Figure 6.2 Precedence relations for the hypothetical example

The duration of an activity with no risks involved is estimated in a deterministic way. The activity duration under risk is calculated using Expression 6.12 under the assumption of "the duration is only affected by the identified risks":

$$d_j' = d_j + \sum_{i=1}^{N_j} (\text{Trigger identifier x Impact})_i \qquad (6.12)$$

where, i: Risk item, N_j: Number of risks assigned to the activity j.

It is assumed that the risks are independent and their impacts are additive at the activity level. It is also assumed that all the risks associated with an activity are identified. Probability of the occurrence of a risk and its impact when it occurs, will be the random numbers generated by Monte Carlo according to the pdf's assigned to them (see Table 6.2. for pdf's). The trigger is a threshold value. The random number generated by Monte Carlo for the probability of occurrence is compared with this value and if it is greater than the trigger, then the risk is concerned as "realised" and "the trigger identifier" gets the value of 1. If it is smaller than or equal to trigger, then "the trigger identifier" gets the value of 0 implying that the risk is not realized. If a risk is realised, its impact on the duration is added to the activity duration.

Table 6.2 Probability density/mass functions of risks

Assigned Risk (Activity No) / Impacts	**Pdf**
Difficulty in defining the project scope(1) / Impact	RiskPert(0; 3; 9)
Changes in standards and regulations(1) / Impact	RiskTriang(0; 2; 4)
Changing objectives/expectations(1) / Impact	RiskTriang(0; 2; 4)
Absence of qualified people(2) / Impact	RiskPert(0; 2; 4)
Use of new-to-the world technology(2) / Impact	RiskTriang(0; 1; 2)
Absence of qualified people (3) / Impact	RiskPert(0; 2; 4)
Changing objectives/expectations(3) / Impact	RiskTriang(0; 2; 4)
No working experience with the consultant(3) / Impact	RiskPoisson(3)
Limited service alternatives (4) / Impact	RiskPoisson(1)
Interruption of the services provided(4) / Impact	RiskExpon(2)
No experience with the use of the equipment (4) / Impact	RiskPert(0; 3; 6)
Payment delays/cash flow irregularities (4) / Impact	RiskPoisson(3)
New technologies developed by competitors (5) / Impact	RiskTriang(0; 2; 4)
Changes in standards and regulations (5) / Impact	RiskTriang(0; 1; 2)
High uncertainty in technical content (6) / Impact	RiskTriang(0; 4; 11)
Inadequacy of project team's working hours because of overloading(6) / Impact	RiskTriang(0; 2; 4)
Inadequacy of project team's working hours because of overloading(7) / Impact	RiskPoisson(1,5)
Changes in standards and regulations (8) / Impact	RiskTriang(0; 4; 6)
Inadequacy of communication within the project team(8) / Impact	RiskPert(0; 2; 3)
Machine breakdown / lack of maintenance (9) / Impact	RiskPoisson(4)
No experience with the use of the equipment (9) / Impact	RiskPert(0; 1; 2)
Inadequacy of laboratories because of overloading (9) / Impact	RiskPert(0; 1; 5)
Inadequacy of project team's working hours because of overloading(9) / Impact	RiskTriang(0; 2; 7)

Table 6.2 Probability density/mass functions of risks (continued)

Assigned Risk (Activity No) / Impacts	Pdf
High uncertainty in technical content (9) / Impact	RiskTriang(0; 4; 8)
High uncertainty in technical content (10) / Impact	RiskTriang(0; 2; 8)
Customer change requests (10) / Impact	RiskPert(2; 4; 12)
Inadequacy of communication within the project team(10) / Impact	RiskPert(0; 1; 2)
High uncertainty in technical content (11) / Impact	RiskTriang(0; 2; 7)
Inadequacy of project team's working hours because of overloading (11) / Impact	RiskTriang(0; 2; 4)
Machine breakdown / lack of maintenance (11) / Impact	RiskPoisson(3)
Inadequacy of laboratories because of overloading (11) / Impact	RiskPert(0; 2; 7)
Payment delays/cash flow irregularities (12) / Impact	RiskPoisson(2,5)
Difficulty in material procurement (12) / Impact	RiskPoisson(1,5)
Inadequacy of laboratories because of overloading (12) / Impact	RiskPert(0; 3; 6)
Assigned Risk (Activity No) / Probability	**Pdf**
Difficulty in defining the project scope(1) / Probability	RiskUniform(0; 1)
Changes in standards and regulations(1) / Probability	RiskTriang(0; 0,3; 0,6)
Changing objectives/expectations(1) / Probability	RiskNormal(0,5; 0,1; RiskTruncate(0; 1))
Absence of qualified people(2) / Probability	1
Use of new-to-the world technology(2) / Probability	1
Absence of qualified people (3) / Probability	1
Changing objectives/expectations(3) / Probability	RiskNormal(0,5; 0,05; RiskTruncate(0; 1))
No working experience with the consultant(3) / Probability	1
Limited service alternatives (4) / Probability	1
Interruption of the services provided(4) / Probability	RiskUniform(0; 0,8)
No experience with the use of the equipment (4) / Probability	1
Payment delays/cash flow irregularities (4) / Probability	RiskTriang(0; 0,2; 0,7)
New technologies developed by competitors (5) / Probability	RiskTriang(0; 0,2; 1)
Changes in standards and regulations (5) / Probability	RiskTriang(0; 0,5; 1)
High uncertainty in technical content (6) / Probability	RiskTriang(0; 0,3; 1)
Inadequacy of project team's working hours because of overloading(6) / Probability	RiskNormal(0,4; 0,2; RiskTruncate(0; 1))
Inadequacy of project team's working hours because of overloading(7) / Probability	RiskNormal(0,6; 0,2; RiskTruncate(0; 1))
Changes in standards and regulations (8) / Probability	RiskTriang(0; 0,5; 1)
Inadequacy of communication within the project team(8) / Probability	RiskTriang(0; 0,2; 0,4)
Machine breakdown / lack of maintenance (9) / Probability	RiskExpon(1; RiskTruncate(0; 1))
No experience with the use of the equipment (9) / Probability	1
Inadequacy of laboratories because of overloading (9) / Probability	RiskNormal(0,5; 0,15; RiskTruncate(0; 1))
Inadequacy of project team's working hours because of overloading(9) / Probability	RiskNormal(0,5; 0,2; RiskTruncate(0; 1))
High uncertainty in technical content (9) / Probability	RiskTriang(0; 0,4; 1)
High uncertainty in technical content (10) / Probability	RiskUniform(0,1; 0,6)
Customer change requests (10) / Probability	RiskPert(0; 0,2; 0,5)
Inadequacy of communication within the project team(10) / Probability	RiskTriang(0; 0,2; 1)

Table 6.2 Probability density/mass functions of risks (continued)

Assigned Risk (Activity No) / Probability	Pdf
High uncertainty in technical content (11) / Probability	RiskTriang(0; 0,2; 0,6)
Inadequacy of project team's working hours because of overloading (11) / Probability	RiskPert(0; 0,4; 0,6)
Machine breakdown / lack of maintenance (11) / Probability	RiskExpon(1; RiskTruncate(0; 1))
Inadequacy of laboratories because of overloading (11) / Probability	RiskNormal(0,5; 0,15; RiskTruncate(0; 1))
Payment delays/cash flow irregularities (12) Probability	RiskTriang(0; 0,2; 1)
Difficulty in material procurement (12) / Probability	RiskUniform(0; 1)
Inadequacy of laboratories because of overloading (12) / Probability	RiskNormal(0,5; 0,15; RiskTruncate(0; 1))

For simplicity, it is assumed that the cost of an activity is represented with one-type resource, with a cost of \$30/manxday. Cost of an activity is calculated as in Expression 6.13.

$$AC_j = \$30 \text{ x No. of workers for activity } j \text{ x } d_j' \qquad (6.13)$$

In this example, the criticality of an activity is defined as the percentage of that activity being on the critical path over all the iterations. If there are 100 iterations, and activity *a* has appeared on critical path in 60 of them, while activity *b* appeared only on 10, then activity *a* is more “critical” than activity *b* (Elmaghraby, 2000).

