DESIGN OF POST PROJECT ANALYSIS AND RISK MANAGEMENT PROCESSES FOR R&D PROJECTS

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ABSTRACT

This study has been performed as a project management process improvement project in the R&D Department of a leading white goods manufacturer in Turkey. Data related to 93 projects executed and finished during 1994-2001 in the R&D Department is compiled. These projects are analyzed to determine the factors that affect the project performance and to identify the risks encountered in the past and to compile a Risk Checklist as an input to the proposed risk management process. Then, a risk management process and a post project analysis process are designed for introducing risk management and organizational learning practice to the R&D Center. The risk management and project analysis processes are tested on a project close to its initiation and on two recently completed projects, respectively. It is observed that learning points are identified upon analyzing risk issues and the risk management process outcomes may provide insights into the weaknesses in the project management process. Thus, both processes are intertwined and evolve around each other.

Keywords: *Managing Projects, Processes, Risk Management, Post Project Analysis, R&D Projects*

INTRODUCTION

This study has been performed for the improvement of processes in project management activities of the Research and Development (R&D) Department of a leading white goods manufacturer in Turkey. This R&D Department was established in 1991. All R&D projects are performed in-house. Occasionally some work-packages of the projects are outsourced but the whole project. Since 1992, there has been a standardized project management system, including the definition of project life cycle, tracking mechanisms and documentation for resource usage. By the year 1997, a database has been developed for use in the planning and monitoring of the projects. Currently employed project planner software Stage Gate™, was introduced in 1999. There are nearly 100 employees from different science and technology disciplines working for the R&D Department. Different science and technology disciplines are grouped under the title "families" in the organizational structure of the R&D Department. A Project Office within the R&D Department provides support to project leaders in the planning and monitoring of projects and maintains an archive and a database for completed projects.

This paper focuses on the post project analysis and risk management processes for R&D projects, aiming to ensure the proper analysis and documentation of the information generated and experience gained throughout the project life. Particularly for a project organization, it is crucial to devise means of accumulating such valuable information and experience. A systematic post project analysis process fulfils this requirement and should be considered a major component of the corporate learning process. The post project analysis is considered to be one of the two outputs of a project; the other being the project itself [1].

The post project analysis process consists of activities performed by a team at the completion of a 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". Documentation of lessons learned is essential for their dissemination within the organization. Case studies can be written from best practices, important issues drawn both from successes and failures can be collected in booklets, lessons learned can be captured in a knowledge base such that similar future projects can benefit from them [2,3,4]. 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 [5].

The steps of the post project analysis process differ among users, but still it is possible to discern the main steps referring to different studies [2,6,7]: (i) Data collection, (ii) analysis, (iii) establishing lessons learned, (iv) verification, (v) documentation, (vi) information dissemination.

Subjects to be dealt with and included in a post project analysis process can be described as follows [8,9,10,11,12,13,14,15]: (i) Basic project information, (ii) project management process, (iii) performance, (iv) teamwork evaluation, and (v) customer feedback.

The lessons learned during the post project analysis process contribute greatly in putting the risk management issues into proper perspective. It is necessary to apply an information capturing process concerning the experiences on project risks gained during the execution of a project for improved risk management in the future projects.

Project risk is an uncertain event or condition that, if it occurs, has a positive or a negative effect on a project objective [16]. In the study reported here, only the negative aspects of project risks are considered. The project risks are defined as the uncertain events that may cause delays, unexpected costs, or unsatisfactory outcomes.

Although a relatively new topic, there are a large number of studies on risk management in the project management setting. But yet one cannot claim that risk management techniques have become part of the mainstream practices in project management like work breakdown structure or scheduling techniques based on critical path analysis [17].

Risk management is the systematic process of identifying, analyzing, and responding to project risks. There are different approaches proposed for risk management process in the literature. But the main steps are common in most approaches and include risk assessment (i.e., risk identification and risk analysis), risk response development, and risk monitoring and control [16,18,19,20,21,22,23,24].

At project termination, the project risks encountered and the experiences gained through various responses to these risks should be integrated into the organization's project management knowledge repository. In future projects, this knowledge base can serve as the starting point for risk identification and analysis. Project managers can use these past real-world experiences to improve the productivity of the project management process and to increase the likelihood of success.

