Ph.D. Thesis A.CERIĆ 2003

A FRAMEWORK FOR PROCESS-DRIVEN RISK MANAGEMENT IN CONSTRUCTION PROJECTS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

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LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
BPF	British Property Federations
CDM	Construction (Design and Management) Regulations
CIRIA	Construction Industry Research and Information Association
CPR	Construction Process Re-Engineering
DAO	Data Access Objects
DBMS	Data Based Management System
DDL	Data Definition Language
DML	Data Manipulation Language
DMS	Document Management System
DSS	Decision Support System
EPSRC	Engineering & Physical Sciences Research Council
ITA	International Tunnel Association
JCT	Joint Contracts Tribunal
MMS	Method management system
PDRM	Process - Driven Risk Management
PP-Risk	Process Protocol - Risk
RAMP	Risk Analysis and Management for Projects
RIBA	Royal Institution of British Architects
RISKMAN	A Risk-Driven Project Management Methodology
SPICE	Structured Process Improvement for Construction Enterprises
SQL	Structured Query Language

GLOSSARY OF TERMS

Activity Zones:	Structured set of sub-processes involving tasks which guide and support work towards a common objective (for example, to create an appropriate design solution).
Alternatives:	The candidates, or options from which the choice is to be made.
Contingency Planning:	Preparing to handle a given circumstance that may arise in the future.
Criterion:	A factor that influences a decision.
Decision Making:	Determining the appropriate action to accomplish goals efficiently and effectively.
Hierarchy:	A tree-like structure. It can be used to represent the spread of influence.
Legacy Archive:	Potentially an IT solution it represents a mechanism for recording, storing and retrieving project/process information which can be used by project participants in current and future projects.
Pairwise comparisons:	The process of making comparison between all alternatives of the same criterion, or all criterion of the goal, taken in pairs.
Stakeholders:	Those persons or organizations whose views, interests and/or requirements can have an impact or are impacted by the initiation and/or formulation and eventual implementation of the project solution.

ABSTRACT

This thesis describes the development of a framework for a systematic approach to risk management in construction projects, whose application in construction practice would lead to changes and improvements in the construction industry. To verify and apply the framework in future construction projects, the author developed the PP-Risk computer programme as IT support.

Before showing how the framework was developed, there is a survey of what has been written on the subject and a systematic analysis of risk management, risk in construction and process in construction. This led to the conclusion that realising a construction project is a process and that the risk management process should be subordinated to the construction process. A new approach was therefore introduced to managing risks: process-driven risk management. This approach will give all the participants in the project better understanding of the construction process, enable changes in the construction industry, and contribute to improvement of quality and efficiency in construction.

An analysis of published plans of work showed that the Construction Process Protocol, developed at the University of Salford under the leadership of Professor R.Cooper, is suitable and appropriate as a construction process in which the framework for process-driven risk management can be placed.

Process-driven risk management implies a cyclical risk management process in all the phases through which the construction project passes according to Process Protocol. Key risks are identified in the framework, which are independent of the size, type and purpose of the project being realized. Project related risks should be separately identified for each specific project. Depending on available data, quantitative and qualitative analysis is carried out for the identified risks, their risk probability and risk impact determined, and the corresponding risk exposure calculated. Then the adequate risk response is given for each identified risk, depending on its exposure. As the process unfolds new risks appear in each phase and the risk management process begins a new.

1 INTRODUCTION

1.1 BACKGROUND

The construction industry has many specific features and is inert, because of which it lags behind other industries in keeping to deadlines and realising production with minimum expenses and satisfactory quality, in other words, in developing an efficient production process (Latham, 1994; Egan, 1998; Egan, 2002). The development of construction as an industry depends on improving process in construction (Hammer and Champy, 1993; Love and Li, 1998; Kagioglou, Cooper and Aouad, 1999; Finnemore *et al*., 2000; Holt, Love and Nesan, 2000).

Every construction project passes through phases, each of which has a purpose, duration and scope of work. Breaking the project down into phases is an important part of every construction process. The project must start from some kind of definition of need, after which follow design, contracting, construction and project completion (Huges, 2000). Risk and uncertainty are inherent in all the phases through which the construction project passes, from Demonstrating the Need do Operation and Maintenance. Latham (1994) said that no construction project is risk free. Risk can be managed, minimised, shared, transferred or accepted. It cannot be ignored. Risks do not appear only in major projects. Although size may be a cause of risk, complexity, construction speed, site and many other factors that affect time, cost and quality to a greater or lesser degree cannot be overlooked. All the participants in the deciding process should observe risks and their effects on all key points of decision-making before and during project realisation.

Process in construction needs important changes and should be continuously improved. The process itself, and the changes and improvements made to it, are accompanied by risks whose adverse effects may increase planned costs and the time necessary for project completion, and decrease execution quality. Efficient and quality management of risks should make these changes in the construction industry possible and enhance quality and efficiency. The Process Protocol developed by R.Cooper *et al.* provides a structure for managing risk in construction projects.

Process Protocol is used to manage the project from Recognition of a Need to Operation and Maintenance and is basically a generic process. It is a result of a research project at the University of Salford headed by Professor R.Cooper in cooperation with several companies which were in various ways included in the construction industry (Cooper *et al*., 1998; Kagioglou *et al*. 1998a.; Kagioglou *et al*., 1998b; Kagioglou *et al*., 1998c; Aouad *et. al*,, 1998; Kagioglou, Cooper and Aouad, 1999; Wu, Aouad and Cooper, 2000; Fleming *et al.*, 2000; Lee, Cooper and Aouad; 2000; Wu *et al.*, 2001). Chapter 5 explains the reasons why the Process Protocol was chosen as the basis for the proposed framework in this thesis.

Changes may be brought to the construction industry through improved risk management in several ways. One possibility is to study the causes of risks, their probability and their impact on time, cost and quality for a particular type and size of facility. In this case it is possible to muster the help of experts in that field, to identify the risks in all the phases of the project life cycle in great detail, to use a large database compiled from prior experiences on similar facilities, and to propose the most adequate risk response. Another is to improve risk management developing quantitative and qualitative risk analysis techniques and use them in particular phases of the project life cycle. Finally, risk management may be improved by developing a decision support system under conditions of uncertainty, which would considerably decrease the risk of poor risk management.

The above approaches to improved risk management are partial solutions with limited applicability. This research starts from the fact that executing a construction project is a process and risk management should be adapted to this process.

Risk management is a continuous process needing an integral risk management system in all the phases that the construction project passes through, which is accomplished by developing a framework for process-driven risk management. The framework should be generic by nature and bring together all the above approaches to improve risk management. It is necessary to identify the key risks that appear in all the phases through which the construction project passes, regardless of the type and size of the facility. Risk analysis depends on the quality of the data available, so the system should include both qualitative and quantitative risk analysis. Risk response should be continuously developed on the basis of what has been learned in earlier cases, but it is also necessary to allow changes to take place in the construction industry.

1.2 AIM OF THE RESEARCH

The primary aim of this research is to develop a framework that will provide a systematic process-driven approach for managing risk in construction, from the beginning of the project to operation and maintenance. Moreover, if companies adopt this approach as an integral part of managing projects it will enable the project management team to monitor improvement in construction performance.

1.3 RESEARCH OBJECTIVES

The objectives of this research are :

To investigate how to deal with risks and uncertainties in each phase of the project.

To investigate and assess key-risks in each phase of the project.

To suggest risk response for identified key-risks.

To identify and develop a suitable framework and IT support for implementing process-driven risk management.

To implement and test the proposed framework using a real case which will demonstrate the benefit of the proposed framework.

1.4 HYPOTHESIS

A framework for managing risk in construction projects, based on the Process Protocol developed by Cooper *et al.*, is an improvement on current construction project practice.

Improvement can be recognised in:

1. Better understanding of the construction process by all participants in project realisation.
2. Identifying the key risks in every phase of the construction process that are independent of the size, type and purpose of the facility.
3. Enabling a combination of qualitative and quantitative risk assessment from Demonstrating the Need to Operation and Maintenance.
4. Introducing a new approach to risk management by placing it in the function of the construction process, i.e., by implementing process-driven risk management.

1.5 RESEARCH METHODOLOGY

The research was carried out in five phases:

Phase I - Literature review

The first step was to systematically review earlier writings so as to learn more about the subject and about different approaches to connecting risk management with the construction process as a basis for developing an integral system for managing risk in construction projects. The knowledge gathered about *Risk management* is presented in Chapter 2, *Risk in Construction* in Chapter 3, *Process in Construction* in Chapter 4 and *Process Protocol* in Chapter 5.

Phase II - Identifying and structuring risk within Process Protocol

Each Process Protocol phase is divided into sub-processes, activities that should be performed during the phase. A systematic analysis of the division helped identify and describe the key risks that appear in all construction projects, regardless of size or type.

Phase III - Developing a framework for managing risk in construction projects

The results of Phase I and Phase II served as a foundation for developing a framework for managing risk in the construction project. The framework provides holistic risk assessment from Demonstrating the Need to Operation and Maintenance.

After determining risk probability and risk impact, and thus also risk exposure, for each identified key risk or project related risk, a priority risk list is formed and, depending on risk acceptability, a strategy of risk response. If risk response leads to the appearance of new risks, a new cycle of identification, analysis and risk response begins.

Phase IV - Developing an IT Support for the proposed framework

In this phase an integral decision support system was developed, the PP-Risk computer programme, which supports all the elements of the framework for process-driven risk management developed in the preceding phase.

Phase V - Application and Verification of the process-driven risk management framework

The last phase shows the application and verification of the proposed process-driven risk management framework using the PP-Risk computer programme developed in the preceding phase.

Figure 1.1 shows the research methodology map.

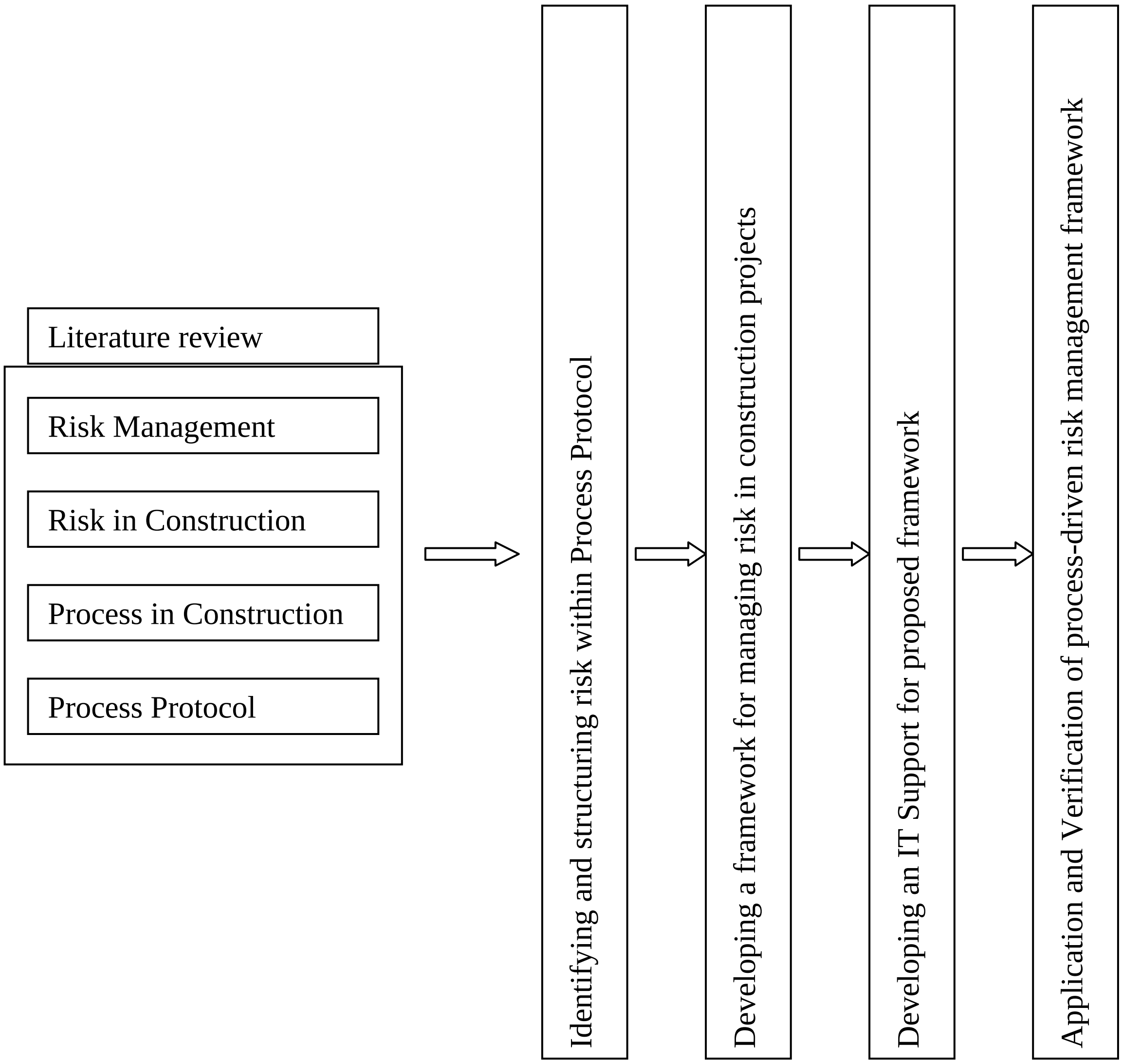


Figure 1.1: Research methodology map

1.6 STRUCTURE OF THE THESIS

This thesis consists of 10 chapters, including this one. The contents of the other chapters are as follows:

1.6.1 CHAPTER 2: RISK MANAGEMENT

The first part of the chapter defines and explains the concepts of risk, certainty, uncertainty, risk exposure and risk acceptability. The second part analyses several risk management processes, and shows and gives a detailed explanation of the development of cyclical risk management, which will be part of the framework for managing risks in construction projects that is proposed in this work.

1.6.2 CHAPTER 3: RISK IN CONSTRUCTION

This chapter shows research on risk management in construction that had an influence on the development of the framework proposed in this work. It showes two integral but different approaches to systematic risk management in construction, the CIRIA Guide to the Systematic Management of Risk from Construction and the RISKMAN as a Risk-driven Project Management Methodology. It shows the need for a new approach to managing risks as part of the construction process. This kind of approach is implemented in the framework for risk management in construction proposed in this work.

1.6.3 CHAPTER 4: PROCESS IN CONSTRUCTION

This chapter shows research into process in construction and its specific features in relation to process in other industries, which make it more difficult to introduce changes that would lead to continuous process improvement. It shows that the process in construction, and changes and improvements that are made to it, are accompanied by risks inherent in the process itself. If the risk management process becomes part of the construction process any improvements in risk management will automatically lead to process improvement. The framework for risk management in construction proposed in this work hinges on process-driven risk management and the risk management process is completely subjected to the construction process.

1.6.4 CHAPTER 5: PROCESS PROTOCOL

This chapter shows the concept and principles underlying the Construction Process Protocol as a generic construction process and as a plan of work that makes it possible to manage the project from Demonstrating the Need to Operation and Maintenance. It shows the advantages of Process Protocol as an industry standard, which is why it was chosen as the construction process for the development of the proposed framework for process-driven risk management.

1.6.5 CHAPTER 6: IDENTIFYING AND STRUCTURING RISK WITHIN PROCESS PROTOCOL

This chapter shows the identification of the key risks in all phases through which the construction project passes according to Process Protocol. The process of identification starts from the fact that every phase the project passes through contains sub-processes, elementary activities that should be performed for the successful realisation of that project phase. These activities are a source of risk and can be used as the basis for making a list of key risks in each phase. The key risks are part of the proposed framework. The management of key risks identified in this way is in the service of the construction process, and leads to the better understanding of process and process improvement.

1.6.6 CHAPTER 7: FRAMEWORK FOR MANAGING RISKS IN CONSTRUCTION PROJECTS

This chapter shows the development of the framework for process-driven risk management in construction projects. The framework contains the cyclical risk management process shown in Chapter 2, the approach to risk management shown in Chapter 3, process-driven risk management shown in Chapter 4, and is based on the Construction Process Protocol shown in Chapter 5. It contains the list of key risks identified in Chapter 6 and enables the identification of project related risks in every phase. The chapter also shows various approaches to forming the risk priority list.

1.6.7 CHAPTER 8: THE PP-RISK MANAGEMENT PROGRAMME

This chapter shows the PP-Risk computer programme as a Decision Support System developed by the author for the proposed framework for risk management in Process Protocol based construction projects. The program is made in MS Visual Basic 6 on a Microsoft Windows platform.

1.6.8 CHAPTER 9: APPLICATION AND VERIFICATION OF THE PROCESS-DRIVEN RISK MANAGEMENT FRAMEWORK

This chapter tests and verifies the proposed framework on the example of the future *Sveta tri kralja* tunnel planned as part of the future Zagreb-Macelj Motorway, that will connect the capital of the Republic of Croatia with the Republic of Slovenia. Eighteen experts, who had in various ways significantly participated in the execution of similar projects in the past and who are expected to significantly participate in future projects, helped verify the efficiency and applicability of the proposed framework and the PP-Risk computer programme.

1.6.9 CHAPTER 10: CONCLUSION AND GUIDELINES FOR FUTURE WORK

This chapter gives the conclusion of the thesis and recommendations for future research.

1.7 SCOPE

The proposed framework for process-driven risk management can be applied to all kinds of construction projects regardless of their size or type. The proposed approach to risk management may also be extended to other industries if the plan of work is adapted to their production process. Risk management is often limited by the non-existence of a relevant, statistically significant database about similar past projects, which could be used for quantitative analysis of the identified risks. The proposed framework, through the PP-Risk computer programme developed, enables the formation and updating of such a database that would be accessible to all, and at the same time provides for qualitative risk analysis if no such database is available.

2 RISK MANAGEMENT

2.1 INTRODUCTION

The first part of this chapter defines and explains the basic concepts connected to risk management, such as risk, certainty, uncertainty, risk exposure and risk acceptability. These concepts are not linked only to risk management in the construction industry, they are part of the conditions and circumstances of the decision-making process as such. People make decisions every day, in private life, in all kinds of business organisations, fields of industry, and on all levels of the business cycle. It could easily be said that human life is one endless sequence of decision-making. Most simple decisions are reached spontaneously without much thought and analysis. However, a certain number of complex, even very complex decisions depends on the systematic study of many factors of influence, adequate and quality information, choosing among numerous alternatives, and using suitable models and techniques for choosing the optimum, i.e. the most favourable alternative.

The second part of the chapter analyses the role of process in risk management and the role of risk management in project management. It gives an analysis of several published risk management processes that served as a foundation for the development of the cyclical risk management process, which will be part of the framework for managing risks in construction projects that is proposed in this work.

2.2 RISK, CERTAINTY AND UNCERTAINTY

Decision-making occurs under conditions of certainty, risk or uncertainty. Certainty is a condition in which all the factors of influence can be quantified and where the use of adequate decision-making methods results in an exactly predictable outcome. This happens very rarely and is met only in closed systems. Construction practically never runs under conditions of certainty.

If two or more alternatives are to be decided among, in which all the factors of influence cannot be quantified, then decision-making occurs under conditions of risk or uncertainty. A decision is made under conditions of risk if the decision-maker is able to assess rationally or intuitively, with a degree of certainty, the probability that a particular event will take place, using as a basis his information about similar past events or his personal experience. An example for deciding under conditions of risk is a cost estimate for the foundations of a structure made prior to research defining the load on the foundations. This estimate can be made, with a degree of certainty or a degree of risk, on the basis of existing information about similar structures built under similar ground conditions and on the basis of the estimator's experience. If there is no such information, and if the estimator has no experience with similar structures and ground conditions, then decisions are made under conditions of uncertainty. Risk, therefore, becomes uncertainty when sufficient information or experience to make a mathematical model and predict the probable result are not available.

One of the basic roles of modern businesses management is to maximally reduce the probability of risk, i.e. to gather sufficient information or experience to turn uncertainty into risk and make it easier to reach a decision.

The *Oxford Dictionary of Current English* defines risk as a chance or possibility of loss or adverse consequences. Chapman and Cooper (1983) define risk as exposure to the possibility of economic or financial loss or gains, physical damage or injury or delay as a consequence of the uncertainty associated with pursuing a course of action. Wideman (1986) defines risk as a chance of certain occurrences adversely affecting project objectives. It is the degree of exposure to negative events, and their probable consequences. Godfrey (1996) defines risk as a chance of an adverse event, depending on circumstances. Kliem and Ludin (1997) define risk as the occurrence of an event that has consequences for, or impacts on, projects. According to Smith (1999), risk exists when a decision is expressed in terms of a range of possible outcomes and when known probabilities can be attached to the outcomes.

2.3 RISK EXPOSURE

Common to all the above definitions of risk is that it includes two independent components: risk probability and risk impact. Both these components should be quantified if different risks are to be analysed, compared and classified.

In the exact mathematical sense risk probability, i.e. the probability of an adverse event, is a random variable with its own probability distribution, and statistical methods can be used to calculate the probability of the event, mean, dispersion, confidence interval and all the other statistically significant parameters. This demands an extensive and statistically relevant database about similar past events on which to base the probability distribution. In practice this is very difficult to achieve because relevant databases exist for a very small number of potentially risky events.

When there is no relevant database to draw from, risk is determined subjectively on the basis of available information and greatly depends on the experience and knowledge of the manager who assesses probability. If there is sufficient information probability is usually estimated at a numerical value between 0 and 1. If there is little or very little information risk probability is verbally assessed as low, medium or high.

Risk can impact a project in various ways. It can adversely affect planned expenses, project duration and project quality. In the final issue both longer duration and quality loss may be expressed through increased expenses. If there is enough information risk impact can be calculated. But in practice it is often impossible to calculate risk impact quantitatively so a qualitative appraisal is made estimating the impact as a low, medium or high.

Risk quantification should reflect both the above components, either quantitative or qualitative. This is done by introducing risk exposure, which is the product of risk probability and risk impact: risk *exposure = risk probability x risk impact* (Carter et al., 1994).

Risk exposure has no importance in the case of a single risk. If only one risk was analysed in a particular project phase, it would be enough to calculate its probability and its impact on the project. However, if two or more risks may occur risk exposure can be used to compare them and decide about how to respond to each of them.

An example of determining priorities among three risks will be used to show how risk managers use risk exposure to reach decisions.
Three risks shall be analysed: R1, R2 and R3.

R1 has 0.1 probability and ₤10,000 impact.

The exposure for risk R1 is 0.1x10,000 = 1,000.

R2 has 0.02 probability and ₤50,000 impact.

The exposure for risk R2 is 0.02x50,000 = 1,000.

R3 has 0.7 probability and ₤2,000 impact.

The exposure for risk R3 is 0.7 x 2,000 = 1,400.

Risks R1 and R2 have different probabilities and impacts but the same exposure. Risk R3 has a high probability but a relatively low impact. Risk R3 has the highest exposure and will have top priority in determining risk response.

2.4 RISK ACCEPTABILITY

Depending on the level of risk exposure, risks are classed as unacceptable, undesirable, acceptable or negligible, and a plan is made about how to manage each one. Godfrey (1996) suggested risk categories and the appropriate way of managing each category:

UNACCEPTABLE	- Intolerable, must be eliminated or transferred.
UNDESIRABLE	- To be avoided if reasonably practicable, detailed investigation and cost benefit justification required, top level approval needed, monitoring essential.
ACCEPTABLE	- Can be accepted provided the risk is managed.
NEGLIGIBLE	- No further consideration needed.

For each project a decision can be made to link a certain level of risk exposure with a particular category, and thus also with the proposed plan for risk management.

If the risk probability has been qualitatively assessed as improbable, remote, occasional, probable and frequent (Godfrey, 1996) and the risk impact as negligible, marginal, serious, critical and catastrophic the acceptability of each risk can be assessed independently of any others.

This may be as follows (Godfrey, 1996):
frequent probability and catastrophic impact = unacceptable risk.
probable probability and critical impact = unacceptable risk.
occasional probability and serious impact = undesirable risk.
remote probability and marginal impact = acceptable risk.
improbable probability and negligible impact = negligible risk.

2.5 RISK MANAGEMENT PROCESS

Risk management is a discipline for living with the possibility that future events may cause adverse effects (Flanagan and Norman, 1993). *In the global sense, risk management is the process that, when carried out, ensures that all that can be done will be done to achieve the objective of the project, within the constraints of the project* (Clark, Pledger and Needler, 1990). The basic goal of project management is to realise the project within the predicted time, planned costs and satisfactory quality. Contrary to this is project realisation under conditions of uncertainty, and when the outcomes of all foreseen events cannot be predicted with certainty. This is what makes it necessary to turn uncertainty into risk, and to manage that risk.

The management of risk is a continuous process and should span all the phases of the project (Smith, 1999). Risks and their effects should be observed on all the key sites of decision-making throughout the project and by all the participants in the decision-making process. All through the project's life cycle it is necessary to continuously identify causes that may have a detrimental effect on the project, analyse their possible adverse consequences and prepare a response to them. The investor and his project manager have the greatest responsibility for identifying risks, analysing them and responding to them. Project managers should do all they can to realise the project, undertaking activities that decrease or eliminate the effects of risk or uncertainty. Thus risk management is inseparable from project management and cannot be viewed as a separate activity.

The risk management process may consist of elements more or less closely connected. According to Perry and Hayes (1985), the risk management process consists of three phases (see Fig. 2.1):

1. risk identification;
2. risk analysis;
3. risk response.

Figure 2.1: Linear risk management process, Perry and Hayes (1985)

During the project’s entire life cycle, qualitative or quantitative analysis are carried out for every identified risk and an adequate response prepared. This kind of process is linear by nature and is a good starting point for successful risk management.

However, any activity undertaken as a risk response may produce new risks, which should be in their turn be identified, analysed and responded to. Thus some authors view risk management as a cyclical process.

According to Carter et al. (1994), the risk management process consists of 6 phases that cyclically repeat themselves (see Fig. 2.2):

1. Risk identification and documentation;
2. Risk quantification and classification;
3. Risk modelling (often called risk analysis);
4. Risk reporting and strategy development;

5. Risk mitigation, reduction and/or optimisation;
6. Risk monitoring and control.

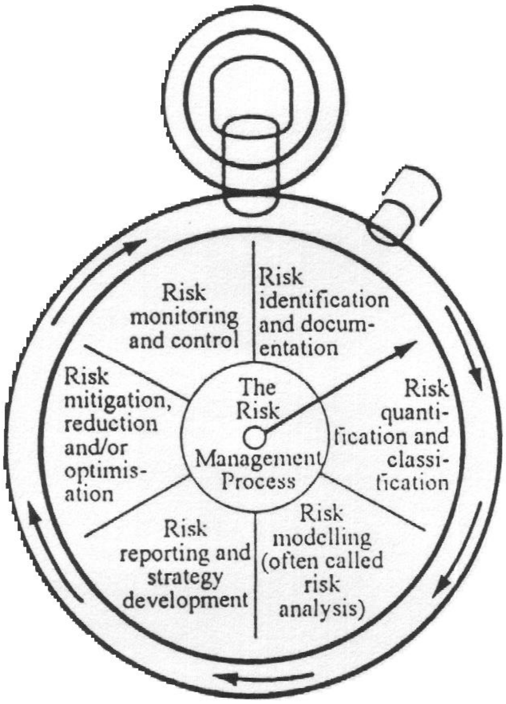


Figure 2.2: Cyclical risk management process, Carter et al. (1994)

Kliem and Ludin (1997) divided the risk management process into 4 phases (see Fig 2.3):

1. Risk identification;
2. Risk analysis;
3. Risk control;
4. Risk reporting.

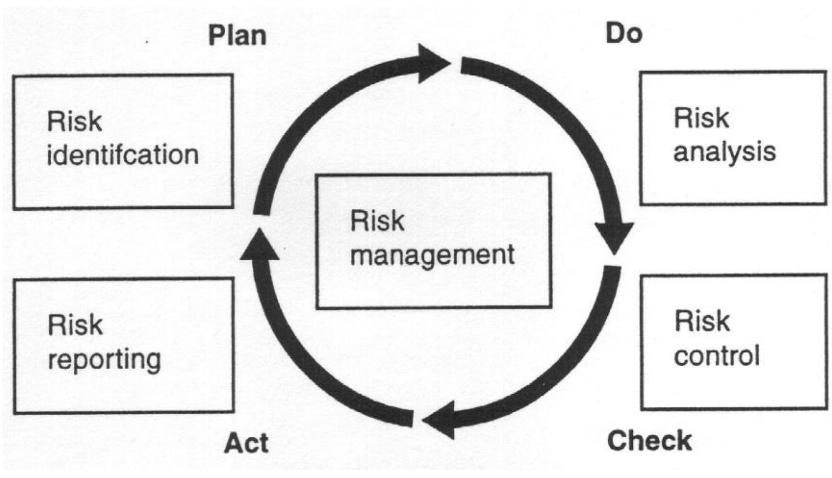


Figure 2.3: Cyclical risk management process, Kliem and Ludin (1997)

Baker, Ponniah and Smith (1998) divided the risk management process into 5 phases (see Fig. 2.4):

1. Risk identification;
2. Risk estimation;
3. Risk evaluation;
4. Risk response;
5. Risk monitoring.

Figure 2.4: Cyclical risk management process, Baker, Ponniah and Smith (1998)

Chapman (1997) suggested the generic risk management process divided in 9 phases (see Fig. 2.5):

1. Define;
2. Focus;
3. Identify;
4. Structure;
5. Ownership;
6. Estimate;
7. Evaluate;
8. Plan;
9. Manage.

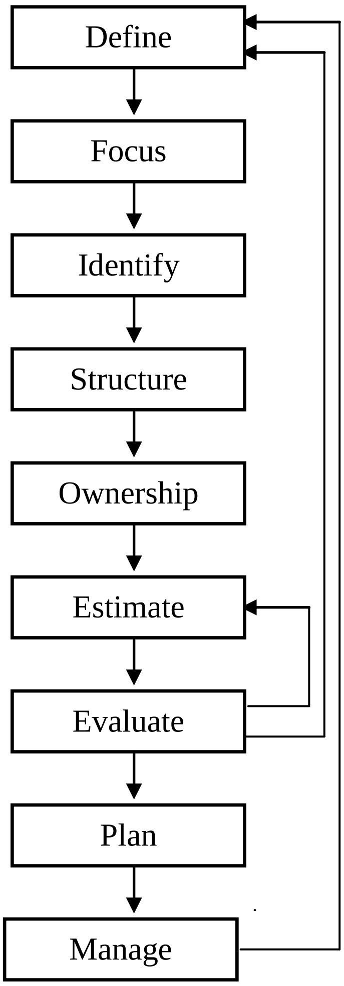


Figure 2.5: Generic risk management process, Chapman (1997)

Grammer and Trollope (1993) realised the cyclical risk management process divided in 5 phases (see Fig. 2.6):

1. Identify risks;
2. Analyse risks;
3. Reduce risks;
4. Plan against and manage risks;
5. Review risks;

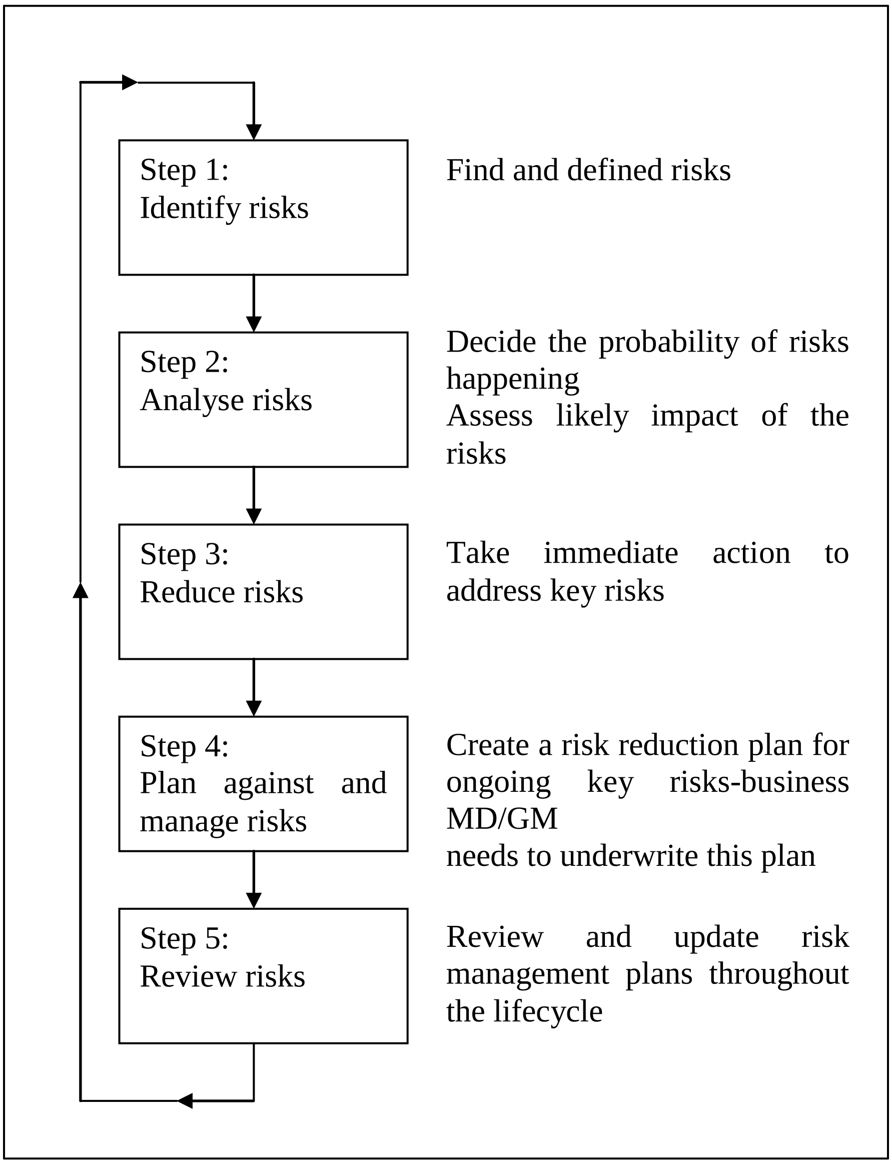


Figure 2.6: Cyclical risk management process, Grammer and Trollope (1993)

The continuation will show in detail all the elements of the cyclical risk management process proposed in this work, which served as the basis for the proposed framework for managing risks throughout the project’s life cycle (see fig. 2.7).

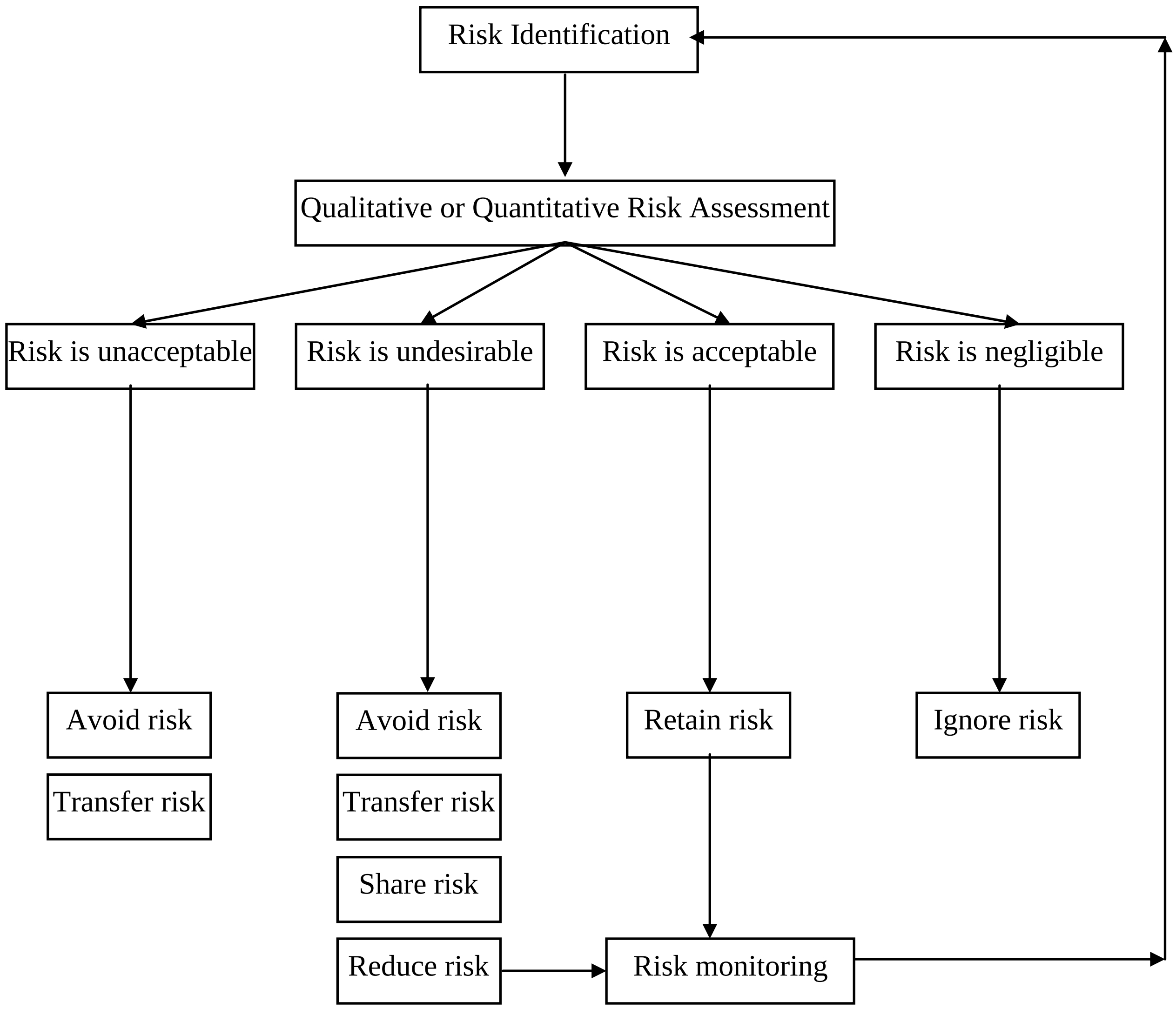


Figure 2.7: Proposed cyclical risk management process

The proposed cyclical risk management process basically contains the same elements as the published risk management processes that are shown, and is adapted to computer programming. The process begins by risk identification, followed by qualitative or quantitative assessment of risk probability and risk impact, and calculation of the corresponding risk exposure. Depending on the value of risk exposure a decision is made about risk acceptability, which serves as the basis for one of the methods of risk response. The application of risk response is followed by risk monitoring, and if new risks appear the process returns to the beginning, that is, to their identification.

2.5.1 RISK IDENTIFICATION

Risk management always starts with risk identification, which may be considered the most important phase of the risk management process (Baker, Ponniah and Smith, 1998). Its purpose is to compile a list of risks important for a particular project. To form this list, it is first necessary to research the potential sources of risk, adverse events that include risk, and the unfavourable effects of an undesirable scenario. For example, weather is a source of risk, extremely bad weather is an adverse event, and its effect is work running behind schedule due to extremely bad weather conditions. Risk identification greatly depends on the manager’s experience. If his experience with particular methods and techniques of risk identification is good he will continue to use them, whereas bad experience leads to avoiding approaches prepared earlier. Managers use various techniques for risk identification, the best-known of which are: brainstorming, interviews, questionnaires, Delphi technique, expert systems, etc.

2.5.1.1 Brainstorming

Brainstorming is a meaningful and open discussion in which participants discuss their views on possible sources of risk in the project, on how uncertainty is manifested and how to turn it into risk, on risk probability, on potential risk impact, and on possible risk responses (Smith, 1999). The project or risk manager usually chairs the discussion and success greatly depends on his experience in conducting discussions of this kind. This method is efficient and often results in a very comprehensive risk list. A problem may be the participation of a very authoritarian and domineering personality who dominates others and imposes his stands. The number of participants is also important because discussions with a large number of participants become inefficient and long-lasting.

2.5.1.2 Interviews

The interview is a technique in which the respondent answers prepared questions and discusses the issues involved (Carter et al. 1994). The purpose of the interview is to register answers to questions, and later use them as a basis for analysis. The questions can be unstructured, freely formulated, allowing the respondent to answer them as he chooses. Structured questions require a *yes* or *no* answer from the respondent, or that he accepts one of several alternatives offered. The project or risk manager, who frames the questions and conducts the interview, should have great knowledge and experience, primarily in formulating and drawing up questions but also in conducting interviews. There are two forms of interview: one to one and several to one. A one to one interview enables greater depth in identifying each risk, while the several to one interview makes it possible to approach the respondent's knowledge from several angles. This technique is very time consuming because after the interview its results should be systematised and analysed.

2.5.1.3 Questionnaires

Questionnaires are definitely the fastest and most efficient way of learning the opinion of all the project team members and allowing these opinions to be analysed and compared (Godfrey, 1996). Questions can be structured or unstructured. The main disadvantage of this method is that is does not stimulate creative thinking. Question quality depends on the person who compiled the questionnaire, but unlike the case of the interview, the respondents cannot discuss their answers nor present any stands outside the questions.

2.5.1.4 The Delphi technique

The Delphi technique is an attempt to obtain objective results from a subjective discussion (Powel, 1996). It starts by the risk manager handing out a questionnaire to all the project team members, who answer the questions and return the questionnaire to the risk manager. Then the risk manager hands out the answers to all the project team members, who use them to reconsider their approach, give new answers to the same questions and return them to the risk manager. The revised results are again distributed to the team members, who are again asked to reconsider their stands and give new answers. This iterative process continues until the risk manager decided that a consensus has been reached and that there is no more need to examine the stands of all the team members. The main advantage of this technique is that the project team members are independent and that there is no predominance of “strong personalities”. The disadvantage is that a very large number of iterations are often necessary for a consensus to be reached, which can be very time consuming.

2.5.1.5 Expert systems

An expert system is developed by using knowledge about earlier projects and the experiences of all the participants in the project to identify potential risks (Carter et al., 1994). The expert system will not expose all the hidden risks, but it will incorporate all the experiences from earlier projects. One of the basic characteristics of expert systems is that they provide an explanation of how a problem was solved, thus providing the user both with the knowledge they contain and the reasoning mechanism used to reach it, which he may examine. This significantly contributes to the confidence people have in expert systems and why they accept them as reliable tools for risk identification.

2.5.2 QUALITATIVE ASSESSMENT

Once all the major risks have been identified and the risk list compiled, it is necessary to make a qualitative risk assessment and record it in a document called the risk register (Patterson i Neailey, 2002). The first step in forming the risk register is a short description of each particular risk, which should be clear and unambiguous to avoid confusing risks. When they have been described, the risks should be classed into categories according to their sources. The categories should cover as many risk sources as possible. Godfrey (1996) proposed one such categorisation:

political	government policy, public opinion, change in ideology, dogma, legislation, disorder
environmental	contaminated land, pollution liability, noise, permissions, internal corporate policy, environmental law or regulations or practice or “impact” requirements
planning	permission requirements, policy and practice, land use, socio-economic impacts, public opinion
market	demand, competition, obsolescence, customer satisfaction, fashion
economic	treasury policy, taxation, cost inflation, interest rates, exchange rates
financial	bankruptcy, margins, insurance, risk share

natural	unforeseen ground conditions, weather, earthquake, fire or explosion, archaeological discovery
project	definition, procurement strategy, performance requirements, standards, leadership, organisation, planning and quality control, programme, labour and resources, communications, culture
technical	design adequacy, operational efficiency, reliability
human	error, incompetence, ignorance, tiredness, communication ability, culture, work in the dark or at night
criminal	lack of security, vandalism, theft, fraud, corruption
safety	CDM regulations, Health and Safety work, hazardous, substances, collisions, collapse, flooding, fire and explosion

When the sources have been defined it is necessary to determine, for each risk, the adverse event that will produce the risk. This is especially important for the later establishment of risk response. Risks are often interconnected, which should also be defined. For example, an activity undertaken as risk response may give rise to another risk. In this phase of risk management it is necessary to allocate a person or team responsible for every identified risk.

After determining the probability and impact of every risk, and thus also its exposure, a risk list can be compiled according to priority and, depending on risk acceptability, the strategy of response defined.

Once risks have been qualitatively assessed and measures taken to respond to them, they are monitored and in this process new risks will probably be discovered resulting from risk response. Since new risks should be treated in the same way as the original risks, risk management becomes a cyclical process.

2.5.3 QUANTITATIVE RISK ANALYSIS

Risks are quantitatively analysed if it is possible to estimate the probability of an event on the basis of available information about similar past events, or information reached in another way, or on the basis of personal experience.

Many methods of quantitative risk analysis are in use today, the best-known being: simple assessment, probabilistic analysis, sensitivity analysis, decision trees and Monte Carlo Simulation (Evans and Olson, 1998; Baker, Ponniah and Smith, 1998; Vose, 2000).

2.5.3.1 Simple assessment

This is a relatively simple arithmetical method that addresses significant risks separately and examines the potential total effect (Powell, 1996). The evaluation is based on calculating the expected impact of every significant risk. The impacts are then added up and the sum impact is used as the foundation for a contingency plan. This technique is satisfactory for small and simple projects

2.5.3.2 Probabilistic analysis

This is a statistical method that enables calculating the exposure for every separate risk or for the project as a whole (Powell, 1996). First optimistic, most probable and pessimistic cost and time estimates are given for every event. For example, an optimistic price estimate for building a block of flats may be £500/m^2, construction will most probably cost £750/m^2, and a pessimistic price estimate is £1,000/m^2. Then the probability for each evaluation is subjectively defined. For example, let the probability for the optimistic evaluation be 0.3, the probability for the most probable evaluation 0.6, and the probability for the pessimistic evaluation 0.1. It is important for the sum of all the probabilities to equal 1. Multiplying the estimated construction costs with the corresponding probabilities and adding up the products gives exposure, i.e. the Expected Value (EV). In the above example EV = 500*0.3 + 750*0.6 + 1000*0.1 = £700/m^2. The EV differs from the optimistic evaluation by £200/m^2, from the most probable evaluation by £50/m^2, and from the pessimistic evaluation by £350/m^2. This means that the pessimistic evaluation that is the maximum likely risk and represents the basis for making the contingency plan. Probabilistic analysis is simple to use and very understandable, but subjective evaluation makes it dependent on the experience and knowledge of the risk manager who makes it.

2.5.3.3 Sensitivity analysis

Sensitivity analysis shows the impact of every separate risk, i.e. the unwanted effect of an event on the project (Flanagan and Norman, 1993). All the parameters that influence the exposure value are varied and how their changes affect the final result is followed. The percentage of parameter change divided by the percentage of result change caused by that parameter change is called the sensitivity factor. The sensitivity factor is not of great importance if the impact of one parameter only is examined. It comes to expression when comparing the sensitivity factors of several parameters affecting the result. This technique is useful for finding the parameter that affects the final risk exposure most, but it does not show the probability that parameters will change within the range rank in which the sensitivity analysis was carried out.

2.5.3.4 Decision trees

Decisions are made when there are several alternatives (Godfrey, 1996). If each alternative has sub-alternatives, and each sub-alternative sub-sub-alternatives, this forms a tree structure showing all the possible paths of deciding. If the impact of every alternative on the tree can be assessed and its probability evaluated, subjectively or in some other way, this will result in exposure, that is in an Expected Value (EV) which will define the risk level of every alternative.

2.5.3.5 Monte Carlo Simulation

Monte Carlo Simulation is a statistical simulation technique (Wall, 1997). Every parameter that influences a particular risk exposure is treated as a random variable with the corresponding value rank and probability distribution function. The distribution function is determined from existing databases or evaluated from experience. One value of each parameter is randomly chosen and its probability determined from the distribution function. The chosen parameter values and the corresponding probabilities are used to calculate the corresponding exposure. This random selection procedure is repeated from 100 to 1,000 times, when exposure becomes a random variable as well. It is now possible to calculate the Expected Value, maximum likely risk, the probability for exposure to assume a value within a particular interval, etc. Considering the large number of calculations, this technique demands computer use.

2.5.4 RISK RESPONSE

Each identified risk, depending on the level of risk exposure, is classed as unacceptable, undesirable, acceptable or negligible. This classification affects the decision about how to respond to it (Baker, Ponniah and Smith, 1999).

If a risk is classed as unacceptable the response to it may be risk avoidance or risk transfer.

If a risk is classed as undesirable the response to it may be risk avoidance, risk transfer, risk reduction or risk sharing with the appropriate risk monitoring.

If a risk is classed as acceptable the response to it may be risk retention with the appropriate risk monitoring.

If the risk is classed as negligible no response to it is necessary.

2.5.4.1 Risk avoidance

In practice risk avoidance means refusing to accept the risk at all (Flanagan and Norman, 1993). Qualitative assessment has shown such high risk exposure that the risk should simply be eliminated. To eliminate the risk, research is necessary into whether the potential source of risk can be eliminated, the unfavourable event in which the risk is inherent. The most drastic way of avoiding risk is not to accept the contract, to give up the project. Risks can also be avoided by introducing a contract clause whereby some risks, that is their consequences, shall not be accepted.

2.5.4.2 Risk transfer

This response means transferring the risk to any other participant in the project but the investor through contracting (Carter et al. 1994). The investor can transfer the risk to the contractor or the designer, the contractor to his sub-contractors or, the investor, contractor or sub-contractors to the insurance company, and the contractor and sub-contractors to their guarantee. When choosing a risk transfer strategy through contracting, account should always be taken of which participant in the project can best control events that may lead to the appearance of the risk. Account should be taken of which participant can best control the risk if it occurs, or assume a risk that cannot be controlled.

2.5.4.3 Risk sharing

When a project participant cannot control risk exposure then he can share it with other participants (Barnes, 1991). Part of the risk may be transferred but part should be assumed and one of the risk responses applied.

2.5.4.4 Risk retention

When a project participant estimates that the risk probability is small, or that its impact is acceptable, the risk is simply retained and no response is made (Powell, 1996). This does not mean that the risk is ignored; it is monitored and controlled and its exposure is constantly checked.

2.5.4.5 Risk reduction

Most risks need not be avoided or transferred, they need not be shared with other project participants nor need they simply be retained and not responded to (Baker, Ponniah and Smith, 1999). Certain measures can be undertaken to reduce risk exposure, that is to decrease the probability of an event with adverse effects, or decrease the impact of these effects on the project. Risk reduction demands certain initial investment. It goes without saying that this investment should be smaller than the expenses entailed by the occurrence of the adverse event. For example, tunnel excavation in weak rock mass is subject to the risk of rock-mass stability loss due to inadequate substructuring or water penetration. Additional research is an expense but considerably decreases these risks. The costs of additional research should be smaller than the costs of repair if caving does occur. Risk reduction also provides new knowledge about the project and the conditions under which it is being performed. An attempt to reduce risk may lead to more detailed designing plans, an alternative contracting strategy or some other method for executing the project.