The objective of the analysis is to determine the distribution function of the project duration and project cost in order to find out a set of possible non-dominating scenarios to help the decision-maker. Critical Path Method (CPM) calculates the total duration. The target duration is 125 days for the project. Otherwise, there’s a penalty cost of \$50 /day for each day the project duration exceeds 125 days. The penalty cost is added to the total cost of the project. Total project cost is determined by the Expression 6.14 (overhead costs are added to the total cost as \$30 per day for the sake of simplicity):

$$TC = \left(\sum_{j=1}^{12} AC_j \right) + (EFT_{12} - 125) \text{ x } \$50 + \$30 \text{ x } EFT_{12} \qquad (6.14)$$

This project is modelled by Microsoft Excel ® to be simulated using the commercial software package @Risk®. This software package allows easy simulation of projects represented as project networks and yields data that show the probability of completing a project at specific times.

@Risk 4.0 is developed by Palisade Corporation, compatible with Excel. This package allows defining uncertain cell values in Excel as probability distributions using functions. @Risk adds over thirty new functions to the Excel function set, each of which allows you to specify a different distribution type for cell values. Distribution functions can be added to any number of cells and Expressions throughout worksheets and can include arguments, which are cell references, and expressions - allowing extremely sophisticated specification of uncertainty. To help you assign distributions to uncertain values, @Risk includes a graphical pop-up window where distributions can be previewed and added to Expressions. Monte Carlo sampling technique is supported and distributions of possible results may be generated for any cell or range of cells in the spreadsheet model.

In general, the techniques in an @Risk analysis encompass four steps:

- **Developing a Model** - by defining the problem or situation in Excel worksheet format.
- **Identifying Uncertainty** - in variables in the Excel worksheet and specifying their possible values with probability distributions, and identifying the uncertain worksheet results wanted to be analyzed.
- **Analyzing the Model with Simulation -** to determine the range and probabilities of all possible outcomes for the results of the worksheet.
- **Making a Decision** - based on the results provided and personal preferences.

There is sufficient interest in the literature to the minimization of project duration and cost by using time-cost trade-off (Kolisch, 1995; Kolisch and Padman, 2001). In this study, decreasing the impacts of risks on activity duration using response strategies, we attempt to decrease total cost and duration. Heuristically, attacking the risks, which affect the project cost at most, will be an efficient way of minimizing the cost/duration. There are three dimensions of this effect:

- Exposure of the particular risk for the particular activity,
- Criticality of the activity,
- Number of workers needed for the activity, because of the multiplicative impact on the cost.

The model for the hypothetical example (see attached floppy disk) is simulated using Monte Carlo with @Risk, for 5000 iterations. The distributions of "Total Cost" and "Project Duration" for the baseline simulation can be seen in Figures 6.3 and 6.4.

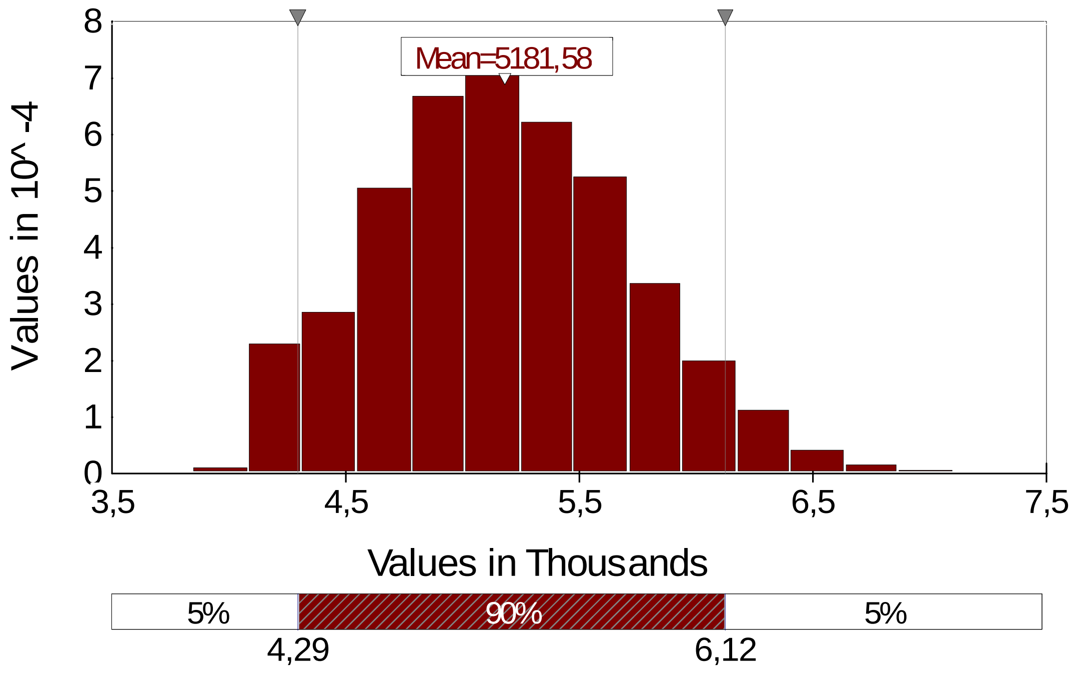

Figure 6.3 The distribution for total cost (Baseline Simulation)

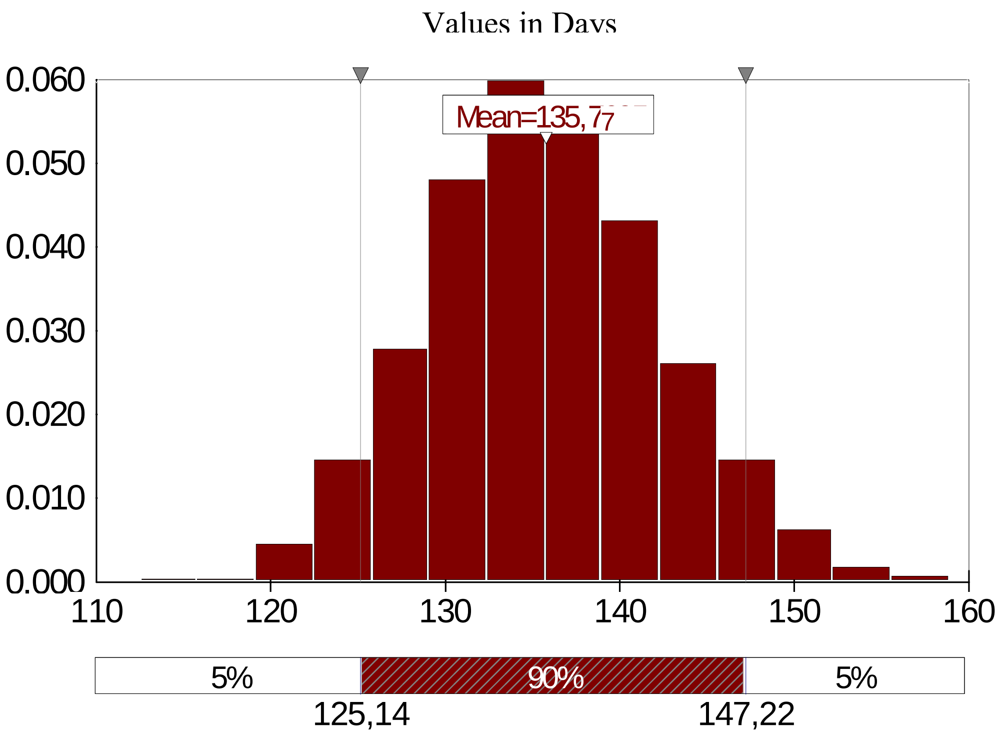

Figure 6.4 The distribution for project duration (Baseline Simulation)

The bar under each histogram represents the % 90 confidence interval for the corresponding distribution.