OUTLINE OF THE STUDY

As the initial step of the study, data related to 160 R&D projects conducted and completed during 1994-2001 is compiled and verified with the staff of the R&D Department. Sixty-seven projects are eliminated from further consideration mainly due to improper documentation and lack of crucial data. The remaining 93 projects are analyzed to determine the factors that affect the project performance and to identify the risks encountered during the conduct of these projects. Then, in order to standardize and to systematize the risk identification process, a Risk Checklist is compiled. The Risk Checklist is not only derived from past projects' analysis but also from a review of relevant R&D management literature [16,21,22,25,26,27,28,29].

After the analysis of the current project management system, the post project analysis and risk management processes are designed and integrated into the current process. Finally, the risk management process is tested on a project close to its initiation and the post project analysis process is tested on two recently completed projects.

PROJECT MANAGEMENT PERFORMANCE ANALYSIS

Project management performance is defined here as the amount of deviations from the baseline project duration and manpower usage, where the baseline corresponds to the project plan adopted at the initiation of the project.

Deviations (DEV) are calculated according to expression [Eq. 1]:

$$DEV = | \text{Baseline} – \text{Actual} | / \text{Baseline} \qquad \text{[Eq. 1]}$$

To determine the factors that affect project management performance, past projects are analyzed through a series of hypothesis tests.

Formulation of the Hypothesis Tests

With the definition of project management performance in mind, five hypotheses are formulated for testing it. The first two are related to the size of the project; namely, the planned project duration and the amount of manpower to be employed during the project. The next three are associated with the project leader and the project team, i.e., related to organizational issues.

H1: *The length of project duration has a positive impact on project management performance.*

H2: *Amount of manpower employed expressed in terms of man-months has a positive impact on project management performance.*

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

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

H5: *Multi-disciplinary approach to project team formation has a positive impact on project management performance.*

To test these hypotheses, *t*-tests and one-way ANOVA are used at a level of significance α=95%. Each hypothesis is tested once with respect to each component of project management performance, i.e., project duration and manpower usage.

Results of the Hypothesis Tests

The results of the t-tests and the one-way ANOVA are grouped in Table 1 and Table 2, respectively.

Tables 1 and 2 about here

H1: The length of project duration has a positive impact on project management performance.

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: $\mu_2-\mu_1<0$.

where μ_i stands for the mean duration deviation of Group *i*.

Since $p<0.05$, H_0: $\mu_2-\mu_1\geq 0$ is rejected. Schedule performance is better in the projects with duration of 2 years or more.

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: $\mu_2-\mu_1<0$.

where μ_i stands for the mean manpower deviation of Group *i*.

Since $p<0.05$, H_0: $\mu_2-\mu_1\geq 0$ is rejected. Manpower usage performance is better in the projects with duration of 2 years and more.

H2: Amount of manpower resource employed has a positive impact on project management performance.

H2.1: Duration deviations of the projects that employed less than 6 man-months manpower resource (Group 1) are less than that of the projects that employed 6 man-months or more manpower resource (Group 2). Thus,

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

where μ_i stands for the mean duration deviation of Group i.

Since $p<0.05$, 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 resource.

H2.2: Manpower deviation of the projects that employed less than 6 man-month manpower resource (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-$\mu_1 < 0$.

where μ_i stands for the mean manpower deviation of Group i.

Since $p<0.05$, H_0: μ_2-$\mu_1 \geq 0$ is rejected. Manpower usage performance is better in projects that employed 6 man-months or more manpower resource.

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

The mean experience of the project leaders in the projects analyzed is about 4 years of participation in project work in the Company. Based on this observation, a project leader is classified as inexperienced if his/her experience is less than 4 years (Group 1); and as experienced if his/her experience is 4 years or more (Group 2).

H3.1: For schedule performance, the hypothesis is formulated as:

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

where μ_i stands for the mean duration deviation of Group i.

Since $p<0.05$, we can reject H_0: μ_2-$\mu_1 \geq 0$. It is concluded that the schedule performance is better in projects directed by project leaders with more than 4-years of experience.