2.6 SUMMARY AND CONCLUSIONS

This chapter researched the role of risk management in decision-making independently of the industry in which the decisions are made. It explained all the elements of the risk management process and proposed cyclical risk management, which will be part of the framework for managing risks in construction projects proposed in this work.

Decisions are made by all the participants in the execution of a project but are realised by the project management team that has the task of executing the project in the given time, with planned costs and a satisfactory quality.

To successfully realise a project it is necessary to identify events that may cause unwanted effects, this means, to identify potential risk sources. Once a risk is identified, it is necessary to assess the probability that it will occur, risk probability, and to estimate the damage that it may cause to the project, risk impact. The concept of risk exposure as the product of risk probability and risk impact is introduced to enable the relative comparison of several risks within a project. The values of risk exposure are used to make a risk priority list and define the appropriate response to each risk depending on its exposure and position on the risk priority list. Risk response may produce new events that may adversely affect the project and which it is necessary to identify, analyse and anticipate the appropriate response. This is why the risk management process is by its nature cyclical, and why risk management is part of project management and cannot be viewed as a separate whole.

The next chapter will show research on managing risks in construction projects, various approaches to risk management, and propose a new approach to risk management that will be implemented in the framework for managing risks in construction projects proposed in this work.

3 RISK IN CONSTRUCTION

3.1 INTRODUCTION

The preceding chapter researched the role of risk management in project management, showed all the elements of the risk management process and proposed cyclical risk management as part of the framework for managing risks in construction projects proposed in this work.

This chapter will show various approaches to risk management in construction projects and show the need for a new approach to managing risks as part of the construction process.

A lot of research has been performed and many papers published on the subject of risk management. Methods have been sought for risk identification, qualitative and quantitative risk analysis and risk response. Various risk management models have been proposed throughout the project life cycle. Theoretic risk management models have been used in the construction industry with more or less success. An explanation follows of the published research results that influenced the model for the risk management framework in construction projects proposed in this work. After that *CIRIA - A Guide to the Systematic Management of Risk from Construction* and *RISKMAN - A Risk-driven Project Management Methodology* will be shown, both of which are complete but different approaches to systematic risk management in construction.

3.2 DEALING WITH RISK IN CONSTRUCTION

Construction companies are more at risk than other industrial sectors. Almost sixty percent of all contracting and construction companies are at risk of failure or forced financial restructuring, making building the weakest industrial sector in the UK (Ruddock, 1994). Between 1982 and 1985, Professor Peter Thompson and Dr. John Perry of the University of Manchester Institute of Science and Technology (UMIST), supported by the Science and Engineering Research Council, carried out important research on how to deal with risk in construction. This research resulted in the report Risk Management in Engineering Construction (Hayes at el, 1986).

During research they realised that in construction projects risk was too often either ignored or treated in a completely arbitrary, that is, a simplified way. For standard construction projects a 10% contingency was simply added to the estimated building costs or deadlines, and for non-standard projects a different percentage, thereby covering all uncertainty or possible risks. This kind of approach does not allow for the specific features of every construction project and in fact excludes risk management.

The UMIST team proposed that instead of contingency, the risk in evaluating total project costs or duration should be quantified by introducing the most probable top and bottom tolerance in the estimated costs and time. This tolerance, and thus also the estimate of total costs, would change throughout the project life cycle. Hamburger (1990) described the role of the project manager as contingency planner, Murray, Ramsaur and Andersen (1983) showed project reserves as a key to managing cost risks. Mak, Wong and Picken (1998), and Picken and Mak (2001), used a methodology for capital cost estimating using risk analysis (ERA). According to them, the sum of the average risk allowance for the identified risk events becomes contingency. Jackson and Flanagan (2002) developed a systematic approach to managing budget risks during project appraisal. Odeyinka and Love (2002) investigated the risk factors responsible for variation between the forecast and actual construction cash flow.

The UMIST team concluded that the greatest uncertainties and/or risks appear in the earliest phases of the project life cycle, and that risk management as part of project management should be a continuous activity throughout the project life cycle. Franke (1987) also made a similar conclusion: *Being a dynamic process, risk management presupposes regular updating in order to analyse the development of the project risks continuously*. Traylor et al. (1984) addressed project management under conditions of uncertainty.

Smith (1999) confirms that risk diminishes with the advance of project realisation: Risks change through the life cycle of a project. The earliest stages of the project are concerned more with risks than other stages. As a project progresses risk diminishes. He also shows his views that risk management is a continuous process: At the end of each phase an appraisal and assessment can be made of the risk involved in proceeding with the project. The management of risk is therefore a continuous process and should span all the phases of the project.

The project team, under the project manager, is required to design, engineer and construct the facilities, to an agreed specification, budget and time, without sacrifice of quality, safety, operability or maintainability - in other words, fit for the purpose (Baker, 1986). Chapman (1990) researched the role of risk engineering in risk management. According to Perry (1986), risk management should be implemented creatively, not as a set of rules. Mikkelsen (1990) introduced risk management in product development projects. White (1995) showed the Application of Systems Thinking to Risk Management. Mills (2001) described a systematic approach to risk management in construction.

Risk and uncertainty are inherent in all construction work no matter what the size of the project (Hayes et al., 1986). Lam (1999), and also Songer, Diekmann and Pecsok (1997), researched risk identification in major infrastructural projects such as power, telecommunication and process plants. Bajaj, Olowoye and Lenard (1997) researched the contractor's approaches to risk identification

Willams (1994) considers that the risk register should be central to the risk management process. In addition to identifying risks, the risk register includes risk probability and risk impact, thereby also risk exposure, and in the final issue, depending on risk acceptability, also the strategy of risk response. Patterson and Neailey (2002) proposed a very comprehensive risk register database. Ward (1999) also worked on the content of the risk register. In his opinion, organising the risk register should start from the fact that resources available for risk management are limited and that risk management should be cost effective.

Meeting time and cost objectives in complex projects presents additional specific risks (Haabison, 1985). Raz and Michael (2001) showed how various tools can be used as support in different phases of the risk management process. They analysed which tools successful companies use as support in risk management and what theses companies do that others do not. Their survey categorises 38 tools and techniques and is a good guide and starting basis for successful risk management.

Baker, Ponniah and Smith (1998) researched and compared the frequency with which different qualitative and quantitative risk analysis techniques were used. They showed that about 80% project managers combine qualitative and quantitative methods and the remaining 20% use qualitative techniques. A very small percentage of managers use quantitative techniques only. Akintoye and MacLeod (1997) showed a similar trend in the methods used for qualitative and quantitative risk analysis.

Raftery, Csete and Hui (2001) carried out the qualitative analysis: Are Risk Attitudes Robust. Kartam and Levitt (1991) used an artificial intelligence approach in qualitative risk analysis. Tah and Carr (2000) showed how fuzzy logic is used in qualitative risk analysis. Al-Bahar (1991), Dey, Tabucanon and Ongunlana (1994), Dey (1999) and Dey (2001) used An Analytic Hierarchy Process (AHP) in qualitative risk analysis.

Quantitative risk analysis greatly depends on the availability of data and experience from similar earlier projects. The most reliable and most complete data are provided by the company's own experience and databases from similar past projects. Other important data sources are the experience of the project management team and the experience of other companies that executed similar projects in the past. *Numerous techniques are available for the quantitative analysis of project risk, but without competent data they are worthless* (Bowers, 1994).

Hayes et al. (1986) emphasised the importance of analytical techniques in risk assessment, and Ward and Chapman (1991) researched the role of risk analysis in project management. Cooper, D.F., MacDonald, D.H and Chapman, C.B. (1985) researched the role of risk analysis in construction cost estimate. Yeo (1991) analysed project cost sensitivity. Berny and Towsend (1993) addressed macro-simulation analysis, and Orman (1991) showed the use of simulation risk analysis in project insurance. Newton (1991) showed Monte Carlo Simulation in analysing risks from innovative design alternatives, and Hull (1990) showed Monte Carlo Simulation in proposal assessment. Williams (1990) applied risk analysis using an embedded CPA package. Kangari and Riggs (1988) described the role of risk analysis in portfolio management in construction. Wall (1997) researched distributions and correlations in Monte Carlo Simulation. Xu and Tiong (2001) implemented risk assessment on contractors' pricing strategies.

In construction, as in life in general, it is necessary to strike a balance between rigid adherence to the status quo, avoiding all risks on the one hand, and rash risk-seeking behaviour on the other (Raftery, 1994). Baker, Ponniah and Smith (1999) analysed risk response techniques in major construction projects. Their main conclusion is that risk reduction is used as a risk response in practically 90% cases. Barnes (1991, 1983) showed risk sharing in contracts and how to allocate risks in construction contracts. Berkeley, Humphreys and Thomas (1991) described the role of risk action management in project management. Flanagan and Norman (1993) addressed the client's role in risk management. They say: *Clients can have very different objectives, but their needs can be grouped under the headings of time, cost, quality*. Time can mean both the need for rapid construction and completion on the stipulated date. Cost means obtaining value for money and completing the project within budget. Quality is used to cover technical standards, including such areas as safety and fitness for purpose. The relative importance of time, cost and quality will vary from client to client (and between similar clients in different countries). What is, however, certain is that the clients of the industry do not want surprises. They want to achieve their desired objective and to this end a professional approach to risk management is required. Thompson (1991) also wrote about the client's role in risk management. Katavic (1994) showed risk reduction in early phases of the investment project.

Baccarini and Archer (2001) developed a methodology of project choice based on estimating the project's total risk and comparing this with the risks of other projects by introducing the overall risk rating. Moselhi and Deb (1993) used the multi-objective decision-criteria method to choose a project under conditions of uncertainty. Burchett, J.F., and Tummala V.M.R. (1998) showed a risk management model for project selection. Wong, Norman and Flanagan (2000) showed a fuzzy stochastic technique for project selection.

Risk is minimised using one of the existing optimisation methods known as search techniques. The better-known methods include: genetic algorithms (Mitchell, 1996), simulated annealing (Kirkpatrick, 1983), and hill climbing (Ferry and Brandon, 1991). Winston (1998, 1999) showed the use of computers in decision making under uncertainty.

The literature review shows that most authors have tended to focus on different techniques for quantitative or qualitative risk assessment, risk registers, the role of risk management in project management, and other mechanisms. This thesis argues that realising a construction project is a process and that the risk management process should be subordinated to the construction process

Therefore, the proposed framework introduces a new approach to risk management by embedding it within the construction process, and has thereby developed process-driven risk management approach.

This chapter will show two approaches to risk management in construction projects: Firstly one developed by CIRIA - A Guide to the systematic management of risk from construction and secondly the RISKMAN methodology developed by Eureka research programme. Both approaches have provided useful guidance for developing proposed framework. They give a sytematic approach to risk management from risk identification to risk response in all construction projects regardless of the syze, type and purpose of the project.

3.3 CIRIA - A GUIDE TO THE SYSTEMATIC MANAGEMENT OF RISK FROM CONSTRUCTION

Godfrey (1996) showed a comprehensive approach to systematic risk management in construction. In 1993-1995 the Construction Industry Research and Information Association (CIRIA) funded research in risk management, undertaken by Sir William Halcrow and Partners Ltd, in co-operation with Professor Peter Thompson, University of Manchester Institute of Science and Technology, and Professor Philip Capper, King's College, University of London.

The research resulted in a *Guide* by Patrik Godfrey (1996), made to help implement the systematic risk management process.

The objective of the *Guide* was to:

- introduce a simple, practical method of identifying, assessing, monitoring and managing risk from construction in an informed and structured way;
- provide advice on how to develop and implement risk control strategy that is appropriate to your business;
- identify when and how to seek and evaluate specialist advice in assessing risks.

Systematic risk management makes it possible to:

- identify, asses and rank risks making risks explicit;
- focus on the major risks from project;
- make informed decisions on provision for adversity, e.g. mitigation measures;
- minimise potential damage should the worst happen;
- control the uncertain aspects of construction projects;
- clarify and formalise your role and the roles of others in the risk management process;
- identify opportunities to enhance project performance.

The *Guide* contains 4 toolboxes designed as a step-by-step procedure for implementing a systematic risk management process in practice. Using these 4 toolboxes enables systematic risk management regardless of the type and volume of a construction project.

Toolbox 1: *Risk identification techniques* is a tool that can be used to identify risks in the systematic risk management process. The *Guide* shows the practical use of some of the most widespread risk identification techniques, such as:

- free and structured brainstorming,
- prompt lists,
- use of records and
- structured interviews.

Toolbox 2: *Risk registers and risk assessments* is a tool that helps form and update the risk register and implement risk assessment. The *Guide* suggests a risk register that can be directly implemented in practice. In its simplest form risk register will:

- describe the existing risk and
- record possible risk reduction or mitigation actions.

Depending on circumstances, it can also provide:

- subdivision of risk into more detail,
- a measure of probability and impact,
- identification of ownership of the risks,
- importance/cost/acceptability of the risk,
- practicality of mitigation actions,
- cost and ownership of action,
- timing of action,
- assessment of residual risk and measure of cost benefit.

Toolbox 3: *Systematic capture of the problem* is a tool that shows the use of some advanced techniques in quantitative risk analysis. The *Guide* describes the practical use of the following techniques:

- Decision trees,
- Fault trees,
- Event trees,

- Sensitivity analysis,
- Cost contingency analysis and
- Programme risk analysis.

Toolbox 4: *Methods of presentation of risk analysis result* is a tool that shows the use of some advanced techniques of presenting the results of risk analysis. The *Guide* describes the use of the following techniques:

- Improving estimates,
- Retiring contingency during the project,
- Decision consequence model and
- Cost and time plot.

3.4 RISKMAN - RISK-DRIVEN PROJECT MANAGEMENT METHODOLOGY

Carter et al. (1994) showed a methodology of risk management throughout the life cycle of a structure. The methodology resulted from studies made as part of the Eureka research programme in 1990-1993.

The objective of the RISKMAN methodology is forming a framework for professional analysis, controlling project risks and providing guidance for implementing the framework proposed. The RISKMAN methodology approaches risk management in all its complexity. The following guidelines show the foundations of this risk management methodology:

- Risk, or uncertainty, is an integral, inevitable and important feature of all project scenarios, and one which has not been given sufficient attention since the advent of critical path analysis in the 1960s;
- Risk should be respected, but not feared. It should be handled systematically and carefully;
- The pro-active control of significant risks and threats to the achievement of project objectives is so important, that it should be the highest priority for the project manager;

- When managed professionally, risk-taking can provide real opportunities to maximise potential benefits for all concerned, and yield higher profit and/or benefit returns than low-risk enterprises;
- If risk is to be managed professionally, an analytical and quantitative approach is essential, combined with a real understanding of probability and uncertainty theory;
- The mathematical approach is essential, combined with a real understanding of probability and uncertainty theory;
- The mathematical approach is essential for the evaluation of risk, but alone it is impotent. People should be involved if risk is to be controlled and risk opportunities exploited. The human approach should run kind with the mathematical approach;
- Since the project manager must bring in all project deliverables within budgeted time and cost, that budget should include a contingency budget sufficient to address all uncertainties or risks as best can be forecast. This also means that the contingency should be justified explicitly in advance of commitment to the budget;
- Advance justification of risk contingency will encourage honesty in the estimating process and the acceptance of progressive management combining openness with responsibility;
- Risks must be owned by individuals. Risk causes must also be owned, monitored and mitigated. Early action is usually lower in cost and more effective than management by crisis.

The basic goals of the RISKMAN methodology are:

- To increase professional capability in the taking of risks in project environments.
- To promote general understanding of risk and probabilistic theory amongst management and staff at all levels.
- To provide general principles for effective risk management.
- To provide specific guidance on a framework within which project risk can be effectively managed.

- To clarify terminology which may form a sound basis for effective communication about risk.
- To examine, clarify, assess and provide guidance on the methods and techniques available for risk analysis and management.

The RISKMAN methodology demands:

- that all risks are uniquely identified and described;
- that care is taken to include consequential risks and combinations of risks;
- risk to be assessed for probability of occurrence and potential impact on the programme, cost or performance;
- all non-cost impacts to be calculated out on their cost implications;
- each major risk to have a mitigation strategy;
- major risks to be assigned a trigger event in the project programme;
- each risk to have an owner responsible for its management;
- risk to be prioritised;
- risk to be reviewed at regular intervals;
- risk status to be reported at regular intervals;
- a risk model to be developed, that contains all the uncertainties and risk estimates that may effect the programme timescales or costs;
- risk contingencies to be identified against the event that will incur the risk;
- subcontractors to be assessed for risks;
- risk management plans to be in place.

The RISKMAN methodology has eight steps: risk identification, risk assessment, risk evaluation, risk mitigation, risk budget provisioning, risk monitoring and control, risk audits and continuous improvement.

Risk management takes place through risk audits in all the stages of the structure’s life cycle. The objectives of the project risk audit are:

- to confirm that risk management in accordance with the company's procedures has been applied at each stage in the project life-cycle;
- to confirm that the project is well managed and that the risks are under control;

- to verify that the project reporting and project management is effective;
- to assist in the transfer across projects of experience gained in resolving risks;
- to assist in identifying early signs of deterioration and the profit potential of the project;
- to verify that the project history file is maintained.

The risk management process is repeated at every stage in a project lifecycle so that a continuity and growing assessment of risk to success are obtained.

3.5 SUMMARY AND CONCLUSIONS

This chapter showed how various authors in the construction industry have tried to answer the question *How to deal with risk in construction*? With the purpose of improving risk management, investigations were made about the importance of all the project participants in minimizing the adverse effects of risks, about risk identification, qualitative and quantitative risk analysis, minimizing risk by using optimisation techniques, and risk response.

It also showed and gave a detailed analysis of two approaches to systematic risk management in construction projects, CIRIA, A Guide to the Systematic Management of Risk from Construction, and RISKMAN, A Risk-driven Project Management Methodology. Both approaches have provided useful guidance for developing proposed framework. They give a sytematic approach to risk management from risk identification to risk response in all construction projects regardless of the syze, type and purpose of the project.

The CIRIA Guide contains a step-by-step procedure for implementing systematic risk management in construction projects. A step-by-step procedure can be an effective way of managing and controlling risk in construction. Risk should be managed throughout the structure life cycle. Different phases of the life cycle have their own specific features, they continue one onto another and demand a separate approach to risk management. The least that can be done is to prescribe a set of procedures for managing risk in every separate phase. Furthermore, the risk management process should be adapted to the structure’s life cycle as a process.

RISKMAN is a risk-driven project methodology. However, even this methodology does not make an allowance for the fact that the construction’s life cycle is a process and that risk management should be adapted to this process. Therefore, what is necessary is process-driven risk management.

The next chapter will show the specific features of the construction industry that make it more difficult to introduce changes leading to construction process improvement. It will research the breakdown of the construction process into phases so as to discover the group of activities necessary during the realisation of any construction project. Finally, it will research the connection between risk management and the construction process.

4 PROCESS IN CONSTRUCTION

4.1 INTRODUCTION

The preceding chapter analysed various approaches to managing risks in construction projects and showed the need for a new approach to risk management in the construction process.

The first part of this chapter will show the specific features of the construction process that make it different from other industry processes and which make it more difficult to introduce changes leading to construction process improvement. The group of activities necessary for product realisation should be developed and continuously advanced for every industry, including construction. Every industry strives to create products as quickly as possible, with minimum expenses and of satisfactory quality. Because of its specific features and inertia, the construction industry lags considerably behind other industries in the achievement of these goals, that is, in developing an efficient production process (Latham, 1994; Egan, 1998; Egan, 2002).

The second part of the chapter will research various approaches to breaking down the construction process into discrete phases, each of which has its purpose, duration and scope of work. To introduce a new approach to managing risks, it studies the connection between risk management and the construction process.

4.2 PROCESS IMPROVEMENT

A process is a series of activities (tasks, steps, events, operations) that takes an input, adds value to it, and produces an output (product, service, or information) for a customer. Customers are all those who receive that process output (Anjard, 1998).
In comparison with other industries, many special features burden process in construction and this makes changes leading to process improvement difficult. Structures are often very large and complex and it is necessary to organise construction processes on the building site according to space and time, while

making optimum use of existing capacities. A production process of this kind is almost impossible to simply transfer among structures of different sizes and complexities. Production processes in construction last for a very long time, which increases the probability of detrimental events and the risk of running behind schedule. In its level of mechanisation construction still lags significantly behind other industries, and although machinery is increasingly replacing human work this is taking place much more slowly than elsewhere. Unlike industries predominated by production for an unknown client, structures are almost as a rule commissioned by a client or investor who stipulates the location, size, quality and purpose of the future product. Thus the investor should take part in the production process. Investors are usually inexperienced in this, which makes process development in construction additionally difficult.

Construction developed as an industry when the approach to it changed and the process was introduced in building. Many research works on process in construction, implemented in the last ten or so years, show this.

Latham (1994) made a joint review of procurement and contractual arrangements in the UK construction industry with the objectives of making recommendations to the Government, the construction industry and its clients regarding reform to reduce conflict and litigation and encourage the industry's productivity and competitiveness. He studied current procurement and contractual arrangements and current roles, responsibilities and performance of the participants, including the client. He noticed that, due to the character of the production process, poor communication among all the participants in the project is a great drawback. He concluded that real savings of up to 30 % of construction costs are possible with a will to change.

Egan (1998) reported on the scope for improving the quality and efficiency of UK construction. Construction should learn from other industries how to change and improve the process through which it delivers its projects with the aim of achieving continuous improvement in its performance and products. For Egan construction is a repeated process. He considers that not only are many buildings, such as houses, essentially repeat products which can be continually improved, but, more importantly, the process of construction is itself repeated in its essentials from project to project. His research suggests that up to 80% of inputs into buildings is repeated. Much repair and maintenance work also uses a repeat process. A problem is the lack of integration in the process, evidenced by the largely sequential and separate operations undertaken by individual designers, contractors and suppliers with little commitment to the overall success of the project. Egan considers it especially important to establish a system for measuring process improvements in terms of predictability, cost, time and quality. The results of such measurements would enable clients to recognise those companies that have improved performance through process development. He concluded that targets of UK construction industry should include annual reductions of 10% in construction cost and construction time, and defects in projects should be reduced by 20% per year.

To accelerate change Egan (2002) identifies three key drivers, to secure a culture of continuous improvement, which will help to transform the industry, starting with those sectors where the leadership exists and where the ideas for change and improvement can most readily be taken up:

1. The need for client leadership,
2. The need for itegrated teams,

The need to address 'people issues', especially health and safety.

Hammer and Champy (1993) define Business Process Re-Engineering (BPR) as the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance, such as cost, quality, service and speed.

Love and Li (1998) concluded that BPR can only improve the intra-organisational business process of an organisation and cannot be applied for inter-organisational processes used to procure a project. That is why they proposed a conceptual project-based approach to re-engineering in construction, which they call Construction Process Re-Engineering (CPR). They define CPR as an integrated and holistic approach that focuses on managing and optimising process flows and eliminating waste whilst simultaneously fulfilling customer requirements and satisfying the individual business needs of each participating organisation in a project so that the added-value to the final product is enhanced.

SPICE (Structured Process Improvement for Construction Enterprises) is a research project that developed a process improvement framework for the construction industry (Sarshar, 1998; Finnemore and Sarshar, 2000; Finnemore, Sarshar and Haigh, 2000, Finnemore et al., 2000). According to its authors, the SPICE framework is not prescriptive. It does not tell an organisation how to improve. SPICE describes the major process characteristics of an organisation at each maturity level, without prescribing the means for getting there. However, part of the SPICE methodology is to encourage a systematic approach to process improvement in construction taking the lessons from other industries, particularly the software and aircraft industries. This thesis attempts to provide part of that systematic approach by embedding risk management in the overall process of design and occupation of buildings.

Holt, Love and Nesan (2000) developed an implementation model for process improvement. Tzortzopoulos, Betts and Cooper (2002) engaged in implementing the process model in construction companies. Kamara, Anumba and Evbuomwan (2000) developed the process model for client requirements processing in construction. They too, encouraged a systematic approach.

4.3 PROJECT PHASES

It has been recognised for some time that projects exhibit a life cycle comprising a number of discrete stages (Smith,1999).

Every project can be divided into discrete phases each of which has its purpose, duration and scope of work. The end of every phase is a decision point where past progress is revised and all key decisions made for the continuation of the project. Thus the division of the project into phases, i.e. the plan of work, is an important part of every process.

The division of the project into phases resulted from the desire to find a set of activities that should be carried out in the realisation of every construction project. This is the first step in establishing the construction process.

Flanagan and Norman (1993) divided the construction process in 4 phases:

1. Investment Decision (Appraisal / Feasibility / Budget),
2. Design,
3. Construction,
4. Occupancy.

The RIBA Plan of Work (Philips and Lupton, 2000) proposes 11 phases:

1. Appraisal
2. Strategic Briefing
3. Outline Proposals
4. Detailed Proposals
5. Final Proposals
6. Production Information
7. Tender Documentation
8. Tender Action
9. Mobilisation
10. Construction to Practical Completion
11. Construction After Practical Completion

The BPF Manual (British Property Federation, 1983) proposes 5 phases:

1. Concept
2. Preparation to brief
3. Design development
4. Tendering
5. Construction

The Construction Industry Board (Construction Industry Board, 1997) also divides the process in construction in 5 phases:

1. Getting started
2. Defining the project
3. Assembling the team
4. Designing and constructing
5. Completion and evaluation

The Process Protocol Map (Kagioglou, et al. 1998a) divides the construction process in 10 phases:

1. Demonstrating the Need
2. Conception of Need
3. Outline Feasibility
4. Substantive Feasibility Study & Outline Financial Authority
5. Outline Conceptual Design
6. Full Conceptual Design
7. Coordinated Design, Procurement & Full Financial Authority
8. Production Management
9. Construction
10. Operation and Maintenance

According to Hughes (1991), every project goes through similar phases in its evolution. The phases may vary in size and intensity, depending on the project. Hughes compared 7 plans of work published to date and concluded that many of them are more than a check list. Activities in construction projects to make up plans of work should be described in as much detail and in such a way that different projects may be compared. It is much more useful to concentrate on common aspects among projects than to begin analysis by describing the unique points of each project. He stated that the uniqueness is at a greater level of detail than the commonality, and therefore it should be modelled as such. Comparing plans of work resulted in a list of 8 phases that are common to all construction projects:

1. *Inception.* Define need and determine financial implications and sources.
2. *Feasibility.* Preliminary design, costing and investigations of alternatives.

3. *Scheme Design.* Programming, budgeting, briefing, outline design etc.
4. *Detail Design.* Development of all sub-systems within the design, detailed cost control, technical details etc.
5. *Contract*. Contract specification, pricing mechanism, sufficient documentation for selection of contractor etc.
6. *Construction.* Execution and control of all site work and associated activities, further contract documentation.
7. *Commissioning.* Snagging, operating instructions, maintenance manuals, opening ceremonies, occupation, evaluation, managing the facility, staff training etc.

Huges (2000) carried out similar research in which he analysed and compared 9 plans of work. He concluded that a project must always begin with some kind of definition of what will be built, followed by the design. After the design follows the contracting process, construction work and the completion of the project. This leads to the compilation of 5 basic phases through which every construction project must pass.

1. *Defining the project*. There are usually two steps in the process of defining the project: selecting appropriate expert advisors and using their advice to define the purpose of the project. Generally, the work at this phase involves some kind of feasibility study, an assessment of the extent to which a construction project will fulfil the client's needs, planning the control and management strategies, and initial ideas for the design of the project.
2. *Design work*. There is a broad consensus among plans of work that an initial idea for the project arises during the earliest stages of brief development and assessing the need for a project. This then forms the basis for three distinct stages of design, which differ from each other in that each adds significantly to the detail of the previous stage as the various aspects and sub-systems of the design are rationalised and documented.
3. *Contract formation*. Between design and construction, a decision is generally required about who is going to build the project, and under what contractual conditions. The process at this point often incorporates the development of bills of quantity, or some other documentation for pricing, and the preparation

of highly specific production information, which may be dependent on a propriety installer. Contract formation seems generally to encompass three distinct types of activity: information for site work, information for tendering and contractor selection (tendering).

4. *Construction work*. Once the contractor is appointed, work starts on site. Most plans of work acknowledge the impossibility of documenting everything before construction work begins, by identifying continuing documentation during the construction process. Construction is the most obvious phase of a building project, but there is much variability in the detail of the various source documents.
5. *Completion of the project*. This later phase may include such activities as putting right defective work, commissioning and ascertainment of the final account.

4.4 RISK AND PROJECT PHASES

Risk is inherent in each phase of the life cycle of a construction project regardless of the size of the project. As every project can be divided into several phases, and there are sets of common activities in each project, this suggests that there is a generic way of looking at risk, i.e. it may be possible to establish a generic risk management approach for all construction projects which could be adopted by the whole of the construction industry. Different phases though which the project passes have their specific points, they continue one after another and require a different approach to risk management. The planned risk management process is implemented for each phase. At the end of each phase risks are re-identified and analysed for the remaining phases and the decision is made about how to manage the risks in them.

Smith (1999) stated that the earliest phases of the project are concerned with value management to improve the definition of design objectives; the design stage is concerned more with value engineering to achieve necessary function at minimum cost; and the construction phase is centred around quality management to ensure that the design is constructed correctly without the need for costly rework.

Every phase contains several key requirements that must be satisfied before making the decision to continue the process. As the project progresses information is obtained that confirms or denies the starting assumptions. If the starting assumptions are denied then completely new risks may appear, which have to be managed. Smith (1999) stated that, generally speaking, risks should diminish as the project progresses.

Uncertainties and risks are the greatest in early phases of the project. As the project advances the number of unknowns decreases. The level of uncertainties is inversely proportional with the progression of the project. Godfrey (1996) stated that as a project progresses, cost assumptions become facts and cost uncertainty therefore reduces. Contingency can be retired progressively giving better control of the project by preventing surpluses being used later to cover up mismanagement.

Risks, that is, their exposure, can change within a project phase. Construction projects are long lasting and one phase can take several months or even years to complete. This makes it necessary to predict risk identification and analysis during the phase, not only at its end.

Risk management is a continuous process and takes place throughout the process life cycle. However, often the project does not run continuously. It may be interrupted within a phase for several reasons, such as lack of resources, market changes, political reasons and so on. This is one of the crucial risks and does not depend on a particular phase.

All that has been said shows that risk management must be subjected to the construction process, not to the phases through which the project passes. All parties involved in decision making should consider risk and its impact through the whole life cycle of a project. Risk management should therefore be *process-driven risk management*. Risk management improvement must be a composite part of process improvement.

4.5 SUMMARY AND CONCLUSIONS

This chapter showed the specific features of the construction process in comparison with other industry processes, breaking down the project into the phases every project must pass through during its realisation, and the role of risk management in the construction process.

All the above research concluded that the Process in construction needs significant changes and continuous improvement. These changes and improvements are accompanied by risks that may have a detrimental effect on planned costs, project duration and project quality. Efficient risk management must enable changes in construction and contribute to quality improvement and greater efficiency.

The framework for risk management in construction proposed in this work is based on process-driven risk management, which completely subordinates the risk management process to the construction process.

The next chapter will show the concept of and the principles underlying the Construction Process Protocol as a generic construction process within which the framework for process-driven risk management will be developed.

5 PROCESS PROTOCOL

5.1 INTRODUCTION

The preceding chapter showed the specific features of the construction process, how the project is broken down into phases, and the role of risk management in the construction process. The conclusion was that the risk management process should be subordinated to the construction process through process-driven risk management.

This chapter will show the concept and principles underlying the Construction Process Protocol that makes it possible to manage the construction process from Demonstrating the Need to Operation and Maintenance. It will show the advantages of Process Protocol over other plans of work, which is why it was chosen as the construction process for the development of the proposed framework for process-driven risk management.

The Process Protocol is a common set of definitions, documentations and procedures that will provide the basics to allow the wide range of organisations involved in a construction project to work together seamlessly (Kagioglou et al. 1998a).

The Generic Design and Construction Process Protocol was developed as the result of a research project at the University of Salford by Professor R.Cooper and her team, in cooperation with several companies that were in various ways connected with the construction industry. The EPSRC (Engineering and Physical Sciences Research Council) under the IMI (Innovative Manufacturing Initiative) financed the project.

The following is a summary of the main findings of the Generic Design and Construction Process Protocol project (Kagioglou et al. 1998b):

- The front-end of the design and construction process is frequently very fuzzy, often with a lack of effective combined process and IT focus in many companies.

- With the exception of some large organisations the majority of companies do not employ a design and construction process.
- Frequently the IT aspects of a project are poorly co-ordinated resulting in non-compliance and compatibility issues.
- The stakeholder involvement in a design and construction project is often limited to those persons or bodies that have a financial stake in the project outcome, thus ignoring the needs and/or requirements of the wider group of stakeholders that could have an impact or be impacted by the project solution, formulation and/or implementation.
- The utilisation of teams within a design and construction project could enable effective communications and improve information visibility, in particular when operating under a consistent process and IT framework.
- The use of a consistent design and construction process could enable effective project co-ordination in conjunction with traditional tools such as project management.
- The operational process aspects of a design and construction project are at a defined maturity level but what is a lacking is a strategic process which is only observed in it's infancy in the majority of organisation in construction.
- There is a need for key principles which are used in manufacturing and could be transferred successfully to construction.
- A method of process and IT alignment through the application of technology within a process framework is presented.
- The culture within an organisation will play a significant part in implementing a 'new' design and construction process.
- A legacy archive IT system could enable the effective collection and interactive exchange of project and product data about current and past projects, improving visibility of project data and communications between the project participants.

5.2 THE CONCEPT OF THE PROCESS PROTOCOL

The concept of the Process Protocol was based on the following (Kagioglou, Cooper and Aouad, 1999):

- A need for a model which is capable of representing the diverse interests of all the parties involved in the construction process or which is able to provide a complete overview.
- There will be no best way for all circumstances but a generic and adaptable set of principles will allow a consistent application of principles in a repeatable form.
- A need for a coherent and explicit set of process-related principles, a new process paradigm, which can be managed and reviewed across the breadth and depth of the industry, which focuses on changing and systematising the strategic management of the potentially common management processes in construction whilst accommodating the fragmentary production idiosyncrasies.
- A need for design and construction operations to form part of a common process best controlled by an integrated system
- A need for a process protocol which is sufficiently repeatable and definable to allow IT to be devised to support its management and information management; also to allow systematic and consistent interfaces between the existing practices and IT practice-support tools to be operated. Simplicity in the protocol and its operation are essential. There should be clarity in terms of what is required, from whom, when, and with whose cooperation, for whom, for what purposes, and how it will be evaluated.
- Standardised deliverables and roles associated with achieving, managing and reviewing the process.
- Requirement for Industry-Wide Coordinated Process Improvement programme.
- A clear plan for future IT needs to support the development of a repeatable and generic protocol.
- A philosophy of early entry into the process for the key functionaries. Emphasise effort on design and planning to minimise error and reworking

during construction. An extended process - earlier entry than traditional to allow a coordinated and recognisable/manageable professional contribution to the requirements capture and pre-project phases of client project planning - termed pre-project phases.

- o Extension of the recognised construction industry involvement in the process beyond completion - a post-completion phase.

The Process Protocol is based on 6 key principles taken from the manufacturing industry (Kagioglou et al. 1998c):

1. *Whole Project View.* The process of design and construction has to cover the whole 'life' of the project from recognition of a need to the operation and maintenance of the finished facility. This approach ensures that all the issues are considered from both a business and a technical point of view as well as ensuring informed decision making at the ‘front-end’ of the design and construction development process.
2. *Progressive Design Fixity***.** Drawing from the ‘stage-gate’ approach in manufacturing new product development (NPD) processes, the Process Protocol adopts a Phase Review Process which applies a consistent planning and review procedure throughout the project. The benefit of this approach is fundamentally the progressive fixing of design information throughout the Process, allowing for increased predictability of construction works.
3. *A Consistent Process*. The generic properties of the Process Protocol allow a consistent application of the Phase Review Process irrespective of the project in hand. This together with the adoption of a standard approach to performance measurement, evaluation and control, will facilitate the process of continual improvement in design and construction.
4. *Stakeholder Involvement / Teamwork*. Project success relies upon the right people having the right information at the right time. The pro-active resourcing of phases through the adoption of a ‘stakeholder’ view should ensure that appropriate participants (from each of the key functions) are consulted earlier in the process than is traditionally the case. Furthermore, the correct identification and prioritisation of the stakeholders and their needs should enable effective decision making throughout the project life cycle.

5. *Co-ordination*. The need for effective co-ordination between the project team members is paramount. Appointed by the client, Process Management will be delegated authority to co-ordinate the participants and activities of each phase, throughout the process. With a focus on the design and construction process, Process Management ensures the correct application of the Process Protocol to the project in hand.
6. *Feedback*. Success and failure can offer important lessons for the future. The Phase Review Process facilitates a means by which project experiences can be recorded, updated and used throughout the Process, thereby informing later Phases and future projects. The creation, maintenance and use of a Legacy Archive will aid a process of Continual Improvement in design and construction.

5.3 STAGE-GATE PROCESS

One of the main characteristics of the Process Protocol is the stage-gate process taken from manufacturing industry. From idea to realisation, every product passes through a certain number of phases (stages). Each phase incorporates a set of activities that must be undertaken if the production process is to continue. At the end of each phase there are gates that represent a checkpoint where prior activities are reviewed and a decision is made to commence the following stage. The gate is a so-called Go/Kill quality control checkpoint. One such stage-gate process is shown in Fig. 5.1. (Cooper, 1990).

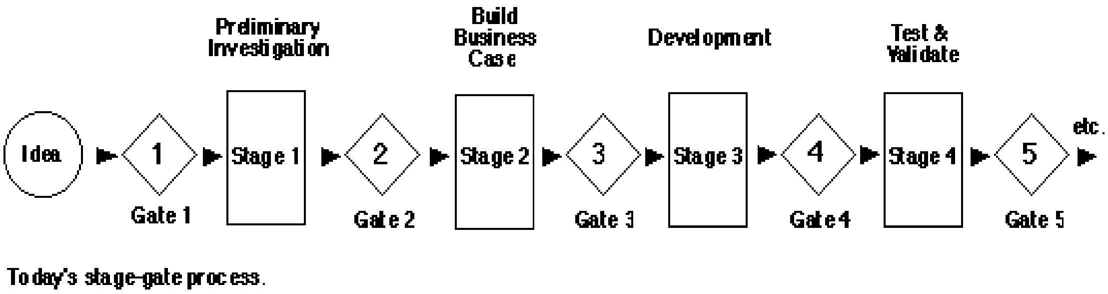


Figure 5.1: Stage-gate process (Cooper, 1990)

The stage-gate process shown has certain deficiencies that decrease its practical efficiency (Cooper, 1994):

1. The project must wait at each gate until all tasks have been completed. Thus, projects can be slowed down for the sake of one activity that remains to be completed.
2. The overlapping of activities is not possible.
3. Projects must go through all stages and gates, where in some circumstances it might be quicker to eliminate or bypass some activities, especially for small firms.
4. The system does not lead to project prioritisation and focus, as it was originally designed for single projects.
5. Some new product processes are very detailed, accounting for minute details of the process, and therefore making it hard to understand, manage and learn.
6. Sometime it tends to be bureaucratic, making the process too slow.

To overcome these deficiencies, Cooper (1994) proposed a "third generation new product development process (see Fig. 5.2.).

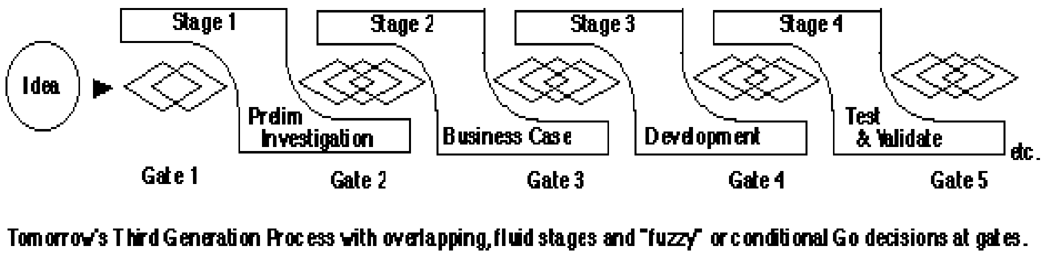


Figure 5.2: Third generation new product development process (Cooper, 1994)

The basic characteristic of the new proposal is that stages may overlap so the project need not wait for each activity within a stage to be completed before moving on to the following stage. The process conditionally continues until this activity is completed, after which it is decided how it has affected the project as a whole. This enables greater flexibility and speed in implementing projects.

The process is still sequential in nature, which means that stages cannot be skipped or eliminated.

The process protocol has two types of gates: 'soft' gates and 'hard' gates. A 'soft' gate allows conditionally moving on to the following phase without completing all activities of the preceding phase. A 'hard' gate cannot be passed until all the activities of the preceding phases have been completed and the decision made to continue or not to continue the project.

5.4 PROCESS PROTOCOL STAGES/PHASES

According to the Process Protocol, the construction process can be divided into 4 stages that comprise 10 phases (see Appendix 1). The stages are:

Stage 1: Pre-Project Stage
Stage 2: Pre-Construction Stage
Stage 3: Construction Stage
Stage 4: Post-Construction Stage

5.4.1 PRE-PROJECT STAGE

The Pre-Project Stage is geared to researching or investigating all the project solutions that will best satisfy the client's need, and ensuring the outline financial authority to proceed for those solutions. It contains phases 0, 1, 2 and 3:

Phase 0: Demonstrating the Need
Phase 1: Conception of Need
Phase 2: Outline Feasibility
Phase 3: Substantive Feasibility Study & Outline Financial Authority

5.4.2 PRE-CONSTRUCTION STAGE

The Pre-Construction Stage turns the client's needs into the appropriate project on various levels of completion and ensures full financial authority to proceed. It contains phases 4, 5 and 6:

Phase 4: Outline Conceptual Design

Phase 5: Full Conceptual Design

Phase 6: Coordinated Design, Procurement & Full Financial Authority

5.4.3 CONSTRUCTION STAGE

The Construction Stage is that of executing the structure, i.e. it produces the project solution. It contains phases 7 and 8:

Phase 7: Production Management

Phase 8: Construction

5.4.4 POST-CONSTRUCTION STAGE

The Post-Construction Stage has the purpose of managing structure maintenance. It contains phase 9:

Phase 9: Operation and Maintenance

5.5 ACTIVITY ZONES

The Process Protocol classifies project participants in Activity Zones. Each project participant is determined by his responsibility for project realisation. In a small project one person can perform all the tasks of an activity zone. In complex projects one activity zone may include several participants or even several companies. The zones are multifunctional, overlapping and are a structured set of tasks and processes. They cover the whole spectrum of skills needed for a construction project. According to Kagiogolu, et al. 1998a, the Process Protocol contains 9 activity zones:

1. *Development Management* is responsible for creating and maintaining business focus throughout the project, which satisfies both relevant organisational and stakeholder objectives and constraints.
2. *Project Management* is responsible for effectively and efficiently implementing the project to agreed performance measures, in close collaboration with Process Management.
3. *Resources Management* is responsible for the planning, co-ordination, procurement and monitoring of all financial, human and material resources.
4. *Design Management* is responsible for the design process which translates the business case and project brief into an appropriate product definition. It guides and integrates all design input from other activity zones
5. *Production Management* is responsible for ensuring the optimal solution for the buildability of the design, the construction logistics and organization for delivery of the product.
6. *Facilities Management* is responsible for ensuring the cost efficient management of assets and the creation of an environment that strongly supports the primary objectives of the building owner and/ or user.
7. *Health & Safety, Statutory and Legal Management* is responsible for the identification, consideration and management of all regulatory, statutory and environmental aspects of the project.
8. *Process Management* develops and operationalises the Process Protocol and is responsible for planning and monitoring each phase.
9. *Change Management* is responsible for effectively communicating project changes to all relevant activity zones and the development and operation of the legacy archive.

5.6 PROCESS PROTOCOL MAPS

A process map is a visual aid for picturing work processes which shows how inputs, outputs and tasks are linked. A process map prompts new thinking about how work is done. It highlights major steps taken to produce an output, who performs the steps, and where these problems consistently occur (Anjard, 1998). Winch and Carr (2001) explored empirically the use of process maps and protocols. A Process Protocol map (Cooper et al., 1998) is shown in Fig. 5.3.

The protocol IT map was developed as a support tool for a generic design and construction process (Aouad et. al, 1998). The IT map is shown in Fig. 5.4.

The Process Protocol toolkit was developed to automate process map creation by using Process Protocol as a framework, and to allow users to create and customise their specific project process map and manage the process and project information (Wu, Aouad and Cooper, 2000; Wu,et al, 2000; Wu,et al, 2001, Fleming et al, 2000).

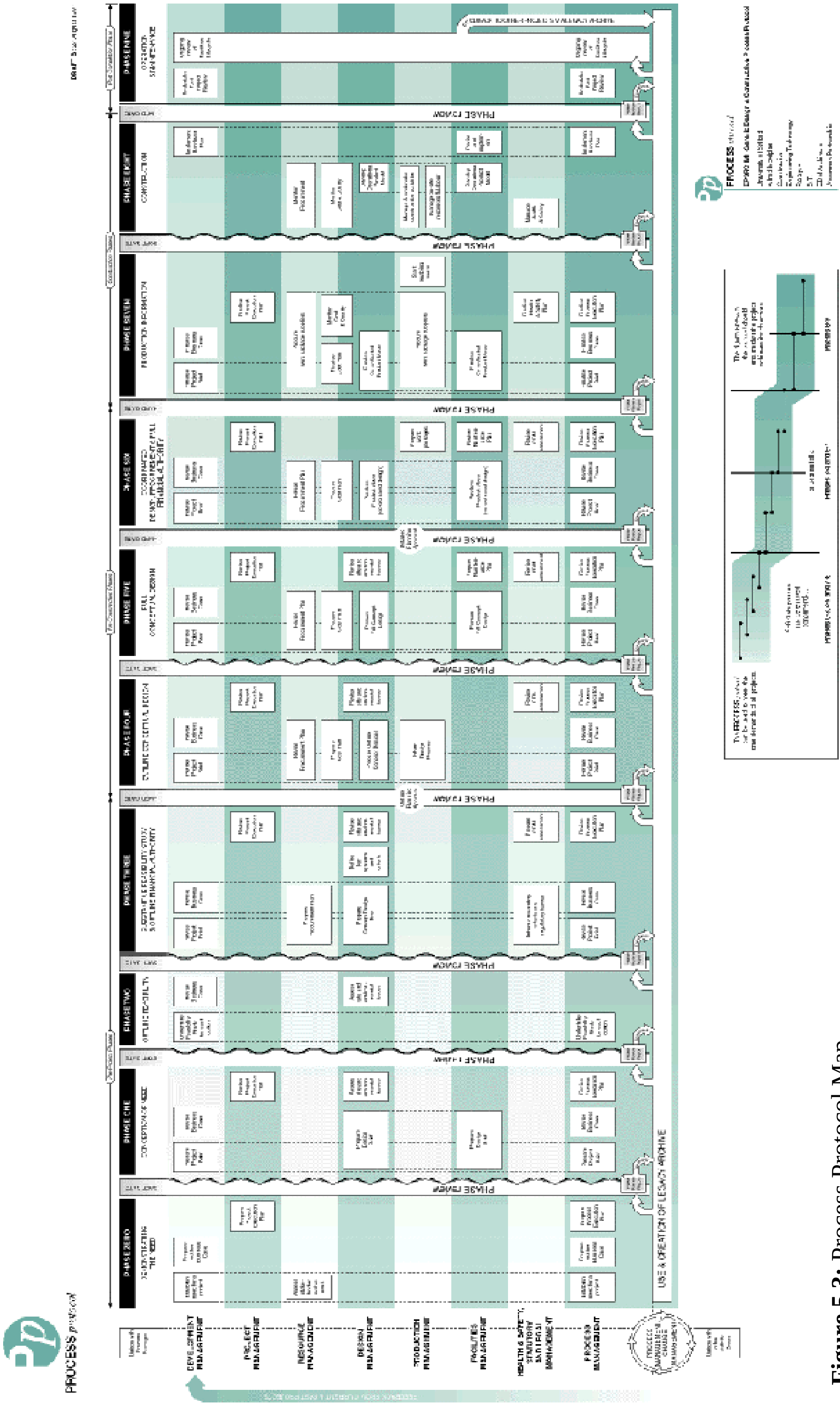


Figure 5.3: Process Protocol Map

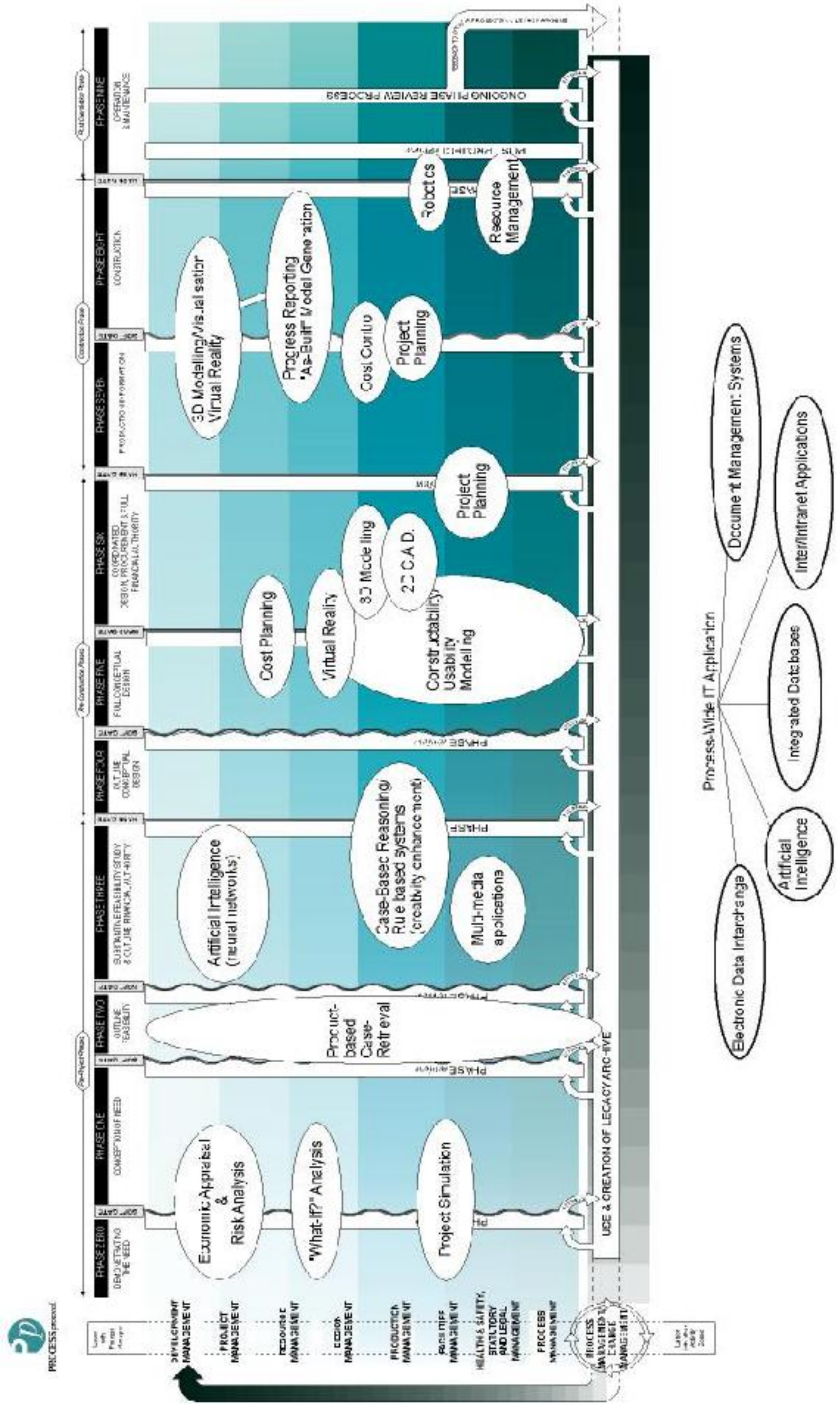


Figure 5.4: IT Map

5.7 RISK AND PROCESS PROTOCOL

The construction process consists of a group of activities that must be carried out within every phase through which the construction project passes during its execution. These activities are potential risk sources and are the foundation for risk identification. If there is no division into activities, that is of processes into sub-processes on several levels, it is much more difficult to apply the RIBA Plan of Work, BPF Manual or Constructing Industry Board Guide for identifying and structuring key risks that appear in every project phase. The Construction Process Protocol gives a division of activities in sub-processes on 3 levels and enables the risk management process to be subordinated to the construction process.