The frequency for each activity of appearing on the critical path through the 5000 iterations and its resulting criticality ratio are given in Table 6.3.

Table 6.3 Criticality values for the activities (Baseline Simulation)

Activity No	Frequency	Criticality (%)
Activity 1	5000	100.00
Activity 2	397	7.94
Activity 3	4602	92.04
Activity 4	1	0.02
Activity 5	4999	99.98
Activity 6	4999	99.98
Activity 7	0	0.00
Activity 8	1072	21.44
Activity 9	3928	78.44
Activity 10	1072	21.44
Activity 11	5000	100.00
Activity 12	5000	100.00

Heuristically, the risks assigned to the activities 2, 4, 7, 8, and 10 have no impact on the project duration or cost. The significant risks of activities 1, 3, 5, 6, 9, 11, and 12 are determined and sorted by their relative impacts on the expected project duration and expected total cost.

Risk exposure is defined as the product of the likelihood that the risk will occur and the magnitude of the consequences of its occurrence. Here, the risk exposure is calculated by multiplying the expected values of the distributions associated with the risk's probability and impact (Expression 6.15).

$$\text{Risk Exposure} = \text{E(Probability distribution) x E(Impact distribution)} \qquad (6.15)$$

The estimated impact on the project duration (EIPD) is determined by multiplying the risk's exposure and the criticality of the activity (Expression 6.16).

$$EIPD = \text{Risk Exposure x Criticality} \qquad (6.16)$$

The estimated impact on the total cost (*EITC*) is determined by multiplying the *EIPD* and the number of workers needed for that activity (Expression 6.17).

$$EITC = EIPD \text{ x No. of workers} \qquad (6.17)$$

Risks are sorted in a descending order of EITC values, representing a decreasing contribution to the expected total cost. This list and response costs for the risks can be seen in Table 6.4.

Table 6.4 Prioritized risk list

Risks (Activity No. Risk No)	Criticality (%)	No. Of Workers	Risk Exposure	*EIPD* (Normalized)	*EITC* (Normalized)	Cost of Response ($)	EITC / Cost of response
Risk 1.1	100	4	1.75	0.63	1	50	0.020
Risk 6.1	99.98	3	2.17	0.79	0.93	150	0.006
Risk 3.3	92.04	2	3	1	0.79	20	0.040
Risk 12.3	100	3	1.5	0.54	0.64	200	0.003
Risk 9.5	78.56	3	1.87	0.53	0.63	200	0.003
Risk 1.2	100	4	1	0.36	0.57	100	0.006
Risk 9.1	78.56	3	1.67	0.48	0.56	100	0.006
Risk 3.1	92.04	2	2	0.67	0.53	200	0.003
Risk 12.1	100	3	1.2	0.43	0.51	200	0.003
Risk 9.4	78.56	3	1.5	0.43	0.51	60	0.009
Risk 12.2	100	3	1	0.36	0.43	30	0.014
Risk 11.3	100	2	1.25	0.45	0.36	100	0.004
Risk 11.4	100	2	1.25	0.45	0.29	200	0.001
Risk 9.3	78.56	3	0.75	0.21	0.29	100	0.003
Risk 3.2	92.04	2	1	0.33	0.17	120	0.001
Risk 1.2	100	4	0.6	0.22	0.14	100	0.001
Risk 9.2	78.56	3	1	0.28	0.14	200	0.001
Risk 11.1	100	2	0.8	0.29	0.14	100	0.001
Risk 5.1	99.98	2	0.8	0.29	0.14	100	0.001
Risk 5.2	99.98	2	0.5	0.18	0.14	100	0.001
Risk 6.2	99.98	3	0.82	0.3	0.09	60	0.002
Risk 11.2	100	2	0.73	0.26	0.09	60	0.002

We have made two more simulations to see the effect of responding to the risks. This is a multi-objective problem aiming to decrease the total cost and project duration. These simulations are employed to see the trade-off between these two objectives. In the first experiment, first 5 risks of the above list with the highest impact on the expected duration (according to EIPD) are responded with a total response cost of $620. These risks are Risk 3.3, Risk 6.1, Risk 3.1, Risk 1.1, and Risk 12.3. The results of this simulation experiment are displayed in Figures 6.5 and 6.6.

In the second experiment, risks, whose response costs are under $100, are responded to with a total response cost of $280 to decrease the expected total cost. These risks are Risk 6.2, Risk 12.2, Risk 9.4, Risk 3.3, Risk 11.2, and Risk 1.1. The results of this simulation are displayed in Figures 6.7 and 6.8.

As we can see from the results, both experiments result in solutions with both being dominant over the baseline solution with decreased expected cost and expected project duration. But these two results are not dominant over each other. When we plot the results, we obtain a Pareto optimal time cost trade-off structure (Figure 6.9).