H3.2: For the manpower deviation dimension, the hypothesis is formulated as:

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

where μ_i stands for the mean manpower deviation of Group i.

Since $p>0.05$, we cannot reject H_0: μ_2-$\mu_1 \geq 0$. Thus, there is no significant finding about the impact of the project leader's experience on manpower deviations.

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

H4.1: 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_i represents the mean duration deviation of Group i.

The results of this analysis are reported under H4.1 in Table 2. The p-value is sufficiently small and therefore, H_0: $\mu_1=\mu_2=\mu_3=\mu_4=\mu$ is rejected.

Analysis of the means of duration deviations of individual Groups leads to the conclusion that there is a statistically significant difference between those means. Furthermore, a tendency of decrease in mean duration deviations is observed with increasing Group number. The conclusion then is that schedule performance is better in projects with relatively larger project teams.

H4.2: 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_i represents the mean manpower deviation of Group i.

The p-value is sufficiently small and therefore, H_0: $\mu_1=\mu_2=\mu_3=\mu_4=\mu$ is rejected.

A similar analysis as in H4.1 leads to the conclusion that manpower usage performance is better in projects with relatively larger project teams.

H5: Multi-disciplinary approach has a positive impact on project management performance.

Group 1: Projects where 1 or 2 different disciplines contribute.

Group 2: Projects where 3 or more different disciplines contribute.

H5.1: To test the hypothesis in its duration deviation component, t-test is employed under the null hypothesis:

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

where μ_i represents the mean duration deviation of Group i.

The p-value is sufficiently small and therefore, H_0: $\mu_2-\mu_1 \geq 0$ is rejected. Thus, the schedule performance is better in projects with multi-disciplinary project teams consisting of 3 or more disciplines.

H5.2: For the component of manpower usage performance, the null hypothesis is stated as:

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

where μ_i represents the mean manpower deviation of Group *i*.

Since $p<0.05$, we can reject H_0: μ_2-$\mu_1 \geq 0$. Thus, manpower usage performance is better in projects with multi-disciplinary project teams consisting of 3 or more disciplines.

Summary of the Findings

(i) Projects with duration of less than 2 years are more likely to deviate from their baseline duration and baseline manpower requirements.

(ii) Projects with manpower resource usage less than 6 man-months are more likely to deviate from their baseline duration and baseline manpower requirements.

The findings reported in (i) and (ii) indicate that for relatively small projects it is harder to keep to the baseline project plan.

(iii) Projects executed by project leaders with more than 4 years of experience are more likely to be successful in following their baseline schedules. This result is expected because experience helps in accumulating knowledge and employing this knowledge, the experienced project leader has a better chance to plan more accurately; to be aware of risks and to manage them well; and to prevent conflicts or to resolve them more quickly. Therefore, possible schedule deviations are decreased in those projects managed by experienced project leaders.

(iv) Projects with relatively large project teams are more likely to be successful in following their baseline schedules and baseline manpower requirements. This might be due to the control exercised by team members over each other and also due to the possible covering up of team members for each other within the same discipline.

(v) Projects with project teams consisting of 3 or more disciplines are more likely to be successful in keeping to their baseline project duration and manpower requirements. When there are several disciplines involved in a project, then a dependency structure emerges among those disciplines. A delay in one discipline's assignment automatically delays the other disciplines' assignments. Since each discipline is usually involved in more than one project, it is difficult for them to reschedule and they are quite sensitive against such delays. As a result, this dependency structure leads to tighter cross-team control on the project activities.

The project management performance analysis resulted also in extensive documentation, which is later employed in the preparation of the Risk Checklist.

POST PROJECT ANALYSIS PROCESS

In the proposed post project analysis process, a project once completed can be subjected to a brief or detailed post project analysis. The flow chart of this process is given in Appendix 1.

In a brief post project analysis, the project leader with assistance from the Project Office summarizes the lessons learned in the closing document; such as planning and monitoring issues, communication with the stakeholders and within the project team, what went right and what went wrong. This document is put into the knowledge base and made available for future use.