Lee, Cooper and Aouad, 2000, gave some advantages of the Process Protocol as an industry standard. It is these advantages that form the basis for an efficient framework for managing risk in construction projects:

1. *It takes a whole project view*. Process Protocol manages the project from recognition of the need for a building to its operation and maintenance and it is basically a generic process. Risk must also be managed through all the project phases independently of project type and size. Risk management must be placed in the function of the generic process, which means it is necessary to develop process-driven risk management.
2. *It recognises the interdependency of activities throughout the duration of projects*. Every activity that takes place within a project includes potentially risky events. Identification, analysis and response to these risks are the basis of every risk management framework. However, some activities are interdependent, overlapping or stretch through one or several phases of the project. This interdependence carries new risks which the framework must manage.
3. *It focuses on the front-end activities, paying attention to the identification, definition and evaluation of client requirements*. This makes it possible, at the end of each phase, to implement a new identification, analysis and find an appropriate response to the risks of the following phase.

4. *It provides the potential to establish consistency to reduce ambiguity, and it provides the adoption of a standard approach to performance measurement, evaluation and control to facilitate continuous improvement in construction*. Consistency, performance measurement and continuous improvement in construction are the foundation on which every risk management framework must develop.
5. *The stage-gate/phase-review process approach used facilitates concurrency and progressive fixity and/or approval of information throughout the process*. It illustrates the need for completing all necessary phase activities before proceeding to the next phase (hard gates) or allows concurrency (soft gates) without jeopardising the overall project success. Some types and/or sources of risk stretch through several project phases. Gates are the checkpoints where prior activities are reviewed and the decision made to start the next phase. The hard gate/soft gate philosophy may be directly applied to the risk acceptancy philosophy. Thus in risk terminology hard gate means that the risk is unacceptable and must be eliminated or transferred, and soft gate means that the risk is acceptable provided it is managed.
6. *It enables co-ordination of the participants and activities in construction projects and identifies the responsible parties*. Process Protocol groups project participants in Activity Zones according to their responsibilities. In Process Protocol risk is managed by introducing a new Activity Zone: risk management.
7. *It encourages the establishment of multi-functional teams including stakeholders. This fosters a team environment and encourages appropriate and timely communication and decision making*. One of the greatest risks in the early phases of the project is misunderstanding the client's real demands. As an answer to this risk, Process Protocol anticipates the client's active participation in all the project phases.
8. *It facilitates a legacy archive whereby all project information is collectively stored and can be used as a future learning vehicle*. The legacy archive is a very good place for accommodating the Risk Register and database that may serve to identify, or analyse risk.

5.8 SUMMARY AND CONCLUSIONS

This chapter showed the Construction Process Protocol within which the framework for process-driven risk management will be developed. It showed the principles on which it was developed, the state-gate process, Process Protocol Stages/Phases, Activity Zones, and the Process Protocol and IT Map.

It also showed the advantages of Process Protocol in comparison with other plans of work, which is why it was chosen as the construction process within which the proposed framework for process-driven risk management was developed.

The next chapter will show the identification of the key risks in all the phases through which the construction project passes according to Process Protocol.

6 IDENTIFYING AND STRUCTURING RISK WITHIN THE PROCESS PROTOCOL

6.1 INTRODUCTION

The preceding chapter presented the idea of the Process Protocol and described the principles on which it developed. It showed the division into phases through which, according to the Process Protocol, every construction project passes in its development. It showed the advantages of the Process Protocol with respect to other plans of work. The risk management framework in construction projects proposed in this paper is based on the Process Protocol developed by Cooper R. et al (1998).

In this chapter the key risks that may appear in all construction projects, regardless of size or type, are identified and described from the aspect of the description, goals and status of each phase in the Process Protocol and the activities that must be performed before and during the phase. The list of key risks and identification of project-related risks are the first step in implementing the proposed framework. Using this framework, risk will be managed in all the project phases, regardless of the type and size of the project. Risk management will become part of a generic process and lead to the development of process-driven risk management.

6.2 IDENTIFYING RISK IN CONSTRUCTION PROJECTS

As it unfolds the construction projects passes through several phases and in each of them it is possible to identify a large number of potential risks, i.e. events whose unfavourable outcome may be adverse for project success. Something could go wrong during practically any activity in project realisation. It would be very difficult to make a general list of all the risks for construction projects of any size or type, which would cover all the specific features of a particular project. A list of this kind would contain a certain number of high-exposure risks, but also a great number of risks whose exposure is such that they could practically be neglected. There would never be enough data for a quantitative analysis of a large number of risks, whereas a qualitative analysis of a large number of risks would be a time-consuming process subject to inconsistent assessments because of the great number of decisions that the risk manager would have to make to obtain their exposure and determine risk acceptability.

Reference sources provide a large number of attempts to compile a specific risk list in construction projects (table 6.1.). Most of these lists group risks in categories thus forming a hierarchical risk structure. The risk manager may analyse and compare the risk exposures of entire risk categories, he may select one or more key risks from a category and disregard all the others, or he may analyse risk acceptability for all the identified risks in a particular category.

Table 6.1 shows risk categories in construction projects according to several authors (Carter *et al.*, 1994; Godfrey, 1996; Smith, 1999; Dey, 2001; RAMP, 2002). The risk categories in other industries are similar. These risks may appear and be analysed in all construction projects regardless of size or type. Although similar risks often appear under different names, the table shows the great diversity in identifying risk categories among different authors. The five risk lists in the table contain as many as 31 risk categories.

Risk identification with the help of previously existing risk lists is completely adapted to risk-driven project management and does not take into account that executing a construction project is a process and that risk management must be subordinated to that process. Thus none of the risk lists in the table, or their combination, can be used for process-driven risk management, which is the approach to risk management proposed in this work.

Table 6.1: Risk lists

	RISK	CARTER at al. (1994)	GODFREY (1996)	SMITH (1999)	DEY (2001)	RAMP (2002)
1	Political		x	x	x	x
2	Environmental		x	x		
3	Planning		x			
4	Market	x	x			
5	Economic		x		x	x
6	Financial	x	x	x	x	x
7	Natural/Act of God		x		x	x
8	Project		x			x
9	Technical		x		x	
10	Human		x			
11	Criminal		x			
12	Safety		x			
13	Strategic	x				
14	Contractual	x				
15	Master Plan	x				
16	Definition	x				
17	Process	x				
18	Product	x		x		
19	Organisational	x			x	
20	Operational	x				
21	Maintenance	x				
22	External	x				
23	Legal			x		
24	Social			x		
25	Communications			x		
26	Geographical			x		
27	Geotechnical			x		
28	Construction			x		
29	Technological			x		
30	Statutory clearance risk					x
31	Business					x

6.3 RISK IDENTIFICATION BASED ON PROCESS PROTOCOL

Process-driven risk management implies that the risk management process, and thus also risk identification, which is part of it, are subordinated to the construction process. A process is a group of activities undertaken with the goal of successful project realisation, and these activities are potential risk sources that may lead to an unsuccessful project. The construction process consists of phases through which the project passes. Regardless of the project characteristics, the key risks of the construction project are the risks that may prevent the goals of a particular phase in the process from being achieved.

The goals of each phase depend on several activities or processes that affect phase realisation in various ways. Not achieving the goals of one or more of these processes may lead to non-achievement of the goals of the phase they belong to. Depending on their complexity, some processes contain sub-processes that may be broken down even further.

Independently of level, the processes in a particular phase that have the greatest probability and the greatest impact on the time, cost and quality, and thus also the greatest bearing on successfully achieving the goals of that phase, are the optimum choice as sources of key risks that are not project related. This means that the key risks on which the success of the process depends can be reached by analysing the construction process. In this way risk management is placed in the service of the construction process, and leads to process improvement.

Process Protocol II, developed by R.Cooper at Salford University in cooperation with Lougborough University, resulted in breaking down high level processes (Level I) into sub-processes (Level II and Level III) in each phase through which, according to Process Protocol, the construction project passes from Demonstrating the Need to Operation and Maintenance (Wu, Aouad and Cooper, 2000). Process maps were made for each level. These process maps show the advantage of Process Protocol over other plans of work because they provide better insight into the elements of the process and thus also into risk identification. Figure 6.1 shows an example of dividing a process into sub-processes according to Process Protocol II. For Phase Zero, *Demonstrating the Need*, it shows the division of the high-level process *Establish the Need for a Project* (Level I) into sub-processes (Level II and Level III). The author of this research used process maps of this kind (see Appendix 2) to compile the proposed list of key risks (see Figures 6.2, 6.3 and 6.4) for all the phases through which the project passes according to Process Protocol, from *Demonstrating the Need* to *Operation and Maintenance*. It should by emphasized that this is the proposed list of key risks. In the future this list might be modified and extended applying the framework to construction projects in practice.

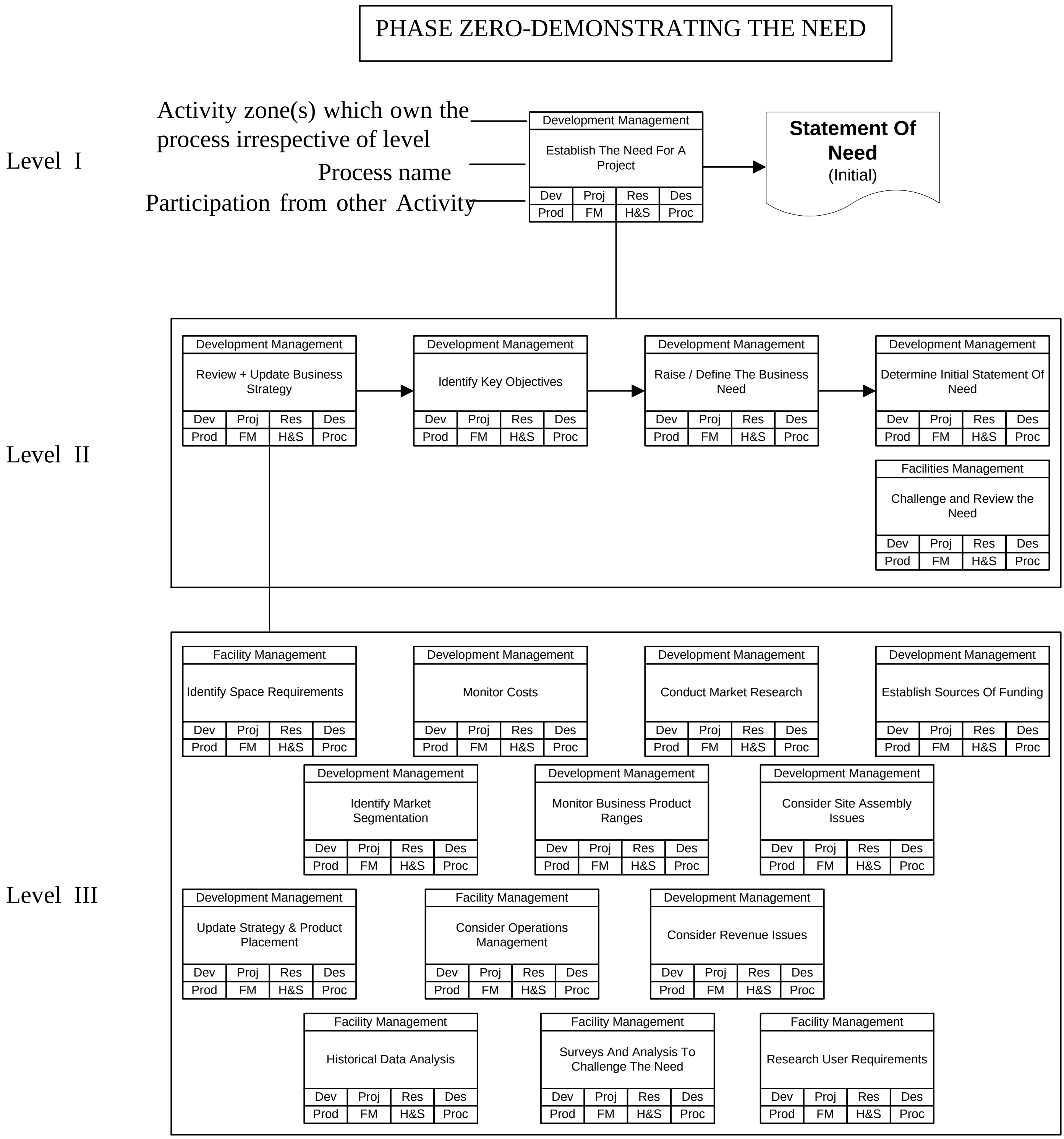


Figure 6.1: Development of sub-processes

Abbreviations: Dev - Development Management, Proj - Project Management, Res - Resource Management, Des - Design Management, Prod - Production Management, FM - Facility Management, H&S - Health and Safety Management, Proc - Process Management

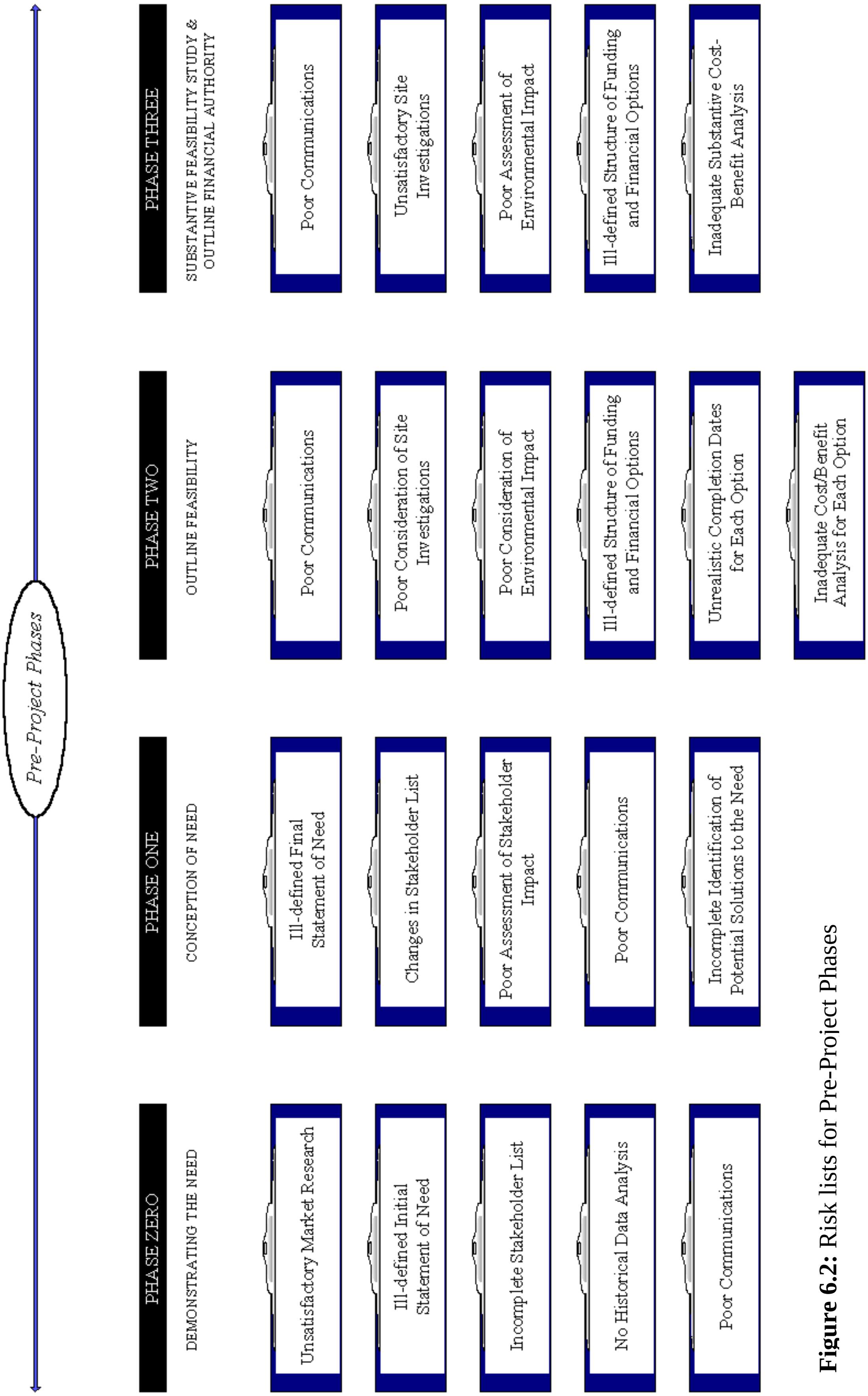


Figure 6.2: Risk lists for Pre-Project Phases

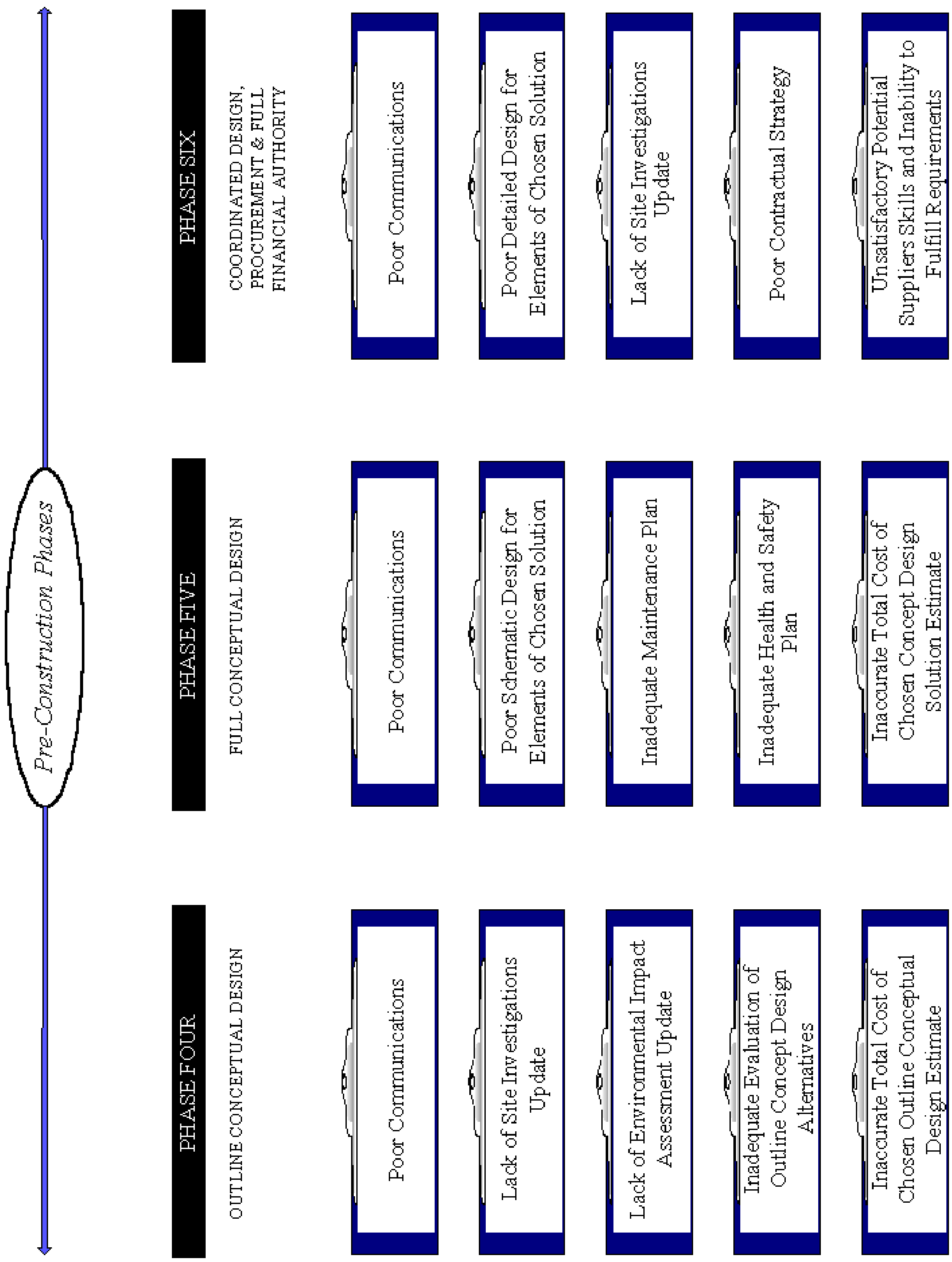


Figure 6.3: Risk lists for Pre-Construction Phases

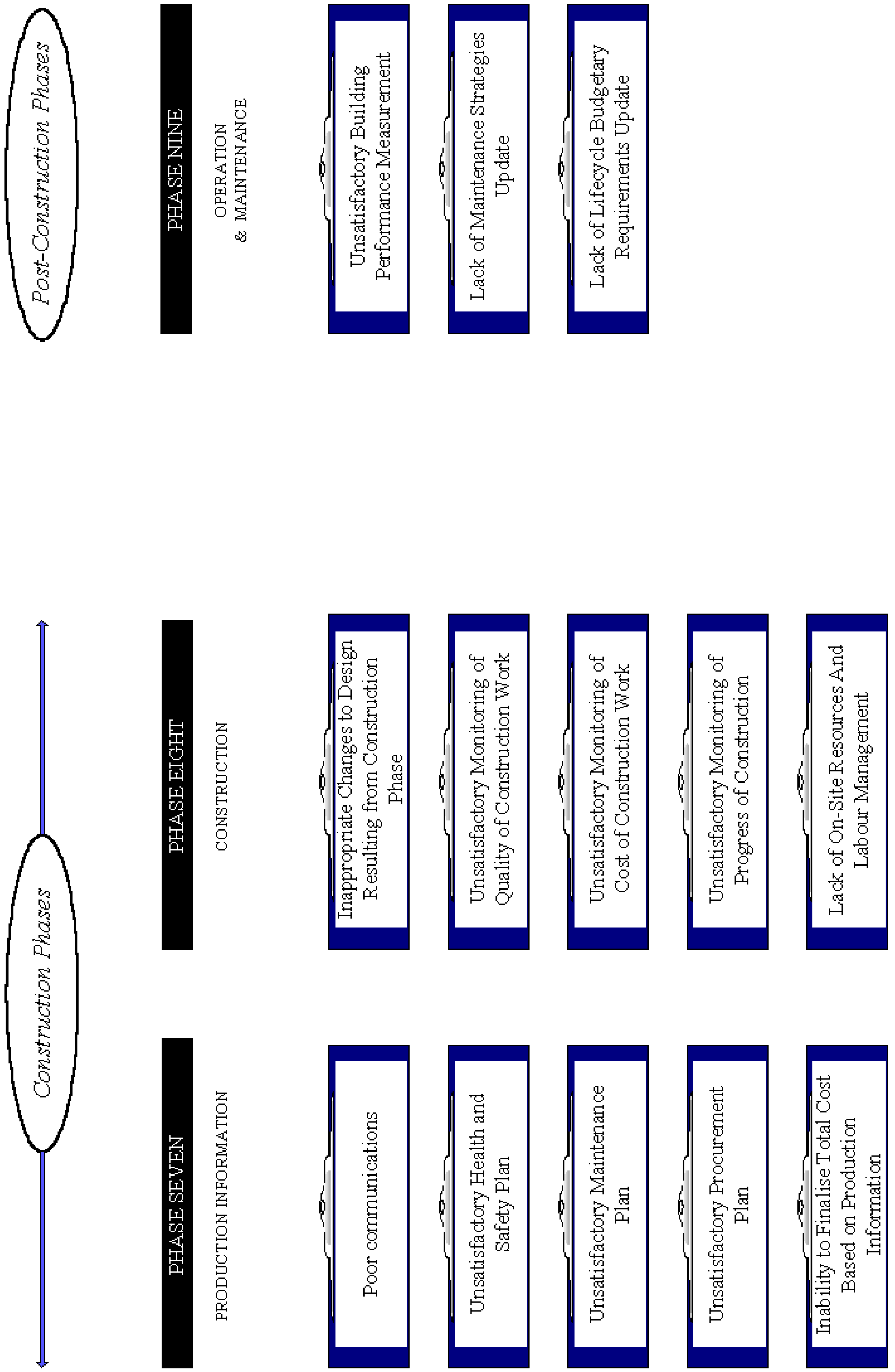


Figure 6.4: Risk lists for Construction and Post-Construction Phases

PHASE ZERO – DEMONSTRATING THE NEED

Risk 0-1: Unsatisfactory Market Research

In this earliest project phase it is necessary to research the market of existing structures which may help the client express his requirements or demands as clearly as possible. This is especially important as some of the stakeholders will be participating in the realisation of such a project for the first and only time. When they see what they could obtain, clients will be able to express what they really want much more clearly. Without market research and the presentation of the research results to clients there is a significant risk that the goals of phase zero will not be fulfilled.

Risk 0-2: Ill-defined Initial Statement of Need

All the client's needs, goals and demands should be described in as much detail as possible in a document according to Process Protocol called Statement of Need. In this early project phase it is very difficult to define all the demands and needs. In further project phases the elaboration and evaluation of potential solutions will lead to their reduction or may even extend the demands of the client, i.e. the stakeholder.

Risk 0-3: Incomplete Stakeholder List

Each stakeholder has his needs and demands, depending on his investment in the project. An incomplete stakeholder list makes it impossible to form all sources of funding and means that demands differing from earlier ones may appear. An incomplete stakeholder list is a risk for the entire phase zero not fulfilling its basic goals.

Risk 0-4: No Historical Data Analysis

In the earliest project phase, after the client's needs, goals and demands have been defined, it is necessary to analyse available data about all risk sources on similar projects that have already been executed. There is also a risk of leaving out of the risk list a risk that in the past showed significant risk exposure in a project phase. Analysing available data considerably contributes to a better understanding of the problem.

Risk 0-5: Poor Communication

In the earliest project phase it is necessary to establish a communication strategy within the management team participating in the project phase (development, resources, facilities, project and process management) and between the management team and the client and stakeholders. Success in realising the goals of phase zero greatly depends on this communication.

6.3.1 PHASE ONE – CONCEPTION OF NEED

Risk 1-1: Ill-defined Final Statement of Need

In this phase all the client's needs, goals and demands should be finally defined and the Statement of Need finalised. This will serve as the basis for defining potential solutions. There is a risk of leaving out potentially good solutions because all the client's needs were not sufficiently investigated.

Risk 1-2: Changes in Stakeholder List

Since this is the phase when potential solutions are proposed any change in the stakeholder list leads to the risk that introducing new stakeholders will change earlier demands and in fact lead to the rejection of some solutions already proposed.

Risk 1-3: Poor Assessment of Stakeholder Impact

A stakeholder's investment in the project defines his impact. The greater a stakeholder's impact the higher his needs will rank over the needs of others. A poor assessment of stakeholder impact may lead to stakeholders with a smaller impact having their needs satisfied and stakeholders who consider they were assigned too small an impact in relation to their investment being dissatisfied and abandoning the project.

Risk 1-4: Poor Communication

The communication strategy must be added to in every project phase. In this phase there is a risk of bad communication between all the previous participants and the design management, which joins the project in this phase and proposes potential solutions on the basis of needs, investigations and environmental impact assessment.

Risk 1-5: Incomplete Identification of Potential Solution to the Need

The design management should propose a sufficient number of potential solutions to be used as a basis for feasibility studies. All the proposed solutions must be as well defined as possible, must be practicable, contain a description of the necessary investigations and a preliminary analysis of possible environmental impact.

6.3.2 PHASE TWO – OUTLINE FEASIBILITY

Risk 2-1: Poor Communication

The design management, which proposed the potential solutions, must among other things exchange additional information with the management team about needs, investigations, environmental impact and funding, and carry out feasibility studies for every potential solution. Bad communication may directly affect feasibility study results because all the relevant information remains inaccessible.

Risk 2-2: Poor Consideration of Site Investigations

Various kinds, volume and intensity of investigations must be planned for every potential solution. In this phase it is necessary to gather all the available information about the soil on which the object is planned and make detailed plans for all the investigations necessary for each option, so as to assess the costs of investigations and foundations. Investigation work is expensive as a rule and its inadequate planning risks entering the feasibility study with a wrong estimate of investigation costs and choosing the wrong solution for foundation.

Risk 2-3: Poor Consideration of Environmental Impact

Any potential solution must be satisfactorily incorporated in the environment. Poor consideration of environmental impact risks later analysis showing that the solution must be rejected or that its realisation will cost too much. It is necessary for the feasibility study to exhaustively predict how the facility will affect the environment and which measures must be undertaken for any potential solution, so that the costs may be calculated.

Risk 2-4: Ill-defined Structure of Funding and Financial Options

To make a feasibility study for every proposed solution detailed knowledge of the sources, structure and manner of funding is necessary.

Risk 2-5: Unrealistic Completion Dates for Each Option

Unrealistic assessment of completion dates for each option greatly affects feasibility study results.

Risk 2-6: Inadequate Cost/Benefit Analysis for Each Option

A cost/benefit analysis must be made for each option on the basis of available information, not doing this risks the optimal option not being chosen.

6.3.3 PHASE THREE – SUBSTANTIVE FEASIBILITY STUDY & OUTLINE FINANCIAL AUTHORITY

Risk 3-1: Poor Communication

This phase covers, among others, site investigations, environmental impact assessment and substantive feasibility study. Quality information exchange between site, laboratory and office is necessary to realise the goals of this phase.

Risk 3-2: Unsatisfactory Site Investigations

Planned site and laboratory investigations for the chosen solution are carried out in this phase. The quality and scope of investigations is especially important because their results serve to choose the foundation concept, estimate costs and make the substantive feasibility study. Risk exposure evaluation must take into account that designing will begin in future phases and that this will require additional investigation. The risk become very great if additional investigation is not undertaken in the design phases.

Risk 3-3: Poor Assessment of Environmental Impact

The costs of environmental impact assessment that are included in the feasibility study of the solution chosen. The design solution that will be developed in the following phases may change the results of the environmental impact assessment made in this phase. As in the case of investigations, risk become significant if environmental impact is not assessed in future phases according to the design solution developed.

Risk 3-4: Ill-defined Structure of Funding and Financial Options

It is necessary to precisely define the structure and manner of funding, with all elements, for the needs of the substantive feasibility study. There must be no more unknowns about the structure of funding in this phase.

Risk 3-5: Inadequate Substantive Cost-Benefit Analysis

It is always possible that the cost-benefit analysis chosen might be inadequate, or poorly implemented. Its results strongly impact the entire feasibility study and thus also the success of this phase.

6.3.4 PHASE FOUR – OUTLINE CONCEPTUAL DESIGN

Risk 4-1: Poor Communication

Making the outline conceptual design requires good communication and coordination between the designing office, the site where the necessary onsite investigations are performed and the laboratory where the necessary laboratory investigations are performed. Good communication becomes even more important when we consider that making the outline conceptual design is an iterative process.

Risk 4-2: Lack of Site Investigations Update

Investigations carried out for the needs of the substantive feasibility study are not sufficient to turn the option into the outline design. It is necessary for each design solution to predict the foundation concept, which demands additional information about the site and this means new investigations.

Risk 4-3: Lack of Environmental Impact Assessment Update

A new environmental impact assessment must be made for every design solution because this can considerably influence the option chosen.

Risk 4-4: Inadequate Evaluation of Outline Concept Design Alternatives

Several design solutions are presented in this phase, which are evaluated and one chosen for further elaboration. The criteria are costs, functionality, aesthetics, fitting into the environment etc. The variety of the criteria makes it very difficult to carry out the evaluation and select the optimum design solution. After this phase only one conceptual design is left.

Risk 4-5: Inaccurate Total Cost of Chosen Outline Conceptual Design Estimate

The estimate of total costs for the chosen outline conceptual design depends on how far the design solution has been elaborated and is important for closing the structure of financing. Considering the many details that must still be resolved, significant mistakes are possible. Estimating total costs already in this phase of the project makes it possible to keep planned expenses for project realisation under control.

6.3.5 PHASE FIVE – FULL CONCEPTUAL DESIGN

Risk 5-1: Poor Communication

For the needs of the full conceptual design, the communication system now also includes information about what potential suppliers can provide. Good communication and coordination between the designing office, the site where the necessary onsite investigations are performed and the laboratory where the necessary laboratory investigations are performed continues to be necessary.

Risk 5-2: Poor Schematic Design for Elements of Chosen Solution

Deficiencies in an inadequate elaboration of the full conceptual design are a limiting factor for making the coordinated design in the next phase. In this phase the full conceptual design must be elaborated in as much detail as possible on the basis of available information.

Risk 5-3: Inadequate Maintenance Plan

In this phase it is necessary to define the maintenance strategy to be implemented in Phase 9. Periodic inspections must be planned, maintenance work defined, maintenance costs estimated, and forecasts made for work organisation, human resource requirements and cost and quality control. An adequate maintenance plan must provide adequate maintenance resources for the maintenance work to be performed, ensure that any particular maintenance work on the building is necessary and inevitable, and provide an answer to whether spending more on maintenance would be advantageous.

Risk 5-4: Inadequate Health and Safety plan

In accordance with valid CDM regulations, all the necessary measures must be anticipated to ensure safety and health of all the participants in construction. It is the client's responsibility to comply with the CDM regulations and therefore provisions for reporting on those issues should be made.

Risk 5-5: Inaccurate Total Cost of Chosen Concept Design Solution Estimate

Total costs can be calculated with considerable precision on the basis of the full conceptual design because all the elements that significantly affect costs are known. Thus the cost estimate in this phase is very important because significant changes can still be made in the project to achieve lower costs.

6.3.6 PHASE SIX – COORDINATED DESIGN, PROCUREMENT & FULL FINANCIAL AUTHORITY

Risk 6-1: Poor Communication

In this phase all the major elements are finally designed. All the main details of execution, supply and funding are elaborated thus completing the coordinated product model. It is indispensable for good communication and coordination to exist between all previous participants in the project.

Risk 6-2: Poor Detailed Design for Elements of Chosen Solution

Deficiencies in an inadequate elaboration of the coordinated design make it impossible to execute the facility. Designing must also address issues such as possibilities of supplying material, number of workers and amount of equipment that can be used at the same time and all the other elements that affect the construction process.

Risk 6-3: Lack of Site Investigations Update

Detailed designing that includes execution technology may demand additional investigations for adapting the coordinated design to the given technology.

Risk 6-4: Poor Contractual Strategy

A good contracting strategy identifies events and factors that could affect the quality, time and costs for completing the facility. In developing an adequate contracting strategy it is necessary to bear in mind the selection of organisation structure in project control, type of contract, method of choosing contractors, selection and execution of tender documentation, including contract clauses that allow shifting risks between investor and contractor, sub-contractors, suppliers and insurance.

Risk 6-5: Unsatisfactory Potential Suppliers Skills and Inability to Fulfil Requirements

Before execution it is necessary to analyse whether potential suppliers can satisfy all the demands that will be placed before them. Their capacities and limitations may affect some of the design solutions and building planned speed.

6.3.7 PHASE SEVEN – PRODUCTION INFORMATION

Risk 7-1: Poor Communication

Preparations for construction require good communication and coordination between all the project participants.

Risk 7-2: Unsatisfactory Health and Safety Plan

Before construction begins it is necessary to complete a Health & Safety Plan in accordance with current CDM regulations.

Risk 7-3 Unsatisfactory Maintenance Plan

Immediately before construction begins it is necessary to complete a maintenance strategy and make a maintenance plan. Maintenance should be viewed in the context of the entire construction process. The maintenance plan also contains a maintenance cost estimate during the life cycle of the structure, so an unsatisfactory maintenance plan may threaten the future function and safety of the facility.

Risk 7-4: Unsatisfactory Procurement Plan

Immediately before construction begins all the participants in construction must be known, their human and mechanical resources and their material supply potentials. Construction must be divided into work packages to the smallest detail.

Risk 7-5: Inability to Finalise Total Cost Based on Production Information

In this phase sufficient information must be available to calculate total construction costs with significant certainty. The risk of exceeding construction costs must be solved through a contract with the contractor.

6.3.8 PHASE EIGHT – CONSTRUCTION

Risk 8-1: Inappropriate Changes to Design Resulting from Construction Phase

Unexpected circumstances always appear during construction that demand changes in project solutions to adapt them to the situation onsite. The design management must adapt quickly, that is find new solution to continue construction with the necessary quality, minimum costs and in the planned time.

Risk 8-2: Unsatisfactory Monitoring of Quality of Construction Work

Construction work quality control must run parallel with construction. In addition to quality control required by standards, it is necessary to monitor whether work is running according to project demands. If there is deviation from project demands leading to decreased safety, changes must be made in the project and their effects monitored.

Risk 8-3: Unsatisfactory Monitoring of Cost of Construction Work

Controlling costs during construction must ensure that the forecasted total costs are not overstepped. If this should occur the reasons must be analysed and necessary measures undertaken to return costs to the planned level. Although the risk of exceeding construction costs is solved through contracts with the contractor, these costs must nevertheless be properly monitored.

Risk 8-4: Unsatisfactory Monitoring of Progress of Construction
Monitoring construction progress enables keeping given construction deadlines under control. Poor construction progress could be the contractor's fault, but it could also arise from circumstances no one can control, such as bad weather and the like.

Risk 8-5: Lack of Onsite Resources And Labour Management
Any lack of planned onsite resources and poor labour management lead to overstepping the planned deadline, inadequate quality and increase of planned costs.

6.3.9 PHASE NINE – OPERATION & MAINTENANCE

Risk 9-1: Unsatisfactory Building Performance Measurement
To ensure a satisfactory level of the structure's safety and functionality during its life cycle it is necessary to make building performance measurements at the appropriate level and of appropriate quality.

Risk 9-2: Lack of Maintenance Strategies Update
Maintenance strategies must often be changed and supplemented during the facility's use. It is especially important to determine maintenance priorities in accordance with planned and ensured resources.

Risk 9-3: Lack of Lifecycle Budgetary Requirements Update
Expenses unforeseen in the maintenance plan will appear during the facility's lifecycle. The safety and functionality of the facility depends on whether new maintenance funding can be obtained, and how much.

6.4 SUMMARY AND CONCLUSIONS

This chapter has shown the identification of key risks for every Process Protocol based construction project. Every risk management process in the construction industry (see Chapter 3) starts with the identification of risks in such a way that risks are chosen from the proposed risk list or risk categories, which are the same for all projects, after which project related risks are added to them. The risk exposures of entire risk categories can be analysed and compared, or one or more key risks may be selected from a particular category. A risk identification methodology of this kind is adapted to what is known as risk-driven project management.

To increase efficiency in the construction industry it is also necessary to develop and to continuously advance the group of activities needed for successful project realisation. Process Protocol I resulted in 10 phases through which the construction project passes in its evolution. High-level processes that have to be performed are identified in each phase. Process Protocol II proclaimed these high-level processes as Level I, and then proceeded to divide the Level I processes into Level II sub-processes, and these, in turn and if necessary, into Level III sub-processes. Thus the realisation of any construction project is broken up into elementary processes. The processes on any level are potential risk sources and may serve as the basis for a risk list in each phase. The risk list in the proposed framework has a total of 49 risks, that is, an average of 5 risks per phase, to which project related risks can be added in each phase. This makes risk management part of a generic process leading to the development of process-driven risk management.

The next chapter shows how the framework for managing risk in construction projects is developed. The framework calls for cyclical risk management in every phase the construction project passes through according to the Process Protocol. The risk identification described in this chapter will be followed by quantitative or qualitative risk analysis, the determination of risk exposure and risk acceptability, and a proposal of adequate risk response. Risk response may produce new risks in the same or in the next phase, which must be included in process-driven risk management.

7 A FRAMEWORK FOR MANAGING RISKS IN CONSTRUCTION PROJECTS

7.1 INTRODUCTION

The preceding chapter provided the proposed generic list of key risks that appear in all construction projects, for each phase of the project according to the Process Protocol, from *Demonstrating the Need* to *Operation and Maintenance*. The risk management team may also identify other project-related risks in each phase.

This chapter shows the framework for process-driven risk management in Process Protocol based construction projects. The Process Protocol divides the execution of a construction project in the 10 phases shown in Chapter 5. According to the proposed framework, cyclical risk management in performed in each phase of the construction process. First risk probability and risk impact are determined for each identified key risk, and thus also risk exposure, and then a risk priority list is formed and a risk response strategy defined, depending on risk acceptability. If risk response leads to the appearance of new risks, a new cycle of risk identification, analysis and response begins. Risk management is a dynamic process because it is carried out continuously in every subsequent project phase in accordance with the changeable circumstances in which the process runs.

7.2 THE CYCLICAL RISK MANAGEMENT PROCESS

Chapter 2 shows the cyclical risk management process, which is part of the proposed framework and which is carried out independently for each phase of the construction project in accordance with the Process Protocol. It is necessary to determine risk probability and risk impact for each identified risk in a particular phase, calculate the corresponding risk exposure, and depending on risk acceptability define a strategy of risk response. The procedure is repeated for each successive phase.

The risk list analysed in a particular phase is compiled by adding to the risk list common to all construction projects, a risk list connected to that specific project.

These specific risks are identified after investigating potential risk sources linked with the project, unfavourable events that include risks and unfavourable effects that will occur should an undesirable scenario take place. After the risks have been identified, they are numbered. A risk is designated by a three-digit number, for example: Risk 503. The first digit marks the number of the phase under analysis (the 5th phase in the example), i.e. the phase that the risk appears in according to the Process Protocol. Since the Process Protocol has phases from 0 to 9, one digit is sufficient to designate the phase. The other two digits show the order of the risk in the phase under analysis (risk no. 3 on the list belonging to Phase 5). Two digits are quite sufficient for this purpose because each list will contain less than 99 key risks important for the phase. Figure 7.1 shows the risk list with the corresponding designations.

Figure 7.1: Risk list for Phase X with the corresponding designations

For each identified risk it is necessary to determine risk exposure, and depending on it risk acceptability. Risk exposure is the product of risk probability and risk impact. Risk probability is a dimensionless value. Risk may impact time, cost or quality, but in the end any impact can be expressed in monetary units. This means that risk exposure has the dimension of the monetary unit used in calculations. Consequently, risk exposure for a particular risk may acquire any value and it is calculated independently of all the other risks in the phase. The absolute value of risk exposure for a particular risk, viewed in itself, has practically no usable value so it is important to determine how much smaller or larger the risk exposure of a particular risk is with respect to the risk exposures of the other risks in the phase. Determining the risk exposures of all the identified risks in a particular phase and placing them in an interrelationship allows the formation of a risk priority list. The position of the risk in this list, that is the relative value of its exposure with reference to that of the other risks in the phase, determines which resources will be engaged in the planned risk response. The risk priority list can be determined using a quantitative, qualitative or mixed approach.

7.3 RISK PRIORITY LIST - QUANTITATIVE APPROACH

The quantitative approach in forming the priority list implies that risk probability and risk impact can be explicitly calculated using one of the known quantitative risk analysis methods. For this a relevant database must be available, to use in forming the probability distribution, i.e. to enable the direct calculation of impact on time, cost and quality. In this case a completely determined and consistent procedure can be used to determine the priority list, which is shown below.

7.3.1 RISK PROBABILITY - QUANTITATIVE APPROACH

Risk probability must be determined for each identified risk. The probability that a certain risk will occur can be calculated if all the necessary elements for this kind of analysis exist, especially a statistically relevant database about past experiences and similar events, which can be used as a basis for the distribution function.

After the probability associated with each risk has been determined by one of the known methods of quantitative analysis, all the risks in a particular phase are weighted to obtain their relative values, that is, the order of risks according to their probability. The weighting or normalisation of probability is carried out by dividing the risk probability of each risk with the sum of the risk probabilities of all the risks in the phase. This gives new probabilities whose sum is 1, which means that the risks in the phase have now become a random variable.

Let, for example, the probabilities of the 5 risks in Phase X be, respectively, 0.32, 0.21, 0.75, 0.93 and 0.44.

The sum of all the probabilities is 0.32 + 0.21 + 0.75 + 0.93 + 0.44 = 2.65.

The normalised probabilities are now, respectively:

pX01 = 0.32/2.65 = 0.12

pX02 = 0.21/2.65 = 0.08

pX03 = 0.75/2.65 = 0.28

pX04 = 0.93/2.65 = 0.36

pX05 = 0.44/2.65 = 0.16.

The sum of all the normalised probabilities is 0.12 + 0.08 + 0.28 + 0.36 + 0.16 = 1.

Figure 7.2 shows the normalised or relative probabilities for the above example. These normalised probabilities will be used to calculate risk exposure.

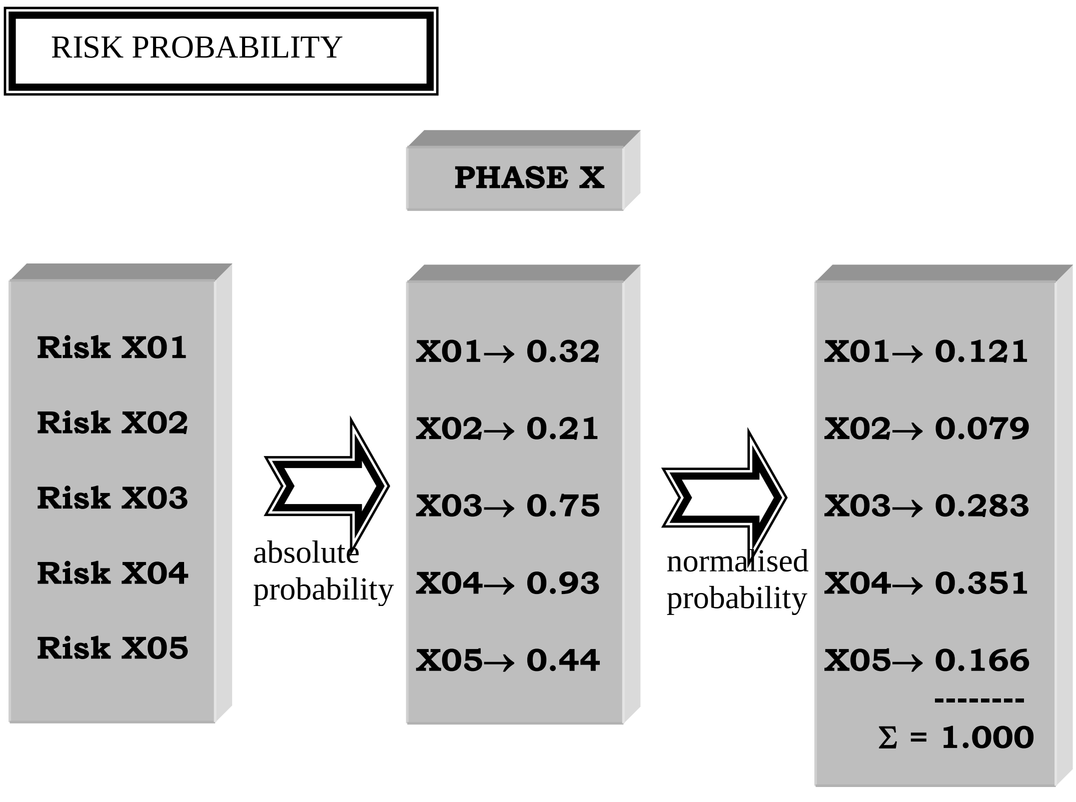


Figure 7.2: Normalised or relative probabilities for the occurrence of each risk in Phase X

7.3.2 RISK IMPACT- QUANTITATIVE APPROACH

There are many ways in which a risk source can affect the project unfavourably. The consequences can vary, but they show as longer construction, that is project realisation, decreased quality and, finally, increased costs. The basic purpose of risk management in a project is to keep under control the impacts on time, cost and quality.

Impacts on time, cost and quality are not interdependent although the prolongation of planned construction time and the decrease of quality may, for most projects, finally be expressed in terms of money so that every risk impact has the dimension of a monetary unit. However, for a certain number of projects it is not enough to express all impacts through money, instead, priorities must be clearly determined with respect to time, cost and quality. Often the project has to be finished in a given time so additional resources must be engaged to increase efficiency. This leads to higher costs than had the work lasted longer using the existing resources. In this case the goal is to weight the risk sources that affect time higher than those that affect cost. There are also cases when quality is much more important than costs, so risks that affect quality but have low costs, should they be realised, must be given greater impact than those that affect time but cause higher costs.

Time, cost and quality are weighted by defining their normalised interdependency, i.e. their relative impacts on the project where the sum of all the impacts is 1. Figure 7.3 shows an example of weighting.