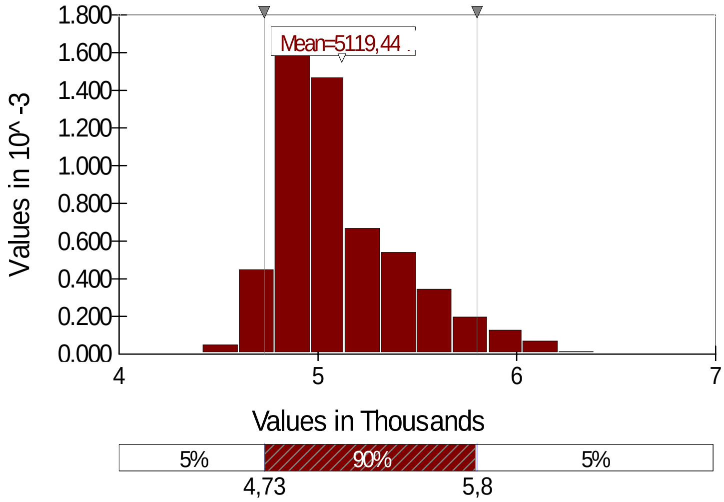

Figure 6.5 The distribution of total cost for simulation experiment #1

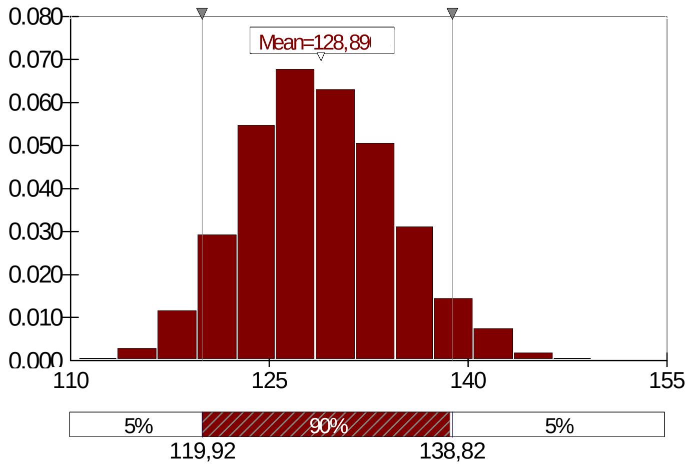

Figure 6.6 The distribution of project duration for simulation experiment #1

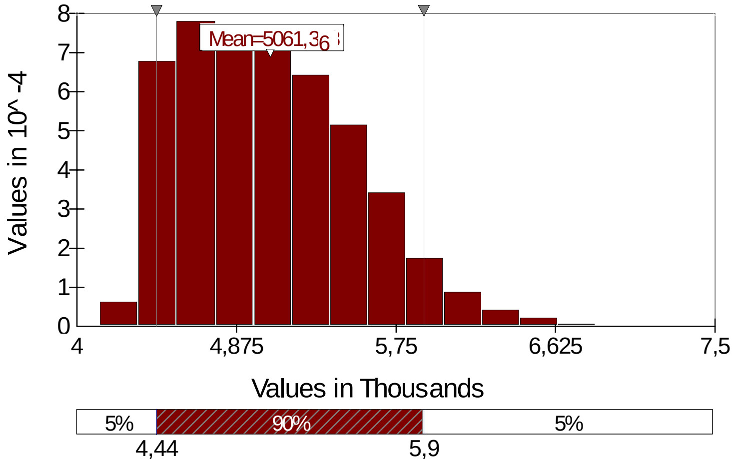

Figure 6.7 The distribution of total cost for simulation experiment #2

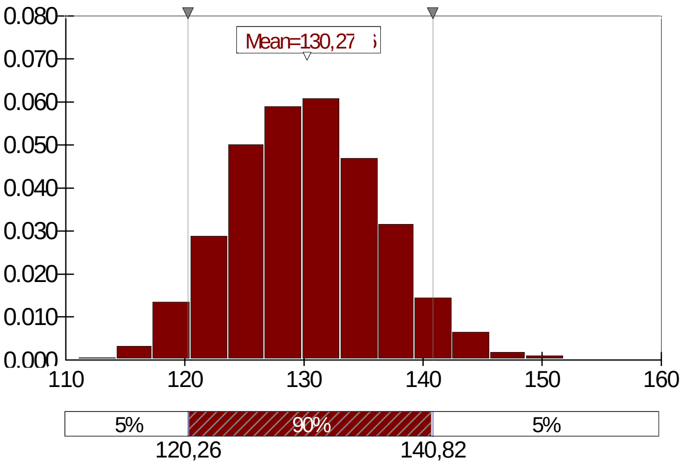

Figure 6.8 The distribution of project duration for simulation experiment #2

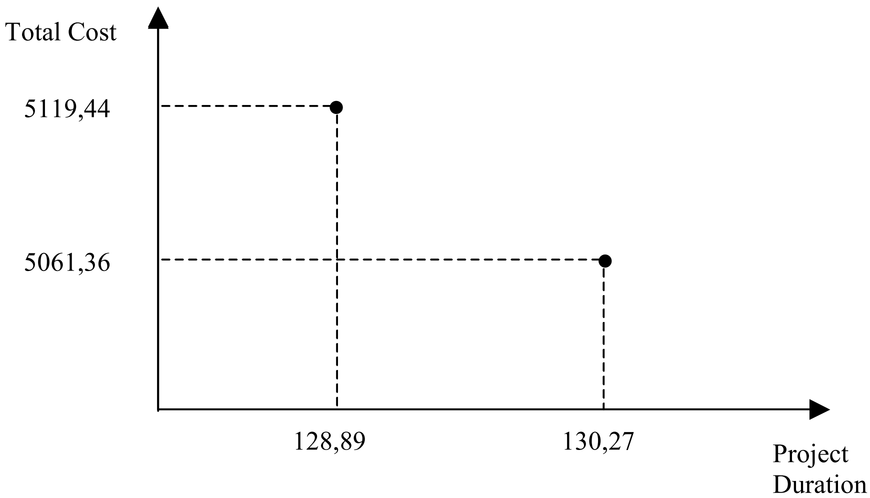

Figure 6.9 Results of experiments #1 and #2

Heuristically it is beneficial to attack on the risks, which have significant effects on the project duration, if the objective is focused on duration. If the focus is on the total cost, it would be rational to attack on the risks, which have significant impact on total cost and have low response costs at the same time. But any approach is applicable to this analysis. In practice, employing the easily applicable responses might be preferable. The main point here is the determination of the criticalities. Developing and employing a response on a risk, which does not affect the project duration, has no meaning at all.

Risk analysis is employed to provide help to the risk response development phase. To demonstrate a possible use of risk analysis in developing risk response plans, the following example is constructed. In the same hypothetical project, it is assumed that there's a limited budget of $ 400 for response activities. Decreasing expected total cost is the dominant objective for the response plan. The prioritized list of risks is given in Table 6-4. *EITC* / Cost of response is in the last column of this table. This value represents the reduced amount of impact on the total cost for unit response cost. In other words, the amount of impact reduction on the response investment. The bigger is this value, the expected benefit from attacking this risk is higher. Then, we can interpret this problem as a knapsack problem. The decision variable determines whether to response a particular risk or not.

Four simulation experiments has been done to demonstrate the distribution of total cost and duration for different response plans. It is possible to design further experiments with employing fewer risk responses, without trying to use all the reponse budget. The purpose here is to find out a non-dominating scenario set for the multi-objective problem to help the decision-maker. The total value of marginal impacts, total cost of responses, and the risks that are responded for each activity is given in Table 6.5.

Table 6.5 Simulation experiments for constructing a set of response plans

Exp. No	Total Marginal Impact	Total Cost of Responses ($)	Risks Responded
3	0,757	370	3.3, 1.1, 12.2, 9.4, 6.1,6.2
4	0,761	360	3.3, 1.1, 12.2, 9.4, 1.2, 9.1
5	0,757	370	3.3, 1.1, 12.2, 9.4, 6.1, 11,2
6	0,750	400	3.3, 1.1, 12.2, 1.2, 9.1, 11,3

The results of these experiments can be seen in Figures 6.10, 6.11, 6.12, 6.13, 6.14, 6.15, 6.16, 6.17.