The conditions under which a detailed analysis is performed are the following: (i) If there are extreme deviations from the project objectives (time, cost, and quality as defined in accordance with the technical specifications). (ii) If it is a project subject to unusual and/or high-risk applications. (iii) If it is an example to a specific project type (for example, it is relatively large in terms cost or duration, or is a joint project of several corporations). (iv) If the project involves an application or a problem, which is rarely met in practice and thus should be definitely shared with other prospective project leaders.

The steps of the detailed analysis begin with the preparation for a structured interview. The interview aims at identifying the lessons learned. The Project Office reviews project documents and generates questions, which may help the team members to recall the project details and to state explicitly the lessons learned. Such a list of questions is definitely helpful when conducting the interview [38,39]. The Project Office conducts interviews with the project leader, the team members, and if necessary, with other people involved in the project. After conducting an interview, the Project Office decodes the tape records, organizes the meeting notes, and produces a draft document containing all the information discussed in the meetings. Then, if any, vague or incomplete points in this draft document are verified with the person(s) involved.

Following all these activities, the Project Office prepares a short report under the title "Project Summary", summarizing important learning points. The Project Summary is written in a case format to be used later in project management training as an internal case study. After the approval of the Project Summary by the project leader, it will be recorded with the associated key words in the knowledge base for future use.

DESIGN OF A RISK MANAGEMENT PROCESS

The proposed risk management process is designed to include the following four main activities:

(i) Risk identification, } Risk assessment
(ii) Risk analysis,

(iii) Risk response development,

(iv) Risk monitoring and control.

The first three of the above main activities constitute the planning phase of risk management. The operation phase, on the other hand, is based mainly on risk monitoring and control, but risk identification, analysis, and response development are employed also in the operation phase whenever an update associated with the existing and newly perceived risks is needed. The flow chart of the proposed risk management process is displayed in Appendix 2.

When designing the risk management process, it is necessary to decide on which techniques such as Analytic Hierarchy Process (AHP) to include in the process and how to create a decision environment where those responsible to implement these techniques can do so easily and effectively.

To provide ease for use, complex quantitative techniques are omitted from the process. To ensure objectiveness, a standardized Risk Checklist is developed and scales for scoring are defined for the risk analysis phase.

The risk identification phase. In this phase, the risks associated with the project activities are identified. The project team analyses the project and identifies the possible causes of potential problems and their effects. As a helpful tool, cause-effect diagrams can be used to identify risks. The risks thus identified are entered into the knowledge base. The basic output of this phase is the Risk Checklist (Appendix 3).

The Risk Checklist is prepared in four steps. At the first step, problems encountered in the past projects are determined by analyzing historical data from the project documents.

In the second step, this set of problems is further enlarged with the problems reported in the literature, especially in the context of R&D projects. Then, the risks in this list are classified under main risk categories denoted as technical, resource management, non-technical internal, customer related, external- predictable, and external-unpredictable.

In the third step, overlaps between the risks and ambiguities in the definitions are eliminated and to ensure that the Risk Checklist covers all problems encountered before, past projects are analyzed again with the new format.

Finally, to determine whether the project leader would consider the Risk Checklist as comprehensible and sufficiently complete, it is tested on a project, which is still in its planning phase. It is concluded that this Risk Checklist is applicable in the R&D Department. The final form of the Risk Checklist is given in Appendix 3. In a recent study, a reference list of potential risk issues in the innovation process has been developed in a similar fashion [32].

Table 3 about here

The risk analysis phase. The risks identified are analyzed to determine their severities and then to assign priorities to them. The decision to be made here is the selection of the analysis method. AHP and scoring methods are considered as potential methods to be used in the process. Weights, scores on probability and impacts, and matrices combining those factors to determine severities of risks are widely used in project risk management literature [16,18,22,33,34,35,36,37,38,39]. The scoring method has the advantage of simplicity that can be viewed as commensurate to the nature of use of expert-opinion elicitation [40]. As a result of consultation with the R&D Department personnel, it is found that simplicity is considered as the main factor for adoption of an analysis method. Thus, scoring is preferred for risk analysis in the proposed process. Scales of 1-5 determine the likelihood and the impact of a single risk. Then, these are combined into a matrix to determine the severity of risks. These severities result in the prioritized list of project risks with high severity corresponding to high priority.