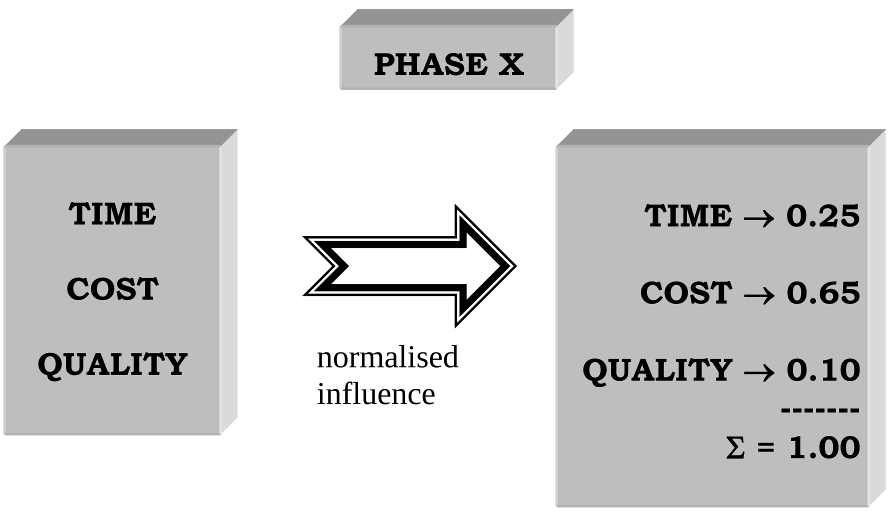


Figure 7.3: Normalised impact of time, cost and quality on the project

It is impossible to determine these values exactly because they reflect stakeholder-generated priorities. If no such priorities have been given, and time and quality may be expressed through increased costs, then it is enough to assign all the impacts the value of 1/3 of the project and thus avoid any kind of preference between time, cost and quality.

After weighting and finding the interdependency of time, cost and quality, the impact of each identified risk in the phase under analysis must be determined independently of time, cost and quality. Impacts on time may be expressed in arbitrary units, for example in days, and impacts on quality in expected percentage of quality loss. This is irrelevant for the proposed framework because all the impacts are normalised to obtain their comparative interdependency. Normalisation is performed in the same way as for probability, by dividing the impact of each risk on time, cost or quality with the sum of all the impacts in the phase, thus making the sum of all the impacts equal to 1.

Figures 7.4, 7.5 and 7.6 show an example of this kind of normalisation.

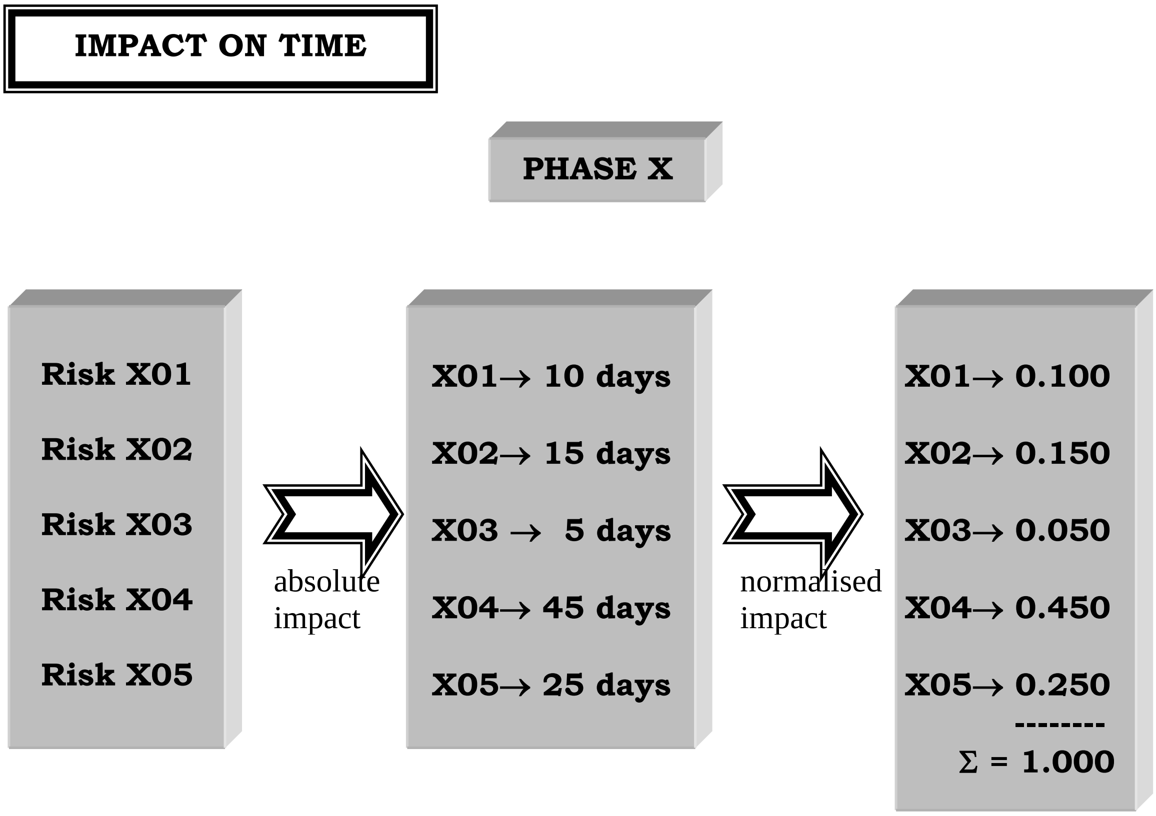


Figure 7.4: Normalised risk impact on time in Phase X

IMPACT ON COST

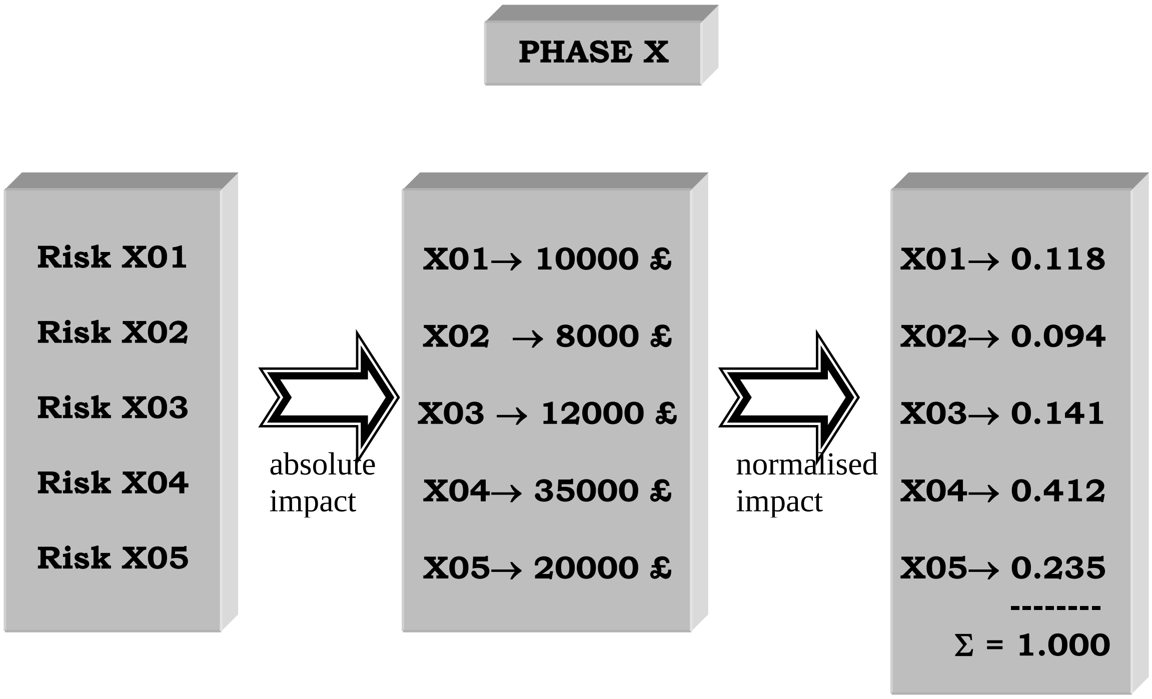


Figure 7.5: Normalised risk impact on cost in Phase X

IMPACT ON QUALITY

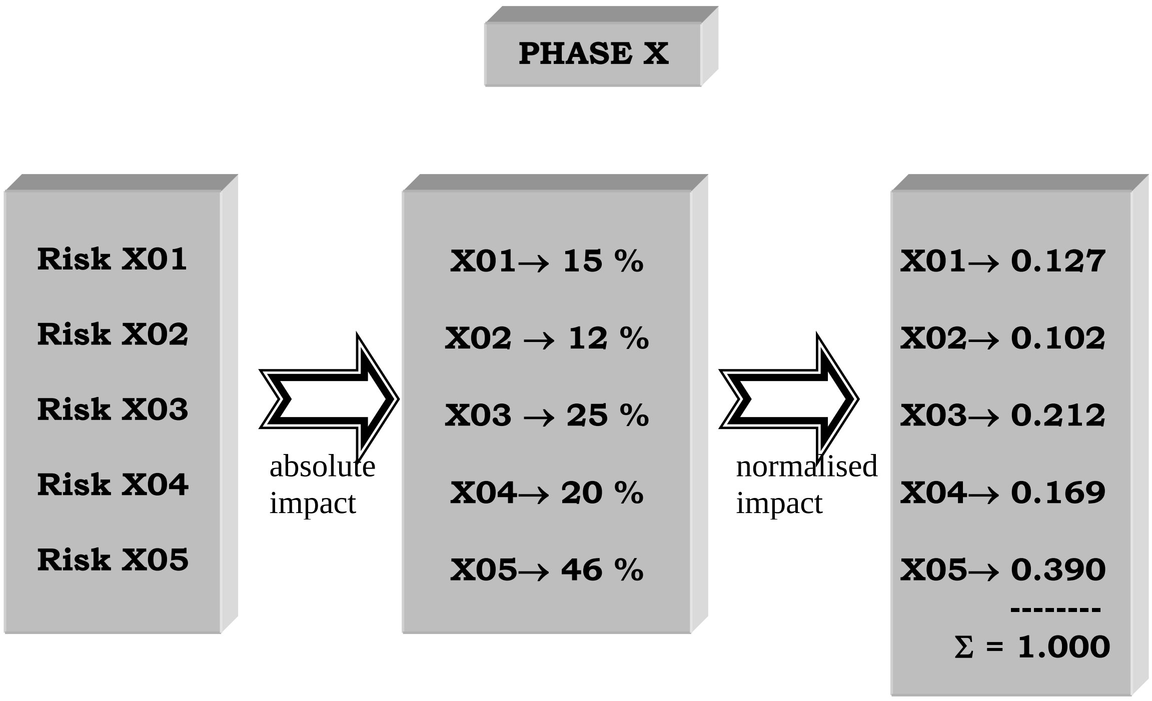


Figure 7.6: Normalised risk impact on quality in Phase X

The final normalised risk impact for every identified risk in each phase is obtained by combining the normalised impacts of time, cost and quality on the project with the individual impacts of the analysed risks on time, cost and quality. This is done by using the method of simple weighting with averaging shown in Table 7.1.

Table 7.1: Calculating normalised risk impact in Phase X

	TIME		COST		QUALITY	Risk impact
Risk X01	0.25 x 0.100	+	0.65 x 0.118	+	0.10 x 0.127	= 0.114
Risk X02	0.25 x 0.150	+	0.65 x 0.094	+	0.10 x 0.102	= 0.109
Risk X03	0.25 x 0.050	+	0.65 x 0.141	+	0.10 x 0.212	= 0.126
Risk X04	0.25 x 0.450	+	0.65 x 0.412	+	0.10 x 0.169	= 0.397
Risk X05	0.25 x 0.250	+	0.65 x 0.235	+	0.10 x 0.390	= 0.254
					Total	= 1.000

Table 7.2 shows the calculation of risk impact in cases when priorities between time, cost and quality have not been defined. In this case each of them is assigned the normalised value of 1/3.

Table 7.2: Calculating normalised risk impact in Phase X in cases when priorities between time, cost and quality have not been defined

	TIME		COST		QUALITY	Risk impact
Risk X01	1/3 x 0.100	+	1/3 x 0.118	+	1/3 x 0.127	= 0.115
Risk X02	1/3 x 0.150	+	1/3 x 0.094	+	1/3 x 0.102	= 0.115
Risk X03	1/3 x 0.050	+	1/3 x 0.141	+	1/3 x 0.212	= 0.134
Risk X04	1/3 x 0.450	+	1/3 x 0.412	+	1/3 x 0.169	= 0.344
Risk X05	1/3 x 0.250	+	1/3 x 0.235	+	1/3 x 0.390	= 0.292
					Total	= 1.000

The above example shows that when there are special priorities between time, cost and quality, the impact of some risks increases and the impact of others decreases, but on the whole this has no significant influence.

7.3.3 RISK EXPOSURE- QUANTITATIVE APPROACH

After risk probability and risk impact have been determined for every risk in Phase X, risk exposure can be calculated as the product of risk probability and risk impact. Table 7.3 shows the calculation.

Table 7.3: Calcualting risk exposure in Phase X

PHASE X	PROBABILITY		IMPACT		RISK EXPOSURE
Risk X01	0.121	x	0.114	=	**0.014**
Risk X02	0.179	x	0.109	=	**0.020**
Risk X03	0.283	x	0.126	=	**0.036**
Risk X04	0.351	x	0.397	=	**0.139**
Risk X05	0.166	x	0.254	=	**0.042**

The risk exposures obtained serve to form a risk priority list, which will be used to plan risk response and anticipate and distribute the resources to implement it. Table 7.4 shows the priority list in Phase X.

Table 7.4: Priority list in Phase X

PHASE X	RISK EXPOSURE
Risk X04	**0.139**
Risk X05	**0.042**
Risk X03	**0.036**
Risk X02	**0.020**
Risk X01	**0.014**

7.4 RISK PRIORITY LIST - QUALITATIVE APPROACH

What happens most often in real life is that the risk management team does not have at its disposal the relevant database about earlier projects that could be used to form the probability distribution function and determine risk probability. It does not have, either, all the necessary indicators for directly calculating the effects, that is the impact the risky event would have on time, cost and quality. In such cases the risk priority list is determined by using one of the three techniques for qualitative risk analysis that various authors have already used in risk management. These are:

1. Multi-attribute Utility Theory,
2. Fuzzy Analysis,
3. Analytical Hierarchy Process.

A short description and the possible use of these techniques in the proposed framework follows, including the reasons why one of them is more suitable for forming the risk priority list within the proposed framework than the other two.

7.4.1 MULTI-ATTRIBUTE UTILITY THEORY

The multi-attribute utility theory is a well-known decision-making technique used under conditions of certainty and under conditions of uncertainty (Luce and Raiffa, 1957; Keeney and Raiffa, 1976, Chankone and Haimes, 1983, Saaty, 1994; Flanagan and Norman, 1993). It is used in cases when the best alternative solution must be chosen, i.e. for compiling a priority list of the alternatives offered. Alternatives are weighted with respect to one or more given criteria with the purpose of calculating the overall utility function for each alternative. The value of the overall utility function is used to form the priority list of alternatives, that is, to provide the best alternative. Kangari and Boyer (1981), Hwang and Yoon (1981), Ibbs and Crandall (1982), Moselhi and Deb (1993) and others used the multi-attribute utility theory as a technique for qualitative risk analysis.

The value of the overall utility function for each alternative is calculated in 4 steps.

The first step is defining one or more criteria or attributes with respect to which the alternatives offered will be valued.

The second step is weighting the given criteria. All criteria are not equally important for the decision-maker. He assigns each criterion the corresponding importance or weight taking care that the sum of all the weights equals 1. In this step alternatives are not taken into consideration and they have no effect on the result.

The third step is determining the utility function for each given criterion. First each alternative is assessed with respect to the given criteria. The values may be expressed numerically or statistically by their distribution function. Qualitative assessments by decision-making managers are turned into a statistical distribution function used to calculate the statistical parameters of the distribution, such as mean, variance etc. For the sake of simplicity this presentation of how to apply the multi-attribute utility theory in the proposed framework will use only the mean (μ). Moselhi and Deb (1993) showed the use of the other statistical parameters. A utility function is then formed for each criterion, using the so-called certainty equivalent method in which the decision-maker subjectively assesses the discrete values of the utility function, after which these values are fitted using an exponential, logarithmic or polynomial function.

The fourth step is calculating the overall utility function for each alternative by adding up the products of the weight of each criterion and the value of the corresponding utility function. Determining the overall utility function in this way, by simply adding up the above products, is possible only if the given criteria are independent of the given goal. The priority list of alternatives is formed according to the value of the overall utility function.

The procedure for determining risk probability, risk impact and risk exposure for one phase in the Process Protocol, using the multi-attribute utility theory, is shown below.

7.4.1.1 Risk probability - multi-attribute utility theory

No additional criteria are given for determining risk probability, that is, risk probability is the goal and the only criterion with respect to which the alternatives are to be weighted. This is an essential simplification and the following is a single-criterion analysis. The alternatives are the risks in Phase X.

A qualitative assessment is first made for the occurrence of each identified risk in Phase X, by assessing its minimum, most likely and maximum probability. Table 7.5 shows one such assessment.

Table 7.5: Probability assessment for each alternative with respect to risk probability

Risk probability	Minimum	Most likely	Maximum
Risk X01	0.20	0.24	0.30
Risk X02	0.10	0.16	0.20
Risk X03	0.46	0.54	0.60
Risk X04	0.60	0.70	0.80
Risk X05	0.24	0.30	0.36

After this the utility function is determined for the criterion of risk probability. First the minimum and maximum probabilities for all the alternatives are taken and the utility function values of 0 and 1 are assigned to them. If U(riskprob) is the utility function, then U(0.10)=0, and U(0.80)=1.

Now the decision-maker is given the option of choosing which probability of risk occurrence he will accept, rather than drawing lots. Drawing lots or tossing a coin means that he will accept the minimum risk of 0.1 for heads, and the risk of 0.8 for tails. Since every decision-maker should be able to manage risks, that is, to rely on his decisions and not on chance, there is always a value that he is ready to accept. The expected risk value is 0.5*0.1 + 0.5*0.8 = 0.45. The value of the utility function is 0.5*1 + 0.5*0 = 0.5. The decision-maker should accept a risk greater than 0.45 rather than rely on chance, that is on the expected value. Let the decision-maker accept the risk probability of 0.58 as the smallest value he is ready to accept instead of drawing lots. Now U(0.58)=0.5. The procedure is continued in such a way that the decision-maker must accept a risk probability between 0.1 and 0.58 for the value of the utility function 0.5*0 + 0.5*0.5 = 0.25. The expected risk value is 0.5*0.1 + 0.5*0.58 = 0.34. Let the accepted value be 0.37, as the smallest value that the decision-maker is ready to accept instead of drawing lots. Now U(0.37)=0.25. The procedure can end by accepting the risk probability between 0.58 and 0.8 for the value of the utility function of 0.5*0.5 + 0.5*1.0 = 0.75. The expected risk value is 0.5*0.58 + 0.5*0.8 = 0.69. Let the accepted value be 0.71 as the largest value that the decision-maker is ready to accept instead of drawing lots. Then U(0.71)=0.75. Table 7.6 shows the value of the utility function obtained in this way for risk probability in Phase X.

Table 7.6: Utility function value for risk probability

Risk probability	U(riskprob)
0.10	0.00
0.37	0.25
0.58	0.50
0.71	0.75
0.80	1.00

The values of the utility function shown in Table 7.6 are fitted by a polynomial function as follows:

$$U(riskprob) = 2.917367244 \cdot riskprob^3 - 2.54623541 \cdot riskprob^2 + 1.589225759 \cdot riskprob - 0.1364856845$$

Any distribution may be assumed for each identified risk in Phase X, and each risk may have a different distribution depending on risk type, and on the experience of the manager who makes decision. If a beta distribution is assumed for each identified risk in Phase X (Moselhi and Deb, 1993) the probability is mean = (minimum + 4*most likely + maximum)/6. Since there is no more than one criterion, the utility function values for μ are the overall utility function (T) for each alternative. The overall utility function is normalised for each alternative as shown in Section 7.3 and this represents the final risk probability that will be used to calculate exposure (Table 7.7).

Table 7.7: Overall and normalised utility function for risk probability

Risk probability	μ	U(μ)=T	normalised T
Risk X01	0.247	0.141	0.091
Risk X02	0.157	0.061	0.039
Risk X03	0.537	0.434	0.279
Risk X04	0.700	0.729	0.469
Risk X05	0.300	0.190	0.122
		Total =	1.000

7.4.1.2 Risk impact - multi-attribute utility theory

Three criteria or attributes are given in determining risk impact: time, cost and quality. The alternatives are the risks in Phase X.

The weight interrelations among the given criteria are defined first in such a way that the sum of all the weights equals 1. Let the following weight values be assessed for the criteria in Phase X:

$W_{TIME} = 0.3$

$W_{COST} = 0.6$

$W_{QUALITY} = 0.1$

The impact of every identified risk in Phase X on time, cost and quality is then qualitatively assessed, in such a way that its minimum, most likely and maximum values are defined (Tables 7.8, 7.9 and 7.10).

Table 7.8: Impact on time assessment

TIME (days)	Minimum	Most likely	Maximum
Risk X01	5	11	15
Risk X02	12	16	20
Risk X03	5	8	10
Risk X04	42	45	50
Risk X05	22	26	31

Table 7.9: Impact on cost assessment

COST (£)	Minimum	Most likely	Maximum
Risk X01	5000	12000	18000
Risk X02	5000	8000	12000
Risk X03	10000	13000	15000
Risk X04	30000	35000	40000
Risk X05	18000	22000	25000

Table 7.10: Impact on quality assessment

QUALITY (%)	Minimum	Most likely	Maximum
Risk X01	10	15	20
Risk X02	10	14	19
Risk X03	20	26	33
Risk X04	15	23	30
Risk X05	35	45	60

Now all the elements exist for determining the utility function for each criterion, and the procedure described in Section 7.4.1.1 is repeated. The procedure results in values of impact on time, cost and quality for discrete values of the utility functions (Table 7.11).

Table 7.11: Values of impact on time, cost and quality for discrete values of utility functions

U(TIME, COST AND QUALITY)	TIME (days)	COST (£)	QUALITY (%)
0.00	5	5000	10
0.25	21	16000	26
0.50	32	25000	39
0.75	42	33000	50
1.00	50	40000	60

The values of the utility functions shown in Table 7.11 are fitted by polynomial functions as follows:

$U(TIME) = 0.0002175018285*TIME^2 + 0.0102269454*TIME - 0.05710946609$

$U(COST) = 2.417766721E\text{-}010*COST^2 + 1.766638533E\text{-}005*COST - 0.09429739803$

$U(QUALITY)=0.0001297253121*QUALITY^2+0.01092973123*QUALITY-0.1222607449$

Tables 7.12, 7.13 and 7.14 show the values of the utility functions for the μ of each identified risk.

Table 7.12: Utility function values for the TIME criterion for the corresponding μ of each risk

TIME	μ	$U_{TIME}(\mu)$
Risk X01	10.667	0.077
Risk X02	16.000	0.162
Risk X03	7.833	0.036
Risk X04	45.333	0.854
Risk X05	26.167	0.359

Table 7.13: Utility function values for the COST criterion for the corresponding μ of each risk

COST	μ	$U_{COST}(\mu)$
Risk X01	11833	0.149
Risk X02	8167	0.066
Risk X03	12833	0.172
Risk X04	35000	0.820
Risk X05	21833	0.407

Table 7.14: Utility function values for the QUALITY criterion for the corresponding μ of each risk

QUALITY	μ	$U_{QUALITY}(\mu)$
Risk X01	15.000	0.071
Risk X02	14.167	0.059
Risk X03	26.167	0.253
Risk X04	22.667	0.192
Risk X05	45.833	0.651

The overall utility function for each identified risk in Phase X is calculated as follows:

$T = W_{TIME} * U_{TIME} + W_{COST} * U_{COST} + W_{QUALITY} * U_{QUALITY}$

For risk X01 - $T_{X01} = 0.3*0.077 + 0.6*0.149 + 0.1*0.071 = 0.120$

For risk X02 - $T_{X02} = 0.3*0.162 + 0.6*0.066 + 0.1*0.059 = 0.094$

For risk X03 - $T_{X03} = 0.3*0.036 + 0.6*0.172 + 0.1*0.253 = 0.139$

For risk X04 - $T_{X04} = 0.3*0.854 + 0.6*0.820 + 0.1*0.192 = 0.767$

For risk X05 - $T_{X05} = 0.3*0.359 + 0.6*0.407 + 0.1*0.651 = 0.417$

Table 7.15 shows the normalised values of the overall utility function that represent the risk impact in Phase X.

Table 7.15: Overall and normalised utility function for risk impact

Risk impact	T	normalised T
Risk X01	0.120	0.078
Risk X02	0.094	0.061
Risk X03	0.139	0.090
Risk X04	0.767	0.499
Risk X05	0.417	0.271
	Total =	1.000

7.4.1.3 Risk exposure - multi-attribute utility theory

After risk probability and risk impact have been determined for every risk in Phase X, risk exposure can be calculated as the product of risk probability and risk impact. Table 7.16 shows this calculation.

Table 7.16: Calculating risk exposure in Phase X

PHASE X	PROBABILITY		IMPACT		RISK EXPOSURE
Risk X01	0.091	x	0.078	=	**0.007**
Risk X02	0.039	x	0.061	=	**0.002**
Risk X03	0.279	x	0.090	=	**0.025**
Risk X04	0.469	x	0.499	=	**0.234**
Risk X05	0.122	x	0.271	=	**0.033**

The risk exposure is used to form the risk priority list on the basis of which risk response will be planned. Table 7.17 shows the priority list in Phase X.

Table 7.17: Priority list in Phase X

PHASE X	RISK EXPOSURE
Risk X04	**0.234**
Risk X05	**0.033**
Risk X03	**0.025**
Risk X01	**0.007**
Risk X02	**0.002**

7.4.2 FUZZY ANALYSIS

Often measured or forecast values are used as input data in decision-making. To obtain a reliable assessment of measurement or forecasting results these values may be expressed in the form of fuzzy numbers, that is, as intervals that are used in further analysis. This analysis is called a fuzzy analysis (Dubois and Prade, 1985; Klir and Yuan, 1995; Cox, 1999). Ross and Donald, 1995; Kangari and Rigs, 1988; Tah and Carr, 2000; Wong, Norman and Flanagan, 2000, and others, used fuzzy analysis in risk management.

To avoid assuming distribution functions for the utility function, Wong, Norman and Flanagan (2000) incorporated fuzzy numbers into the multi-attribute utility theory. The minimum, most likely and maximum value of each utility function is expressed in the form of fuzzy numbers, and the overall utility function for each identified risk is also obtained in the form of a fuzzy number. Their idea served as the starting point for the qualitative risk analysis technique proposed in this framework.

The risk priority list is calculated in 5 steps.

The first, second and third step are almost the same as in the multi-attribute utility theory. In the first step one or more criteria are defined with respect to which the offered alternatives will be weighted. In the second step weight interdependency of the given criteria is defined. In the third step the utility function is formed for every criterion, using the so-called certainty equivalent method in which the decision-maker gives a subjective assessment of the discrete values of the utility function, after which these values are fitted using an exponential, logarithmic or polynomial function.

In the fourth step the minimum, most likely and maximum values of the utility function are calculated for each alternative with respect to all the criteria given, after which these values are turned into the corresponding fuzzy numbers.

In the fifth step the fuzzy representation of the overall utility function is calculated for each alternative, and certain arithmetical operations on elements of the fuzzy numbers give a discrete representation of the overall utility function according to which the priority list of alternatives is formed.

The continuation will show how fuzzy analysis is used to determine risk probability, risk impact and risk exposure for one phase in the Process Protocol.

7.4.2.1 Risk probability - fuzzy analysis

Risk probability is the only criterion with respect to which alternatives are weighted. This is a case of single-criterion analysis. The alternatives are the risks of Phase X.

A qualitative assessment is first made for the occurrence of each identified risk in Phase X, by assessing its minimum, most likely and maximum probability. Since this step is the same as the one shown in Section 7.4.1.1, the assessments in Table 7.5. may be used.

Then the utility function is determined for the risk probability criterion is in the same way as in Section 7.4.1.1. Table 7.6 shows the values of the utility function for risk probability in Phase X obtained in this way.

The values of the utility function shown in Table 7.6 are fitted by a polynomial function as follows:

$$U(riskprob) = 2.917367244*riskprob^3 - 2.54623541*riskprob^2 + $$
$$+ 1.589225759*riskprob - 0.1364856845$$

Then the minimum, most likely and maximum values of the utility function are calculated for each alternative. Table 7.18 shows the calculation for Phase X.

Table 7.18: Value of utility function for risk probability

U(riskprob)	Minimum	Most likely	Maximum
Risk X01	0.103	0.139	0.190
Risk X02	0.000	0.065	0.103
Risk X03	0.340	0.439	0.531
Risk X04	0.531	0.729	1.000
Risk X05	0.139	0.190	0.242

The minimum, most likely and maximum utility function value for each identified risk in Phase X must be turned into the corresponding fuzzy numbers. The same *L-R* representation of fuzzy numbers as the one used by Wang, Norman and Flanagan (2000), will be used. A fuzzy number *M* is called an *L-R* fuzzy number if its membership function is defined by

$L[(m - x) / \alpha]$ $\quad x > m,\ \alpha > 0$

$\mu M(x) = 1$ $\quad x = m$

$R[(x - m) / \beta]$ $\quad x > m,\ \beta > 0$

where L and R are monotonic non-increasing functions, *m* is the mean value of M and α and β are called the left and right spreads, respectively. When the spreads are zero, *M* is a crisp number. As the spreads increase, M becomes fuzzier. Symbolically, the *L-R* fuzzy number *M* is represented by tree parameters and is denoted by $M = (m, \alpha, \beta)_{LR}$.

Table 7.19 shows the fuzzy representation of the minimum, most likely and maximum utility function values for each identified risk in Phase X, that is, the corresponding fuzzy numbers.

Table 7.19: Fuzzy representation of the utility function for risk probability

Fuzzy numbers	m	α	β
Risk X01	0.144	0.041	0.046
Risk X02	0.056	0.056	0.047
Risk X03	0.436	0.097	0.094
Risk X04	0.753	0.222	0.246
Risk X05	0.190	0.051	0.052

Fuzzy numbers are used to obtain reliable risk probability assessment. The mean value m represents the measured value, and α and β represent variability, that is the unreliability of the assessed value. The smaller they are the greater the confidence in the assessed value. This is why the mean value m, decreased by the average of the α and β spreads, is a good representative of the overall utility function. Table 7.20 shows the calculation of the overall utility function for risk probability, and its normalised value that will serve to calculate risk exposure.

Table 7.20: Overall normalised utility function for risk probability

Risk probability	T = m-(α+β)/2	normalised T
Risk X01	0.100	0.091
Risk X02	0.004	0.004
Risk X03	0.341	0.309
Risk X04	0.519	0.471
Risk X05	0.138	0.125
	Total =	1.000

7.4.2.2 Risk impact - fuzzy analysis

There are three criteria or attributes for determining risk impact: time, cost and quality. The alternatives are the risks in Phase X.

First the weighting and interdependency of the given criteria are defined in such a way that the sum of all the weights equals 1. Let the same weight values as in Section 7.4.1.2 be assessed for Phase X:

$W_{TIME} = 0.3$

$W_{COST} = 0.6$

$W_{QUALITY} = 0.1$

A qualitative assessment of impact on time, cost and quality is made for each identified risk in Phase X by defining its minimum, most likely and maximum values. Since this step is the same as that shown in Section 7.4.1.2, the assessments in Tables 7.8, 7.9 and 7.10 may be used.

Then the corresponding utility functions are determined for all the criteria in the same way as in Section 7.4.1.1. Table 7.11 shows the discrete values of the utility functions thus obtained for risk probabilites in Phase X.

The values of the utility functions shown in Table 7.11 are fitted by polynomial functions as follows:

$U(TIME) = 0.0002175018285*TIME^2 + 0.0102269454*TIME - 0.05710946609$

$U(COST) = 2.417766721E\text{-}010*COST^2 + 1.766638533E\text{-}005*COST - 0.09429739803$

$U(QUALITY)=0.0001297253121*QUALITY^2+0.01092973123*QUALITY-0.1222607449$

After that the minimum, most likely and maximum values of the utility functions for each alternative with respect to all the given criteria are calculated and they are turned into fuzzy numbers. Tables 7.21, 7.22, 7.23, 7.24, 7.25 and 7.26 show the calculation for Phase X.

Table 7.21: Values of the utility function for TIME

U(TIME)	Minimum	Most likely	Maximum
Risk X01	0.000	0.082	0.145
Risk X02	0.097	0.162	0.234
Risk X03	0.000	0.039	0.067
Risk X04	0.756	0.844	1.000
Risk X05	0.273	0.356	0.469

Table 7.22: Fuzzy representation of the utility function for TIME

TIME fuzzy	m	α	β
Risk X01	0.076	0.076	0.070
Risk X02	0.165	0.068	0.070
Risk X03	0.036	0.036	0.032
Risk X04	0.866	0.110	0.132
Risk X05	0.366	0.093	0.103

Table 7.23: Values of the utility function for COST

U(COST)	Minimum	Most likely	Maximum
Risk X01	0.000	0.153	0.302
Risk X02	0.000	0.063	0.153
Risk X03	0.107	0.176	0.225
Risk X04	0.653	0.820	1.000
Risk X05	0.302	0.411	0.498

Table 7.24: Fuzzy representation of the utility function for COST

COST fuzzy	m	α	β
Risk X01	0.152	0.151	0.150
Risk X02	0.072	0.072	0.081
Risk X03	0.169	0.063	0.056
Risk X04	0.824	0.171	0.175
Risk X05	0.404	0.102	0.095

Table 7.25: Values of the utility function for QUALITY

U(QUALITY)	Minimum	Most likely	Maximum
Risk X01	0.000	0.071	0.148
Risk X02	0.000	0.056	0.132
Risk X03	0.148	0.250	0.380
Risk X04	0.071	0.198	0.322
Risk X05	0.419	0.632	1.000

Table 7.26: Fuzzy representation of the utility function for QUALITY

QUALITY fuzzy	m	α	β
Risk X01	0.073	0.073	0.075
Risk X02	0.063	0.063	0.069
Risk X03	0.259	0.111	0.121
Risk X04	0.197	0.126	0.125
Risk X05	0.684	0.265	0.317

The overall utility function for each identified risk in Phase X is calculated as follows:

$T = W_{TIME} * U_{TIME} + W_{COST} * U_{COST} + W_{QUALITY} * U_{QUALITY}$

for *m*

For risk X01 - T_{X01} = 0.3*0.076 + 0.6*0.152 + 0.1*0.073 = 0.121

For risk X02 - T_{X02} = 0.3*0.165 + 0.6*0.072 + 0.1*0.063 = 0.099

For risk X03 - T_{X03} = 0.3*0.036 + 0.6*0.169 + 0.1*0.259 = 0.138

For risk X04 - T_{X04} = 0.3*0.866 + 0.6*0.824 + 0.1*0.197 = 0.774

For risk X05 - T_{X05} = 0.3*0.366 + 0.6*0.404 + 0.1*0.684 = 0.421

for α

For risk X01 - T_{X01} = 0.3*0.076 + 0.6*0.151 + 0.1*0.073 = 0.121

For risk X02 - T_{X02} = 0.3*0.068 + 0.6*0.072 + 0.1*0.063 = 0.070

For risk X03 - T_{X03} = 0.3*0.036 + 0.6*0.063 + 0.1*0.111 = 0.060

For risk X04 - T_{X04} = 0.3*0.110 + 0.6*0.171 + 0.1*0.126 = 0.148

For risk X05 - T_{X05} = 0.3*0.093 + 0.6*0.102 + 0.1*0.265 = 0.116

for β

For risk X01 - T_{X01} = 0.3*0.070 + 0.6*0.150 + 0.1*0.075 = 0.119

For risk X02 - T_{X02} = 0.3*0.070 + 0.6*0.081 + 0.1*0.069 = 0.077

For risk X03 - T_{X03} = 0.3*0.032 + 0.6*0.056 + 0.1*0.121 = 0.055

For risk X04 - T_{X04} = 0.3*0.132 + 0.6*0.175 + 0.1*0.125 = 0.157

For risk X05 - T_{X05} = 0.3*0.103 + 0.6*0.095 + 0.1*0.317 = 0.120

for $T = m - (\alpha + \beta) / 2$

For risk X01 -average T_{X01} = 0.121 - (0.121 + 0.119)/2 = 0.001

For risk X02 -average T_{X02} = 0.099 - (0.070 + 0.077)/2 = 0.026

For risk X03 -average T_{X03} = 0.138 - (0.060 + 0.055)/2 = 0.081

For risk X04 -average T_{X04} = 0.774 - (0.148 + 0.157)/2 = 0.622

For risk X05 -average T_{X05} = 0.421 - (0.116 + 0.120)/2 = 0.303

Table 7.27 shows the normalised values of the overall utility function that represent the risk impact in Phase X.

Table 7.27: Overall and normalised utility function for risk impact

Risk impact	T	normalised T
Risk X01	0.001	0.001
Risk X02	0.026	0.025
Risk X03	0.081	0.078
Risk X04	0.622	0.602
Risk X05	0.303	0.293
	Total =	1.000

7.4.2.3 Risk exposure - fuzzy analysis

After risk probability and risk impact have been determined for each risk in Phase X, risk exposure is calculated as a product of risk probability and risk impact. Table 7.28 shows the calculation.

Table 7.28: Calculating risk exposure in Phase X

PHASE X	PROBABILITY		IMPACT		RISK EXPOSURE
Risk X01	0.091	x	0.001	=	**0.000**
Risk X02	0.004	x	0.025	=	**0.000**
Risk X03	0.309	x	0.078	=	**0.024**
Risk X04	0.471	x	0.602	=	**0.284**
Risk X05	0.125	x	0.293	=	**0.037**

The risk exposure obtained is used to form a risk priority list, which will serve to plan risk response. Table 7.29 shows the priority list in Phase X.

Table 7.29: Priority list in Phase X - fuzzy analysis

PHASE X	RISK EXPOSURE
Risk X04	**0.284**
Risk X05	**0.037**
Risk X03	**0.024**
Risk X01	**0.000**
Risk X02	**0.000**

7.4.3 ANALYTIC HIERARCHY PROCESS (AHP)

Thomas L. Saaty (1980) developed the Analytic Hierarchy Process (AHP) as an aid to managers in making decisions. Subjective assessments and objective facts are incorporated into a logical hierarchical AHP framework to provide decision-makers with an intuitive and common sense approach in quantifying the importance of each decision element through a comparison process. This process enables decision-makers to reduce a complex problem to a hierarchical form with several levels (Saaty and Forman, 1993).

Mustafa and Al-Bahar (1991), Dey, Tabucanon and Ongunlana (1994), Dey (1999) and Dey (2001) used the AHP in qualitative risk analysis.

Generally, the hierarchy has at least three levels: goal, criteria and alternatives (Saaty, 1995). Criteria may have sub-criteria (Figure 7.7.).

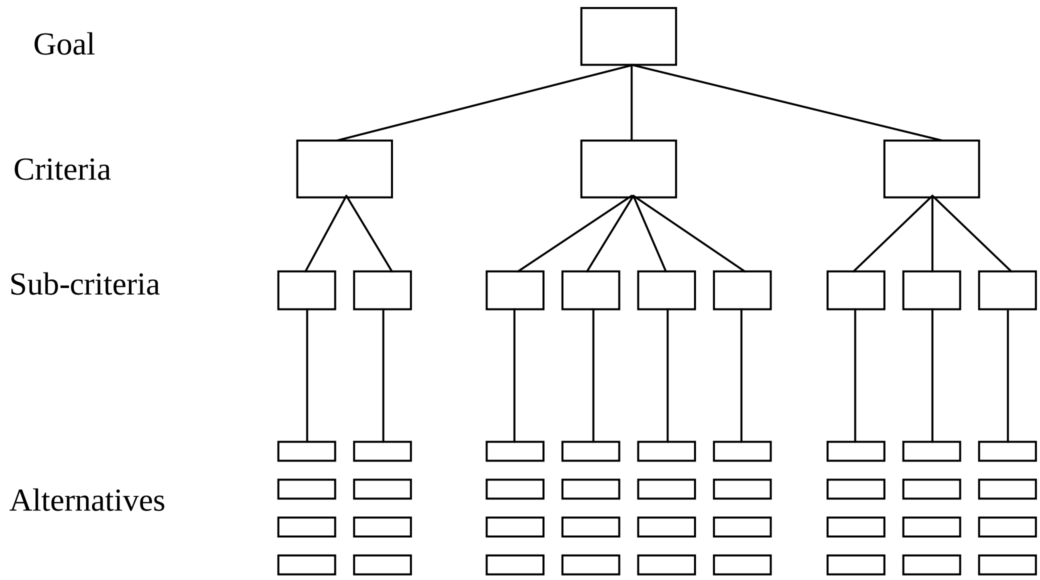


Figure 7.7: Hierarchical model structure

The process starts by determining the relative importance of particular alternatives with respect to the criteria and the sub-criteria (Saaty and Kearns, 1991). Then the criteria are compared with respect to the goal. Finally the results of these two analyses are synthesised by calculating the relative importance of the alternatives with respect to achieving the goal. The process of comparison is represented by forming a comparative matrix (Saaty, 1992). If the analyst has at his disposal *n* alternatives, or criteria that form the comparative matrix, then he must make n(*n*-1)/2 evaluations (Saaty and Vargas, 1991).

The eigenvector of each comparative matrix is the priority list, while the eigenvalue gives the measure of consistency in making the assessment or comparison. The synthesised eigenvector is the global sequence of the alternatives with respect to achieving the goal. A global consistency coefficient smaller than 0.10 is acceptable, otherwise the assessments must be revised.

The eigenvector and the maximum eignevalue of the comparative matrix are determined by solving the general problem of eignevalues:

$$AW = \lambda_{max}W$$

where

A – comparative matrix,

$W = (W_1, W_2, W_3, W_4, W_5)^T$ – eigenvector, and

λ_{max} – maximum eigenvalue.

AHP can best be used for multi-criteria problems in which it is not possible to precisely quantify how alternatives impact decision-making.

The risk priority list is calculated in 5 steps.

The first step in applying this model is dividing the problem into one or more criteria which will be used to weight the alternatives offered. This means that it is necessary to define the hierarchical levels: goal, criteria, sub-criteria and alternatives.

The second step is forming comparative matrices for all hierarchical levels.

The third step is calculating regional eigenvectors and eigenvalues for the comparative matrices for all hierarchical levels. On the level of criteria the regional eigenvector defines the priority, with respect to weight, of the individual criteria for achieving the goal, while on the level of alternatives the regional eigenvector defines the priority of the alternatives with respect to the given criterion.

The fourth step is calculating the consistency coefficient for each comparative matrix on all levels, and this is determined from the eigenvalue of the comparative matrix. If the consistency coefficient exceeds 0.10 then inconsistent assessments were made in forming the comparative matrices on particular hierarchical levels and such matrices must be formed anew. If the consistency coefficient is smaller than 0.10 then it is possible to move on to the next step.

The fifth step is synthesising the calculation results from all levels and weighting each alternative in relation to achieving the goal. The global eigenvector and the global consistency index are calculated. If the global consistency index exceeds 0.10 then inconsistent judgments still exist and the comparative matrices must be redefined. If the consistency index is smaller than 0.10 then the process of defining the weight and interdependency of the alternatives with respect to the given goal has been concluded.

7.4.3.1 Risk probability - AHP

When there is no database for a particular risk and it is impossible to assess the probability of its occurrence quantitatively, a qualitative assessment is made by assessing how much more or less probable the occurrence of this risk is with respect to all the other risks in the phase. Successive qualitative assessments using AHP leads to a relative distribution of risk probability in a particular phase. This makes the sum of the probabilities of all the risks in a phase equal to 1.

For Phase X, whose priority list is being determined, the procedure begins by forming the hierarchical structure. The goal is the risk probability. There are no criteria and sub-criteria. The risks of Phase X are the alternatives. Fig. 7.8 shows the hierarchical structure.

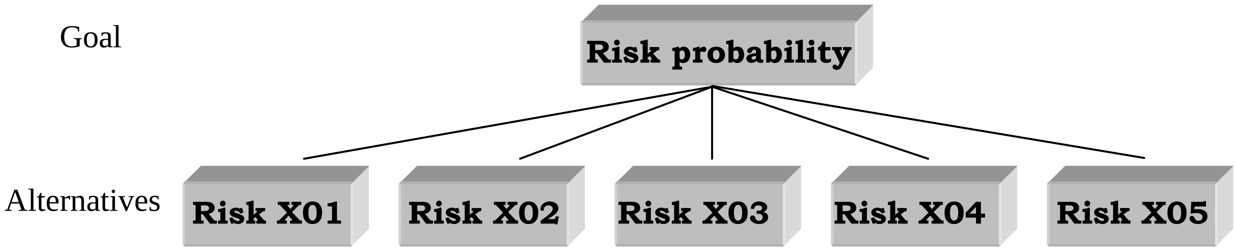


Figure 7.8: Hierarchical structure for risk probability in Phase X

After the hierarchical structure has been defined, the comparative matrix is formed in which the relative interdependency is defined of the probabilities for the appearance of all identified risks in Phase X.

Table 7.30 shows a comparative matrix for Phase X. A total of 10 assessments were made for the relative probability of all the identified risks in Phase X. For example, risk X01 was assessed to be 3 times more probable than risk X02 and 4 times less probable than risk X03.

Table 7.30: Comparative matrix for risk probability in Phase X

Risk probability	Risk X01	Risk X02	Risk X03	Risk X04	Risk X05
Risk X01	1/1	3/1	1/4	1/5	1/3
Risk X02	1/3	1/1	1/6	1/7	1/5
Risk X03	4/1	6/1	1/1	1/2	4/1
Risk X04	5/1	7/1	2/1	1/1	5/1
Risk X05	3/1	5/1	1/4	1/5	1/1

Solving the general problem of eigenvalues gives the eigenvector that represents the corresponding risk probability. Table 7.31 shows the eigenvector, maximum eigenvalue λ_{max}, row n of the matrix, consistency index CI and consistency ratio CR.

Table 7.31: Eigenvector, maximum eigenvalue λ_{max}, row n of the matrix, consistency index CI and consistency ratio CR for risk probability in Phase X

Risk probability	W	λ_{max}	n	CI	CR
Risk X01	0.076	5.312	5	0.078	**0.070**
Risk X02	0.039				
Risk X03	0.302				
Risk X04	0.448				
Risk X05	0.136				
	$\Sigma = 1.000$				

Since CR < 0.1 it may be assumed that consistent judgments were made.

7.4.3.2 Risk impact - AHP

When risk impact cannot be quantitatively calculated it is necessary to qualitatively weight the impacts of all the risks in a phase with respect to time, costs and quality.

For Phase X, whose priority list is being determined here, a hierarchical structure is formed on two levels. The goal is the risk impact. The criteria are time, cost and quality. There are no sub-criteria. The alternatives are the risks in Phase X. Fig. 7.9 shows the hierarchical structure.

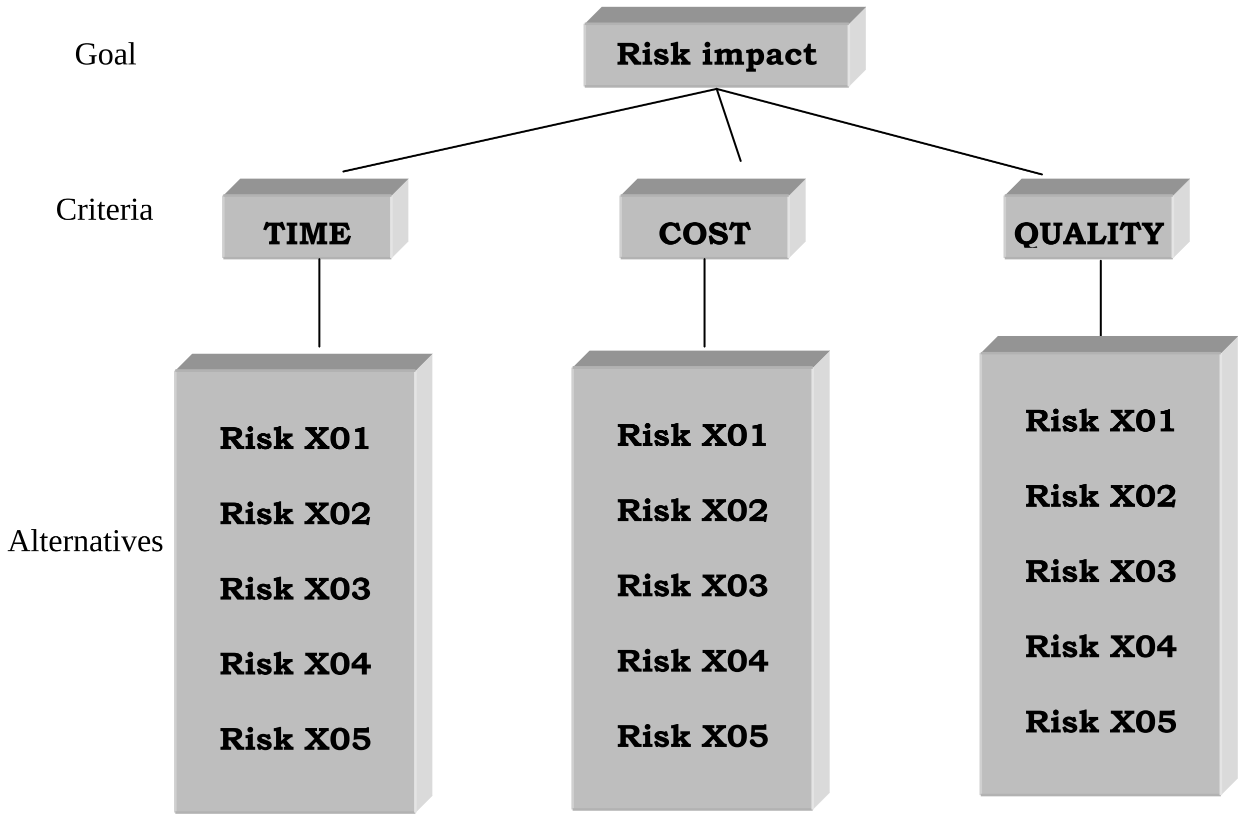


Figure 7.9: Hierarchical structure for risk impact in Phase X

Priorities with respect to time, cost and quality differ among various construction projects depending on many factors. Although it is important to keep the planned costs under control in every project, often the deadline for finishing a project is much more important than increased costs, and when life-threatening situations appear in the execution of a facility, then quality control becomes much more important than both deadlines and costs. This is why the first step for every project phase must be to assess the interdependency of lengthening time, increasing costs and decreasing quality.

Table 7.32 gives an example of a comparative matrix showing the interdependency of time, cost and quality for Phase X. A total of 3 assessments were made. In Phase X time was assessed to be 3 times less important than costs and twice more important than quality, while costs are 6 times more important than quality.