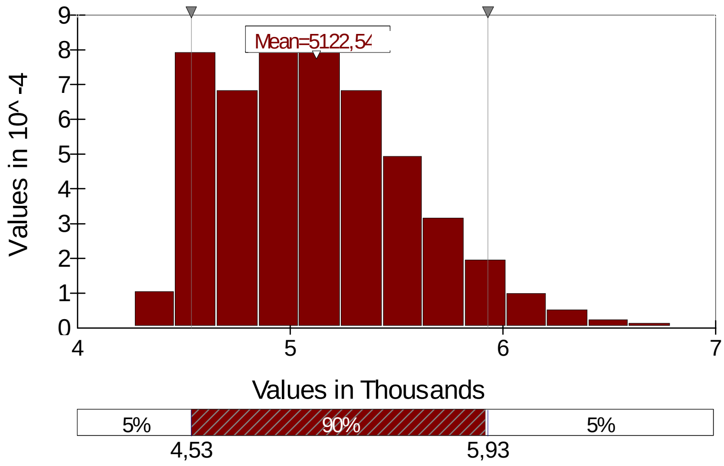

Figure 6.10 The distribution of total cost for simulation experiment # 3

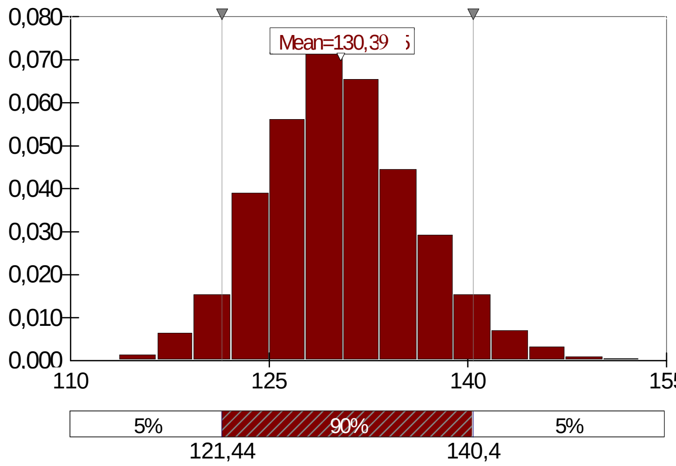

Figure 6.11 The distribution of project duration for experiment #3

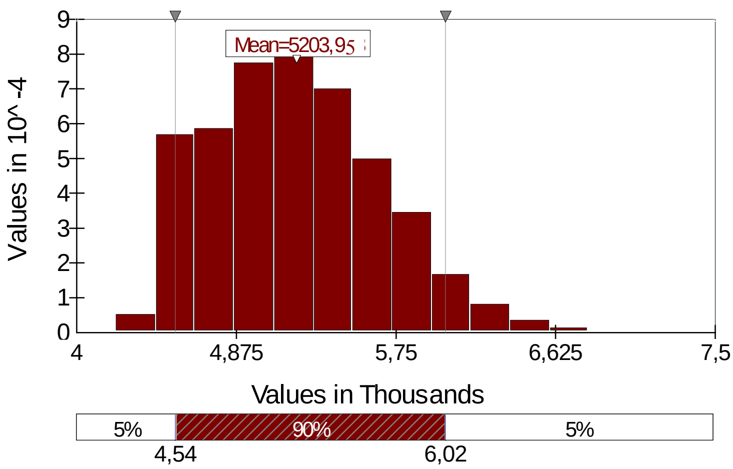

Figure 6.12 The distribution of total cost for simulation experiment #4

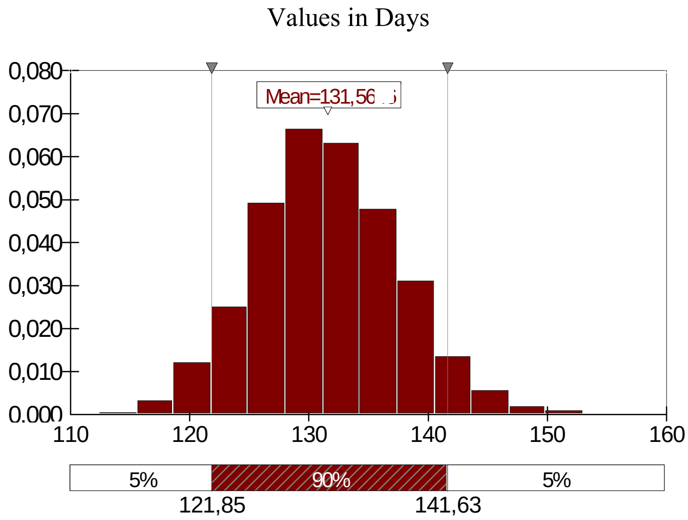

Figure 6.13 The distribution of project duration for simulation experiment #4

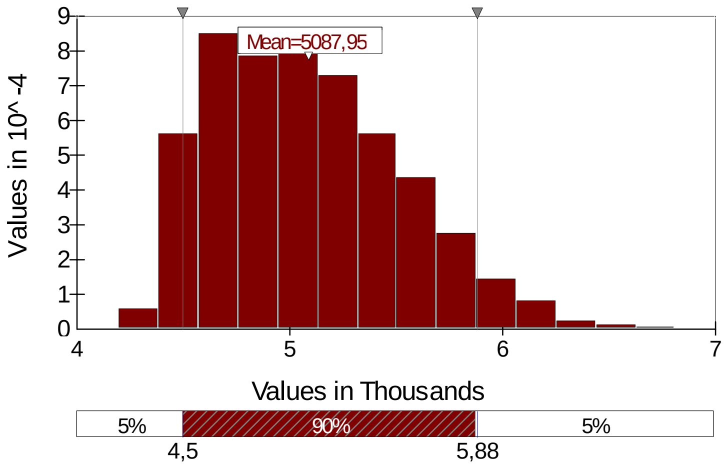

Figure 6.14 The distribution of total cost for simulation experiment #5

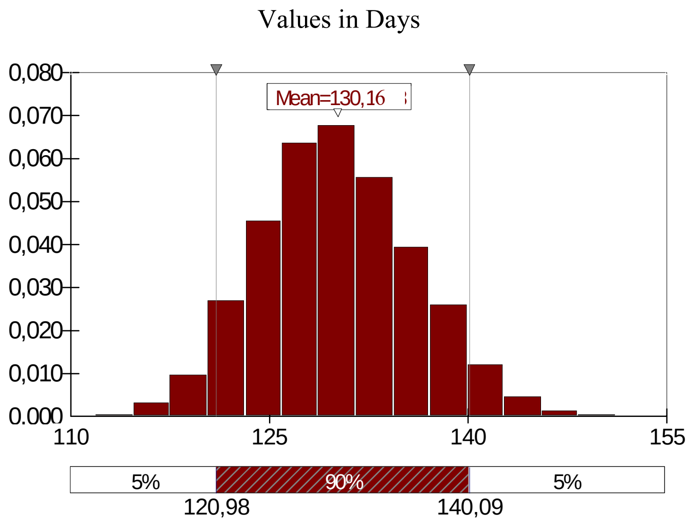

Figure 6.15 The distribution of project duration for simulation experiment #5

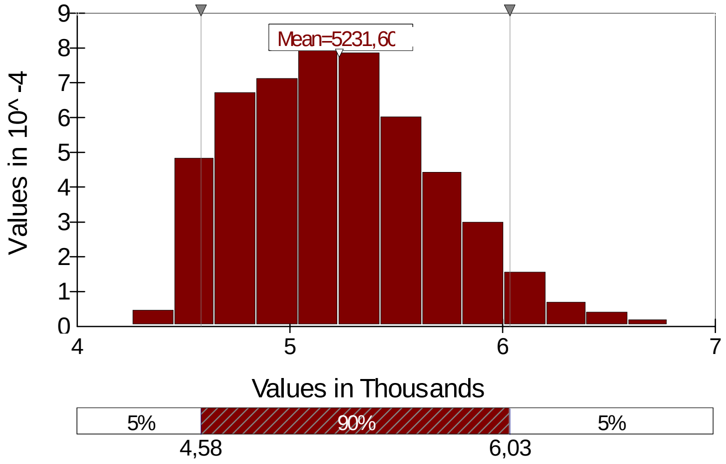

Figure 6.16 The distribution of total cost for experiment #6

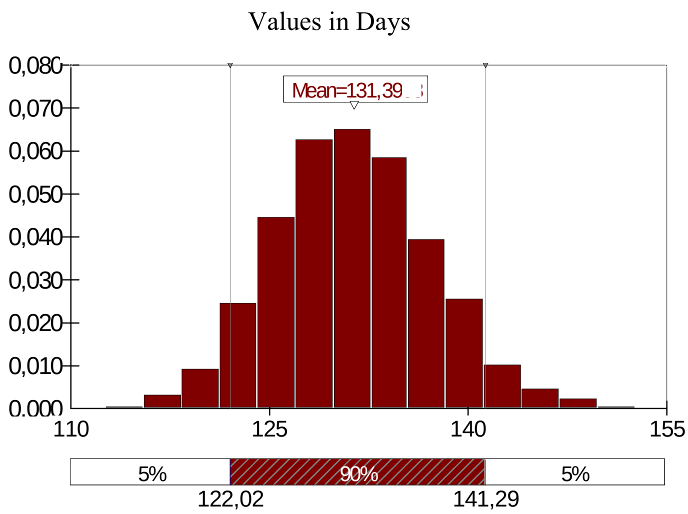

Figure 6.17 The distribution of project duration for experiment #6

As it can be seen from the results, experiment #5 gives the best results for expected total cost. In this plan, Risk 3.3, Risk 1.1, Risk 12.2, Risk 9.4, Risk 6.1, and Risk 11.2 have been responded to with a total cost of $370. The response plans for experiments #3 and #5 are very similar to each other, with the same marginal impact and response costs. They differ between the risks 6.2 (exp.#3) and 11.2 (exp#5). Risk 6.2 and Risk 11.2 have the same *EITC* and the same cost of response. The difference between the experiments results from the criticalities. Activity 11 and activity 6 have criticality levels of 100% and 99.98%, respectively. Although this appears to be a small difference, attacking on the more critical activity has demonstrated a better result.

Interestingly, experiment #4 has been dominated by experiments #3 and #5. Experiment #4 has a bigger marginal impact and lower response cost, but the simulation results are unsatisfactory with respect to #3 and #5. This can be a result of the structure in the response plan. We can think that the responses in this plan reduce the impact of risks less than the responses in other experiments.

7. THE POST PROJECT EVALUATION PROCESS

7.1. Proposed Post Project Evaluation Process