In the proposed process, generic impact scales and probability scales given respectively in [35] and [38] were decided to be used in prioritization (Table 3).

Using this 1-5 scale and consulting with the project team, the project leader assigns probabilities and impacts for the identified risks. Then, based on these values, severity level for each risk is determined (Table 4).

Table 4 about here

When determining the overall impact score, it is possible to accept the highest impact among the impacts on time, quality, and cost [35]. The deficiency of this approach is demonstrated when one considers two risks with the same probability of occurrence and the maximum level of impact being the same for two different dimensions, say, quality and cost at each risk. Both these risks will have the same risk severity. It would be unwise to deal with these two risks in the same manner. In the proposed approach, the impact dimensions could have their own weights called impact coefficients taking on values according to project type and activity within a project. For example, a research project ordered by a customer might have a due date more strict and a schedule tighter than that of an in-house research project and thus, its schedule impact should be counted more heavily. Overall impact will be taken then as the integer value of the average as suggested in [34]. The overall impact *I* is calculated as in [Eq. 2]:

$$I = [a*x + b*y + c*z] \qquad \text{[Eq. 2]}$$

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

where:

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 the scoring model is its failure to incorporate systematic checks on the consistency of judgments [41]. Also, using a scoring model imputes a degree of precision that simply does not exist. A halo effect (i.e., if a risk scores high on one criterion, it tends to score high on many of the remaining criteria) is also possible for a scoring model [42].

The risk response development phase. In this phase, 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, mitigation, transfer and avoidance [16,18,22,27,28]. 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.

The risk monitoring and control phase. The following events, which are of interest in the context of risk management, can take place during the execution of a project:

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 the risks realized.

Changes in the level of severity of risks.

In the proposed process, all these events are entered into the database and then monitored. To adapt to the changing environment, project plan may be revised. In this revision, a document containing for each risk the planned response, applied response (if any), severity of risk as conceived at the initiation of the project, the most recent severity assessment of the risk and the risk owner will be prepared and approved by the project sponsor. Risk monitoring and control is a continuous process.

By the end of the project, all the risk-related data will be stored in the knowledge base and ready for future use. With the closeout documents, identified and realized risks, not identified but realized risks, identified but not realized risks will be separately declared with their applied responses, estimated impact on project objectives at the initial plan, realized impact on project objectives, and recommendations for the future.

CONCLUSION

This study demonstrates the importance of learning from past experiences for successful project management and in particular for project risk management. Through this study, some risk management techniques and post project analysis are integrated into the project management system of the R&D Department with the objective of improving the project management performance.

Both post project analysis and risk management processes are helpful in transforming tacit knowledge into explicit and written information. To exploit this facility a knowledge base is designed and put in place. Tacit knowledge extracted in written form is thus made easily accessible to others in order to increase its impact and to make it part of the corporate knowledge base. Standardization and categorization are introduced for facilitating knowledge sharing. Disorganized and free-format structures create information pollution, and people rightfully do not want to spend hours searching through archives without being able to focus on what they are looking for.

It is observed that risk related issues constitute a major part of post project analyses. Risk management, on the other hand, relies heavily on the experiences gathered through a series of projects and made explicit by post project analysis. These processes interact with each other closely, both serving the same aim of increasing the success of a project by improving its management. Therefore, risk management and post project analysis processes are designed together in an input-output type of collaboration with each other.

Integration of this process innovation into the present project management system required the use of current terminology and harmony with the current procedures prevalent in the R&D Department, simplicity and clarity of the techniques employed, management support and motivation of the employees. Organizational culture and environment are also observed to play a major role in implementing both risk management and post project analysis processes.