Table 7.32: Comparative time, cost and quality matrix in Phase X

Risk impact	TIME	COST	QUALITY
TIME	1/1	1/3	2/1
COST	3/1	1/1	6/1
QUALITY	1/2	1/6	1/1

Solving the general problem of eigenvalues gives the eigenvector that represents the time, cost and quality interdependency in Phase X. Table 7.33 shows the eigenvector, maximum eigenvalue λ_{max} , row n of the matrix, consistency index CI and consistency ratio CR.

Table 7.33: Eigenvector, maximum eigenvalue λ_{max}, row n of the matrix, consistency index CI and consistency ratio CR for time, cost and quality interdependency in Phase X

Risk impact	W	λ_{max}	n	CI	CR
TIME	0.222	3.00	3	0.00	**0.00**
COST	0.667				
QUALITY	0.111				
	$\Sigma = 1.000$				

The consistency index CI and consistency ratio CR equal zero because completely consistent judgments were made. In this case the eigenvalue is equal to the row of the comparative matrix.

The next step is weighting the impact of risks in Phase X on time, cost and quality. First the impact of identified risks in a particular phase on time is observed. In some cases it is possible to calculate the impact precisely, in others a qualitative assessment is necessary. Each risk is viewed with respect to its greater or smaller assessed impact on time in comparison with that of all the other risks in the phase. AHP gives weighting and interdependency of all the risks in a phase with respect to time.

Table 7.34 shows the comparative matrix for Phase X. A total of 10 assessments were made of the interdependency of risk impact on time in Phase X. For example, it was estimated that risk X04 impacts time 3 times more than risk X03, and 6 times less than risk X04.

Table 7.34: Comparative matrix for risk impact on time for Phase X

TIME	Risk X01	Risk X02	Risk X03	Risk X04	Risk X05
Risk X01	1/1	1/2	3/1	1/6	1/4
Risk X02	2/1	1/1	4/1	1/5	1/3
Risk X03	1/3	1/4	1/1	1/8	1/5
Risk X04	6/1	5/1	8/1	1/1	3/1
Risk X05	4/1	3/1	5/1	1/3	1/1

Solving the general problem of eigenvalues gives the eigenvector that represents the impact of each risk on time. Table 7.35 shows the eigenvector, maximum eigenvalue λ_{max}, row n of the matrix, consistency index CI and consistency ratio CR.

Table 7.35: Eigenvector, maximum eigenvalue λ_{max}, row n of the matrix, consistency index CI and consistency ratio CR for risk impact on time in Phase X

TIME	W	λ_{max}	n	CI	CR
Risk X01	0.078	5.180	5	0.048	**0.040**
Risk X02	0.120				
Risk X03	0.041				
Risk X04	0.511				
Risk X05	0.250				
	$\Sigma = 1.000$				

Since CR < 0.1 it may be considered that consistent judments were made.

The process continues by weighting the impact of the risks in Phase X on costs. AHP gives weighting and interdependency of all the risks in the phase with respect to costs.

Table 7.36 is an example of a comparative matrix for Phase X. A total of 10 assessments were made about the relative interdependency of risk impact on cost in Phase X. For example, Risk X01 was assessed to have a twice greater impact on cost than risk X02 and the same impact on cost as risk X03.

Table 7.36: Comparative matrix for risk impact on cost in Phase X

COST	Risk X01	Risk X02	Risk X03	Risk X04	Risk X05
Risk X01	1/1	2/1	1/1	1/4	1/2
Risk X02	1/2	1/1	1/2	1/4	1/4
Risk X03	1/1	2/1	1/1	1/3	1/2
Risk X04	4/1	4/1	3/1	1/1	2/1
Risk X05	2/1	4/1	2/1	1/2	1/1

Solving the general problem of eigenvalues gives a eigenvector that represents the impact of each risk on cost. Table 7.37 shows the eigenvector, maximum eigenvalue λ_{max}, the row n of the matrix, consistency index CI and consistency ratio CR.

Table 7.37: Eigenvector, maximum eigenvalue λ_{max}, the row n of the matrix, consistency index CI and consistency ratio CR for risk impact on cost in Phase X

COST	W	λ_{max}	n	CI	CR
Risk X01	0.126	5.045	5	0.011	**0.010**
Risk X02	0.073				
Risk X03	0.132				
Risk X04	0.418				
Risk X05	0.251				

$\Sigma = 1.000$

Since CR < 0.1 it may be considered that consistent judgments were made.

The procedure ends in the weighting the risk impact on quality in Phase X. AHP gives weighting and interdependency of all the risks in one phase with respect to quality.

Table 7.38 is an example of a comparative matrix for Phase X. A total of 10 assessments were made for the interdependency of risk impact on quality in Phase X. For example, Risk X01 was assessed to have the same impact on quality as Risk X02, and a 4 times smaller impact than Risk X05.

Table 7.38: Comparative matrix for risk impact on quality for Phase X

QUALITY	Risk X01	Risk X02	Risk X03	Risk X04	Risk X05
Risk X01	1/1	1/1	1/2	1/3	1/4
Risk X02	1/1	1/1	1/5	1/4	1/6
Risk X03	2/1	5/1	1/1	2/1	1/2
Risk X04	3/1	4/1	1/2	1/1	1/2
Risk X05	4/1	6/1	2/1	2/1	1/1

Solving the general problem of eigenvalues gives an eigenvector that represents the impact of each risk on quality. Table 7.39 shows the eigenvector, maximum eigenvalue λ_{max}, row n of the matrix, consistency index CI and consistency ratio CR.

Table 7.39: Eigenvector, maximum eigenvalue λ_{max}, row n of the matrix, consistency index CI and consistency ratio CR for risk impact on quality in Phase X

QUALITY	W	λ_{max}	n	CI	CR
Risk X01	0.086	5.136	5	0.034	**0.030**
Risk X02	0.062				
Risk X03	0.259				
Risk X04	0.200				
Risk X05	0.393				

$\Sigma = 1.000$

Since CR < 0.1 it may be assumed that consistent judgments were made.

After all these judgments have been made the calculation results on all levels are synthesised. The global eigenvector and global consistency coefficient are calculated. The global eigenvector is the risk impact of Phase X for each identified risk, and the global consistency index is the total evaluation of assessment consistency on all levels.

As in the case of the quantitative approach, the global eigenvector is calculated by the simple technique of weighting with averaging. The eigenvectors of Level 1 multiplied by the eigenvectors of Level 2, and added up for each criterion, give the global eigenvector. Table 7.40 shows this calculation.

Table 7.40: Calculating impact in Phase X

	TIME		COST		QUALITY	Risk impact
Risk X01	0.222 x 0.078	+	0.667 x 0.126	+	0.111 x 0.086	= 0.111
Risk X02	0.222 x 0.120	+	0.667 x 0.073	+	0.111 x 0.062	= 0.082
Risk X03	0.222 x 0.041	+	0.667 x 0.132	+	0.111 x 0.259	= 0.126
Risk X04	0.222 x 0.511	+	0.667 x 0.418	+	0.111 x 0.200	= 0.414
Risk X05	0.222 x 0.250	+	0.667 x 0.251	+	0.111 x 0.393	= 0.267
					Total	= 1.000

The global consistency ratio is calculated by simply averaging the regional consistency ratios on Levels 1 and 2. For Phase X:

CR = (0.00 + 0.04 + 0.01 + 0.03) / 4 = 0.02

As the global consistency ratio CR=0.02 < 0.10 it is considered that assessment was consistent.

7.4.3.3 Risk exposure

After risk probability and risk impact have been determined for each risk in Phase X, risk exposure can be calculated as the product of risk probability and risk impact. Table 7.41 shows this calculation.

Table 7.41: Calculating risk exposure in Phase X

PHASE X	PROBABILITY		IMPACT		RISK EXPOSURE
Risk X01	0.076	x	0.111	=	0.008
Risk X02	0.039	x	0.082	=	0.003
Risk X03	0.302	x	0.126	=	0.038
Risk X04	0.448	x	0.414	=	0.185
Risk X05	0.136	x	0.267	=	0.036

The priority risk list is formed on the basis of risk exposure, and will be used in planning risk response. Table 7.42 shows the priority list in Phase X.

Table 7.42: Priority list in Phase X

PHASE X	RISK EXPOSURE
Risk X04	0.185
Risk X03	0.038
Risk X05	0.036
Risk X01	0.008
Risk X02	0.003

7.4.4 CHOOSING A QUALITATIVE APPROACH TECHNIQUE

All the three techniques described can be used for qualitative risk analysis in the proposed framework. They can all be programmed and can be included in the corresponding software support for decision-making. The presentation of all the methods for Phase X showed that their use is not complicated or time consuming.

The multi-attribute utility theory is the oldest and certainly the most widespread decision-making support technique. For the decision-maker to use it in the proposed framework, he must have certain knowledge of and experience in statistics and probability theory because the assessed data must be replaced by the corresponding probability distribution function. In applying the method in risk analysis a certain amount of experience is necessary to assess which distribution to choose and how many of its statistical parameters to use in analysis. In the example shown for Phase X one parameter (mean) was used. Since the other statistical moments (variance, skewness, etc.) show a measure of uncertainty or reliability of the assessed values used in analysis, their use would quite certainly enhance confidence in the impartiality of the technique itself. However, a greater number of statistical parameters in a chosen distribution results in a proportionately greater degree of derivability of the utility functions for each criterion. The higher the degree of derivability, the greater the need of discrete utility-function values for its better approximation, and these are reached in a series of assessments made by the decision-maker using the so-called certainty equivalent method. Considering that this is a qualitative technique and that the input data are assessed values, it is rather questionable to introduce a larger number of statistical parameters that in their turn result in the need for making additional assessments. Thus the use of this technique in the proposed framework demands a degree of experience.

The introduction of fuzzy numbers and fuzzy analysis in calculating the overall utility function is an extension, or better a modification, of the multi-attribute utility theory. It is used to avoid assuming the type of the probability distribution function for input data, which are in any case an assessment of the values of the criteria or alternatives. In this method the assessed values are replaced by their fuzzy representation which is completely determined and is increasingly being used to obtain reliable measurement or forecasting results. It is also used to avoid assessing the number of statistical parameters to be used in analysis, and thus also the need for the utility functions to have a higher degree of derivability. Although the final result, the risk priority list, will be rather similar because the technique is basically the same, this kind of approach is simpler, more understandable and faster for the decision-maker. It does not require any additional requirements and is a better solution than the multi-attribute utility theory.

Whereas risk probability, that is risk impact on time, cost and quality are determined independently of one another in the multi-attribute utility theory and in fuzzy analysis, by calculating the values of the overall utility function, in AHP the risk priority list is calculated through their comparison. When there is not enough data to quantify particular values a qualitative approach is used. It is therefore more natural and intuitive for the decision-maker to compare those values with one another than to try to determining their edge values, or at least their minimum, most likely and maximum values. For example, available information and experience often make it easier to assess that an event will do twice more damage than another event, than to try to quantify the extent of the actual damage caused by either or both of them. It has already been said that the risk exposure of one risk is of no usable value and gains significance only when compared with the risk exposure of one or several other risks. Since the goal parameter in the proposed framework is risk exposure, used to determine risk acceptability and risk response, comparing the elements that make up the risk exposure of all the identified risks in a phase imposes itself as the most natural technique. In AHP no knowledge is necessary of statistics, probability distribution functions or fuzzy numbers and their meaning. It is only necessary to consistently compare alternatives with respect to criteria and criteria with respect to the goal.

The most important reason to give AHP priority over the other two techniques is the fact that it is the only method that enables, i.e. allows, what is known as rank reversal. One of the axioms of the utility theory says that adding a new alternative to the decision problem can never change the order of the old alternatives, i.e. that a non-optimal alternative cannot become optimal by adding a new non-optimal alternative to the decision problem (Luce and Raiffa, 1957). If, for example, the value of the overall utility function for the new alternative is smaller than the value of the overall utility function for all the other alternatives, then the new alternative will take the last place on the list and will have no effect on the order of the alternatives above it. The same is true in fuzzy analysis because it uses the same technique for determining the priority list. This situation is logical, expected and desirable in most decision problems. However, there are certain situations, such as multi-criteria decision problems, in which the above axiom essentially restricts all utility theories, i.e. does not allow the decision-making technique to give the expected results. Luce and Raiffa (1957) showed one such example that restricts the usability of utility techniques. At a restaurant of unknown quality, a man who loves and can afford steak, when offered less expensive broiled salmon or more expensive steak, orders salmon rather than risking paying double the price of salmon for a steak of questionable quality. He is then quickly told, with an apology, that the restaurant also has fried snails and frog legs at a price comparable to that of steak. The man shudders quietly at the thought of eating them, but then changes his order from salmon to steak. He reasons that this is a restaurant of high culinary discrimination and would serve a good steak. Thus, the presence of a non-optimal alternative (snails and frog legs, which he hates) can affect the rank of an old alternative. Although the reasons why a restaurant guests chooses a particular kind of food in real life are completely understandable, by applying the utility technique steak could never become more desirable than broiled salmon just because of the appearance of snails and frog legs, as the most undesirable of all the dishes. However, by using AHP steak can jump broiled salmon on the priority list. Let the criteria for choosing food be benefits and risks. The appearance of a new dish will not affect the hierarchy with respect to benefits because the guest hates snails and frog legs. However, the appearance of the new dish will essentially affect the hierarchy with respect to risks because its appearance considerably decreased the risk, in the guest’s eyes, that the restaurant does not serve good steak. Salmon will now lose the advantage it had over steak with respect to risk. By combining benefit and risk, steak will pass salmon on the list and snails and frog legs will remain in bottom place, thus leading to rank reversal.

The restaurant situation described above is very similar to what happens when the risk priority list is formed, where rank reversal is expected. In the proposed framework risk impact is determined and risks are given priority with respect to time, cost and quality. The cyclical risk management process is carried out in each phase of the construction process. After risk probability and risk impact have been determined for every key risk identified, and thus also risk exposure, a priority risk list is formed and risk response strategy is defined, depending on risk acceptability. If new risks appear as the result of risk response, a new cycle of risk identification, analysis and response begins. When risk impact is compared with that of the risks identified earlier, the new risk may have a very great impact on time, a negligible or equal impact on cost and quality. This great impact on time of the new risk will decrease the relative value of the impacts on time of risks that previously dominated in this sense, so risks that dominated with respect to cost or quality may now climb higher on the risk list. In other words, when a new risk appeared that may essentially affect construction time then the longer construction time in earlier risks got less impact than the costs that this prolongation might produce, so rank reversal is natural and expected.

Rank reversal cannot occur in the multi-attribute utility theory or fuzzy analysis. The capacity of AHP to solve cases of this kind will be shown below.

Let a risk priority list of only two risks be formed in a phase. Let time, cost and quality be equally important for the project. Table 7.43 shows the comparative matrix and corresponding eigenvector for time, cost and quality.

Table 7.43: Comparative time, cost and quality matrix in Phase X.

Risk impact	TIME	COST	QUALITY	W
TIME	1/1	1/1	1/1	0.333
COST	1/1	1/1	1/1	0.333
QUALITY	1/1	1/1	1/1	0.333

Now the impact of the two risks on time, cost and quality is weighted. Table 7.44 shows the comparative matrices and the corresponding eigenvector for impact on time, cost and quality for both risks. The comparative matrix shows that Risk X01 predominates over Risk X02 with respect to time, is inferior with respect to cost, and they both have the same impact on quality. All the judgments were made completely consistently so the consistency ratios equal zero on all levels of decision-making.

Table 7.44: Comparative matrix and eigenvector for risk impact on time, cost and quality for two risks

TIME	Risk X01	Risk X02	W
Risk X01	1/1	3/1	0.750
Risk X02	1/3	1/1	0.250
COST	Risk X01	Risk X02	W
Risk X01	1/1	1/2	0.333
Risk X02	2/1	1/1	0.667
QUALITY	Risk X01	Risk X02	W
Risk X01	1/1	1/1	0.500
Risk X02	1/1	1/1	0.500

Synthesising the calculation results on all levels of decision-making gives the global eigenvector that represents the risk priority list. Table 7.45 shows the calculation result. It can be seen that Risk X01 has a greater impact than Risk X02.

Table 7.45: Risk impact on time, cost and quality for two risks

	Risk impact
Risk X01	0.528
Risk X02	0.472

Let a new Risk X03 now appear, which will predominate with respect to time, be inferior with respect to cost and equal to the other risks with respect to quality. Table 7.46 shows the comparative matrix and corresponding eigenvector for time, cost and quality.

Table 7.46: Comparative matrix and eigenvector for risk impact on time, cost and quality for three risks

TIME	Risk X01	Risk X02	Risk X03	W
Risk X01	1/1	3/1	1/2	0.300
Risk X02	1/3	1/1	1/6	0.100
Risk X03	2/1	6/1	1/1	0.600
COST	Risk X01	Risk X02	Risk X03	W
Risk X01	1/1	1/2	4/1	0.308
Risk X02	2/1	1/1	8/1	0.615
Risk X03	1/4	1/8	1/1	0.077
QUALITY	Risk X01	Risk X02	Risk X03	W
Risk X01	1/1	1/1	1/1	0.333
Risk X02	1/1	1/1	1/1	0.333
Risk X03	1/1	1/1	1/1	0.333

Synthesising the calculation results on all levels of decision-making gives the global eigenvector that represents the risk priority list. Table 7.47 shows the calculation results. It can be seen that now Risk X01 has a smaller impact than Risk X02, and that Risk X03 is the lowest-ranking; its predominance with respect to time of has decreased the importance of the predominance of Risk X02 with respect to time and increased the importance of the predominance of Risk X02 with respect to cost.

Table 7.47: Risk impact on time, cost and quality for three risks

	Risk impact
Risk X01	0.359
Risk X02	0.395
Risk X03	0.245

From all the above it may be concluded that AHP is the most suitable technique for qualitative risk analysis in the proposed framework.

7.5 RISK PRIORITY LIST - MIXED APPROACH

The most usual case in real life is a combination of the quantitative and qualitative approach. For some risks in Phase X there will be a database for assessing their probability, that is, their impact on time, cost or quality. For others this will not be available. If risk probability can be calculated for all the risks in Phase X then the normalisation method should be used, i.e. the quantitative approach. If it cannot be calculated for at least one risk, then the risks for which calculation is possible should be normalised, and the qualitative approach used for the interdependency of the probabilities of those risks and the one for which calculation is not possible. The same procedure should be used for risk impact on time, cost or quality.

7.6 RISK ACCEPTABILITY

An acceptability assessment is made for each identified risk in Phase X, depending on its risk exposure, and methods are defined for managing it. Godfrey (1996) proposed a risk classification and the corresponding risk management for each category:

UNACCEPTABLE - Intolerable, must be eliminated or transferred.

UNDESIRABLE - To be avoided if reasonably practicable, detailed investigation and cost benefit justification required, top level approval needed, monitoring essential.

ACCEPTABLE - Can be accepted provided the risk is managed.

NEGLIGIBLE - No further consideration needed.

The link between risk acceptability and risk exposure results from the policy of the risk management team. It depends on the type and complexity of the facility, and on the experience gained in constructing similar facilities. Depending on the success of project realisation, this link may be changed from phase to phase.

In the lack of experience the starting link may be as shown in Table 7.48.

Table 7.48: Risk evaluation depending on risk exposure

RISK ACCEPTABILITY	RISK EXPOSURE
UNACCEPTABLE RISK	0.25 – 1.00
UNDESIRABLE RISK	0.11 – 0.25
ACCEPTABLE RISK	0.01 – 0.11
NEGLIGIBLE RISK	0.00 – 0.01

The values in the table were obtained as follows:

- If risk probability and risk impact are greater than 1/2 then risk acceptability is greater than 0.25 (0.5*0.5=0.25) and, of course, smaller than 1. This means that the risk has a high probability and a great impact, which means that this risk is more probable than all the other risks of the phase put together and that it has a greater impact than all the other risks of the phase put together. If risk probability falls below 0.5 by 20% (0.8*0.5 = 0.4) then risk impact must grow over 0.5 by 25% (1.25*0.5=0.625) for risk acceptability to remain within this category. The opposite is also true. If the risk satisfies all these conditions then it is unacceptable and the response to it may be risk avoidance or risk transfer.
- If risk probability and risk impact are greater than 1/3 and smaller than 1/2 then risk acceptability is between 0.11 and 0.25 (0.333*0.333=0.11). This means that the risk has a mean value and mean impact, and that this risk has between one third and one half probability and impact of all the other risks of the phase put together. Similarly as in the preceding category, if risk probability changes by, for example, 20% with reference to the values of 1/3 and 1/2, risk impact must change by 25% for the risk to remain in this category. Of course, the opposite is also true. If the risk satisfies all these conditions then it is undesirable and the risk response may be risk avoidance, risk transfer, risk reduction or risk sharing with the necessary risk monitoring.
- If risk probability and risk impact are greater than 1/10 and smaller than 1/3 then risk acceptability is between 0.01 and 0.11 (0.1*0.1=0.01). This means that the risk has a small probability and small impact, and it has between one tenth and one third probability and impact of all the other risks in the phase put together. Similarly as in the preceding categories, if risk probability changes by, for example, 20% with reference to 1/3 and 1/2, risk impact must change by 25% for the risk to remain in this category. Of course, the opposite is true as well. If the risk satisfies these conditions then it is acceptable and the response to it may be risk retention with the necessary risk monitoring.
- If risk probability and risk impact are smaller than 1/10 then risk acceptability is between 0.0 and 0.01. This means that the risk has a negligible probability and negligible impact, and that this risk has less than one tenth probability

and impact of all the other risks in the phase put together. Similarly as in the preceding categories, if risk probability changes by, for example, 20% with reference to the values of 1/3 and 1/2, risk impact must change by 25% for the risk to remain in this category. Of course, the opposite holds true as well. If the risk satisfies these conditions then it is negligible and no response to it is needed.

Table 7.49 shows risk acceptability in Phase X for the quantitative approach.

Table 7.50 shows risk acceptability in Phase X for the qualitative approach.

Table 7.49: Risk acceptability for Phase X - quantitative approach

PHASE X	RISK EXPOSURE	RISK ACCEPTABILITY	RISK RESPONSE
Risk X01	0.014	ACCEPTABLE	risk retention and monitoring
Risk X02	0.020	ACCEPTABLE	risk retention and monitoring
Risk X03	0.036	ACCEPTABLE	risk retention and monitoring
Risk X04	0.139	UNDESIRABLE	risk sharing and monitoring
Risk X05	0.042	ACCEPTABLE	risk retention and monitoring

Table 7.50: Risk acceptability in Phase X - qualitative approach

PHASE X	RISK EXPOSURE	RISK ACCEPTABILITY	RISK RESPONSE
Risk X01	0.008	NEGLIGIBLE	none needed
Risk X02	0.003	NEGLIGIBLE	none needed
Risk X03	0.038	ACCEPTABLE	risk retention and monitoring
Risk X04	0.185	UNDESIRABLE	risk sharing and monitoring
Risk X05	0.036	ACCEPTABLE	risk retention and monitoring

This kind of risk analysis is performed for each phase separately. If some activities, or some causes of risk, are carried from one phase to another, the corresponding risk is also transferred. Therefore it is necessary, after every phase, to once more single out all the risks that will be analysed in the next phase.

7.7 SUMMARY AND CONCLUSIONS

This chapter has shown the framework for process-driven risk management in construction projects based on the Process Protocol. For each identified risk in a particular phase it is necessary to determine risk probability and risk impact, and calculate the corresponding risk exposure. By determining risk exposure for all the identified risks in a phase and finding their interrelationship, a priority list can be formed. Depending on the position of the risk in the risk priority list, that is on the relative value of its exposure with reference to the other risks in the phase, resources will be engaged for the anticipated risk response. The risk priority list can be determined using a quantitative, qualitative or mixed approach.

The quantitative approach to forming the risk priority list implies that risk probability and risk impact can be explicitly calculated using one of the known quantitative methods of risk analysis. To do this the relevant database must be available to serve for forming the probability distribution, that is to enable the direct calculation of the impact on time, cost and quality.

The priority list is created using the qualitative approach when there is no database about earlier projects to use for the probability distribution function and for determining risk probability. All the necessary indicators for the direct calculation of the consequences, that is the impact that the risky event would have on time, cost or quality, are also missing. Three techniques are offered for qualitative risk analysis in the proposed framework: Multi-attribute Utility Theory, Fuzzy Analysis and Analytical Hierarchy Process (AHP). All the three are programmable and can be included in the corresponding software for decision-making support. A detailed analysis of all the three techniques shows that AHP is the most complete and most adaptable.

What usually happens in real life is a combination of the quantitative and qualitative approach.

For each identified risk in Phase X, depending on its risk exposure, a decision is made about its acceptability, that is, methods for managing it are defined. The link between risk acceptability and risk exposure is the result of the risk management team's policy. This depends on the type and complexity of the facility, and on experience gained by constructing similar facilities. Depending on success in realising the project, this link can change from phase to phase.

The next chapter deals with the IT support for risk management in construction projects according to the Process Protocol and based on the framework described.

8 THE PP-RISK MANAGEMENT PROGRAMME

8.1 INTRODUCTION

In the preceding chapter the framework was developed for process-driven risk management in Process Protocol based construction projects. The verification of the proposed framework, shown in the following chapter, and its application in future projects, would be very time consuming without the use of information technology.

This chapter shows the PP-Risk computer programme developed by the author, which supports all the elements of the framework for process-driven risk management presented in the preceding chapter. PP-Risk is an independent information system that satisfies all the elements of a decision support system. Holsapple and Whinston (1996) define a decision support system as a computer system that supports the decision-making process by helping the decision-maker to organise information, identify and access information necessary for making a decision, analyse and transform this information, chose methods and models suitable for solving the problem, apply those methods and models, and analyse the modelling results for the needs of the decision-maker. According to Stoner and Wankel (1986), a decision support system is an interactive computer system easily accessible for experts and decision-makers who are not IT specialists, that helps them in the functions of planning and deciding in business.

PP-Risk improves communication among all the Activity Zones of the Process Protocol by integrating all the information relevant for project realisation. Since the realisation of a construction project includes a large number of people with various levels of qualification, knowledge and interests, there is always a problem of communication and information exchange among them. Brandon and Betts (1995) show possibilities and ways of integrating information.

Aouad *et al*. (1997), Betts, (1992); Brandon (1993); Miyatake and Kangari (1993), Nam and Tatum (1992), Oliver (1994), Tucker *et al.* (1994), Wu *et al.* (2000) gave a comprehensive presentation of how to apply information technology in the construction industry and the benefits of this application. Major projects on creating an integrated information environment for construction project development of are ICON (Aouad *et al*., 1994), OSCON (Aouad *et al*., 1997), SPACE (Alshawi *et al*., 1996), COMMIT (Rezgui, 1996), IDAC-2 (Powel, 1996), COMBINE (Augenbroe, 1993; Dubois, 1995), ATLAS (Atlas, 1992), MOB (OTH, 1994), COMBI (Ammerman, 1994), RATAS (Bjork, 1989), IRMA (Luiten, 1993).

8.2 PP-RISK AS A DECISION SUPPORT SYSTEM

As an IT support for risk management in Process Protocol based construction projects the PP-Risk computer programme, as a Decision Support System (DSS), was developed in the MS Visual Basic 6 developmental environment on a Microsoft Windows platform. The basic components of PP-Risk are databases, methods, documents and user interface. Databases, methods and documents are accessed using the corresponding management systems, and the user accesses the entire system through a single user interface. Figure 8.1 shows the PP-Risk structure.

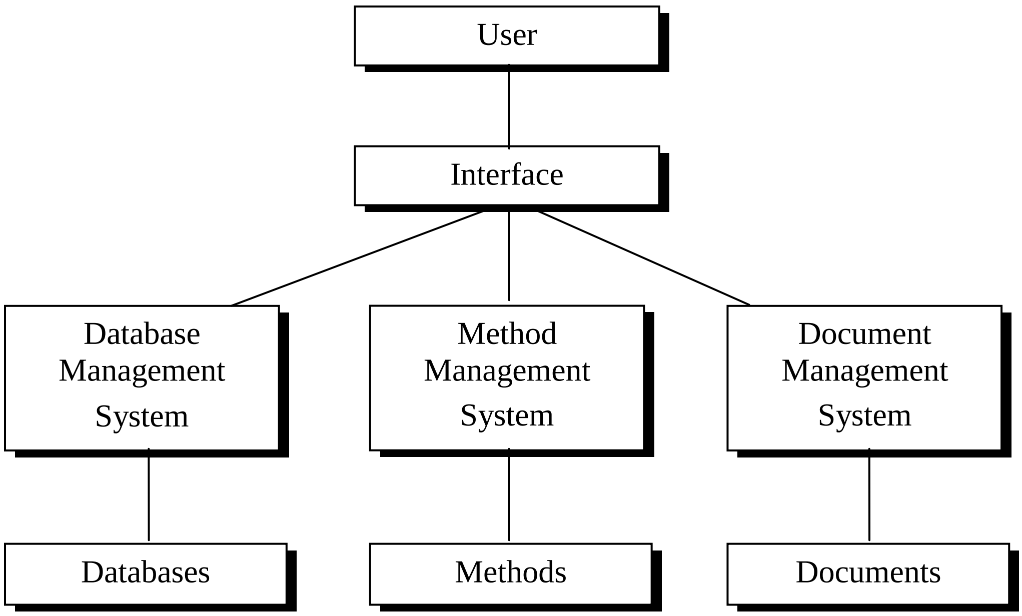


Figure 8.1: Structure of decision support system

8.2.1 INTERFACE

User interface includes the mechanisms necessary for data input, model application and data output. It is an extremely important component of the decision support system because for the user the interface is in fact the system itself. Obviously the user interface cannot make up for weaknesses in other parts of the system, but a badly designed interface may put users off even if the other parts of the system are well made.

The highest quality of user interface should be designed, according to Cook and Russell (1989), on the following principles:

1. Setting standards for the appearance of the screen.
2. Intuitive system use.
3. Easy-to-manage system (changing to different operations).
4. Possibility of changing interface parameters.
5. Short system response time.
6. All the parts, that is modules of the system must be operational from the main menu.
7. Use of standard business terms generally known to users.
8. Involving interface users in interface design.

The first five principles are automatically satisfied by using the MS Visual Basic 6 developmental environment for designing DSS. The appearance of the screen, method of system use, management process, interface parameters and response time are the same as in all standard Windows applications (Word, Excel, Access, PowerPoint) to which a large number of potential system users are already accustomed. The application of MS Visual Basic 6 is thus justified for this kind of application because it practically precludes the programmer from departing from the given principles.

The appearance of part of the main menu of PP-Risk, shown in Figure 8.2, demonstrates how Principle 6 has been satisfied. It can be seen that it is possible, from the main menu, to update the projects list, user list for a particular project, and the list of key risks, that is, of the risks that will be analysed in each phase.

Furthermore, it is possible to determine risk probability and risk impact, which determine risk exposure. Finally, it is possible to directly determine risk acceptability provided that all the necessary decisions have been made and stored in the database.

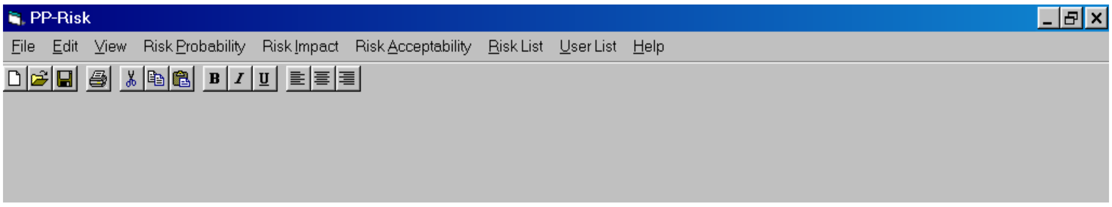


Figure 8.2: Main menu

Figure 8.2 also shows the satisfaction of Principle 7 because the terms used, such as risk probability, risk impact and risk acceptability, are generally accepted in risk management (see Chapter 2).

Principle 8 is satisfied by including the potential user in the process of framework verification, which is shown in the following chapter.

8.2.2 DATABASE MANAGEMENT SYSTEM

According to Smith and Amundsen (1998) the relation database is an integrated set of data saved in various kinds of entries, and is completely independent of the programme package that uses the database. Entries are interconnected through the meaning of the relationship among the saved databases.

The Database Management System (DBMS) allows the creation, use and preservation of interrelated databases. According to Norton and Groh (1998), the DBMS must provide its users with seven basic functions:

1. Definition – The system must ensure a method for creating and changing data structure.
2. Integrity – The system should use rules for data input or editing .
3. Storage - DBMS must contain data structurally defined according to its own rules.
4. Manipulation – System users must be able to add new, edit existing and delete unnecessary data in databases.

5. Recall – Users must be enabled to access and view data in the base.
6. Data share –Several users must be able to access data simultaneously.
7. Security – The system must prevent data damage and data access by unauthorised users.

Databases managed by MS Visual Basic 6 using the set of tools in Data Access Objects (DAO) consist of tables, which in turn consist of fields. Sets of similar data called keys interconnect the tables. A key identifies an entry and can link it with other entries from the same table or entries from another table or other tables.
Structured Query Language (SQL) is used to access and manipulate the database. This is a programme language that most computer programmes use to access dataset-oriented databases. It serves to access data from one or more tables in one or more databases, manipulate data in the tables, add, delete or update entries, and obtain final information on data in the tables, such as total number of entries, minimum, maximum and average values. SQL is divided in two parts, that is, it has two types of commands:

1. Creating or defining the database itself, called Data Definition Language (DDL).
2. Database access, called Data Manipulation Language (DML).

The database needed for the realisation of the proposed framework was created using SQL. This database consists of 9 tables: Phases, RiskList, User, TCQ, Criteria, Probability, ImpactTime, ImpactCost and ImpactQuality. The set of SQL commands that served to create tables and the corresponding keys is shown in Appendix 3.

Figure 8.3 shows a graphic presentation of database tables with the corresponding fields and the links among them. Field qualifiers are used to establish links among the tables. For example, PhaseCode is a qualifier field that serves to link the Phases and RiskList tables using what is known as a "one to many" link, that is, it links one entry in the Phases table with all the entries in the RiskList table that have the same PhaseCode value.

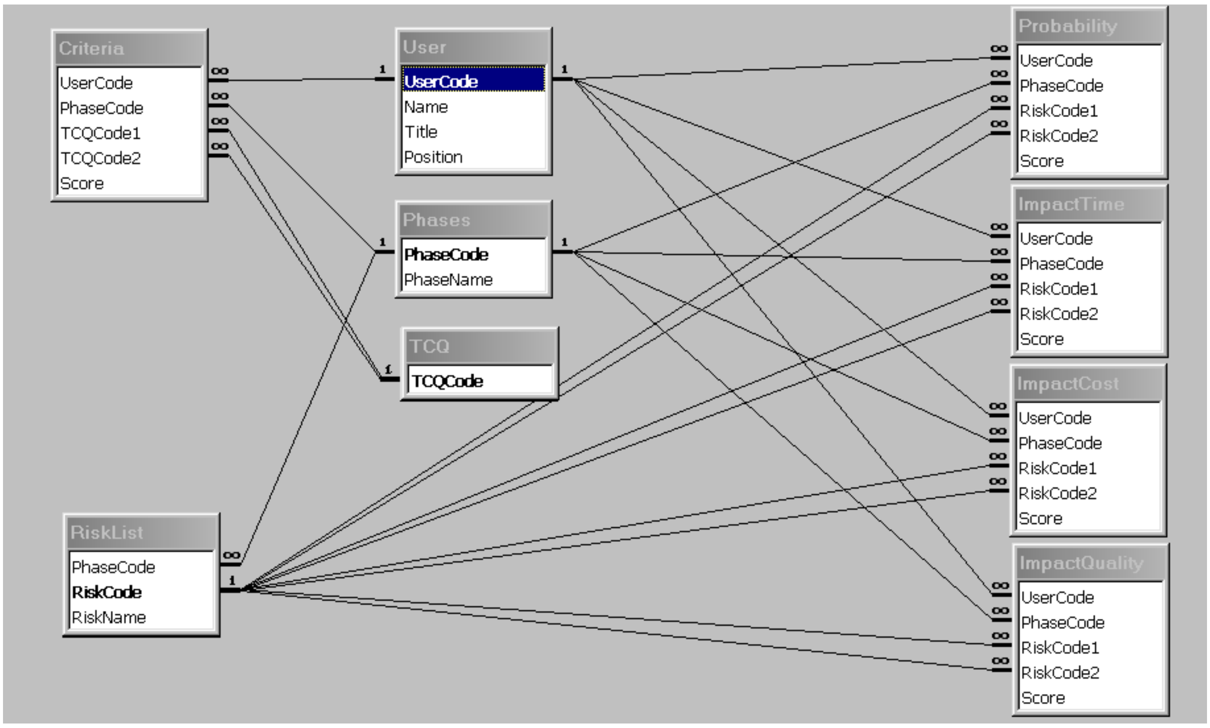


Figure 8.3: Database structure with its tables, fields and links

8.2.3 METHOD MANAGEMENT SYSTEM

The Method Management System (MMS) allows the use of several methods necessary to analyse alternatives. As shown in the preceding chapter, three methods of qualitative risk analysis may be used to successfully determine the risk priority list within the proposed framework. These methods are the Multi-Attribute Utility Theory, Fuzzy Analysis and the Analytical Hierarchy Process. All the three methods can be programmed and can be included in the appropriate decision support software if it is felt appropriate at a later date. Since AHP was found, in the preceding chapter, to be the most suitable method of qualitative risk analysis in the framework proposed, to date it is the only one included in PP-Risk.

The accuracy of the programme code for using the AHP technique was tested on the example in the preceding chapter. It gave the same results, which was the first indicator of successful programming. Results obtained by using PP-Risk and manual calculation were tested on many examples and showed themselves identical. Figures 8.4 to 8.10 show the results of analysis using PP-Risk, which are identical with those obtained in the preceding chapter.

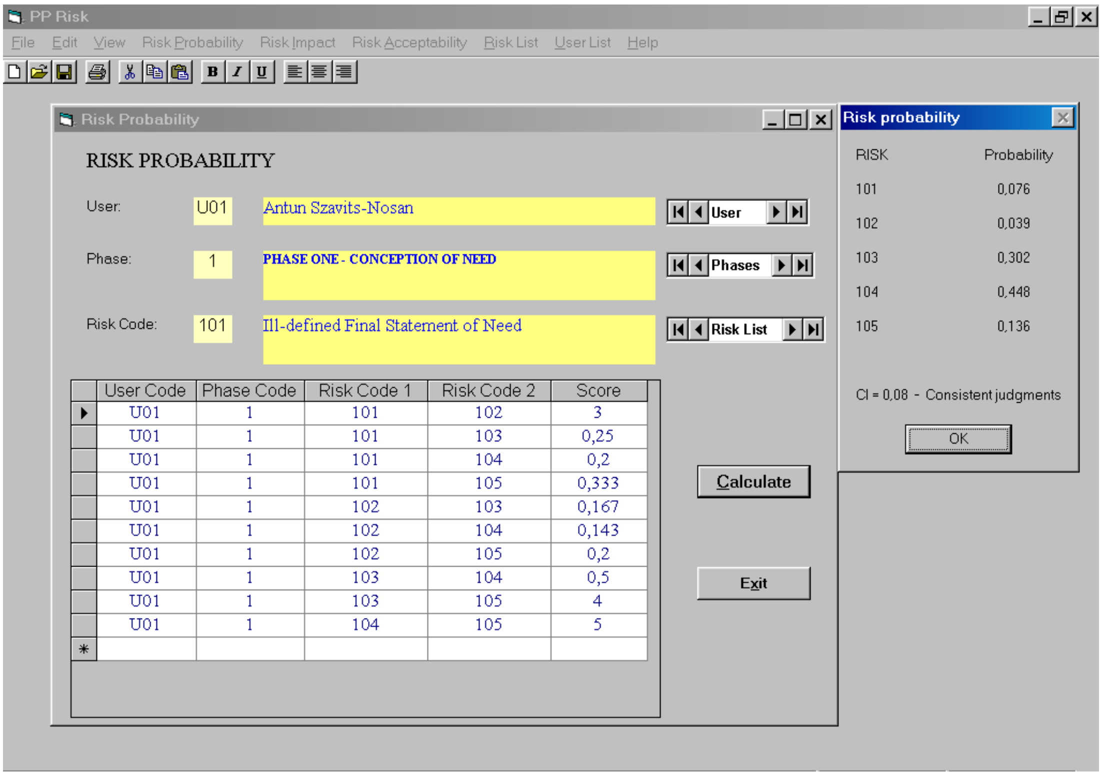


Figure 8.4: Comparative matrix and eigenvector for risk probability obtained by PP-Risk

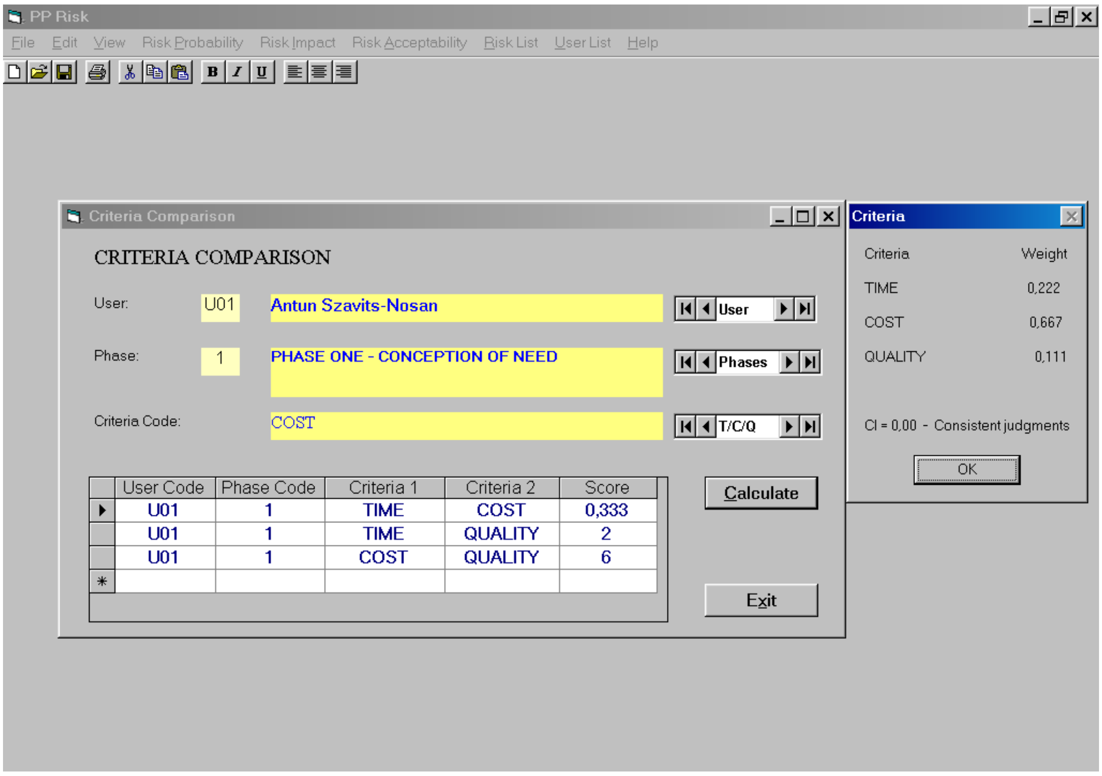


Figure 8.5: Comparative matrix and eigenvector for time, cost and quality obtained by PP-Risk

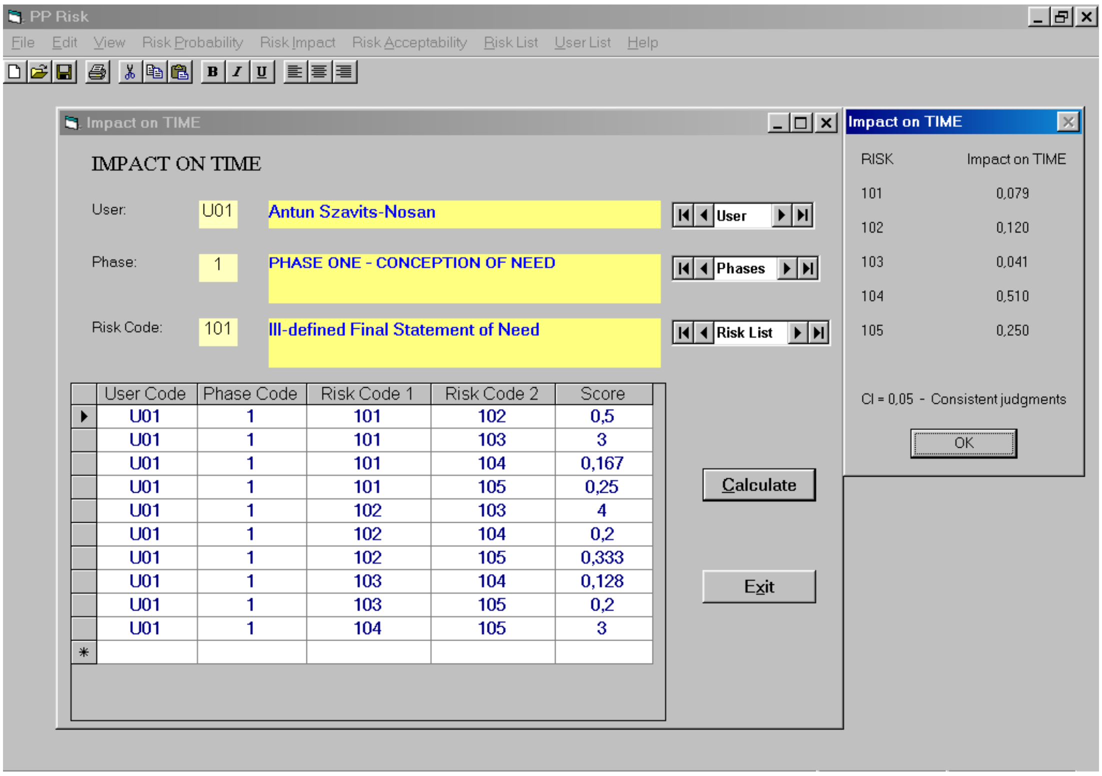


Figure 8.6: Comparative matrix and eigenvector for impact on TIME obtained by PP-Risk

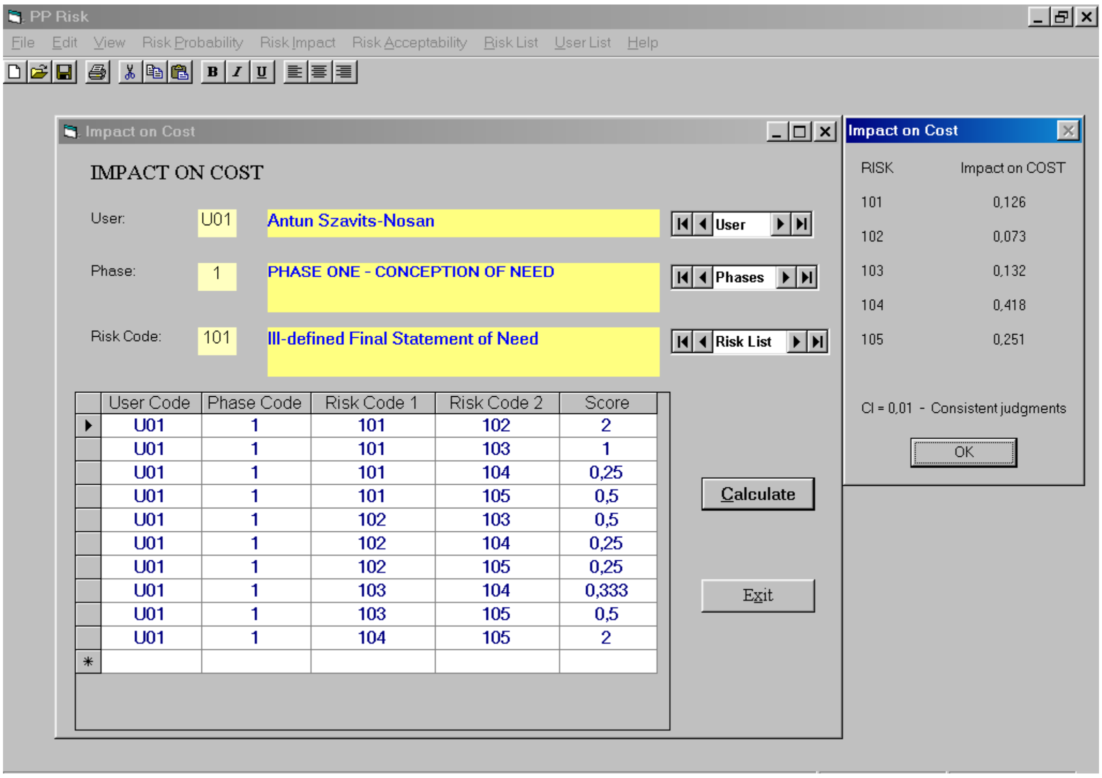


Figure 8.7: Comparative matrix and eigenvector for impact on COST obtained by PP-Risk

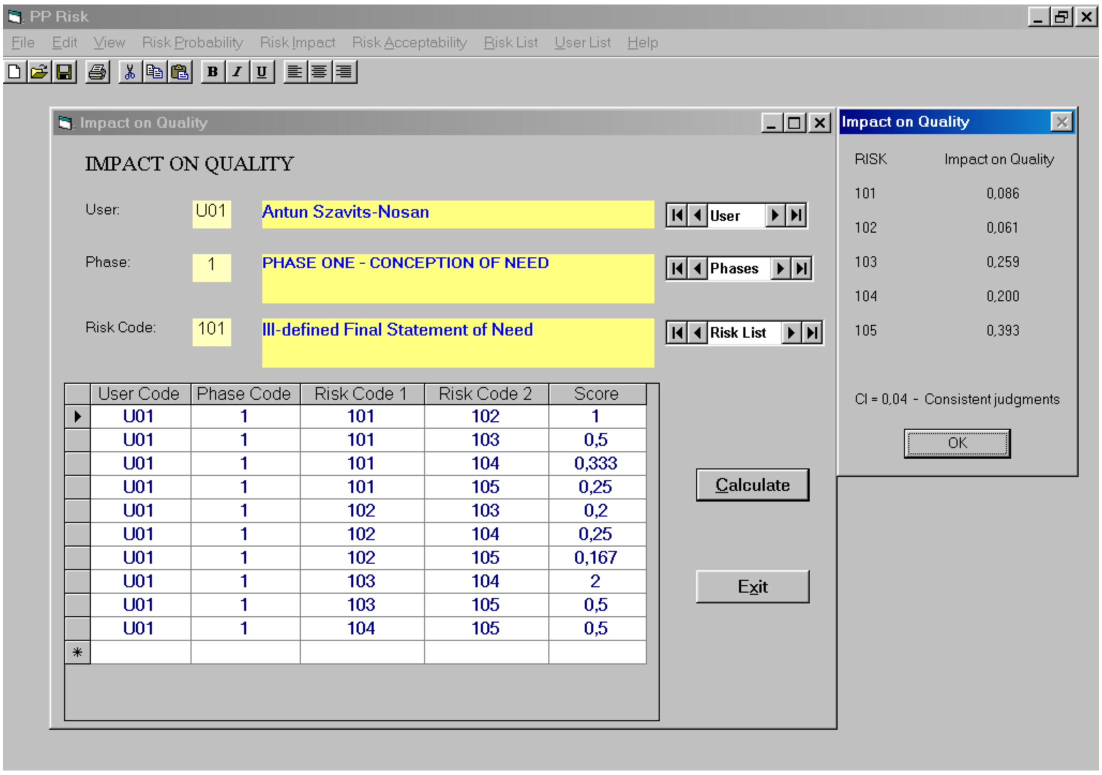


Figure 8.8: Comparative matrix and eigenvector for impact on QUALITY obtained by PP-Risk

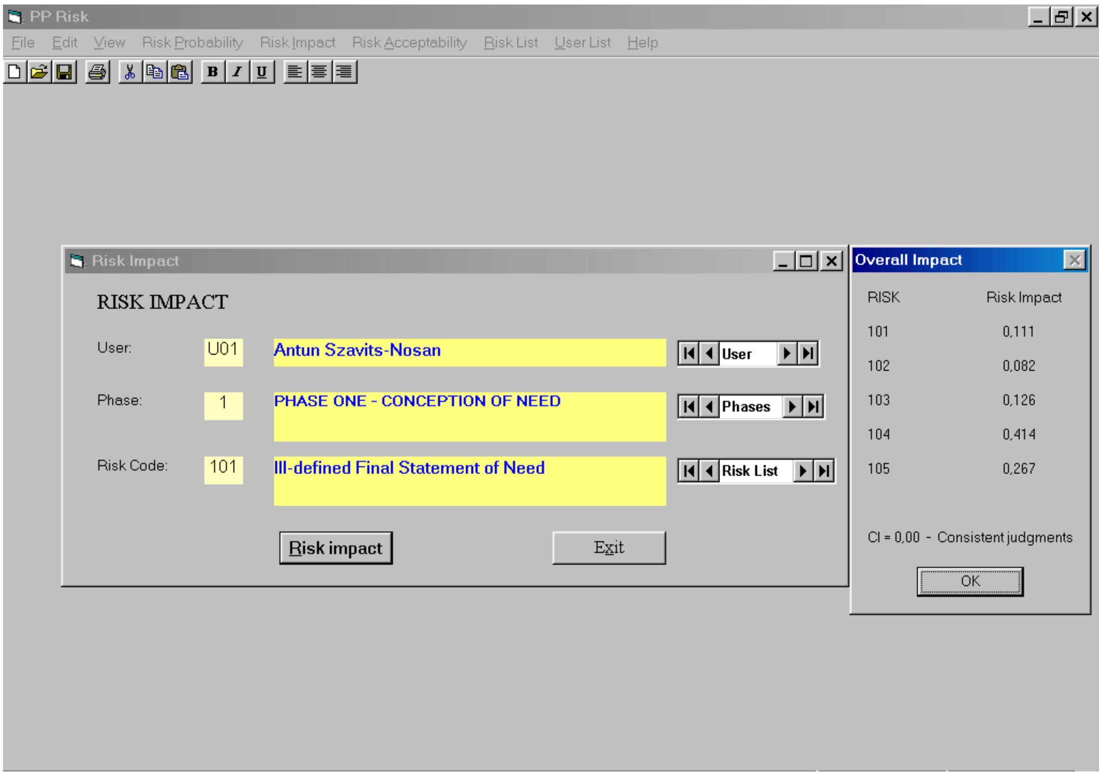


Figure 8.9: Overall risk impact obtained by PP-Risk

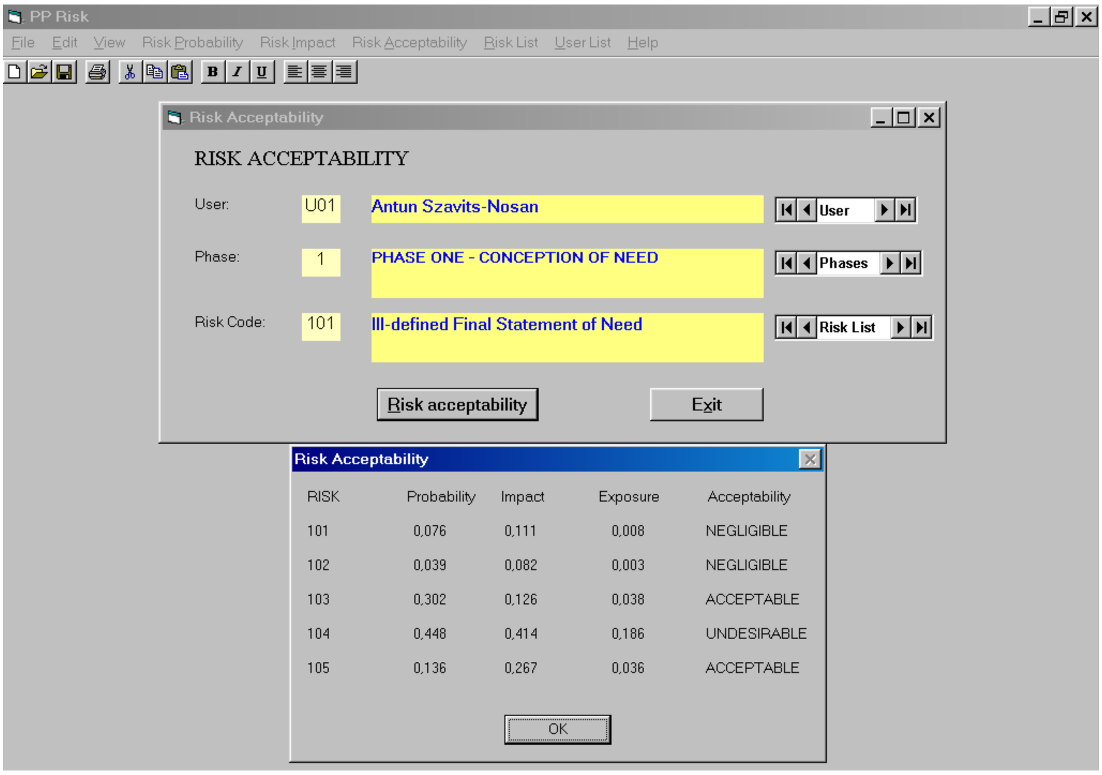


Figure 8.10: Risk exposure and risk acceptability obtained by PP-Risk

8.2.4 DOCUMENT MANAGEMENT SYSTEM

The Document Management System (DMS) implemented in PP-Risk enables the system to use various kinds of unstructured data. Documents are information usually tied to a narrow topic and mostly consist of text, graphs, pictures, voice and video entries. Examples of documents are reports, user letters, internal messages, news and electronic messages. If documents are to be used in decision-making they must be efficiently stored and it must be possible to interpret and search them. Online databases, for various projects, are major data sources available on the Internet. The combination of e-mail, discussion groups, online databases and other Internet services allows a lot of information relevant for making a decision to be gathered quickly, so it is of great practical use to include these activities in the decision support system.