After the completion of the project, it is necessary to determine the lessons learned and document them through post project evaluations. This is an important duty for Project Management Offices to perform these reviews and ensure that new projects are applying lessons learned (Whitten, 2000).

The flow chart of the proposed post project evaluation process is given in Figure 7.1. In this process, there are two main activities differing according to the type of the project.

- If there are extreme deviations from the project objectives (time, cost, quality defined as accordance to the technical specifications);
- If it is a project subjected to different and affluent risk applications;
- If it is an example to a specific project type (for example multi functional, large by cost or duration, multi-corporational, subject to a specific product, innovative, contains different technical applications, multi purpose, etc.);
- If there is a different application, problem or knowledge, which definitely should be shared with others;

then, it is possible to decide on the detailed analysis of this project. After this analysis, a case- similar report of Project History is written for use later on project management training activities as internal examples. The steps of this detailed analysis begin with preparation (Gulliver, 1987; Garvin,1993; Duarte and Synder, 1997).

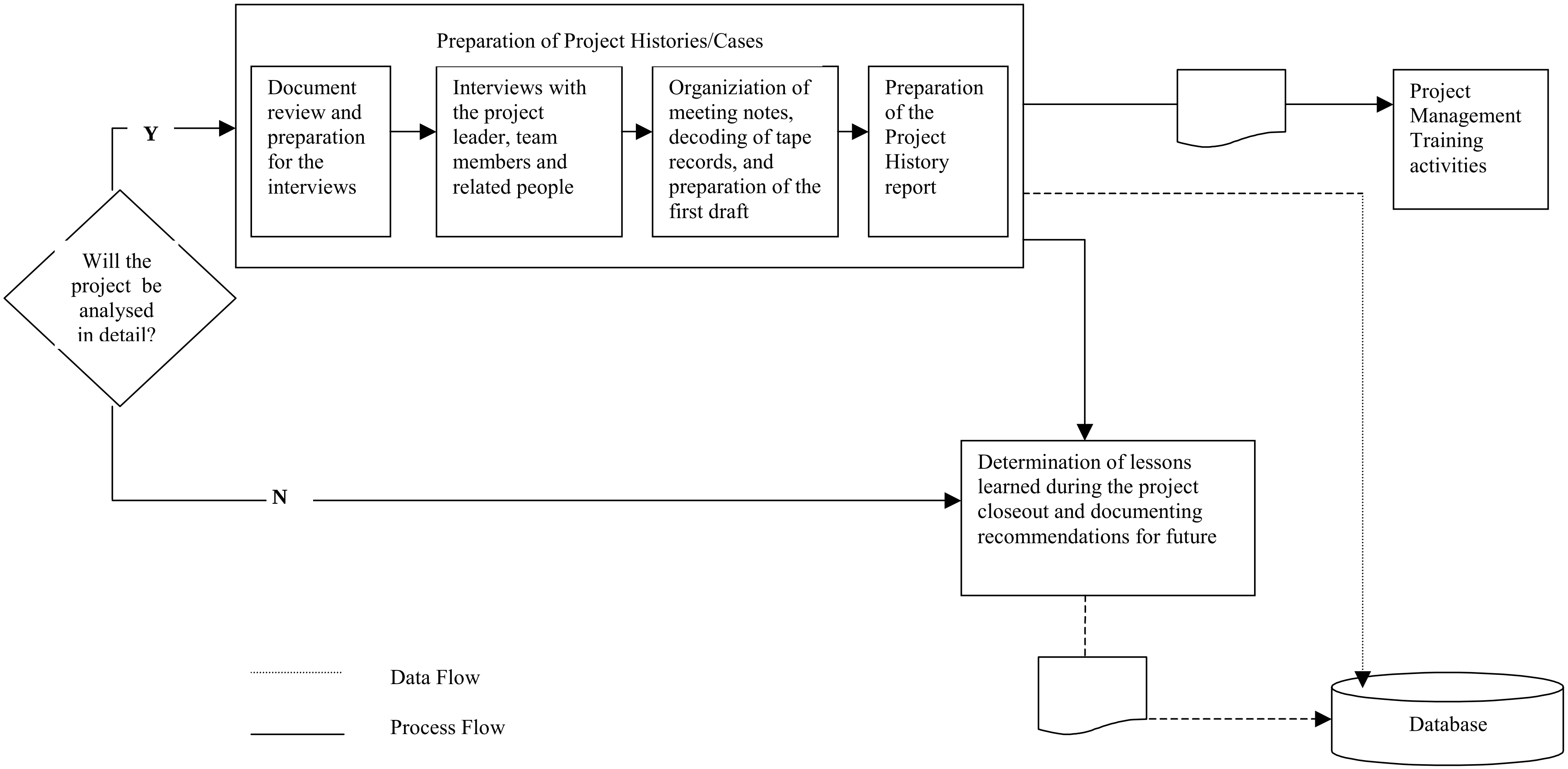

Figure 7.1 The post project evaluation process flowchart

The Project Office review project documents and produces questions, which may help people to remember the project and in determining the "lessons learned", with the help of a standard "Project History Question List". It is not necessary to cover all these questions but it will be helpful in the preparation for the interviews (Kleiner and Roth, 1998; Leenders and Erskine, 1989) (Table 7.1. The Project History Question List).

Table 7.1 The project history question list [3]

Project Planning and Monitoring:

1- Was historical data from past projects consulted for planning purposes? How?
2- Did affected project team members participate in the planning process?
3- What were the monitoring and control activities? (Review meetings with the stakeholders and within the project team, on-line monitoring, etc.)
4- Were there any changes? What has been done to overcome these?