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Table 1. Results of the *t*-tests

Table 2. Results of the one-way ANOVA

Table 3. Scales for probability and impact estimations [35,38]

Table 4. Risk severity matrix [35]

Appendix 1. The Post Project Analysis Process Flow Chart

Appendix 2. The Risk Management Process Flow Chart

Appendix 3. The Risk Checklist

Table 1. Results of the *t*-tests

Hypothesis	Groups	No. of Observations	Mean	Variance	*T statistics*	*P (T≤ t)*	T_{crit}
H1.1 (Duration)	< 2 years	55	0.91	1.9	3.1	0.001	1.06
	≥ 2 years	38	0.29	0.18			
H1.2 (Manpower)	< 2 years	55	0.39	0.08	2.13	0.01	1.66
	≥ 2 years	38	0.26	0.11			
H2.1 (Duration)	< 6 man-months	47	1.07	2.12	3.757	0.0002	1.68
	≥ 6 man-months	46	0.25	0.11			
H2.2. (Manpower)	< 6 man-months	47	0.45	0.13	3.57	0.0003	1.66
	≥ 6 man-months	46	0.23	0.042			
H3.1 (Duration)	< 4 years	54	0.63	0.65	1.92	0.03	1.66
	≥ 4 years	37	0.37	0.22			
H3.2 (Manpower)	< 4 years	54	0.32	0.07	0.41	0.34	1.66
	≥ 4 years	37	0.30	0.06			
H5.1 (Duration)	1 and 2 disciplines	42	0.88	1.30	1.7	0.04	1.66
	≥ 3 disciplines	51	0.48	1.22			
H5.2 (Manpower)	1 and 2 disciplines	42	0.43	1.38	2.465	0.008	1.67
	≥ 3 disciplines	51	0.26	0.05			

Table 2. Results of the one-way ANOVA

Hypothesis	Groups	No of Observations	Mean	Variance	*F Value*	*P Value*	F_{crit}
H4.1	Team size <4 persons	20	1.38	3.78	4.49	0.005	2.71
	Team size ≥4 and < 6 persons	23	0.72	0.86			
	Team size ≥6 and < 10 persons	24	0.35	0.21			
	Team size ≥10 persons	26	0.34	0.27			
H4.2	Team size <4 persons	20	0.52	0.19	4.02	0.009	2.71
	Team size ≥4 and < 6 persons	23	0.36	0.08			
	Team size ≥6 and <10 persons	24	0.25	0.05			
	Team size ≥10 persons	26	0.25	0.04			

Table 3. Scales for probability and impact estimations [35,38]