8.2.5 BENEFITS OF THE PP-RISK PROGRAMME

The PP-Risk programme has been developed as an IT support for the proposed framework. PP-Risk incorporates a data base with the proposed risk list and the AHP techniques for establishing the risk priority list.

The following list illustrates the benefits of using this programme:

1) easier implementation of the proposed framework in the practice
2) improvement in comunication throughout all the Activity Zones
3) help to Project managers in their decision making and improving the consistency of judgments
4) better presentation as outputs are shown quantitatively and graphically
5) easier anslysis and understanding the results obtained

8.3 SUMMARY AND CONCLUSIONS

This chapter has shown the PP-Risk computer programme, as a Decision Support System (DSS) developed for the proposed framework for process-driven risk management in Process Protocol based construction projects. PP-Risk provides an improvement in communication among all Activity Zones within the Process Protocol by integrating, with the help of IT, all the information relevant for project realisation.

PP-Risk was designed on the MS Windows platform using the MS Visual Basic 6 developmental environment. The DSS follows given principles (Cook and Russell, 1989) and consists of four integrated modules: User Interface, Database Management System, Method Management System and Document Management System.

Programme code accuracy was tested on the example shown in the preceding chapter, and gave the same results. Comparison of the time necessary for manual qualitative risk analysis and PP-Risk analysis showed the great advantage of PP-Risk and justified the efforts invested in its development.

In the next chapter the proposed framework will be verified using PP-Risk.

9 APPLICATION AND VERIFICATION OF THE PROCESS-DRIVEN RISK MANAGEMENT FRAMEWORK

9.1 INTRODUCTION

The preceding chapter showed the PP-Risk computer programme the author developed as a decision support system for the proposed framework for process-driven risk management based on Process Protocol.

This chapter will show the application and verification of the proposed framework using the PP-Risk computer programme as IT support. Application and verification are carried out for the following reasons:

1. To test the applicability of and verify the proposed framework on a specific example.
2. To verify the efficiency and applicability of the PP-Risk computer programme described in the preceding chapter.
3. To verify the hypotheses in this research.

Application and verification will be tested on a construction project involving a tunnel as a major infrastructure facility. Dudeck (1987); John (1997); ITA (1988) performed important research on risk in tunnel construction. Smith (1993) gave a case study showing risk assessments and analysis performed during preparations to design, construct and operate the Channel Tunnel Rail Link.

Eighteen experts, who had in various ways significantly participated in the execution of similar projects in the past and who are expected to significantly participate in future projects, helped in the application and verification of the proposed framework.

The experts applied the proposed framework using the PP-Risk computer programme. First they confirmed the identification of the key risks proposed in the various phases of Process Protocol, then they implemented a quality risk analysis within a particular phase, and finally they gave the relevant risk response.

To verify the proposed framework, the experts first used PP-Risk to manage the risks in particular phases and then filled in a structured questionnaire.

9.2 APPLICATION OF THE PROCESS-DRIVEN RISK MANAGEMENT FRAMEWORK

In order to test the Framework it would be possible to create a hypothetical example or to use a real case study. The framework had been developed by using a hypothetical example and therefore it was felt important to apply the approach within the context of a real project. A real example will provide information on applicability of the framework in practice and give some valuable lessons for the future.

The application of the PDRMF (**P**rocess-**D**riven **R**isk **M**anagement **F**ramework) was demonstrated on the *Sveta tri kralja* Tunnel. This tunnel is planned as part of the Zagreb-Macelj Motorway that will link the capital of the Republic of Croatia with the Republic of Slovenia (see Fig.9.1). Motorway Zagreb-Macelj (E-59, M-11) is part of the Pyhrns roadway in Croatia that links North and West Europe with Southeast Europe and Mediterranean. The total length of Pyhrns route in Croatia is 30 miles.

The tunnel will be more than 5 km long, mostly running through the weakest rock categories of the hard soil-soft rock type, with high levels of groundwater and many natural landslides.

The reasons why the tunnel *Sveta tri kralja* was chosen for testing are, firstly that the tunnels are a well known subject for risk management as so many unknowns exist at the start of a project, and secondly, experts who have worked on similar projects in the past were willing to participate in the application and verification of the framework. This enabled satisfactory testing with an informed group who could make useful judgments about the proposals being made.

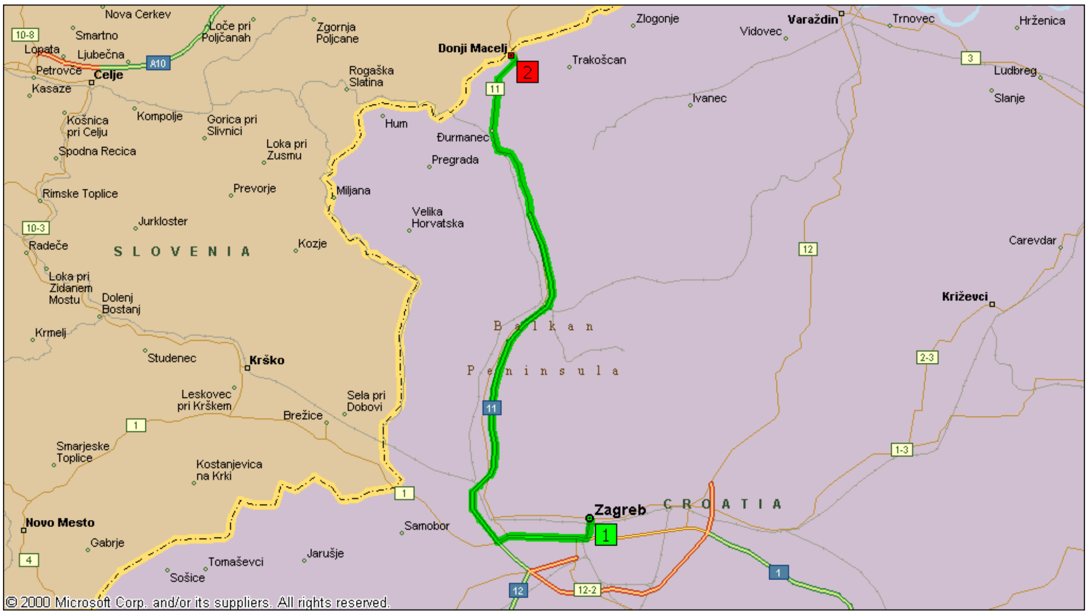


Figure 9.1: Zagreb-Macelj road map

Road construction is of special importance in the Republic of Croatia because of tourism, which is one of the main industrial branches, so the Government made it an investment priority. To secure the efficient execution of infrastructure projects, the Croatian Government founded several firms to engage solely in the construction and maintenance of motorways. One such firm, in the name of the Government, is the investor in this tunnel.

The application of the proposed framework was tested in several steps.

The first step was choice of experts to participate in the testing. A total of 18 experts took part, who had played an important role in the realisation of similar facilities in the past. Considering that the execution of such major facilities is very complex, starting from Demonstrating the Need to Operation and Maintenance, not one of the experts participated in all the phases that the project goes through. For this reason the experts were divided in 4 groups of their own choice, in accordance with the stages of Process Protocol. No expert tested the framework in more than one stage. The number of experts per stage was as follows:

Stage 1: Pre-Project Stage	- 4 experts
Stage 2: Pre-Construction Stage	- 6 experts
Stage 3: Construction Stage	- 4 experts
Stage 4: Post-Construction Stage	- 4 experts

In the second step all the experts were given the list of key risks. Since the tunnel is a future project whose execution has not yet started, all the experts agreed that the proposed list was appropriate for first analysis and that project-related risks may appear during project execution.

The third step was to determine risk exposure and form the risk priority list for each phase through which the tunnel project would pass according to Process Protocol. Since project realisation had not yet begun, a qualitative approach was chosen for risk analysis. Qualitative analysis was carried out as follows:

1. Questionnaire-type forms made for each phase separately were distributed to all the experts, to serve as the first iteration in the process of determining risk exposure for each identified risk. The forms were adapted to the AHP method and enabled making a series of judgmentss about interrelationships among the identified risks with reference to probability, time, cost and quality, and defining the mutual significance of time, cost and quality in each phase. Figure 9.1 shows an example of the form for Phase 0. The experts were allowed as much time as they required to fill in the forms.
2. The comparison results were entered in the database of the PP-Risk computer programme, and a degree of inconsistency in judgments appeared in a certain number of cases. The inconsistencies could have been avoided had the interview method been used, during which the author of PP-Risk would have directly entered the judgmentss after which they would have been corrected until the necessary consistency in deciding was reached. This method was not used because a large number of judgmentss are needed within one phase, which would have led to exhaustion and loss of concentration among the respondents. For 5 risks analysed in one phase it is necessary to make 10 judgmentss for risk probability, 10 for impact on time, 10 for impact on cost, 10 for impact on quality and 3 to determine the mutual significance of time, cost and quality. This is a total of 43 judgmentss for one phase.
3. After the resulted were entered in the database a two-part interview was performed with each respondent. In the first part the experts used the PP-Risk computer programme to correct their judgmentss so as to achieve consistency in deciding. The process was fast and efficient because the experts were now well

acquainted with the risks, had been given time to think about them more, and easily achieved consistency in deciding. In the second part of the interview the experts were requested to provide the appropriate risk response.

4. Finally the author of the research assumed the role of the project manager and made her own judgmentss and risk responses for all the project phases, taking into account all the judgmentss made by the experts, as well as the exposures and the appropriate risk responses obtained (see Appendix 4).

The risk exposure of a particular risk may be directly correlated with the assets available to manage that risk in a particular phase by calculating the participation of its risk exposure in the total risk exposure of that phase. The total risk exposure is obtained by adding up all the exposures in a phase except the exposures of negligible risks, because these risks are disregarded so no investment is necessary to respond to them.

For Phase 0, for example, the total risk exposure is 0.044 (risk 001) + 0.022 (risk 002) + 0.015 (risk 004) + 0.058 (risk 005) = 0.239. Risk 003 is negligible so its exposure is not taken into account. Thus, for example, 0.058/0.239 = 0.508 can be used to manage Risk 002, that is, 51% of the total assets available for risk management in this phase, and 0.242/0.239 = 0.242 can be used for Risk 005, that is, 24 % of the assets.

This calculation of the participation of a particular risk in the total assets available for risk management is made for each analysed risk and is included in the relevant risk response.

The form and results of the application of the framework in all the phases, are shown below.

PHASE ZERO – DEMONSTRATING THE NEED

Possible results of comparison: 1/10. 1/9, 1/8, … , 1/3, 1/2, 1, 2, 3, … , 8, 9, 10

Risk probability	002	003	004	005
001				
002				
003				
004				

Risk impact	COST	QUALITY
TIME		
COST		

Impact on TIME	002	003	004	005
001				
002				
003				
004				

Impact on COST	002	003	004	005
001				
002				
003				
004				

Impact on QUALITY	002	003	004	005
001				
002				
003				
004				

Risk List

001: Unsatisfactory Market Research

002: Ill-defined Initial Statement of Need

003: Incomplete Stakeholder List

004: No Historical Data Analysis

005: Poor Communications

Figure 9.2: Example of a form for the qualitative approach in Phase 0

9.2.1 PHASE ZERO – DEMONSTRATING THE NEED

Risk list

001: Unsatisfactory Market Research

002: Ill-defined Initial Statement of Need

003: Incomplete Stakeholder List

004: No Historical Data Analysis

005: Poor Communications

Table 9.1: Results of risk analysis for Phase 0

Risk	Probability	Impact	Exposure	Acceptability
001	0.320	0.137	0.044	Acceptable
002	0.339	0.360	0.122	Undesirable
003	0.038	0.051	0.002	Negligible
004	0.131	0.118	0.015	Acceptable
005	0.173	0.335	0.058	Acceptable

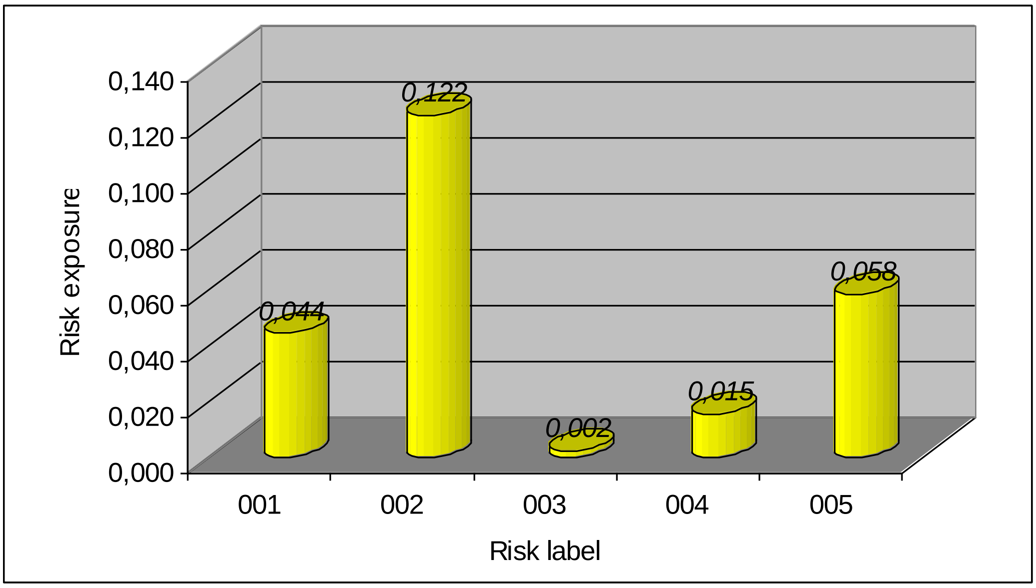


Figure 9.3: Risk exposure in Phase 0

9.2.2 PHASE ONE – CONCEPTION OF NEED

Risk list

101: Ill-defined Final Statement of Need

102: Changes in Stakeholder List

103: Poor Assessment of Stakeholder Impact

104: Poor Communications

105: Incomplete Identification of Potential Solution to the Need

Table 9.2: Result of risk analysis for Phase 1

Risk	Probability	Impact	Exposure	Acceptability
101	0.245	0.251	0.061	Acceptable
102	0.044	0.068	0.003	Negligible
103	0.043	0.076	0.003	Negligible
104	0.184	0.189	0.035	Acceptable
105	0.485	0.416	0.202	Undesirable

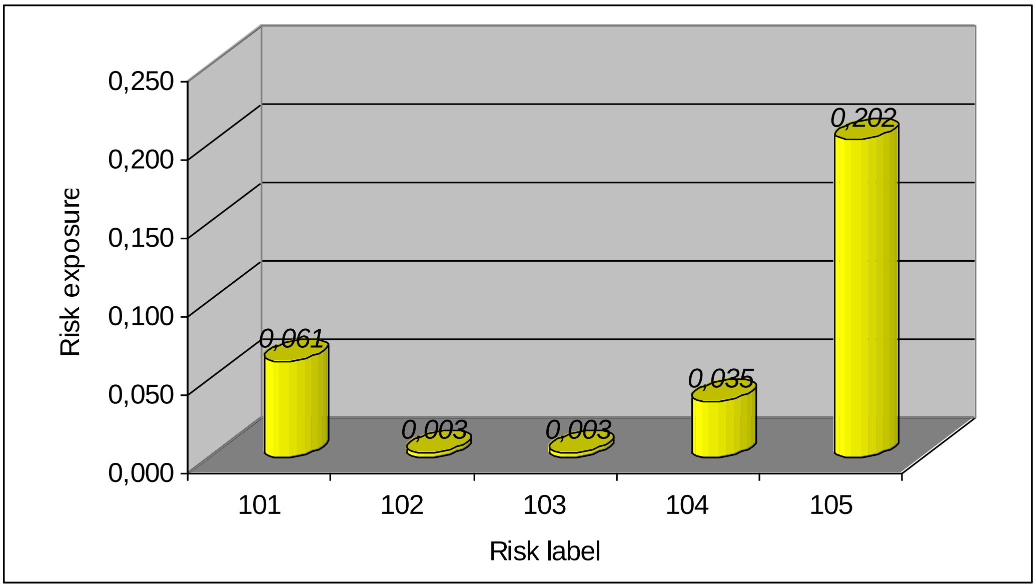


Figure 9.4: Risk exposure in Phase 1

9.2.3 PHASE TWO – OUTLINE FEASIBILITY

Risk list

201: Poor Communications

202: Poor Consideration of Site Investigations

203: Poor Consideration of Environmental Impact

204: Ill-defined Structure of Funding and Financial Options

205: Unrealistic Completion Dates for Each Option

206: Inadequate Cost/Benefit Analysis for Each Option

Table 9.3: Result of risk analysis for Phase 2

Risk	Probability	Impact	Exposure	Acceptability
201	0.144	0.126	0.018	Acceptable
202	0.289	0.251	0.073	Acceptable
203	0.213	0.162	0.034	Acceptable
204	0.073	0.120	0.009	Negligible
205	0.092	0.153	0.014	Acceptable
206	0.189	0.188	0.036	Acceptable

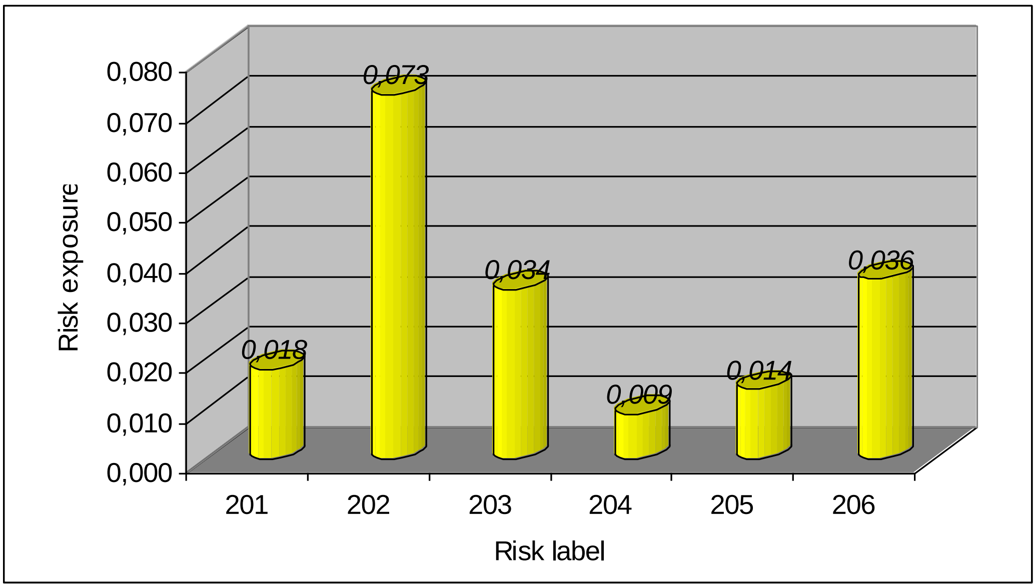


Figure 9.5: Risk exposure in Phase 2

9.2.4 PHASE THREE – SUBSTANTIVE FEASIBILITY STUDY & OUTLINE FINANCIAL AUTHORITY

Risk list

301: Poor Communications

302: Unsatisfactory Site Investigations

303: Poor Assessment of Environmental Impact

304: Ill-defined Structure of Funding and Financial Options

305: Inadequate Substantive Cost-Benefit Analysis

Table 9.4: Results of risk analysis for Phase 3

Risk	Probability	Impact	Exposure	Acceptability
301	0.204	0.171	0.035	Acceptable
302	0.384	0.406	0.156	Undesirable
303	0.224	0.259	0.058	Acceptable
304	0.069	0.042	0.003	Negligible
305	0.119	0.122	0.015	Acceptable

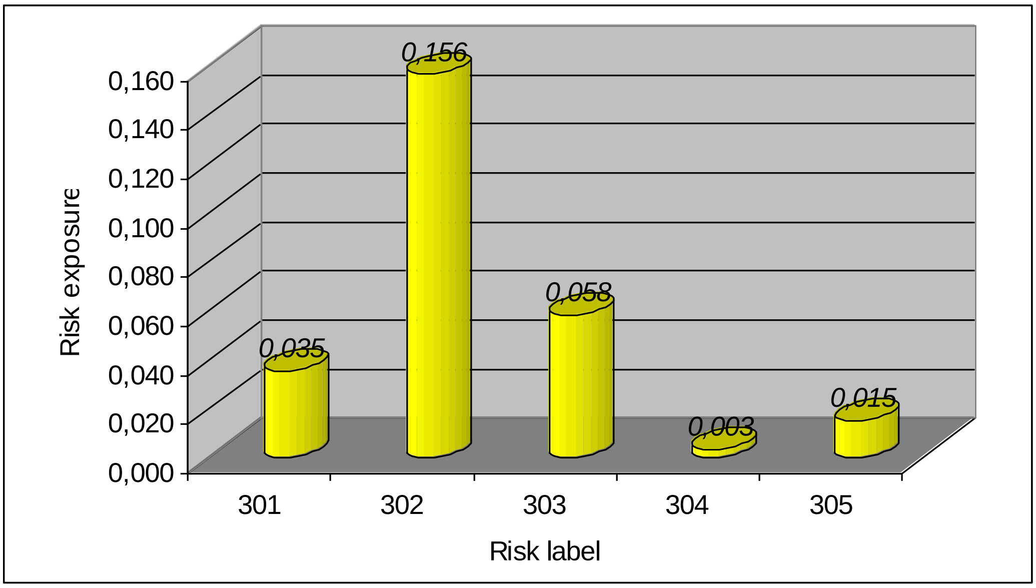


Figure 9.6: Risk exposure in Phase 3

9.2.5 PHASE FOUR – OUTLINE CONCEPTUAL DESIGN

Risk list

401: Poor Communications

402: Lack of Site Investigations Update

403: Lack of Environmental Impact Assessment Update

404: Inadequate Evaluation of Outline Conceptual Design Alternatives

405: Inaccurate Total Cost of Chosen Outline Conceptual Design Estimate

Table 9.5: Result of risk analysis for Phase 4

Risk	Probability	Impact	Exposure	Acceptability
401	0.141	0.134	0.019	Acceptable
402	0.237	0.172	0.041	Acceptable
403	0.136	0.145	0.020	Acceptable
404	0.412	0.342	0.141	Undesirable
405	0.074	0.207	0.015	Acceptable

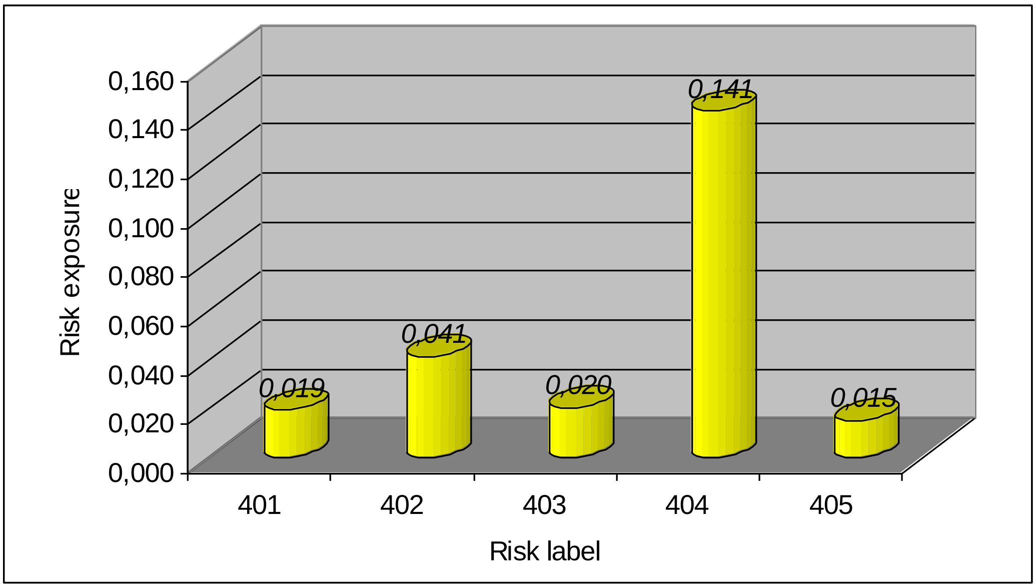


Figure 9.7: Risk exposure in Phase 4

9.2.6 PHASE FIVE – FULL CONCEPTUAL DESIGN

Risk list

501: Poor Communications

502: Poor Schematic Design for Elements of Chosen Solution

503: Inadequate Maintenance Plan

504: Inadequate Health and safety Plan

505: Inaccurate Total Cost of Chosen Concept Design Solution Estimate

Table 9.6: Results of risk analysis for Phase 5

Risk	Probability	Impact	Exposure	Acceptability
501	0.185	0.143	0.026	Acceptable
502	0.460	0.377	0.173	Undesirable
503	0.144	0.127	0.018	Acceptable
504	0.138	0.122	0.017	Acceptable
505	0.072	0.231	0.017	Acceptable

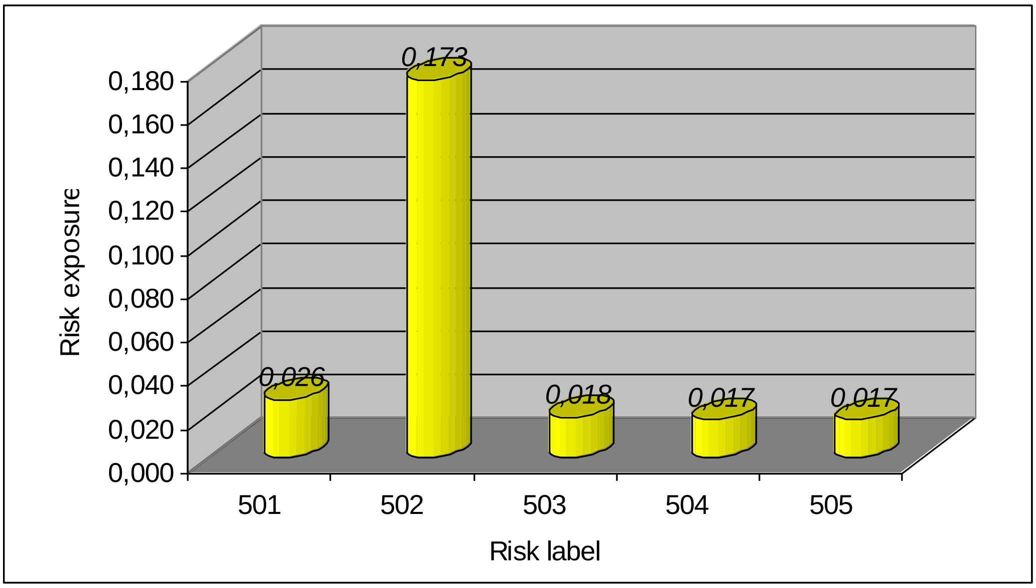


Figure 9.8: Risk exposure in Phase 5

9.2.7 PHASE SIX – COORDINATED DESIGN, PROCUREMENT & FULL FINANCIAL AUTHORITY

Risk list

601: Poor Communications

602: Poor Detailed Design for Elements of Chosen Solution

603: Inaccurate Total Cost Based on Detailed Design Estimate

604: Poor contractual strategy

605: Unsatisfactory Potential Suppliers Skills and Inability to Fulfil Requirements

Table 9.7: Results of risk analysis for Phase 6

Risk	Probability	Impact	Exposure	Acceptability
601	0.169	0.154	0.026	Acceptable
602	0.258	0.178	0.046	Acceptable
603	0.086	0.132	0.011	Acceptable
604	0.332	0.344	0.114	Undesirable
605	0.154	0.193	0.030	Acceptable

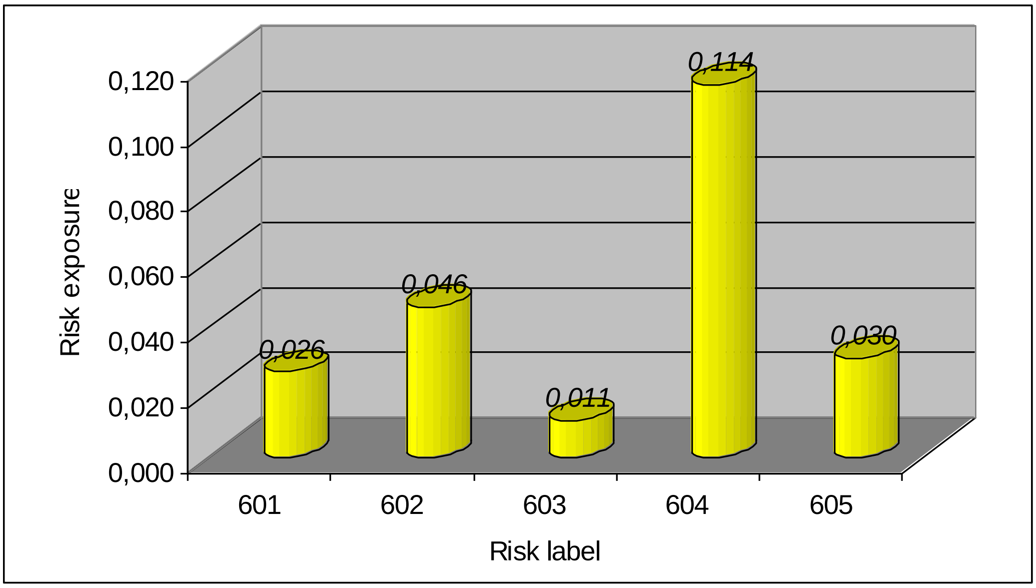


Figure 9.9: Risk exposure in Phase 6

9.2.8 PHASE SEVEN – PRODUCTION INFORMATION

Risk list

701: Poor Communications

702: Unsatisfactory Health and Safety Plan

703 Unsatisfactory Maintenance Plan

704: Unsatisfactory Procurement Plan

705: Inability to Finalise Total Cost Based on Production Information

Table 9.8: Result of risk analysis in Phase 7

Risk	Probability	Impact	Exposure	Acceptability
701	0.358	0.302	0.108	Acceptable
702	0.089	0.174	0.015	Acceptable
703	0.191	0.115	0.022	Acceptable
704	0.249	0.216	0.054	Acceptable
705	0.113	0.194	0.022	Acceptable

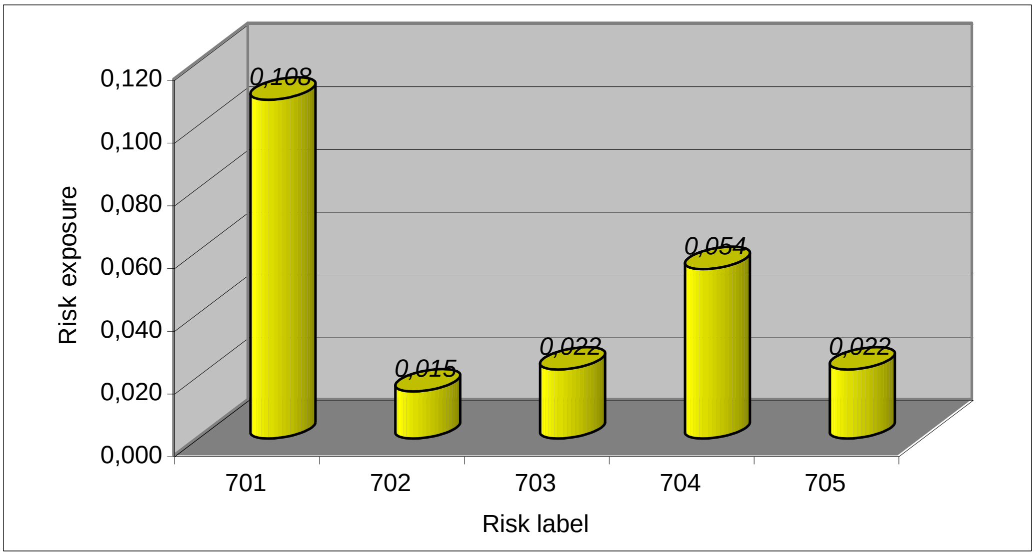


Figure 9.10: Risk exposure in Phase 7

9.2.9 PHASE EIGHT – CONSTRUCTION

Risk list

801: Inappropriate Changes to Design Resulting from Construction Phase

802: Unsatisfactory Monitoring of Quality of Construction Work

803: Unsatisfactory Monitoring of Cost of Construction Work

804: Unsatisfactory Monitoring of Progress of Construction

805: Lack of On-Site Resources And Labour Management

Table 9.9: Result of risk analysis for Phase 8

Risk	Probability	Impact	Exposure	Acceptability
801	0.477	0.287	0.137	Undesirable
802	0.194	0.206	0.040	Acceptable
803	0.090	0.205	0.018	Acceptable
804	0.095	0.133	0.013	Acceptable
805	0.145	0.169	0.024	Acceptable

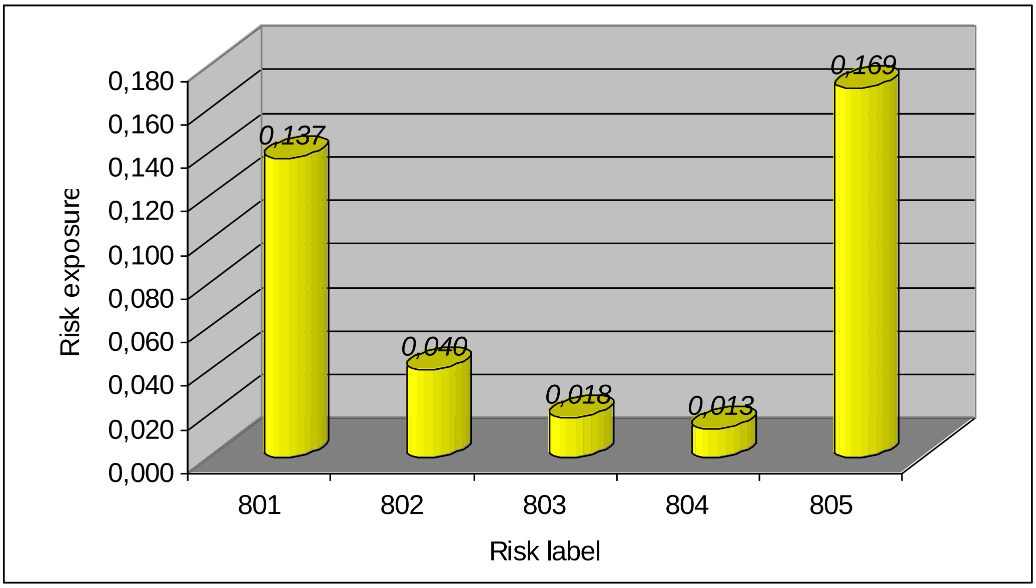


Figure 9.11: Risk exposure in Phase 8

9.2.10 PHASE NINE – OPERATION & MAINTENANCE

Risk list

901: Unsatisfactory Building Performance Measurement

902: Lack of Maintenance Strategies Update

903: Lack of Lifecycle Budgetary Requirements Update

Table 9.10: Results of risk analysis in Phase 9

Risk	Probability	Impact	Exposure	Acceptability
901	0.524	0.492	0.258	Unacceptable
902	0.279	0.331	0.092	Acceptable
903	0.197	0.177	0.035	Acceptable

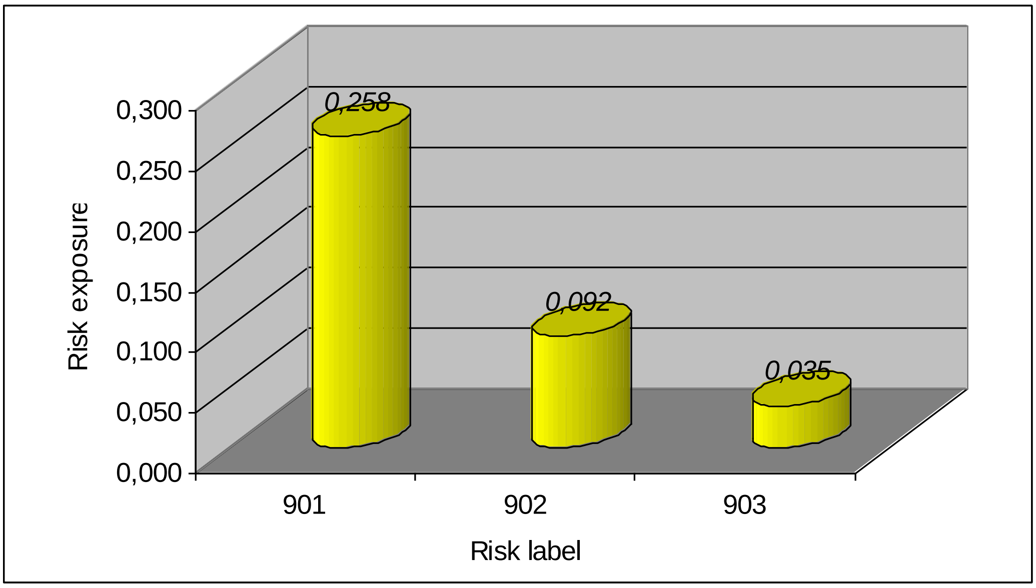
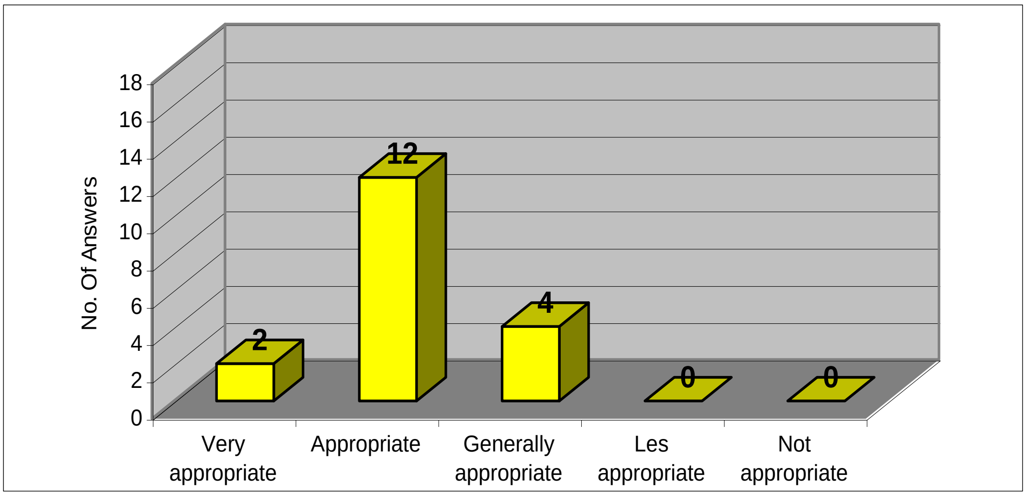


Figure 9.12: Risk exposure in Phase 9

9.3 VERIFICATION OF PDRMF

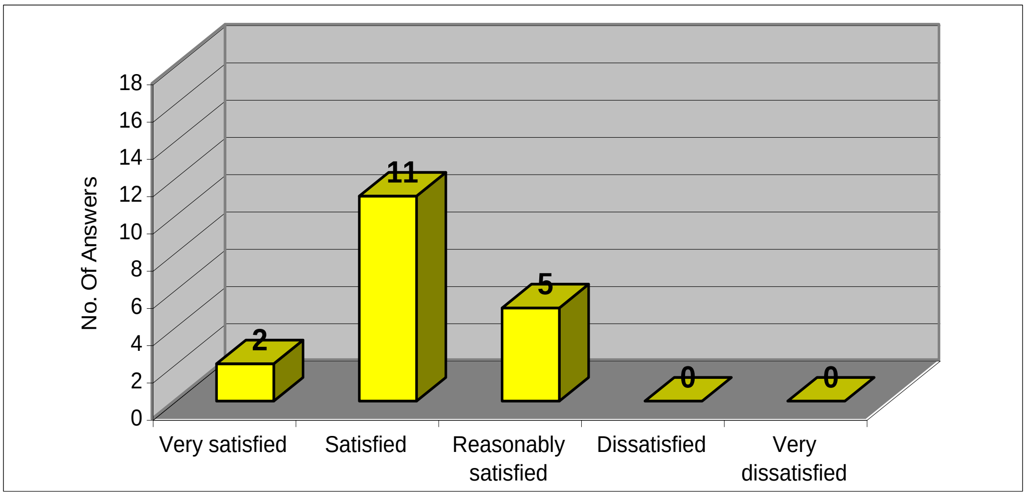
The proposed framework was verified using the questionnaire method. The experts filled in the questionnaire after they had suggested, with the support of PP-Risk, the appropriate risk response and after they were shown the results of risk management in all the phases through which the construction project passes according to Process Protocol. The structural questionnaire has 10 questions (see Appendix 5) that required the experts to choose one of the answeres offered. The explanation of each question, the answers provided by the experts and the conclusions in connection to the answers are shown below.

1. What do you think about the proposed breakdown of the construction project in 10 phases within 4 stages?



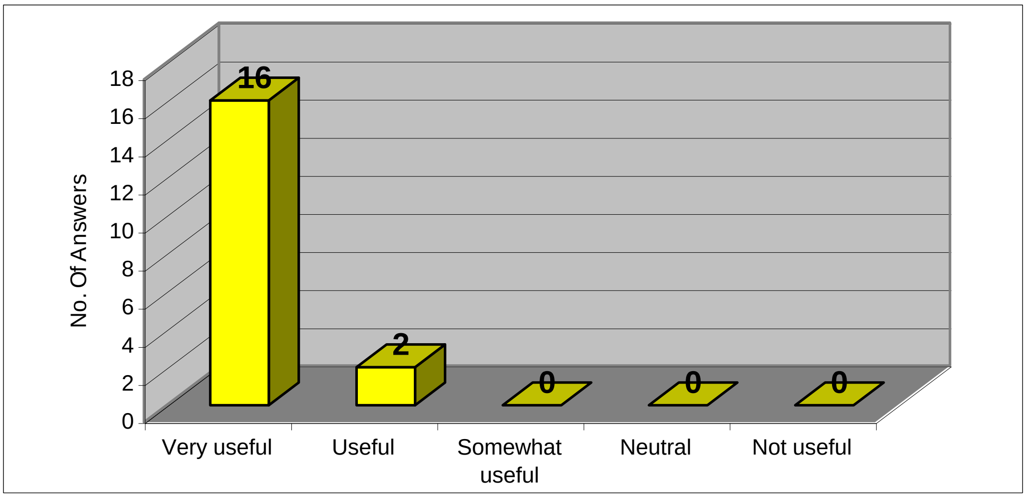
The experts were not acquainted with Process Protocol and this question was asked to obtain their verification of the group of activities necessary during the realisation of any construction project, as the first step in setting up a construction process. 12 experts considered the proposed breakdown in 10 phases within 4 stages *Appropriate*, 4 considered it *Generally Appropriate* and 2 considered it *Very Appropriate*. No experts considered the breakdown *Less Appropriate* or *Not Appropriate*. The experts thus verified the breakdown of the project in the phases proposed in Process Protocol, which is especially important for the potential application of the framework in future projects.

2. How generally satisfied are you with the proposed approach whereby risk management becomes part of the construction process?