Risk Management:

5- Are planning documents used to identify risks? Is historical information reviewed to assist in risk identification?
6- What was the problems encountered during the project? What were their impacts? What has been done to as a response?
7- How were the risks monitored?
8- Were there any risks, that are not identified in the planning phase but realized? Was it possible to predict them?
9- Why were the risks, that are identified but not realized, not realized? Were there any precautions to overcome them, or was it by chance?

Project Team Management:

10- How was the project team selected? Did they have the required levels of technical skills, or if not, are they encouraged or provided with suitable training?
11- Did team members participate effectively in the project? If not, what steps could be taken to improve their participation?

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[3] (www.pmblvd.com; www.ukoln.ac.uk/services/elib/papers/other/annual97.htm; http://marssociety.ca/projects/templates/MS/Post_Project_Evaluation.doc; Wheelwright and Clark, 1992; Wideman, 1991; http://www.dir.state.tx.us/eod/qa/evaluate/index.htm; www.cc.gatech.edu/classes/cs4301_99_spring/TheoryWhy/PostMortem_V1.htm).

Table 7.1 The project history question list (continued)

Communication Issues:

12- What worked or did not work about the team's communication? How did the problems resolve? Did the project leader use any methods to improve team's motivation? (Praising, reward mechanisms, social activities like dinner, trips, etc.)

13- How was the top management's attitude? Were there any problems? What has been done to solve them? What are the recommendations for the future?

14- How was the customers' attitude? Were there any problems? What has been done to solve them? What are the recommendations for the future?

15- How was the suppliers'/cooperating firms' attitude? Were there any problems? What has been done to solve them? What are the recommendations for the future?

Intangibles:

16- What was the most rewarding aspect of this project?

17- What was the most frustrating aspect of this project? Is there any improvement ideas?

18- What did you learned from this project? If you could change anything about the project, what would you have done differently?

19- What did you learn from this project, which could be used in the future?

Other Comments:

Then comes the interviewing phase. The Project Office conducts interviews with project leader, team members, and if necessary, other related people. In these meetings, determining "lessons learned" is aimed, with the help of the preparations made before. Note taking and tape recorders are used in these meetings (Leenders and Erskine, 1989).

After conducting interviews, Project Office decodes tape records, organises meeting notes, and produces a first draft containing all the information discussed in the meetings. Then, if any, vague or incomplete information will be verified.

Following all these work, the Project Office prepares a report of "Project History", including important learning points and excluding ordinary and unnecessary information. After the approval of the report, by the project leader, it will be recorded in the database with key words, for future use. It will also used in project management training as an internal case study.

Project leaders, prepare a document to be attached to the closeout reports for projects not to be analysed in detail. The closeout report typically contains the following issues by means of best practices and open for improvement areas:

- Project planning and monitoring issues,
- Relationships with upper management,
- Relationships within the project team,
- Relationships with customer(s),
- Relationships with supplier(s),
- What went right,
- What went wrong,
- Recommendations for future projects.

Organisational learning provided by the process is expected to diminish the deviations from the project objectives. The performance of this process may be measured by periodic reports, showing the projects' performances in the time. But it is more robust to have a project impact analysis structure instead of measuring just performances.

7.2. Expected Benefits of the Process

- Lessons learned will be transformed from tacit knowledge into explicit and written knowledge. Therefore, dependence on people and the danger of knowledge loss will be decreased.
- It helps to repeat best practices and to strengthen the weak points.
- It provides easiness in the risk identification, risk analysis, and risk response development phases for future projects.
- The energy, which will be spent on solving already solved problems or on doing already done things, can be directed on improvement activities.

7.3. Potential Drawbacks

- The benefits will be observed in the long term, and therefore the leaders can neglect the process.
- It brings extra work and for this reason, will not seem very attractive.
- It won't be efficient if the main goal is to achieve internal political results rather than learning. Post project evaluation process, shouldn't be confused with performance evaluation and grading.
- There can be a resistance to the process because of the transparency it brings to events.
- People, who think it is possible to learn from experience without extra effort, will find the process unnecessary.
- It is difficult to determine and measure what has been learnt, specifically in R&D projects.

8. FUTURE RESEARCH DIRECTIONS

For future research directions, the integration of quantitative techniques to the risk management process, and project impact analysis for measuring project performance more precisely, are recommended.

8.1. Quantitative Risk Analysis

Currently, the most widely used quantitative risk analysis technique is Monte Carlo simulation. It is described at the hand of a hypothetical example in chapter 6. This analysis can be integrated into the process with modifications in the risk identification and risk analysis phases. Quantitative analysis will provide valuable information to the risk response development phase and will help stakeholders and project teams to better understand the project.

Developing solution methodologies for the zero-one programming mathematical model stated in chapter 6 gives a direction for future research. This is a multi-objective problem with the concerns focusing on project duration or total cost depending on the aim of the analysis. Different formulations of this problem concerning the correlations between the risks and the activities may provide more realistic models. Including the resources other than manpower and resource constraints to the model will provide an interesting research area. Also, a similar model may be developed for minimizing the expected total duration.

8.2. Project Impact Analysis

While analyzing the past project data to test the hypotheses in chapter 4, project performance emerged as an important issue. The definition of project performance in the R&D Center was not very clear and valid for the structure of the projects performed in that R&D Center. Also, pressures have increased on the R&D Center to demonstrate economic rationales for the existence of specific R&D programs, after the reorganisation took place in the company.

An R&D project's impact and contribution to the organization are usually observed in the long-term. Thus, a long-term analysis for project performance, in addition to the immediate performance measures, is necessary for a complete evaluation of the impact of an R&D project.

Project impact analysis is a hard but popular issue, especially for the socio-economic development projects, conducted by governments. Social, economic, and environmental effects, their cumulative impact, and the sustainability of the project's performance are very difficult to measure, but are important.

The National Institute of Standards and Technology (NIST) employs ongoing economic impact assessment activities for its Measurement and Standards Laboratory program. NIST undertakes economic impact studies to estimate the contributions of its laboratory research to U.S. industrial competitiveness and also to provide insights into the mechanisms by which such benefits are delivered to industry. From a management perspective, the knowledge gained from economic impact studies is used for evaluation of specific laboratory projects and programs, in strategic planning exercises, and for policy analysis (Tassey, 1999).

For economic impact analysis, outputs and the outcomes of the projects are used. The outputs are the activities performed and the products produced by NIST research. They describe the nature of the immediate impact of the research on industry, including the stage in economic activity affected (R&D, production or marketing).

Outcomes are the bottom-line economic impacts from projects (R&D efficiency, manufacturing productivity, quality enhancement, facilitation of market transactions, etc.). These outcomes are measured quantitatively whenever possible, preferably in one of several generally acceptable forms (net present value, benefit-cost ratio, or internal rate of return). Some frequently used measures such as publication counts, patents, and citation indices are not considered particularly useful metrics. In addition to these statistics, the studies often document anecdotal numerical outcome information such as market share impacts. Finally, qualitative outcomes such as impacts on R&D investment decisions, changes in production and quality strategies, and new market strategies (including innovation) are documented.

In other words, these economic impact studies contain a mixture of quantitative and qualitative outcomes, and the outcomes may be evaluated over time. Such an approach provides a more comprehensive and balanced view of a project's impact than a more focused study in which a single, end-point quantitative impact measure is the only objective.