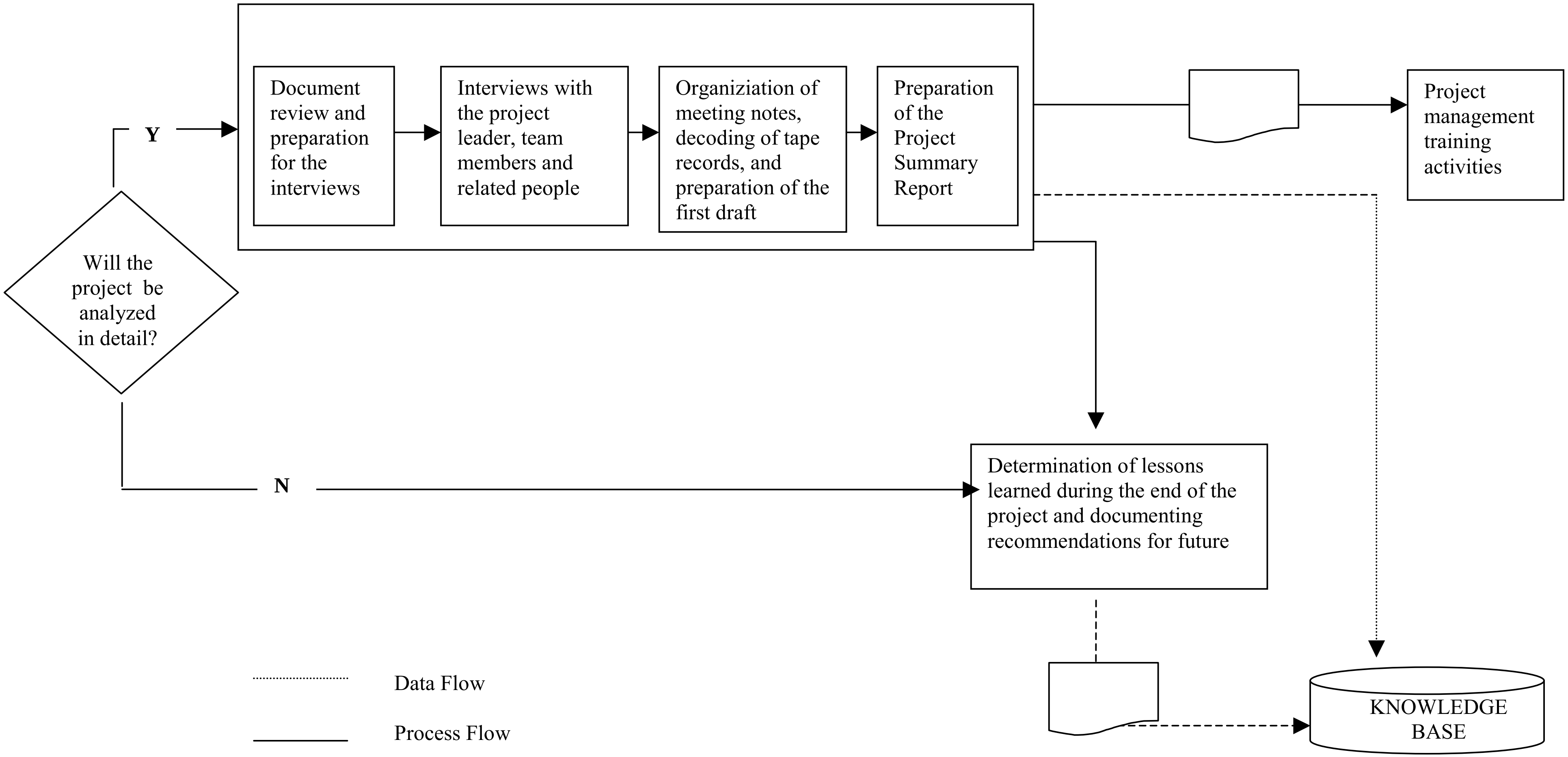
Probability		**Scale**
Very low probability of risk to happen	(%0-%5)	1
The risk less likely to happen than not	(%6-%20)	2
The risk is just as likely to happen as not	(%21-%50)	3
The risk is more likely to happen than not	(%51-%90)	4
The risk will happen almost definitely	(%91-%100)	5
Quality Impact (Quality is defined here as the conformance quality of the project end item with its technical specifications)		
Quality degradation barely noticeable		1
		2
Quality degradation noticeable but acceptable		3
		4
Project end item is effectively not usable		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

Table 4. Risk severity matrix [35]