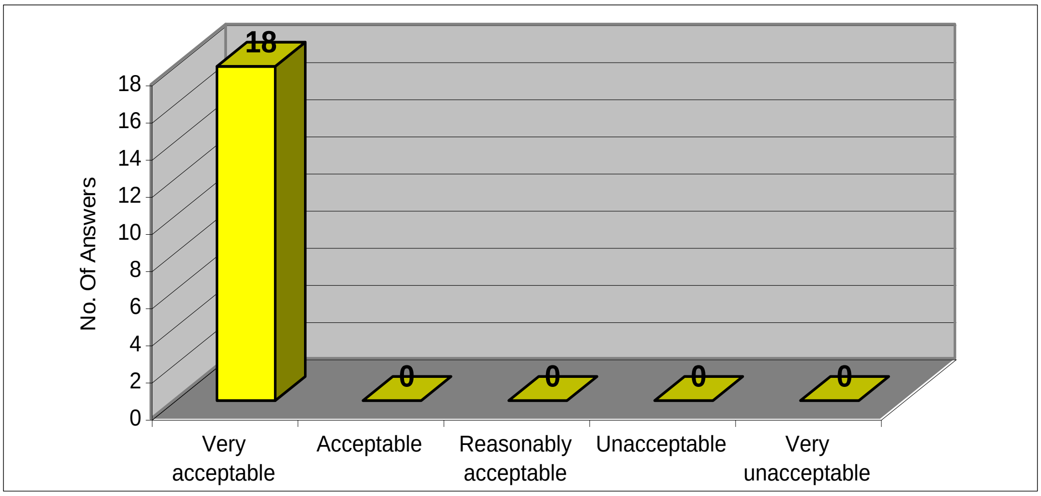
Starting from the fact that executing a construction project is a process, the proposed framework offers process driven risk management as an alternative approach to risk driven project management. This question was asked to verify the fourth hypothesis of this research. The experts confirmed that this is a suitable approach because 11 of them were *Satisfied* with it, 5 were *Reasonably Satisfied* and 2 were *Very Satisfied*. None of the experts were *Dissatisfied* or *Very Dissatisfied* with the approach. The answers obtained verify the starting hypothesis.

3. Do you find the proposed framework useful for risk management in construction projects?



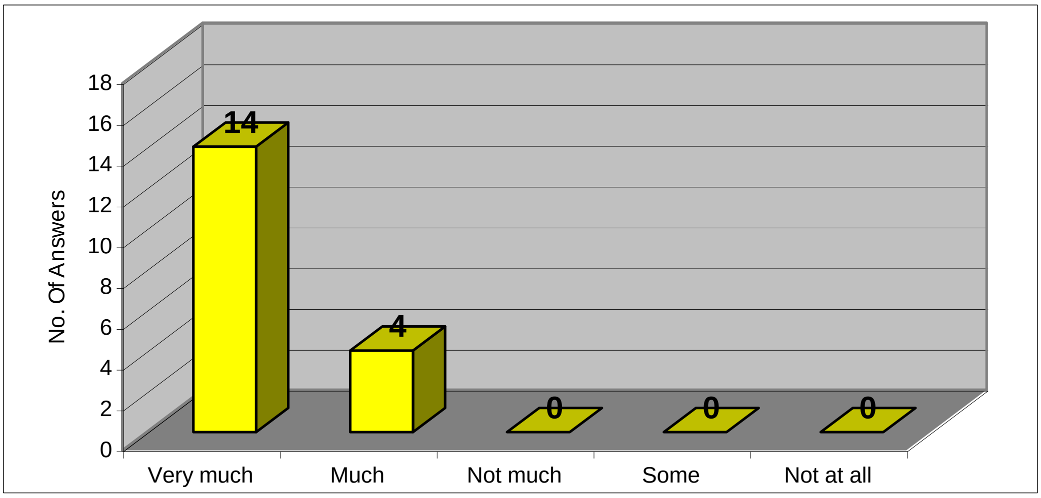
This question tested the whether the goal of this research was successfully realised and the experts' answers are very encouraging. 16 experts considered the framework *Very Useful* and the remaining 2 considered it *Useful*.

4. What do you think of the proposed key risks in the construction process regardless of the project's type and size?



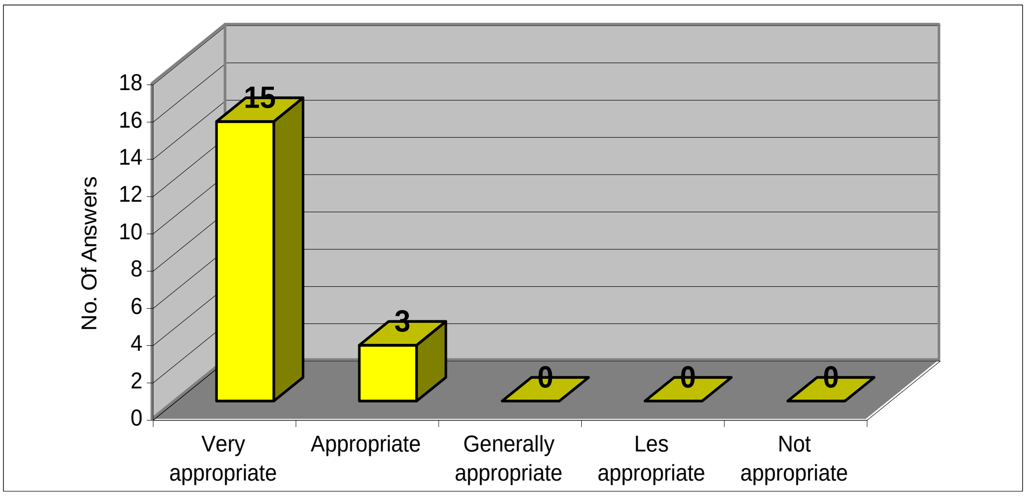
The experts did not know how the key risks had been identified so this question was asked to verify the identification process for the key risks described in Chapter 6, that is, to verify the second starting hypothesis in this research. All the 18 respondents answered that the key risks proposed are *Acceptable*, and this is the only answer in which consensus was achieved. In this way the experts verified the starting hypothesis.

5. To what extent does using the proposed framework improve your understanding of process in construction?



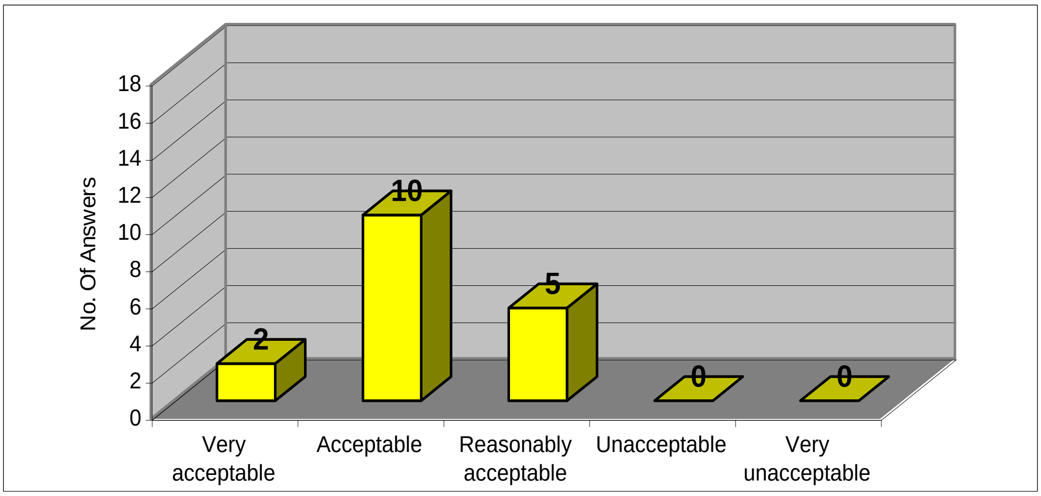
This question was asked to verify the first starting hypothesis in this research. 14 experts considered that using the proposed framework gave them a *Very Much* better understanding of the construction process, and 4 experts gave the answer *Much*. No experts answered *Not Much*, *Some* or *Not at All*. These answered are considered verification of the starting hypothesis.

6. Is the proposed framework appropriate for a risk assessment in the stage in which you managed risks?



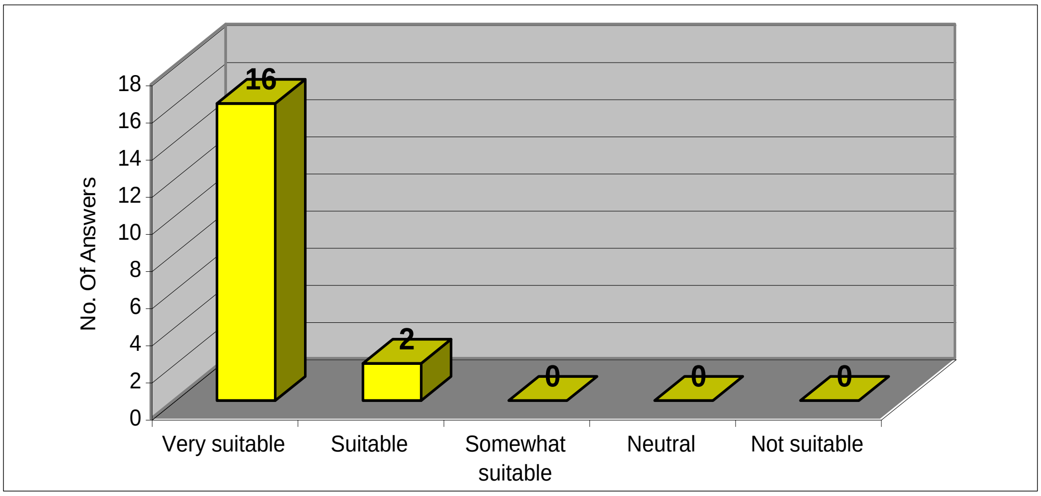
This question was also asked to verify the third starting hypothesis in this research. The framework anticipates a quantitative, qualitative or mixed approach to risk assessment in each project phase. The experts appraised the success in implementing these approaches. 15 experts considered them with *Very Appropriate* and 3 considered them *Appropriate*. No experts gave the answers *Generally Appropriate*, *Less Appropriate* or *Not Appropriate*. This verified the starting hypothesis.

7. What do you think about the acceptability of AHP for qualitative risk analysis in the decision making process?



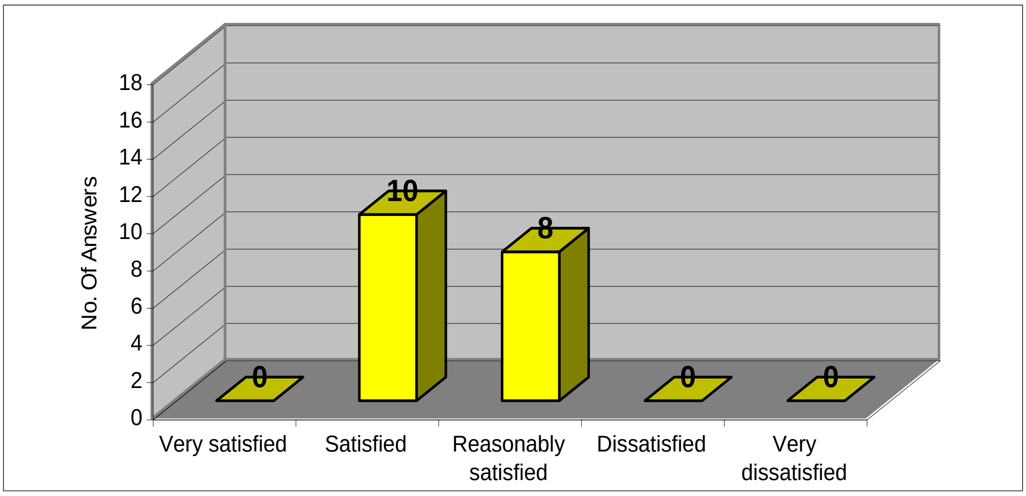
For some of the experts this had been the first encounter with this technique whereby the decision making process unfolds through a series of judgments about the interrelationships of alternatives with reference to given criteria and given goal. 10 experts gave the answer *Acceptable*, 5 experts the answer *Reasonably Acceptable* and 2 experts *Very Acceptable*. None of the experts considered this technique *Unacceptable* or *Very Unacceptable*. This has verified the use of AHP for quantitative risk analysis in the proposed framework.

8. How suited is PP-Risk as a Decision Support System for the proposed framework?



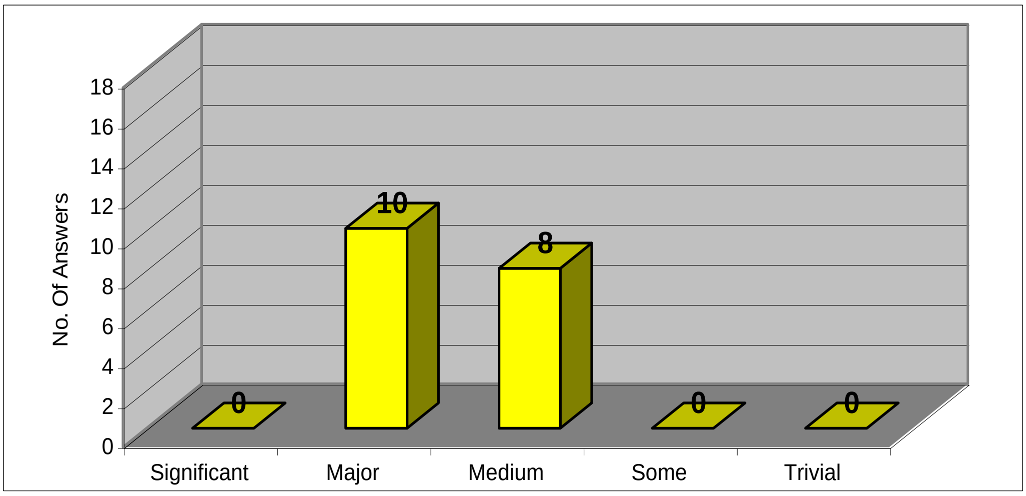
The PP-Risk computer programme, as a decision support system, completely supports all the elements of the proposed framework. 16 experts considered it *Very Suitable*, 2 considered it *Suitable* and none considered PP-Risk *Somewhat Suitable*, *Neutral* or *Not Suitable*. The experts' views encourage the author to continue improving and increasing the potentials of the programme.

9. How satisfied are you with the PP-Risk user interface?



PP-Risk was developed on the MS Visual Basic 6 developmental environment on a Microsoft Windows platform. The appearance of the screen, way of using the system, management procedure, interface parameters and response time are the same as in all standard Windows applications to which a large number of potential users of the system are accustomed. Still, 10 experts said they were *Satisfied* with the user interface, 8 were *Reasonably Satisfied*. No experts were *Dissatisfied* or *Very Dissatisfied* with the user interface, nor were any *Very Satisfied*. The experts made some remarks that the author will try respect in accordance with her knowledge of computer programming.

10. Assess the benefits of using the proposed framework supported by PP-Risk for process-driven risk management, from the aspect of time, cost and quality management?



The experts gave great weight to the fact that the relative values of time, cost and quality could be changed in each project phase, which made it possible to manage them at will. Thus 16 experts considered the benefits *Significant* and 2 experts considered them *Major*. None of the experts considered the benefits *Medium*, *Some* or *Trivial*.

9.4 SUMMARY AND CONCLUSIONS

In this chapter the proposed framework for process driven risk management was applied to and verified on the example of the future *Sveta tri kralja* tunnel planned as part of the future Zagreb-Macelj Motorway that is to connect the capital of the Republic of Croatia with the Republic of Slovenia. The efficiency and applicability of the PP-Risk computer programme, described in the preceding chapter, was verified as a decision support system. The starting hypotheses in this research were also verified.

Eighteen experts, who had significantly participated in the realisation of similar projects in the past, took part in the application and verification of the proposed framework. All the experts were shown the breakdown of the project into 10 phases within 4 stages. Since none of the experts had previously participated in all the phases through which the project passes according to Process Protocol, they were divided in 4 groups. None of the experts tested the framework in more than one stage. This deficiency was compensated for by showing all the experts, before the verification process took place, the results of risk management in all the phases through which the project goes from Demonstrating the Need to Operation and Maintenance.

The application of the proposed framework is the implementation of the risk management process described in Chapter 2, which is carried out separately for each phase of the construction project in accordance with Process Protocol. After the experts confirmed the identification of the key risks in each phase, they used the PP-Risk computer programme to determine risk probability and risk impact, and depending on risk exposure and risk acceptability they proposed the appropriate strategy of risk response. They repeated the procedure for each phase within a stage.

Applying the framework to risk management in this way, before the project begins to be executed, has the drawback of loss of the cyclical nature of the risk management process. During project execution risk response may lead to the appearance of new risks in the phase under analysis or in one of the later phases. Since new risks should be treated equally as the initial risks, risk management is by its nature a cyclical process. Furthermore, if the framework is applied to risk management before the project begins no account is taken of the fact that fundamental changes may occur in the relative values of time, cost and quality depending on success in the realisation of preceding phases and on the circumstances and environment in which the project is being executed. This fundamentally affects risk impact, and thus also risk exposure, risk acceptability, and finally risk response. Thus process driven risk management, and the full application of the proposed framework, can only realised if it is applied to a project during its execution, from Describing the Need to Operation and Maintenance.

After application the proposed framework was verified using the method of the structural questionnaire, which the experts filled in after being shown the results of risk management in all the phases through which the construction project passes according to Process Protocol.

In their answers the experts verified the breakdown of the project in phases suggested in Process Protocol, the proposed risk list and process driven risk management. They marked the PP-Risk computer programme, as the implementation of IT support for the proposed framework, as *Very Suitable*. They marked the user interface as *Satisfactory*. All the experts found that using the proposed framework helped them understand the process in construction *Much* or *Very Much* better, whereby they verified the first hypothesis set forth in this work. They also agreed that the proposed framework is *Appropriate* or *Very Appropriate* for a holistic assessment of risk in the stage in which they managed risks, whereby they verified the second hypothesis in this work.

The next chapter will show the conclusion and recommendations for future research.

10 CONCLUSION AND GUIDELINES FOR FUTURE WORK

This chapter gives an overview of the main conclusions and contributions of this research, and suggests guidelines for future work.

10.1 CONCLUSIONS

The author developed and verified a framework for risk management in construction projects, and the PP-Risk computer programme as IT support for the proposed framework.

The development of the framework was preceded by systematic analysis of prior studies of risk management and construction process, which resulted in several conclusions that were used for developing the framework for risk management in construction:

- Risk management is by nature a cyclical process. Risks must be identified before the beginning of project realisation or the realisation of any phase through which the project passes. The environment in which the project is realised produces new risks during project realisation. The new risks must be analysed together with those identified and analysed earlier, in a continuous attempt to assess the probability and adverse effect of new risks in relation to existing ones. This creates the need for continuous risk management in all phases of project realisation.
- The execution of a construction project is a process. The process in construction contains many special features in comparison with the process of other industries, which are an impediment for changes leading to process improvement. The risk that the project might be unsuccessful is in fact the risk that particular elements in the construction process might be unsuccessful. Risk management should be subordinated to the construction process. This means that the approach to risk management in construction should be changed from risk-driven project management to process-driven

risk management. Improving certain elements of risk management lead to better understanding and to changes, in other words, to improvement of the construction process, which is one of the main goals of the construction industry.

- The Construction Process Protocol is by nature a generic process and is thus suitable for the construction process within which the framework for process-driven risk management will be situated. As a plan of work, Process Protocol enables managing the project from Demonstrating the Need to Operation and Maintenance regardless of the type, size and purpose of the project that is being realised. According to Process Protocol, every project can be executed through the successful execution of 10 phases grouped in 4 stages. Every phase contains so-called high-level processes as a group of activities that must be realised for the successful conclusion of that phase. High-level processes are broken down into sub-processes in as many levels as the Protocol user deems necessary for the project. The break down of the process in sub-processes provides a good foundation for identifying key risks that are independent of the project being realised. Sub-processes are potential risk sources so risk management in fact means ensuring the success of each sub-process within the entire construction process. Ensuring the successful execution of the construction process leads to process improvement, which gives additional weight to Process Protocol.

10.1.1 LESSONS LEARNED FOR FUTURE RESEARCH

The framework for process-driven risk management in construction projects, based on Process Protocol and the PP-Risk computer programme as IT support for the proposed framework, were tested and verified on the example of a tunnel planned in the near future. A group of experts, who in various ways played a major part in the realization of similar projects in the past and who are expected to have major participation in future projects, helped in the application and verification of the proposed framework.

The application of the proposed framework and the experts' verification has provided useful lessons for future research and application. The lessons can be summarized as follows:

1. The experts supported the division of the project into 10 phases following the structure of the Process Protocol (see chapter 5). The Construction Process Protocol is a generic process and thus provides a good basis for generic process-driven risk management.

2. The proposed list of key risks for all the phases through which the project passes related to the Process Protocol (see chapter 6) is appropriate for the first analysis but it might be modified in the future as the project develops incorporating the project-related risks which may appear during project execution.

3. The AHP technique was found appropriate for establishing the risk priority list in the each phase of the construction process. Some participants were not familiar with this technique, so it is possible that this problem might occur in the future. This would suggest that all participants should be made fully aware of the AHP technique before beginning to use the system.

4. There was some difficulty experienced by the experts in trying to be consistent in all judgments, but aided by the PP-Risk computer programme participants were able to achieve consistency in their judgments. It was found difficult to make a large number of judgments at once and keep the consistency. Therefore, it has been suggested use is made of the PP-Risk computer programme at the beginning of the risk analysis. This led to the conclusion that each participant should be provided in the future with the PP-Risk computer programme to avoid this problem.

5. All the experts found that the proposed framework helped them understand the construction process better and the assessment of risk.

6. The proposed framework improves communication throughout all Activity Zones. Project managers gather information on risk from all the relevant participants in the projects no matter which the Activity Zone they participate in.

10.1.2 PROVING THE HYPOTHESES

After analysing the applicability of the proposed framework and the corresponding IT support, and their verification by the experts, the following conclusions may be drawn:

- The proposed framework for process-driven risk management is an improvement on current construction project practice because it provides better understanding of the construction process for all participants in project realisation. To identify risks, that is, events that may threaten the successful realisation of a project phase, and to analyse those risks and find an adequate risk response, all participants in the process must understand the construction process on a much higher level. **This conclusion supports the first hypothesis of this research**.
- The proposed framework calls for the identification of key risks in construction projects that are independent of the size, type and purpose of the project. PP-Risk makes it possible to form and update a database that would contain the key risks and be accessible to all interested project managers. This database will help improve current construction project practice. **This conclusion supports the second hypothesis of this research**.
- If documented experiences from earlier executed projects exist, it will be possible to implement quantitative risk analysis and avoid any subjectivity in deciding. If such experiences do not exist the proposed framework provides qualitative risk analysis with constant control of consistency in subjective decision-making. Furthermore, the framework enables combining quantitative and qualitative risk analysis, thus allowing a holistic assessment of risk from Demonstrating the Need to Operation and Maintenance. This is an improvement on current construction project practice. **This conclusion supports the third hypothesis of this research**.
- The proposed framework, together with the IT support, inaugurates a new approach to risk management by placing it within the construction process,

i.e. it applies process-driven risk management. Implementing this approach is an improvement on current construction project practice. **This conclusion supports the fourth hypothesis of this research**.

It may generally be concluded that the primary goal of this research has been achieved because a framework has been developed enabling a systematic approach to risk management in construction projects, whose application in construction practice would enable changes and improvements in the construction industry. In addition a PP-Risk computer programme has been developed as an IT support for the proposed framework.

10.1.3 CONTRIBUTION TO KNOWLEDGE

The main outcome of this research is an advance of knowledge within the application of risk management to construction projects.

A new approach for managing risk in construction has been developed which has is based on a recently established Process Protocol which is now being widely adopted. This has enabled a process-driven risk management system to be developed which can be overlaid on the Process Protocol maps for basic activities and operations. This is the first time to the author's knowledge that such a protocol has been used for such a purpose. It provides a basis for a generic approach to risk management in construction projects.

Phillips (1991) made a compilation of 21 definitions of "originality " in her studies of supervisors and students undertaking PhD studies in order to establish how a thesis could contribute to knowledge. Of the 21 definitions the originality of this thesis may be found in the following within her list:

1. Making a synthesis of things that have not been put together before

The Process Protocol, developed by Cooper et al. at the University of Salford is a generic process and assists in the management of a project from recognition of need for a building to its operation and maintenance. It was found that Process Protocol is a suitable vehicle for a variety of management control systems but to date no on had developed a risk management system which could overlay the whole process. This thesis outlines such an approach.

2. Adding to knowledge in a way that has not been done before

Every contruction project passes through phases, each of which has purpose, duration and scope of work. Risk and uncertainty are inherent in all the phases of construction process.

The literature review shows that most authors have tended to focus on different techniques for quantitative or qualitative risk assessment, risk registers, the role of risk management in project management, and other mechanisms. This thesis argues that realising a construction project is a process and that the risk management process should be subordinated to the construction process

Therefore, the proposed framework introduces a new approach to risk management by embedding it within the construction process. It has thereby developed a process-driven risk management approach which is appropriate to process related protocols.

10.2 FUTURE WORK

Risk is a part of every day life and the future is largely unknown. It is not possible to predict or colonise future events but it is possible to influence their outcomes.

Consideration of the future always requires thinking. We can never have full information about the future, and yet our actions are going to take place, and have consequences, in the future. So,creative thinking can be required to foresee the consequences of action and to generate further alternatives for consideration (de Bono, 1993).

The proposed framework attempts to establish a creative approach to risk management in construction and at the same time the proposed framework provides a practical and usable tool for managing risk in construction and will assist project managers at the time they need to make decisions.

The framework proposed provides a basis for future evolution and development. As the framework is used in practice so it can be refined and developed. It will also be able to be tailored to the needs of particular applications. This study has shown its usefulness as a generic tool and its application in a single project. The evidence suggests that the potential for risk management in other types of project is significant.

Future research should rely on experiences gained in the application of the framework and might concentrate on three aspects:

- Extend or revise the database that contains the list of key risks identified in each phase through which the construction project passes in its development according to Process Protocol, and which are independent of its type, size and purpose.
- Research and quantify criteria of acceptability of the identified risks depending on the percentage to which the exposure of a particular risk participates in the total risk exposure of the phase in which the risk appears.
- The cyclical risk management process, which is implemented in every phase, should be extended by phase risk adjusted cost estimate and a strategy developed for managing the risk budget in the construction process.

APPENDIX 1: Description of the phases in the construction process according to the Process Protocol

PHASE ZERO – DEMONSTRATING THE NEED

The purpose of phase zero is to answer the question: 'What is the problem?'

Description of Phase

- It is important to establish and demonstrate the client's business needs and ensure problems are defined in detail. Identifying the key stakeholders and their requirements will enable the development of the Business Case as part of the client's overall business objectives.

Before the Phase

- The 'user' t.e. business, customer is communicating the problem to the client.
- A master plan (of the client's strategic issues) should be available.

During the Phase

- Bring together the business case, facilities manageemnt (client and users).
- Carry out the necessary activities to produce the deliverables.

Goals

- Establish the need for a project to satisfy the client's business requirements.
- Gain approval to proceed to Phase 1.

Gate Status

- 'Soft' gate.

PHASE ONE – CONCEPTION OF NEED

The purpose of phase one is to answer the question: 'What are the options and how will they be addressed?'

Description of Phase

- The initial statement of need becomes increasingly defined and developed into a structured brief. To this end, all the project stakeholders need to be identified and their requirements captured. The purpose of this phase is to answer the question 'What are the options and how will they be addressed?'

Before the Phase

- Approval to proceed obtained.
- Approval for funding obtained (probably up to phase 3 depending on the size of the project).
- Results of studies to define need(s) are available.
- Initial stakeholders are identified.

During the Phase

- Identify and refine the statement of need(s).
- Develop the project brief according to the business case developed in phase 0.
- Update stakeholder list/group mambership.
- Identify options i.e. do nothing, manage the problem, develop a solution.

Goals

- Identify potential solutions to the need and plan for feasibility (phase two).
- Gain authority and financial approval to proceed to phase 2.

Gate Status

- 'Soft' gate

PHASE TWO – OUTLINE FEASIBILITY

The purpose of phase two is to answer the question: 'Which option(s) should be considered further?'

Description of Phase

- Many options could be presented as possible solutions to the identified problem. The purpose of this phase is to examine the feasibility of the project and narrow down the solutions that should be considered further. These solutions should offer the best match with the client's objectives and business needs.

Before the Phase

- Facilitate for the introduction of new project participants.
- Appoint the 'core teams' that will form the activity zones.

During the Phase

- Undertake feasibility studies for all options including necessary planning approvals.
- Revise Business Case.

Goals

- Examine the feasibility of the options presented in phase 1 and decide which ones should be considered for substantive feasibility.
- Gain approval to proceed to phase 3 (Substantive feasibility study and outline financial authority).

Gate Status

- 'Soft' gate

PHASE THREE – SUBSTANTIVE FEASIBILITY STUDY & OUTLINE FINANCIAL AUTHORITY

The purpose of phase three is to answer the question: 'Should the proposed solution(s) be financed for development?'

Description of Phase

- The decision to develop a solution or solutions further will need to be informed by the results of the substantive feasibility study or studies. The purpose of this phase is to finance the 'right' solution for concept design development and outline planning approval.

Before the Phase

- Re-define the project brief/business case and project objectives based on outline feasibility results.
- As the options become more defined, consider project success criteria and performance measures.

During the Phase

- Challenge the need(s)/opportunities.
- Conduct substantive cost/benefit analyses.
- Submit application(s) for statutory approval(s).
- Produce the concept design plan.

Goals

- Gain approval to proceed to phase 4.
- Gain financial approval (perhaps until phase 5).

Gate Status

- 'Hard' gate

PHASE FOUR – OUTLINE CONCEPTUAL DESIGN

The purpose of phase four is to answer the question: 'How does the solution translate to an outline design?'

Description of Phase

- The purpose of this phase is to translate the chosen option into an outline design solution according to the project brief. A number of potential design solutions are identified and presented for selection. Some of the major design elements should be identified.

Before the Phase

- Define the systems i.e. sub-assemblies.
- Define the criteria for evaluating the systems e.g. production time scale, cost, resources required, etc.
- Identify major system interfaces and interactions to enable communications and facilitate the introduction of project design teams.
- Facilitate the introduction of key system suppliers.

During the Phase

- Iterative development of outline concept design.
- Refine project / system solutions
- Develop basic schematics i.e. plans, elevatons, etc.
- Identify the implications of system solutions in relation to other system solutions and to the overall project.
- Identify production supply chain.

Goals

- Identify major design elements based on the options presented.
- Gain approval to proceed to phase 5.

Gate Status

- 'Soft' gate

PHASE FIVE – FULL CONCEPTUAL DESIGN

The purpose of phase five is to answer the question: 'Can we apply for planning permission?'

Description of Phase

- The conceptual design should present the chosen solution in more detailed form to include M&E, architecture, etc. A number of buildability and design studies might be produced to prepare the design for detailed planning approval.

Before the Phase

- Review membership of design teams.
- Review evaluation criteria for concept design.
- Some of the major systems are identified.

During the Phase

- Develop system concept design.
- System interface studies.
- Identify resourcing requirements.

Goals

- Conceptual design and all deliverables ready for detailed planning approval.
- Gain approval to proceed to phase 6.

Gate Status

- 'Hard' gate

PHASE SIX – COORDINATED DESIGN, PROCUREMENT & FULL FINANCIAL AUTHORITY

The purpose of phase six is to answer the question: 'Are the Major design elements fixed?'

Description of Phase

- The purpose of this phase is to ensure the coordination of the design information. The detailed information provided should enable the predictability of cost, design, production and maintenance issues amongst others. Full financial authority will ensure the enactment of production and construction works.

Before the Phase

- Review membership of design teams.
- Review evaluation criteria for co-ordinated design.
- Major building elements are fixed.

During the Phase

- Assemble the co-ordinated product model.
- Review and update major deliverables.
- Review supply chain analysis.

Goals

- Fix all major design elements to allow the project to proceed to phase 7.
- Gain approval to proceed to phase 7 and (in most cases) through to the end of the project.
- Gain full financial approval for the project.

Gate Status

- 'Hard' gate

PHASE SEVEN – PRODUCTION INFORMATION

The purpose of phase seven is to answer the question: 'Is the detail 'right' for construction?'

Description of Phase

- The detail of the design should be determined to enable the planning of construction including assembly and enabling works. Preferably no more changes in the design should occur after this stage. Every effort should be made to optimise the design after consideration of the whole lifecycle of the product.

Before the Phase

- Review membership of design teams.
- Review evaluation criteria for co-ordinated design (ideally design 100% complete).
- Review and update communication strategy.

During the Phase

- Develop co-ordinated fabrication design/detail for the co-ordinated product model.
- Develop production process map for on and off-site activities for each system/work package.
- Start 'enabling works'.

Goals

- Finalise all major deliverables and proceed to the construction phase.
- Gain approval to proceed through to phase 9.

Gate Status

- 'Soft' gate

PHASE EIGHT – CONSTRUCTION

The purpose of phase eight is to answer the question: 'Are we ready to hand-over the facility?'

Description of Phase

- The design fixity and careful consideration of all constraints achieved at the previous phase should ensure the 'trouble-free' construction of the product. Any problems identified should be analysed to ensure that they do not re-ocur in future projects.

Before the Phase

- Finalise all major deliverables such as the project brief, business case, project execution plan, etc.
- Finalise drawings for construction along with production information.
- Ensure that all supplier bodies are in place.
- Formulate contingency plans to accommodate possible obstructive elements such as weather.

During the Phase

- Undertake construction works.
- Manage and monitor costs, materials, equipment and quality of supplier's work.
- Manage the construction process and review and implement handover plan.
- Manage health and safety.
- Liaise with stakeholders for future needs.

Goals

- Produce a building that satisfies all client requirements.
- Handover the building as planned.

Gate Status

- 'Hard' gate.

PHASE NINE – OPERATION & MAINTENANCE

The purpose of phase nine is to answer the question: 'What can we learn?'

Description of Phase

- The facility is handed over to the client as planned. The post project review should identify any areas that need to be more considered more carefully in future projects. The emphasis should be in creating a learning environment for everybody involved. As built designs are documented and finalised information is deposited in the Legacy Archive for future use.

Before the Phase

- Construct building as planned.
- Handover the facility with all the relevant documentation.
- Store all the project information and learning lessons in the Legacy Archive.
- Plan for on-going feedback from the client's organisation.
- Management team liaise with contractor team to plan handover.

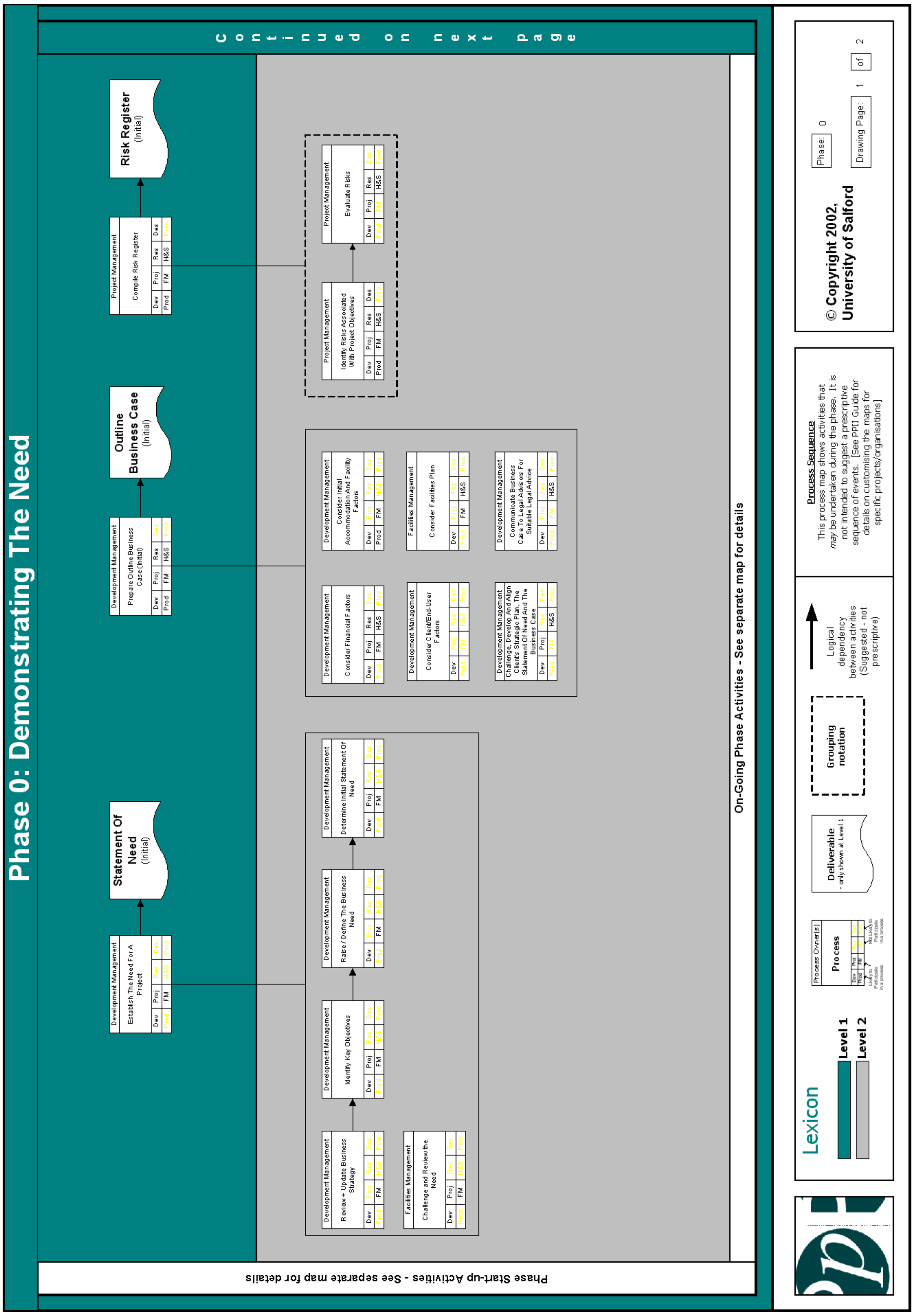
During the Phase

- Undertake a post project review to examine the level of satisfaction by the client.
- Examine the fulfilment of all success and performance criteria.
- Establish continuous communications with the client.
- Ongoing review of assets with regards to: functionality, health and safety and maintining asset information.

Gate Status

- Although there are no formal gates in the process, care should be paid in establishing a programme of continuous improvement that is communicated throughout the company and the company's organisation.

APPENDIX 2: The Process Protocol maps



Phase 0: Demonstrating The Need
Statement Of Need (Initial)
Outline Business Case (Initial)
Risk Register (Initial)
Development Management
Establish The Need For A Project
Prepare Outline Business Case (Initial)
Project Management
Compile Risk Register
Review + Update Business Strategy
Identify Key Objectives
Raise / Define The Business Need
Determine Initial Statement Of Need
Facilities Management
Challenge and Review the Need
Consider Financial Factors
Consider Initial Accommodation And Facility Factors
Consider Client/End-User Factors
Consider Facilities Plan
Challenge, Develop And Align Client's Strategic Plan, The Statement Of Need And The Business Case
Communicate Business Case To Legal Advisers For Suitable Legal Advice
Identify Risks Associated With Project Objectives
Evaluate Risks
Continued on next page
On-Going Phase Activities - See separate map for details
Phase Start-up Activities - See separate map for details
Lexicon
Level 1
Level 2
Process Owner(s)
Process
Deliverable - only shown at Level 1
Grouping notation
Logical dependency between activities (Suggested - not prescriptive)
Process Sequence
This process map shows activities that may be undertaken during the phase. It is not intended to suggest a prescriptive sequence of events. [See PPI Guide for details on customising the maps for specific projects/organisations]
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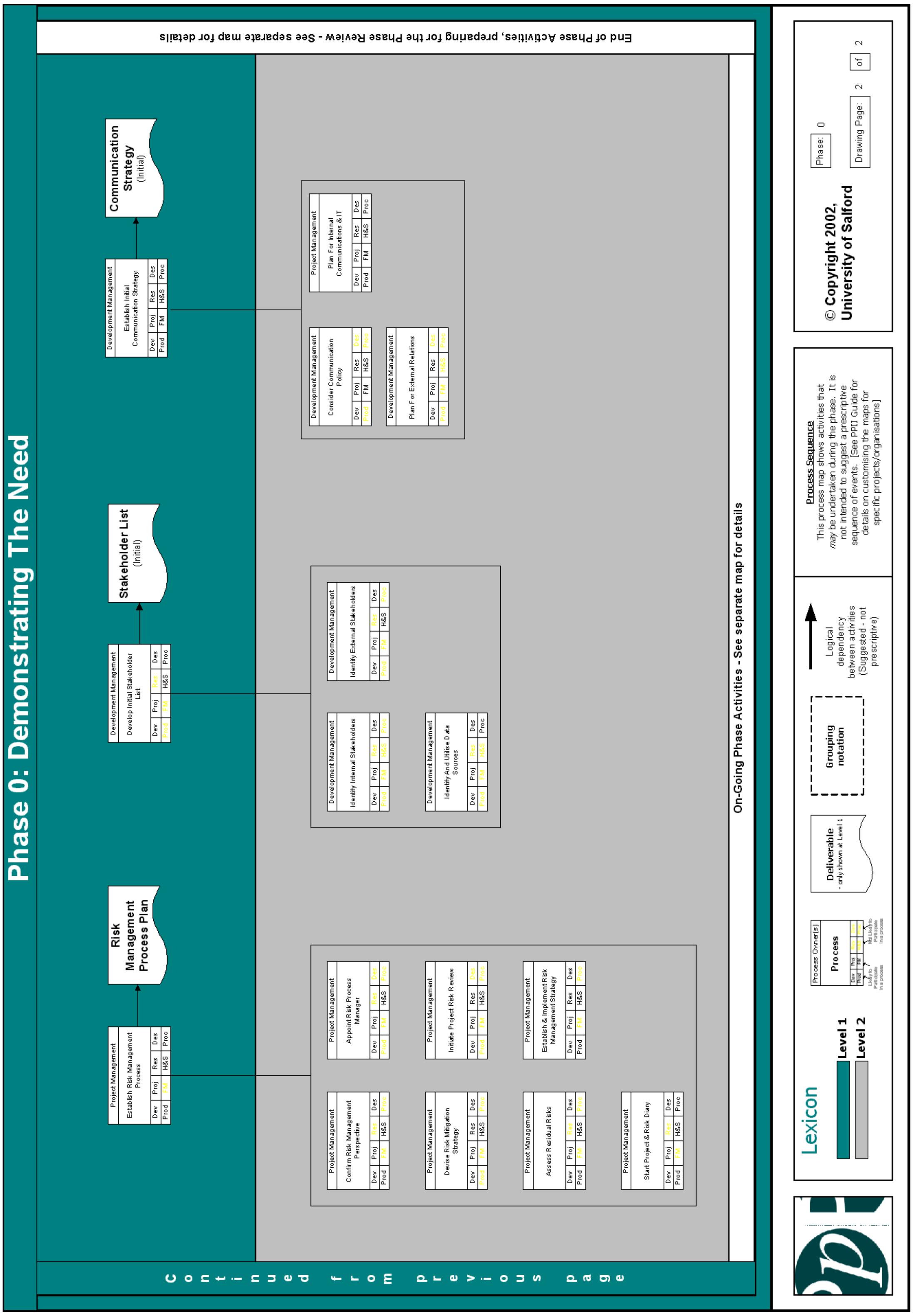
Phase: 0
Drawing Page: 1 of 2



Phase 0: Demonstrating The Need
End of Phase Activities, preparing for the Phase Review - See separate map for details
Continued from previous page
Project Management
Establish Risk Management Process
Risk Management Process Plan
Development Management
Develop Initial Stakeholder List
Stakeholder List (Initial)
Development Management
Establish Initial Communication Strategy
Communication Strategy (Initial)
Project Management
Confirm Risk Management Perspective
Project Management
Appoint Risk Process Manager
Project Management
Devise Risk Mitigation Strategy
Project Management
Initiate Project Risk Review
Project Management
Assess Residual Risks
Project Management
Establish & Implement Risk Management Strategy
Project Management
Start Project & Risk Diary
Development Management
Identify Internal Stakeholders
Development Management
Identify External Stakeholders
Development Management
Identify And Utilise Data Sources
Development Management
Consider Communication Policy
Project Management
Plan For Internal Communications & IT
Development Management
Plan For External Relations
On-Going Phase Activities - See separate map for details
Lexicon
Level 1
Level 2
Process Owner(s)
Process
Deliverable - only shown at Level 1
Grouping notation
Logical dependency between activities (Suggested - not prescriptive)
Process Sequence
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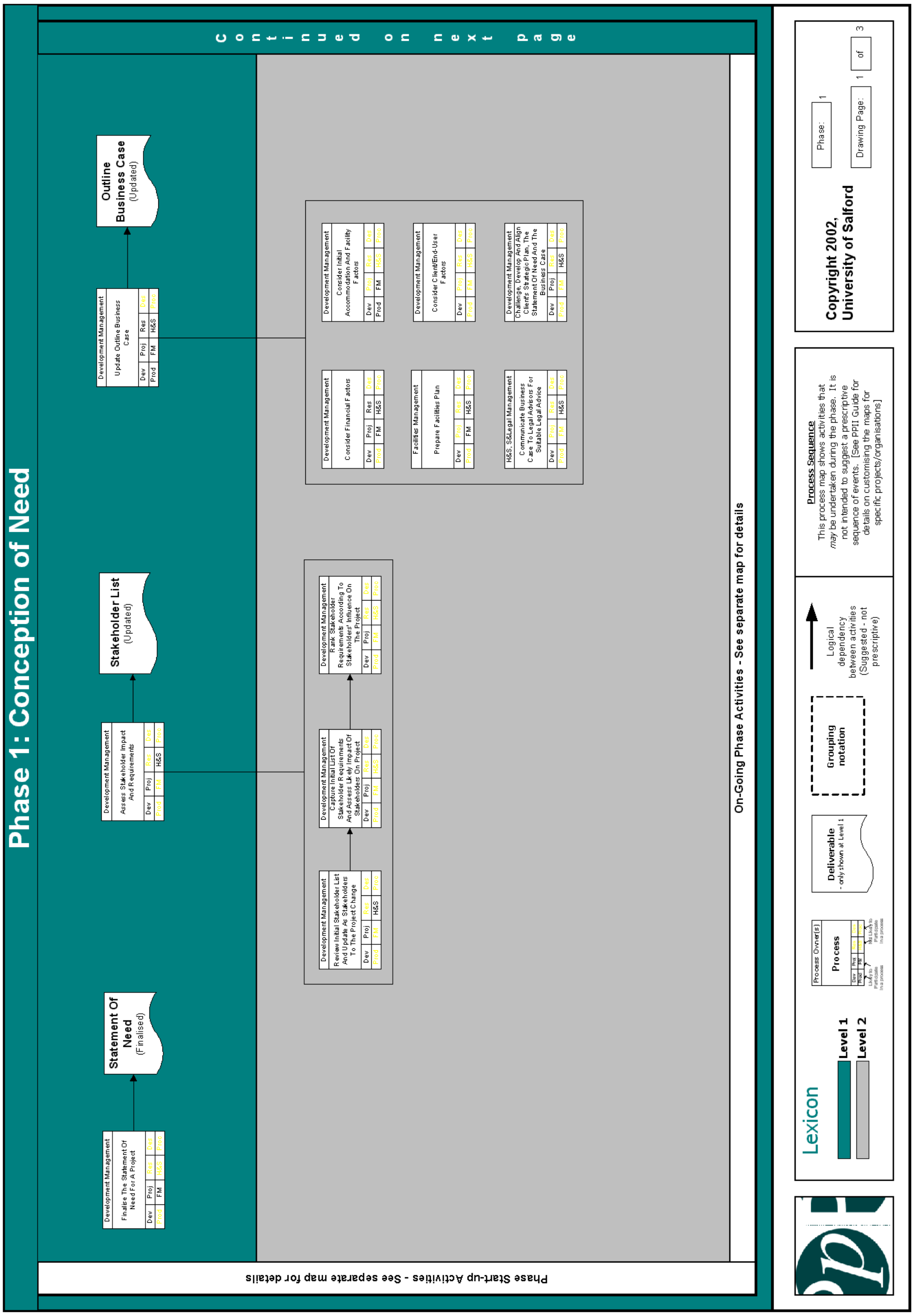
Phase: 0
Drawing Page: 2 of 2


Phase 1: Conception of Need
Statement Of Need (Finalised)
Stakeholder List (Updated)
Outline Business Case (Updated)
Continued on next page
On-Going Phase Activities - See separate map for details
Phase Start-up Activities - See separate map for details
Lexicon
Level 1
Level 2
Process
Deliverable
Grouping notation
Logical dependency between activities (Suggested - not prescriptive)
Process Sequence
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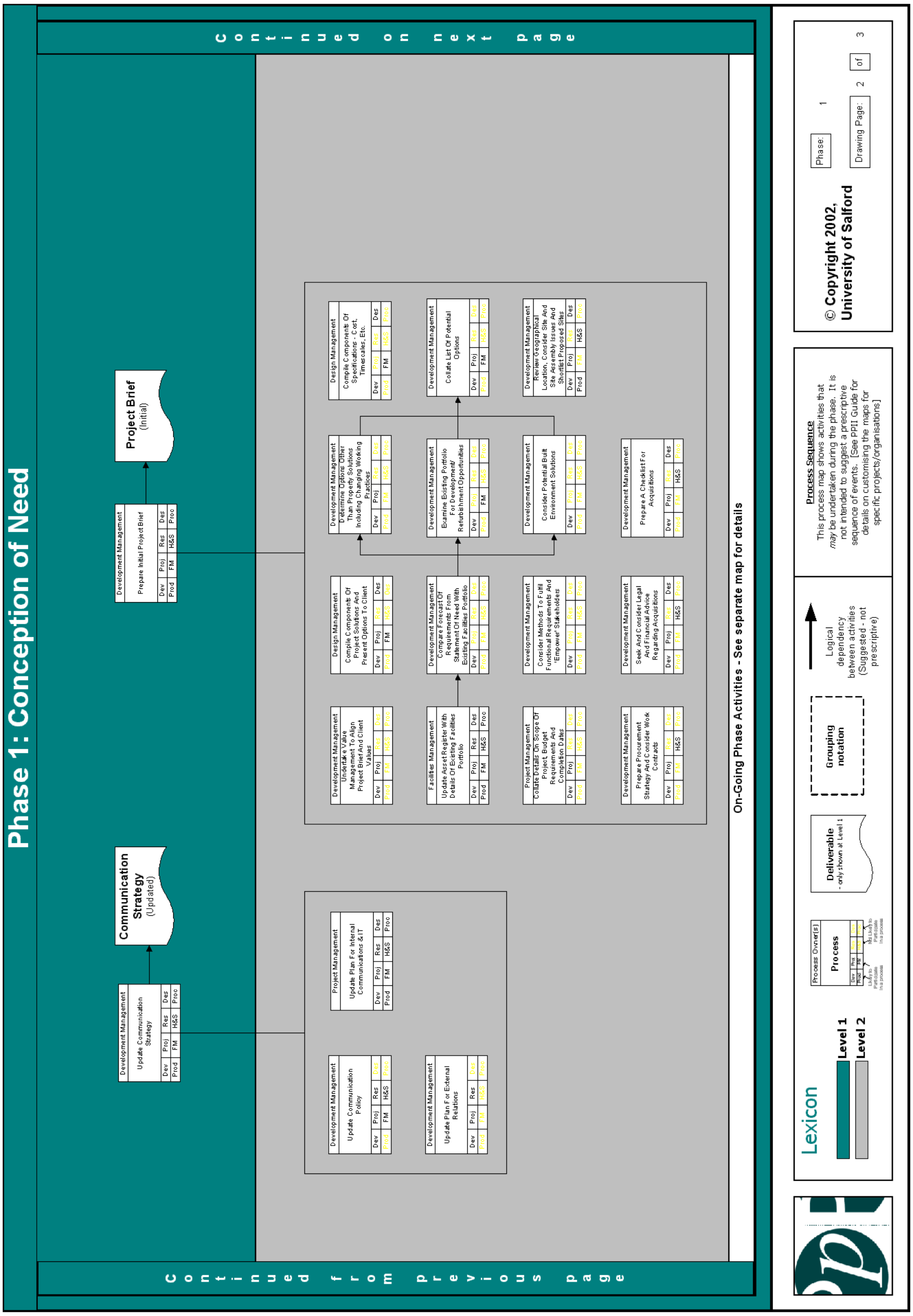
Phase: 1
Drawing Page: 1 of 3