The factors, affecting the quality of impact studies are, 1) The quality of benefit and cost data obtained, 2) The portion of benefiting firms captured by data collection, 3) The coverage of impacted markets, 4) The actual choice of a metric for representing economic benefits and costs.

More recent impact studies benefit from improvements in the following activities; technology assessment, industry structure and behaviour analysis, market failure analysis, impact hypothesis development and impact measure selection, survey designs, post project evaluation (final analysis), and report writing.

Because of the costs associated with any economic impact study, it is recommended to limit the number of the projects that will be studied in any period of time.

Cumulative impacts are calculated based on estimations of single-project effects, first-order interactions among projects, shared project features and, an estimation of the impacts of existing projects. Canter and Kamath (1995) report these results derived from case studies:

- There is no universally adopted method for assessing cumulative impacts.
- The most frequently used methods are matrices and/or indices.
- It is desirable to use a method that can incorporate both qualitative and quantitative information.
- Low quality and/or lack of both baseline data and impact information may limit the effectiveness of the analysis.

These results are in parallel with the factors, stated in the study by Tassey (1999) concerning the quality of impact studies. Based upon their findings, Canter and Kamath stated the desirable features of a cumulative impact methodology as described by Irving *et al*. [(1989), in Canter and Kamath, 1995]. The methodology should;

- enable multiple developments to be addressed,
- be practical with understandable results that would aid in the decision-making process,
- be adaptable to allow for the large array of possible site-resource-impact combinations,
- enable the aggregation of incremental and interactive impacts to give an estimate of the overall impact to which a species or resource is being exposed,
- allow for a differential levels of resolution (the methodology should allow for a more general, extensive analysis of the cumulative impacts of all relevant developments, projects while still allowing project-specific impact analysis).

Canter and Kamath (1995) proposed a questionnaire checklist as a methodology for environmental projects. This checklist has a structured approach for identifying key impacts and/or pertinent environmental factors. It can be modified depending on the project and site characteristics. The major limitations of this methodology are that it does not describe interactions and linkages and does not require the quantification of impacts.

The sustainability of development projects represents a major criterion in assessing whether this goal has in fact been reached. A project is classified as sustained if the project-implementing organization continue the innovations achieved by the project, without external assistance for a long period of time. The sustainability of a project can only be determined after the end of assistance of the project owner (for example, in programs implemented by developed countries to assist the countries of the Third World, when the donor pulls out its assistance after the project closure). In R&D, we can think of an analogous assistance, for example, as the support of the R&D team of the contractor company to the customer company's Product Development team, after the technology transfer.

Stockmann (1997) used the following survey procedure to observe the sustainability and long-term impacts of German vocational training projects in Latin America: document analyses, direct observation and on-site inspections, intensive interviews and standardized interviews; with crosschecks, strengthening the reliability and validity of the information collected. He found the differences between the sustainable and less sustainable projects as;

- goal acceptance among participants,
- the level of qualification of the personnel in the implementing organization,
- the effectiveness of organizational structures at the higher-level and direct implementing organizations.

These performance criteria were met to a high degree only in sustainable projects, where the sustainability is defined with the adequate problem-solving structures of the implementing organization and the diffusion effects achieved in its external environment.

Under these considerations, some possible measures for measuring the impact of the projects in the R&D Center are thought as;

- The sustainability of the project and the economic impact of the project to the customer, if it is used, to be periodically measured in the following 3 years. Some parts or all of the survey procedure used in the study of Stockmann (1997) can be used to collect impact information from the customers.
- Expected value of the new project ideas created by the project, to be periodically measured in the following 3 years.

To sum up, the perceived success of a project is observed in the long term and is a combination of its performance, economic and environmental impacts, and its sustainability in the target organization. Assessing the success of a project is a complex, multi-dimensional, and time dependent issue, but it is necessary for sustaining a continuous improvement environment through learning.

9. CONCLUSION

This study has been accomplished to strengthen the learning process in an R&D Center of an industrial firm. The design of a systematic post project evaluation process was the first step of this attempt for becoming a learning organization. To accomplish this, benchmarking and the analysis of the current project management system were employed. For benchmarking, post project evaluation process implementation examples has been searched from the literature and through the Internet. Then, past project data has been collected to determine the data requirements for effective learning and to determine the deficiencies in the current project management system. With these data, the hypotheses, explained in chapter 4, are tested to identify some learning points and to see the progress in the projects on a time scale. During this data processing, lack of standardisation in the data and lack of knowledge sharing about risks have been emerged as deficiencies in the learning process. It is clear that, to systematically collect data and to create new knowledge by effectively solving the problems of the past, there should be a risk management process. Therefore, risk management and post project evaluation processes have been designed together in an input-output collaboration with each other.

Learning from experiences means learning from R&D projects. But organizational learning is not a natural outcome of R&D projects. The reasons of lack of effective learning in this R&D Center can be listed as follows:

- The performance measures, which are used for assessing the project success, are based on short-term results and therefore, learning and knowledge sharing are often neglected.
- There are procedures and defined documentation in the project management system but the organizational culture drives the project leader to move forward to the next project, rather than analyzing the past, once the project is finished. As a result of the lack of standardization, documentation of “soft learnings”, such as

risk management issues, management lessons, communication issues, etc., are often neglected.

- There is not a knowledge management process supported, proper knowledge database, so it is hard to disseminate “lessons learned”, whether they are documented or not.

The results of this study can be grouped under three categories:

- Significant findings obtained from the analysis of past projects,
- Important issues for designing and implementing a risk management process,
- Important issues for designing and implementing a post project evaluation process.

Significant findings obtained from the analysis of past projects: According to our data, we have found that the projects with small size (with less than 2 years duration and less than 6 man-months manpower requirements) are more likely to deviate from their plans. We have also found that the projects executed by experienced project leaders (with more than 4 years experience) are more likely to be in accordance with their schedules. This result is expected because experience brings knowledge to the individual and with this knowledge, the plans are made more accurately; risks are taken into consideration and managed well; conflicts are prevented, or resolved quickly. Therefore, possible schedule deviations are decreased in those projects, with experienced leaders. Projects, which have relatively large project teams (6 or more persons), have fewer deviations from their plans. This can be a result of synergy between project team members, who are reducing the delays caused by the others. Also, projects handled with a multi-functional approach are more likely to be in accordance with their plans. This result is also expected, because of the synergy created by miscellaneous points of view from different functions. Additionally, the schedule becomes tighter when there are inputs by team members from different functions. A delay in one’s work automatically delays the others and this network structure brings a tighter team control on the project.

Important issues for designing and implementing a risk management process: Learning is an important issue in risk management and vice versa. Experiences should be shared to provide the ability to respond to project risks effectively. Also, risk management process outcomes provide insights into the weaknesses in the project management processes. The management of the project risks provides better understanding of the project, helps decision-makers in go/kill decisions, improves performance, and provides rapid actions to the changing environment.

Important issues for designing and implementing a post project evaluation process: The post project evaluation process is helpful in transforming tacit knowledge into explicit and written information. It should be supported with a database structure for disseminating the knowledge. Without anybody having access to it, written knowledge does not mean anything in fact. Standardization and categorisation is another important issue in sharing knowledge. Disordered and free-format structures create some kind of knowledge pollution, and people do not want to spend hours, reading unnecessary information from the documents or from the database.

Organizational culture and present processes play a major role in implementing both risk management and post project evaluation processes. Integrating the process innovation into the present project management system requires the use of current terminology and harmony with current procedures. New processes should be supported by the top management and should be handled with a systems approach. Otherwise, cultural resistance will be higher and people will participate in neither post project evaluation workshops nor risk management activities.

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