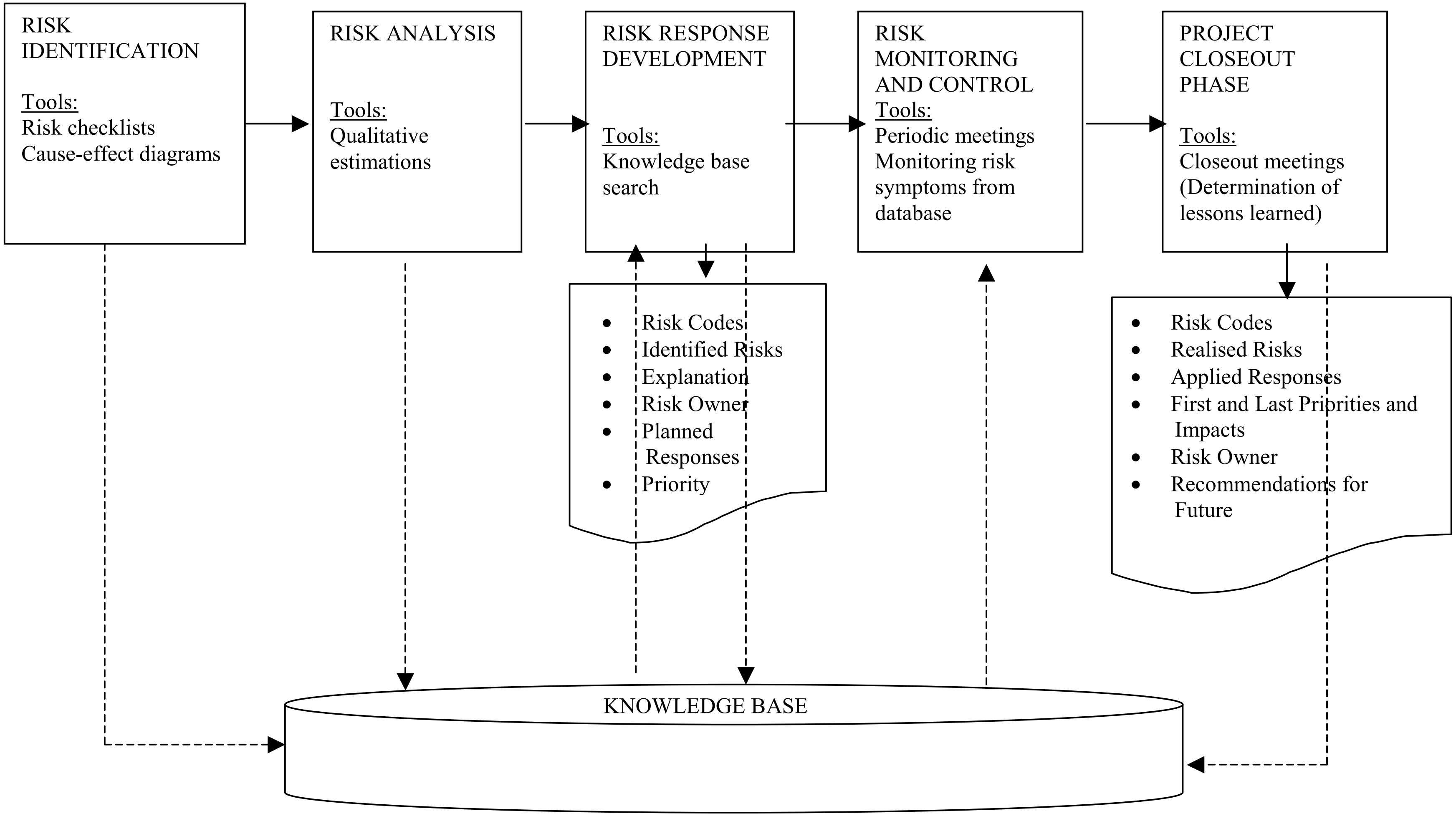
Probability of Occurrence (Likelihood)						
	5	**19**	**14**	**9**	**4**	**1**
	4	**21**	**16**	**11**	**6**	**2 A**
	3	**23 C**	**18**	**13 B**	**8**	**3**
	2	**24**	**20**	**15**	**10**	**5**
	1	**25**	**22**	**17**	**12**	**7**
		1	2	3	4	5
	Overall Impact					

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

Appendix 1. The Post Project Analysis Process Flow Chart



Appendix 2. The Risk Management Process Flow Chart



Appendix 3. The Risk Checklist

Risk Categories	Risk Classes	Risk Causes
Technical	Maturity level of the technology used	Use of new-to-the-firm technology
		Use of new-to-the-world technology
	Complexity and uncertainty of the technical content	High uncertainty in technical content
		Difficulty in defining the project scope
	Inadequacy of the technical personnel	Absence of qualified people (person who has the experience and knowledge about the technology)
Resource Management	Inadequate 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
	Changes in team members	Turnover in project team
Non-technical Internal (Managerial – Project Management)	Inadequate communication	Inadequacy of communication with upper management
		Inadequacy of communication within the project team
	Changes in strategy / project priorities	Changing objectives / expectations
	Inadequate project experience	Inexperienced project leader
		Lack of teamwork experience in the project team
Customer Related	Uncertainty in the communication with the customer	No previous experience of working together with the customer
		Customer violating the written and oral agreements / understandings
	Uncertainty in customer requests	Frequent change requests by the customer
		Project aborted by the customer
	Project budget	Payment delays / cash flow irregularities
External-Predictable	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
	Competitive environment	New technologies developed by the competitors
		Changes in standards and regulations
External-Unpredictable	Natural hazards	Earthquake, flood, etc.
	National / international economic crises	Economic crises and exchange rate fluctuations affecting the project
	International relations and legal regulations	Changes in international relations affecting the project
		Legal and bureaucratic obstructions affecting the project