Phase 1: Conception of Need
Continued from previous page
Continued on next page
Development Management
Update Communication Strategy
Communication Strategy (Updated)
Development Management
Prepare Initial Project Brief
Project Brief (Initial)
Development Management
Update Communication Policy
Project Management
Update Plan For Internal Communications & IT
Development Management
Update Plan For External Relations
Development Management
Undertake Value Management To Align Project Brief And Client Values
Design Management
Compile Components Of Project Solutions And Present Options To Client
Development Management
Determine Options Other Than Property Solutions Including Changing Working Practices
Design Management
Compile Components Of Specifications - Cost, Timescales, Etc.
Facilities Management
Update Asset Register With Details Of Existing Facilities Portfolio
Development Management
Compare Forecast Of Requirements From Statement Of Need With Existing Facilities Portfolio
Development Management
Examine Existing Portfolio For Development/ Refurbishment Opportunities
Development Management
Collate List Of Potential Options
Project Management
Collate Details On Scope Of Project, Budget Requirements And Completion Dates
Development Management
Consider Methods To Fulfil Functional Requirements And 'Empower' Stakeholders
Development Management
Consider Potential Built Environment Solutions
Development Management
Review Geographical Location, Consider Site And Site Assembly Issues And Shortlist Proposed Sites
Development Management
Prepare Procurement Strategy And Consider Work Contracts
Development Management
Seek And Consider Legal And Financial Advice Regarding Acquisitions
Development Management
Prepare A Checklist For Acquisitions
Dev Proj Res Des
Prod FM H&S Proc
On-Going Phase Activities - See separate map for details
Lexicon
Level 1
Level 2
Process Owner(s)
Process
Deliverable
- only shown at Level 1
Grouping notation
Logical dependency between activities (Suggested - not prescriptive)
Process Sequence
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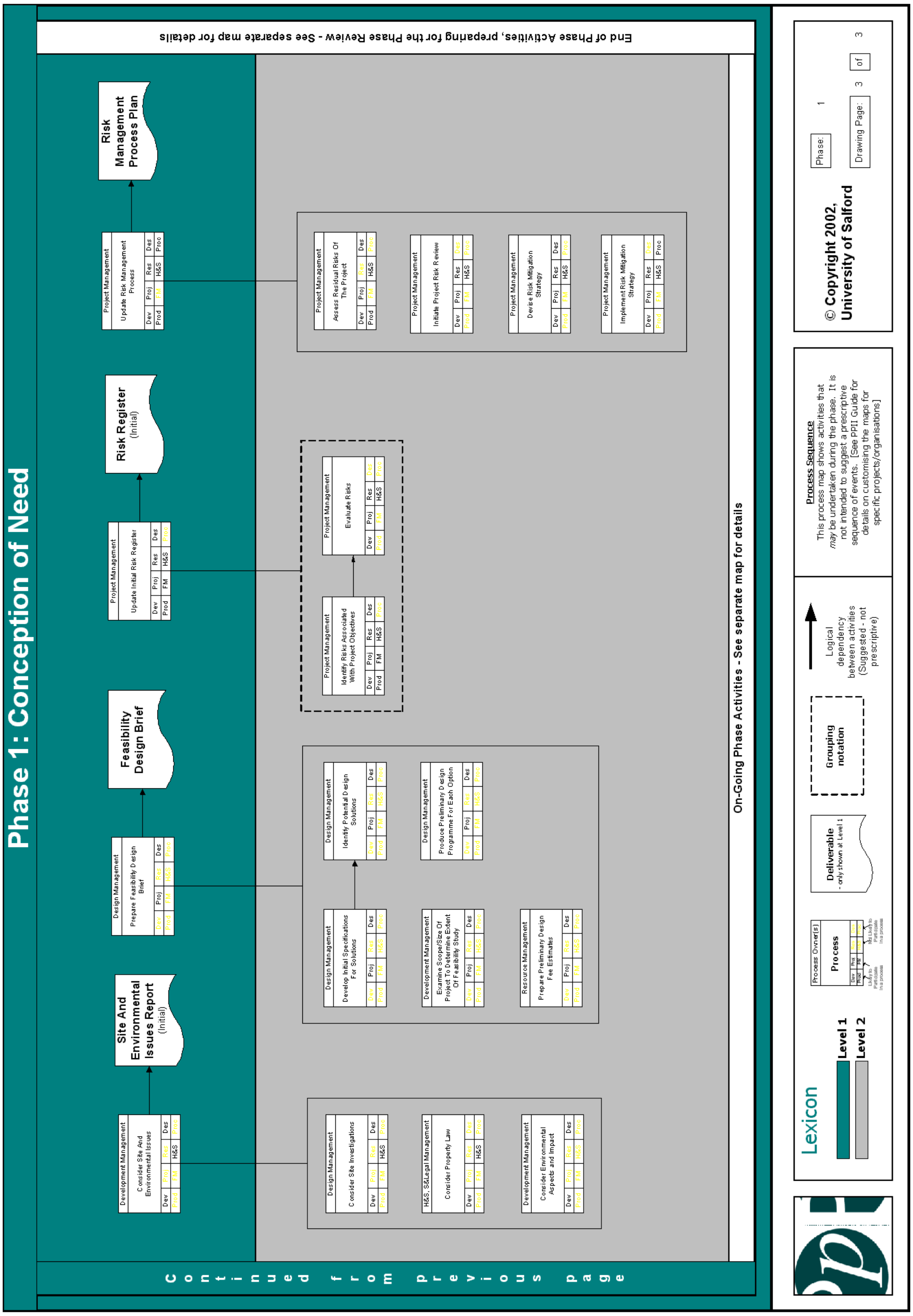
Phase: 1
Drawing Page: 2 of 3


Phase 1: Conception of Need
End of Phase Activities, preparing for the Phase Review - See separate map for details
On-Going Phase Activities - See separate map for details
Continued from previous page
Development Management
Consider Site And Environmental Issues
Site And Environmental Issues Report (Initial)
Design Management
Prepare Feasibility Design Brief
Feasibility Design Brief
Project Management
Update Initial Risk Register
Risk Register (Initial)
Project Management
Update Risk Management Process
Risk Management Process Plan
Consider Site Investigations
H&S, S&Legal Management
Consider Property Law
Consider Environmental Aspects and Impact
Develop Initial Specifications For Solutions
Identify Potential Design Solutions
Examine Scope/Size Of Project To Determine Extent Of Feasibility Study
Produce Preliminary Design Programme For Each Option
Resource Management
Prepare Preliminary Design Fee Estimates
Identify Risks Associated With Project Objectives
Evaluate Risks
Assess Residual Risks Of The Project
Initiate Project Risk Review
Devise Risk Mitigation Strategy
Implement Risk Mitigation Strategy
Lexicon
Level 1
Level 2
Process
Deliverable - only shown at Level 1
Grouping notation
Logical dependency between activities (Suggested - not prescriptive)
Process Sequence
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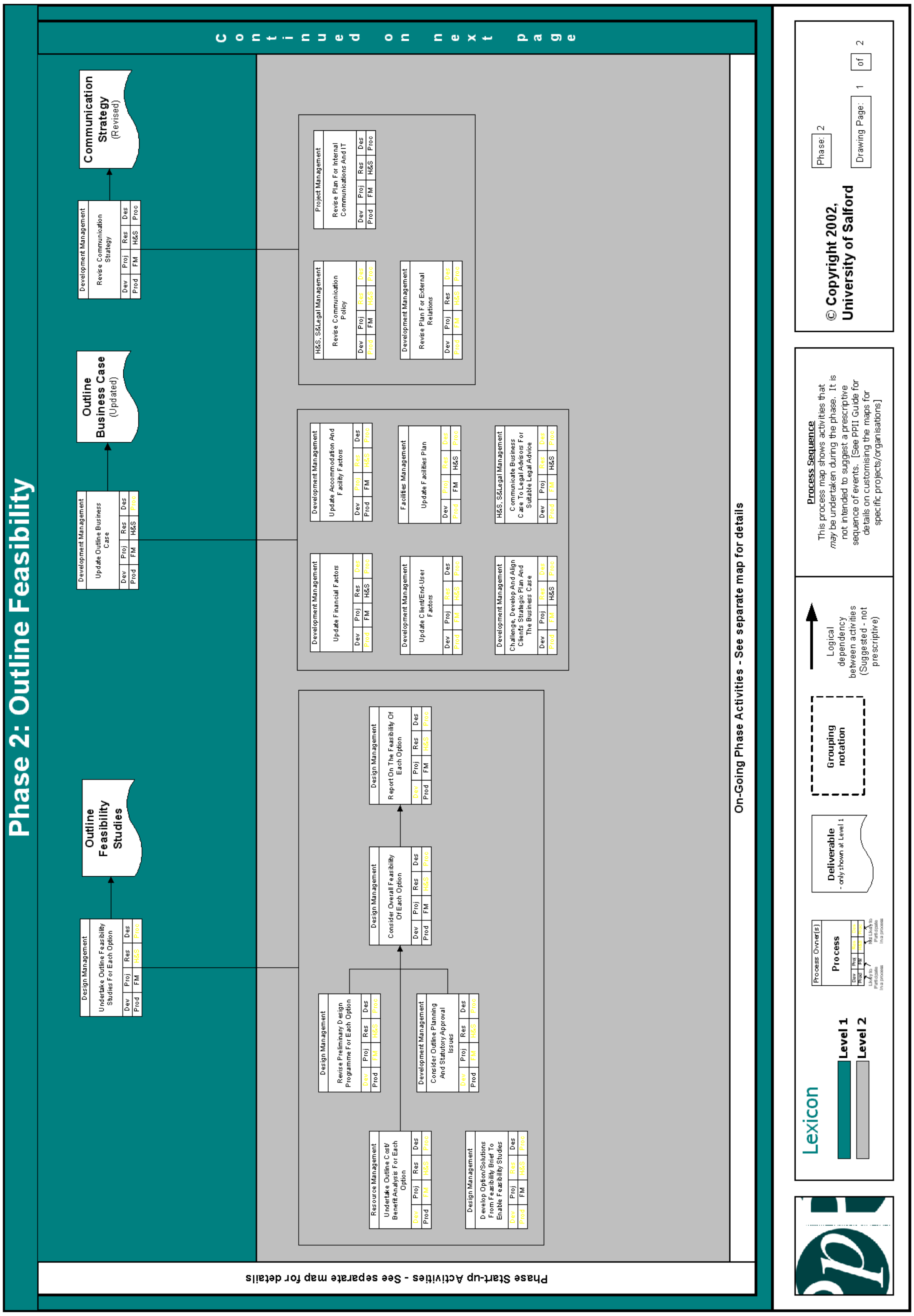
Phase: 1
Drawing Page: 3 of 3


Phase 2: Outline Feasibility
Outline Feasibility Studies
Outline Business Case (Updated)
Communication Strategy (Revised)
Continued on next page
On-Going Phase Activities - See separate map for details
Phase Start-up Activities - See separate map for details
Lexicon
Level 1
Level 2
Process
Deliverable
Grouping notation
Logical dependency between activities (Suggested - not prescriptive)
Process Sequence
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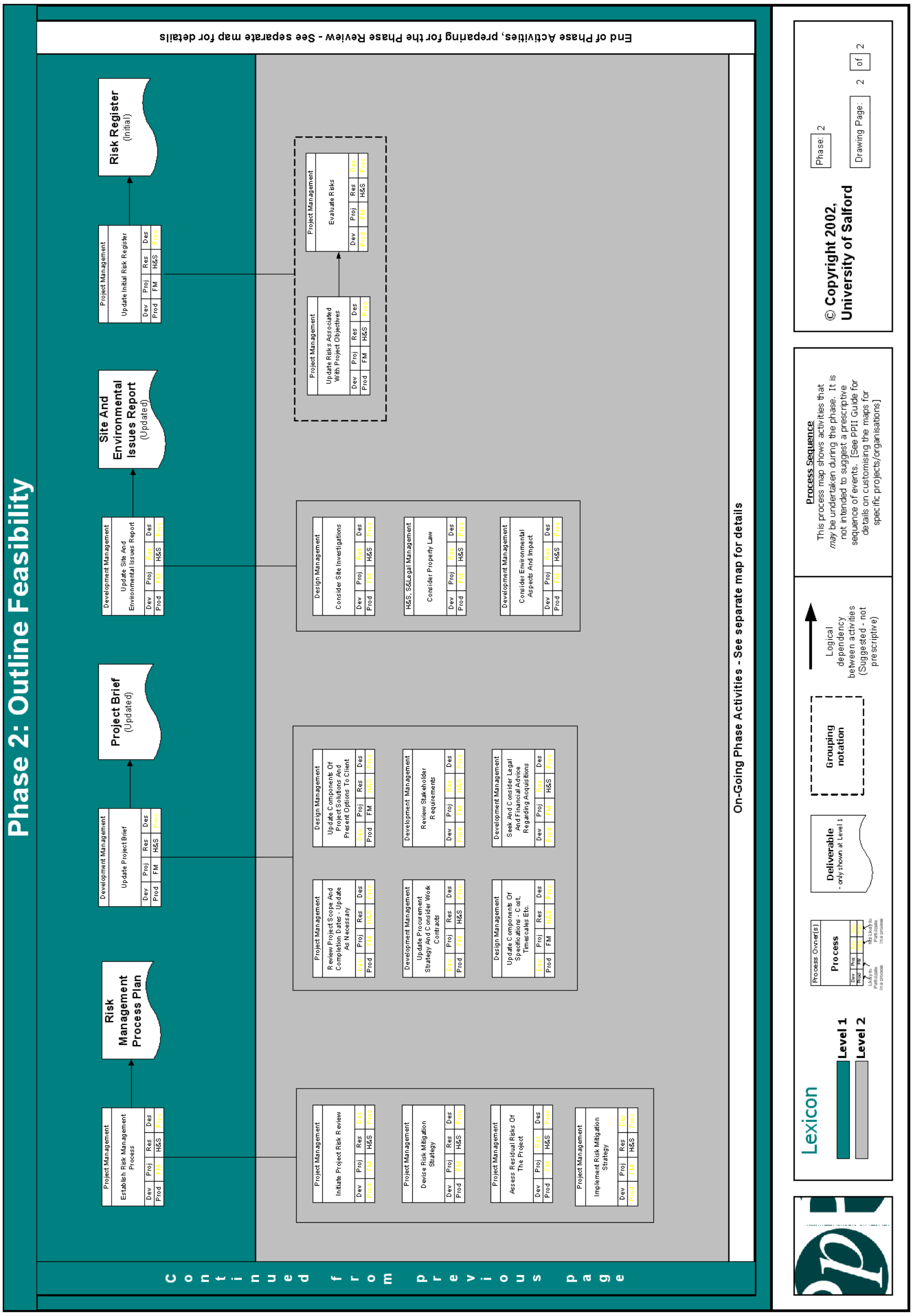
Phase: 2
Drawing Page: 1 of 2



Phase 2: Outline Feasibility
Continued from previous page
Project Management
Establish Risk Management Process
Risk Management Process Plan
Development Management
Update Project Brief
Project Brief (Updated)
Update Site And Environmental Issues Report
Site And Environmental Issues Report (Updated)
Update Initial Risk Register
Risk Register (Initial)
Initiate Project Risk Review
Devise Risk Mitigation Strategy
Assess Residual Risks Of The Project
Implement Risk Mitigation Strategy
Review Project Scope And Completion Dates - Update As Necessary
Update Procurement Strategy And Consider Work Contracts
Design Management
Update Components Of Specifications - Cost, Timescales Etc.
Update Components Of Project Solutions And Present Options To Client
Review Stakeholder Requirements
Seek And Consider Legal And Financial Advice Regarding Acquisitions
Consider Site Investigations
H&S, S&Legal Management
Consider Property Law
Consider Environmental Aspects And Impact
Update Risks Associated With Project Objectives
Evaluate Risks
End of Phase Activities, preparing for the Phase Review - See separate map for details
On-Going Phase Activities - See separate map for details
Lexicon
Level 1
Level 2
Process
Deliverable
Grouping notation
Logical dependency between activities (Suggested - not prescriptive)
Process Sequence
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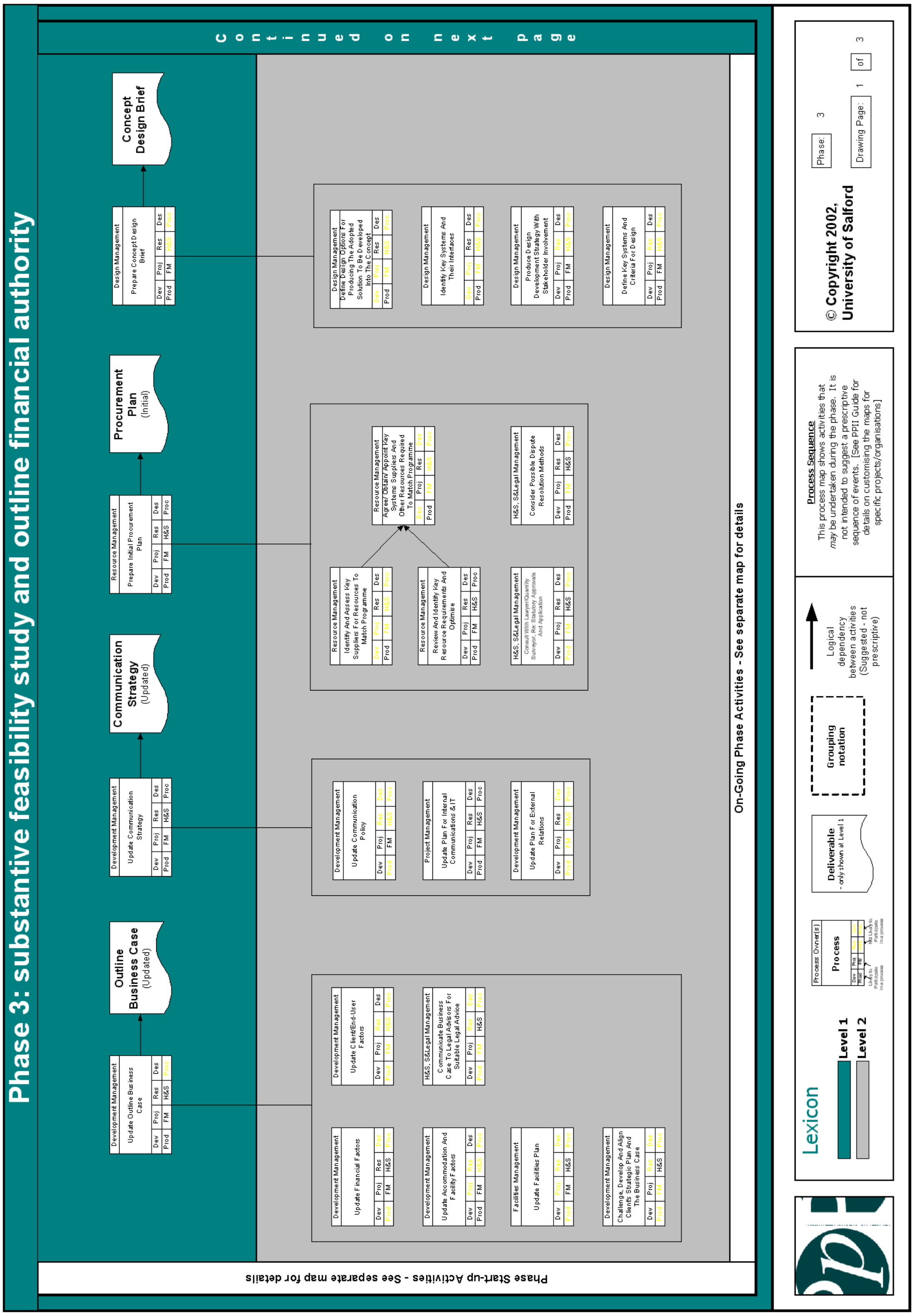
Phase: 2
Drawing Page: 2 of 2



Phase 3: substantive feasibility study and outline financial authority
Outline Business Case (Updated)
Communication Strategy (Updated)
Procurement Plan (Initial)
Concept Design Brief
Development Management
Update Outline Business Case
Development Management
Update Communication Strategy
Resource Management
Prepare Initial Procurement Plan
Design Management
Prepare Concept Design Brief
Continued on next page
On-Going Phase Activities - See separate map for details
Phase Start-up Activities - See separate map for details
Lexicon
Level 1
Level 2
Process
Deliverable
Grouping notation
Logical dependency between activities (Suggested - not prescriptive)
Process Sequence
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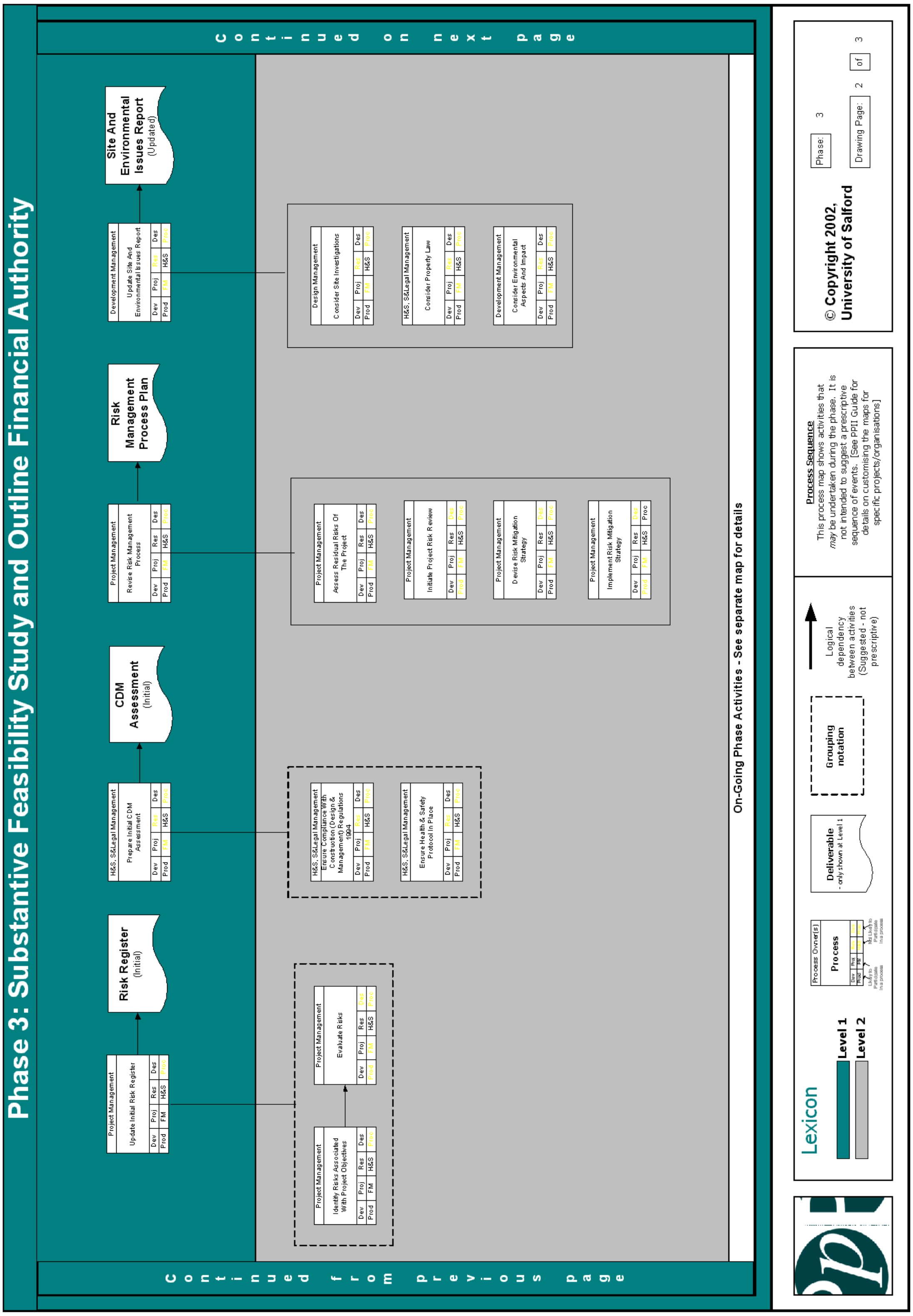
Phase: 3
Drawing Page: 1 of 3


Phase 3: Substantive Feasibility Study and Outline Financial Authority
Continued from previous page
Continued on next page
Risk Register (Initial)
CDM Assessment (Initial)
Risk Management Process Plan
Site And Environmental Issues Report (Updated)
Project Management
Update Initial Risk Register
H&S, S&Legal Management
Prepare Initial CDM Assessment
Revise Risk Management Process
Development Management
Update Site And Environmental Issues Report
Identify Risks Associated With Project Objectives
Evaluate Risks
Ensure Health & Safety Protocol In Place
Assess Residual Risks Of The Project
Initiate Project Risk Review
Devise Risk Mitigation Strategy
Implement Risk Mitigation Strategy
Design Management
Consider Site Investigations
Consider Property Law
Consider Environmental Aspects And Impact
On-Going Phase Activities - See separate map for details
Lexicon
Level 1
Level 2
Process
Deliverable
Grouping notation
Logical dependency between activities (Suggested - not prescriptive)
Process Sequence
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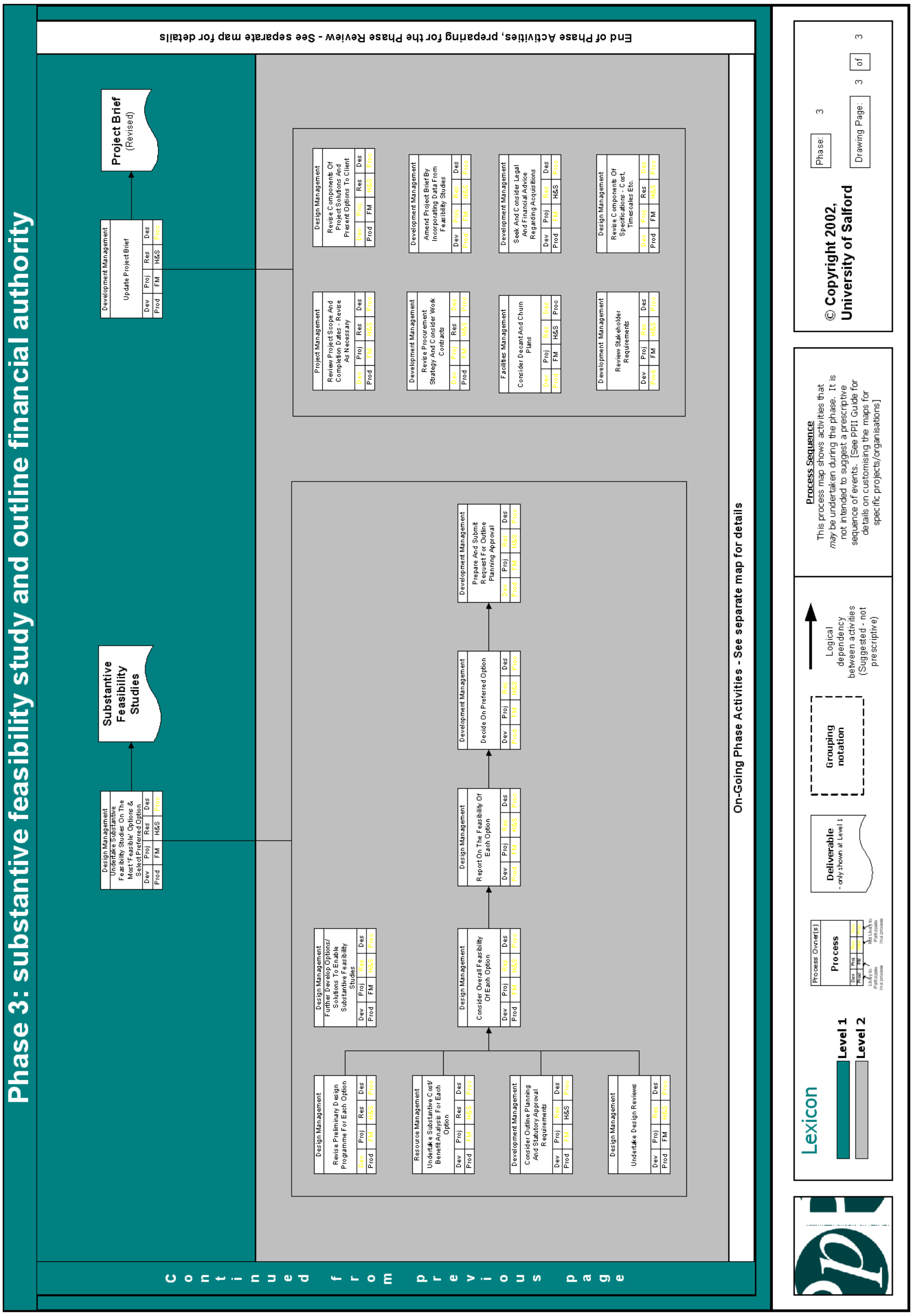
Phase: 3
Drawing Page: 2 of 3


Phase 3: substantive feasibility study and outline financial authority
Continued from previous page
Design Management
Undertake Substantive Feasibility Studies On The Most 'Feasible' Options & Select Preferred Option
Substantive Feasibility Studies
Development Management
Update Project Brief
Project Brief
(Revised)
Design Management
Revise Preliminary Design Programme For Each Option
Design Management
Further Develop Options/ Solutions To Enable Substantive Feasibility Studies
Resource Management
Undertake Substantive Cost/ Benefit Analysis For Each Option
Development Management
Consider Outline Planning And Statutory Approval Requirements
Design Management
Undertake Design Reviews
Design Management
Consider Overall Feasibility Of Each Option
Design Management
Report On The Feasibility Of Each Option
Development Management
Decide On Preferred Option
Development Management
Prepare And Submit Request For Outline Planning Approval
Project Management
Review Project Scope And Completion Dates - Revise As Necessary
Design Management
Revise Components Of Project Solutions And Present Options To Client
Development Management
Revise Procurement Strategy And Consider Work Contracts
Development Management
Amend Project Brief By Incorporating Data From Feasibility Studies
Facilities Management
Consider Decant And Churn Plans
Development Management
Seek And Consider Legal And Financial Advice Regarding Acquisitions
Development Management
Review Stakeholder Requirements
Design Management
Revise Components Of Specifications - Cost, Timescales Etc.
On-Going Phase Activities - See separate map for details
End of Phase Activities, preparing for the Phase Review - See separate map for details
Lexicon
Level 1
Level 2
Process Owner(s)
Process
Deliverable
- only shown at Level 1
Grouping notation
Logical dependency between activities (Suggested - not prescriptive)
Process Sequence
This process map shows activities that may be undertaken during the phase. It is not intended to suggest a prescriptive sequence of events. [See PPII Guide for details on customising the maps for specific projects/organisations]
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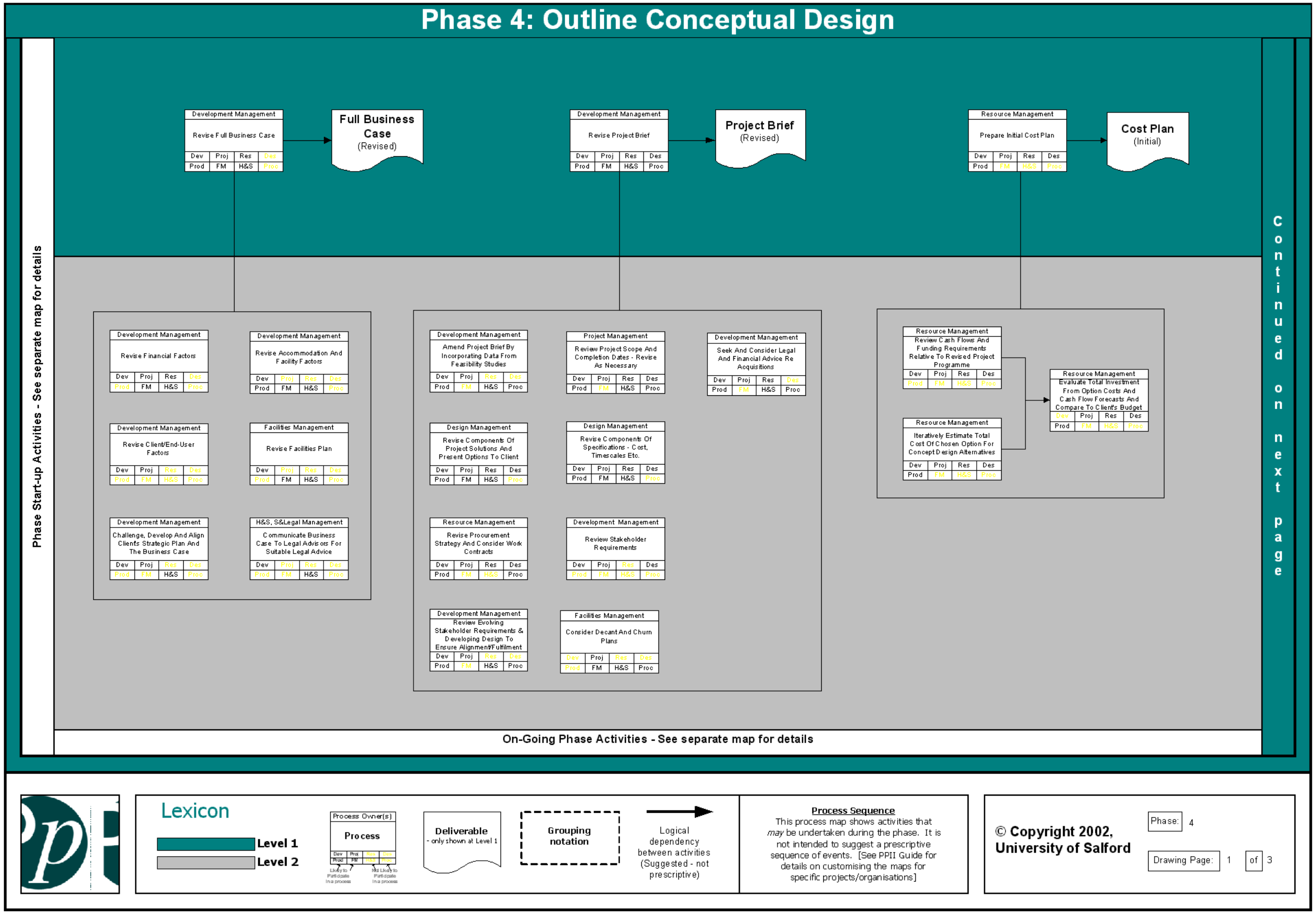
Phase: 3
Drawing Page: 3 of 3


Phase 4: Outline Conceptual Design
Development Management
Revise Full Business Case
Full Business Case
(Revised)
Development Management
Revise Project Brief
Project Brief
(Revised)
Resource Management
Prepare Initial Cost Plan
Cost Plan
(Initial)
Phase Start-up Activities - See separate map for details
Development Management
Revise Financial Factors
Development Management
Revise Accommodation And Facility Factors
Development Management
Revise Client/End-User Factors
Facilities Management
Revise Facilities Plan
Development Management
Challenge, Develop And Align Clients Strategic Plan And The Business Case
H&S, S&Legal Management
Communicate Business Case To Legal Advisors For Suitable Legal Advice
Development Management
Amend Project Brief By Incorporating Data From Feasibility Studies
Project Management
Review Project Scope And Completion Dates - Revise As Necessary
Development Management
Seek And Consider Legal And Financial Advice Re Acquisitions
Design Management
Revise Components Of Project Solutions And Present Options To Client
Design Management
Revise Components Of Specifications - Cost, Timescales Etc.
Resource Management
Revise Procurement Strategy And Consider Work Contracts
Development Management
Review Stakeholder Requirements
Development Management
Review Evolving Stakeholder Requirements & Developing Design To Ensure Alignment/Fulfilment
Facilities Management
Consider Decant And Churn Plans
Resource Management
Review Cash Flows And Funding Requirements Relative To Revised Project Programme
Resource Management
Iteratively Estimate Total Cost Of Chosen Option For Concept Design Alternatives
Resource Management
Evaluate Total Investment From Option Costs And Cash Flow Forecasts And Compare To Clients Budget
Dev
Proj
Res
Des
Prod
FM
H&S
Proc
Continued on next page
On-Going Phase Activities - See separate map for details
Lexicon
Level 1
Level 2
Process Owner(s)
Process
Deliverable
- only shown at Level 1
Grouping notation
Logical dependency between activities (Suggested - not prescriptive)
Process Sequence
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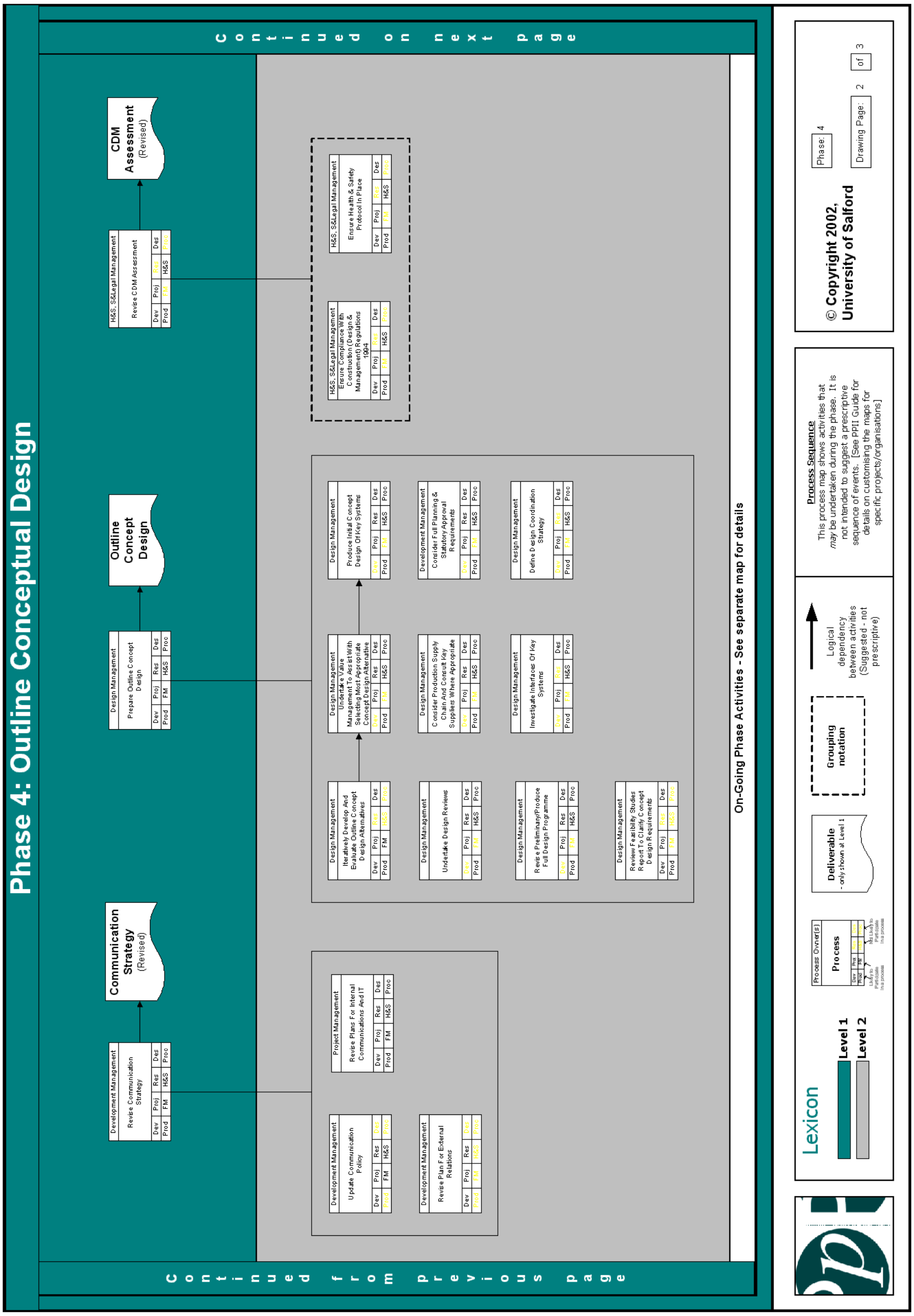
Phase: 4
Drawing Page: 1 of 3



Phase 4: Outline Conceptual Design
Communication Strategy (Revised)
Outline Concept Design
CDM Assessment (Revised)
Development Management
Revise Communication Strategy
Design Management
Prepare Outline Concept Design
H&S, S&Legal Management
Revise CDM Assessment
On-Going Phase Activities - See separate map for details
Continued on next page
Continued from previous page
Lexicon
Level 1
Level 2
Process
Process Owner(s)
Deliverable
Grouping notation
Logical dependency between activities (Suggested - not prescriptive)
Process Sequence
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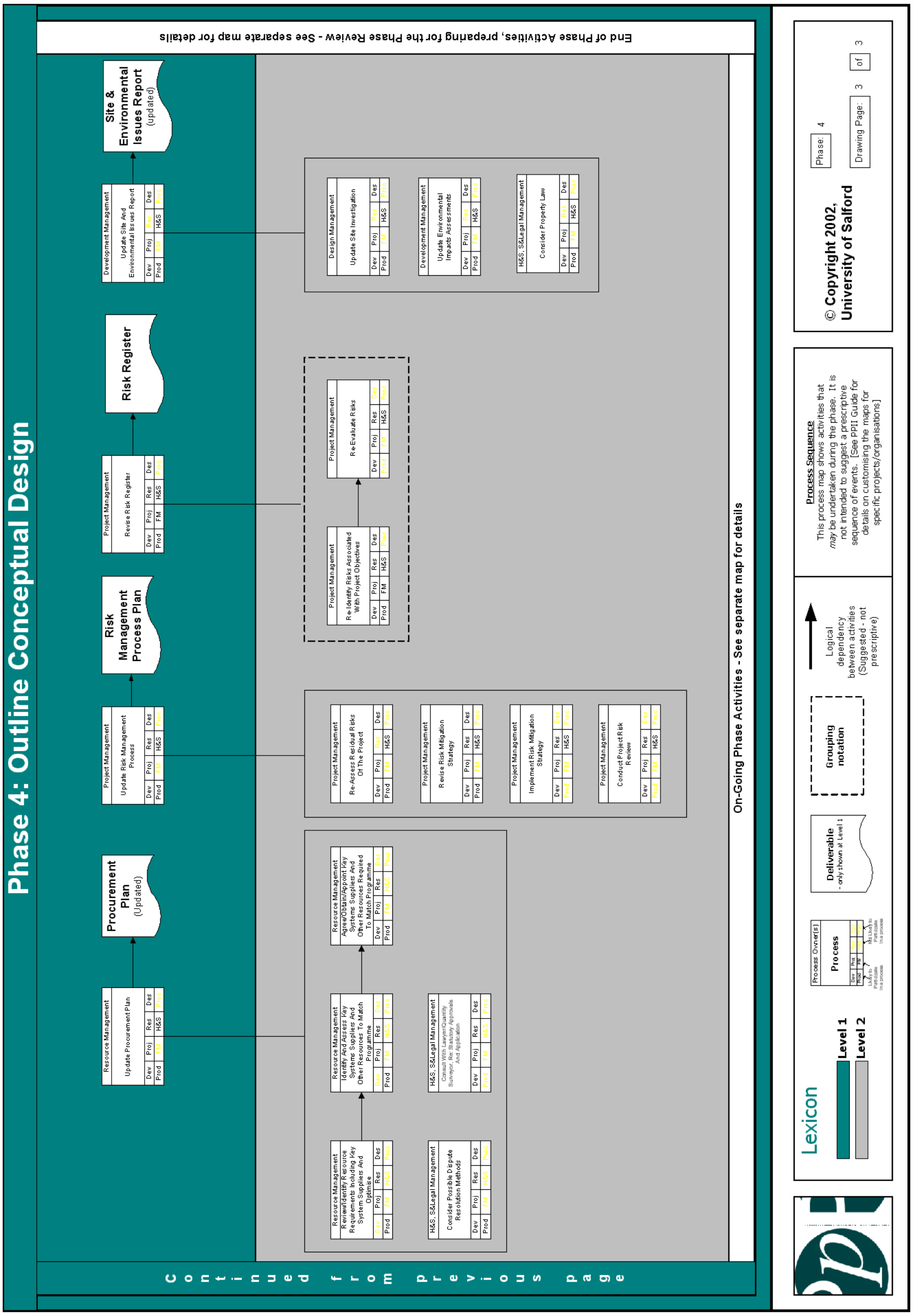
Phase: 4
Drawing Page: 2 of 3


Phase 4: Outline Conceptual Design
Procurement Plan (Updated)
Risk Management Process Plan
Risk Register
Site & Environmental Issues Report (updated)
End of Phase Activities, preparing for the Phase Review - See separate map for details
On-Going Phase Activities - See separate map for details
Continued from previous page
Lexicon
Level 1
Level 2
Process
Deliverable
Grouping notation
Logical dependency between activities (Suggested - not prescriptive)
Process Sequence
This process map shows activities that may be undertaken during the phase. It is not intended to suggest a prescriptive sequence of events. [See PPI Guide for details on customising the maps for specific projects/organisations]
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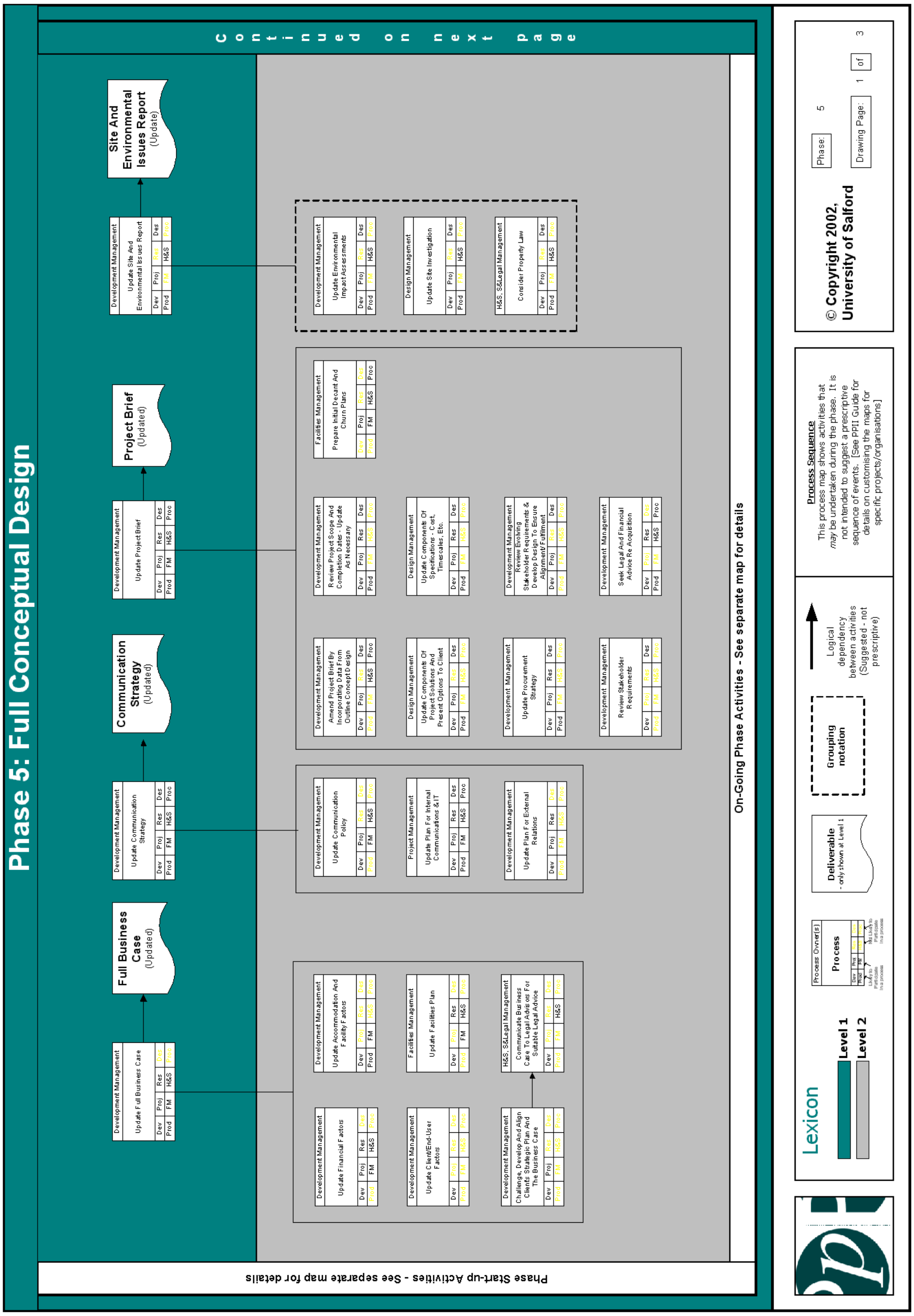
Phase: 4
Drawing Page: 3 of 3


Phase 5: Full Conceptual Design
Full Business Case (Updated)
Communication Strategy (Updated)
Project Brief (Updated)
Site And Environmental Issues Report (Update)
Continued on next page
On-Going Phase Activities - See separate map for details
Phase Start-up Activities - See separate map for details
Lexicon
Level 1
Level 2
Process
Deliverable
Grouping notation
Logical dependency between activities (Suggested - not prescriptive)
Process Sequence
This process map shows activities that may be undertaken during the phase. It is not intended to suggest a prescriptive sequence of events. [See PPI Guide for details on customising the maps for specific projects/organisations]
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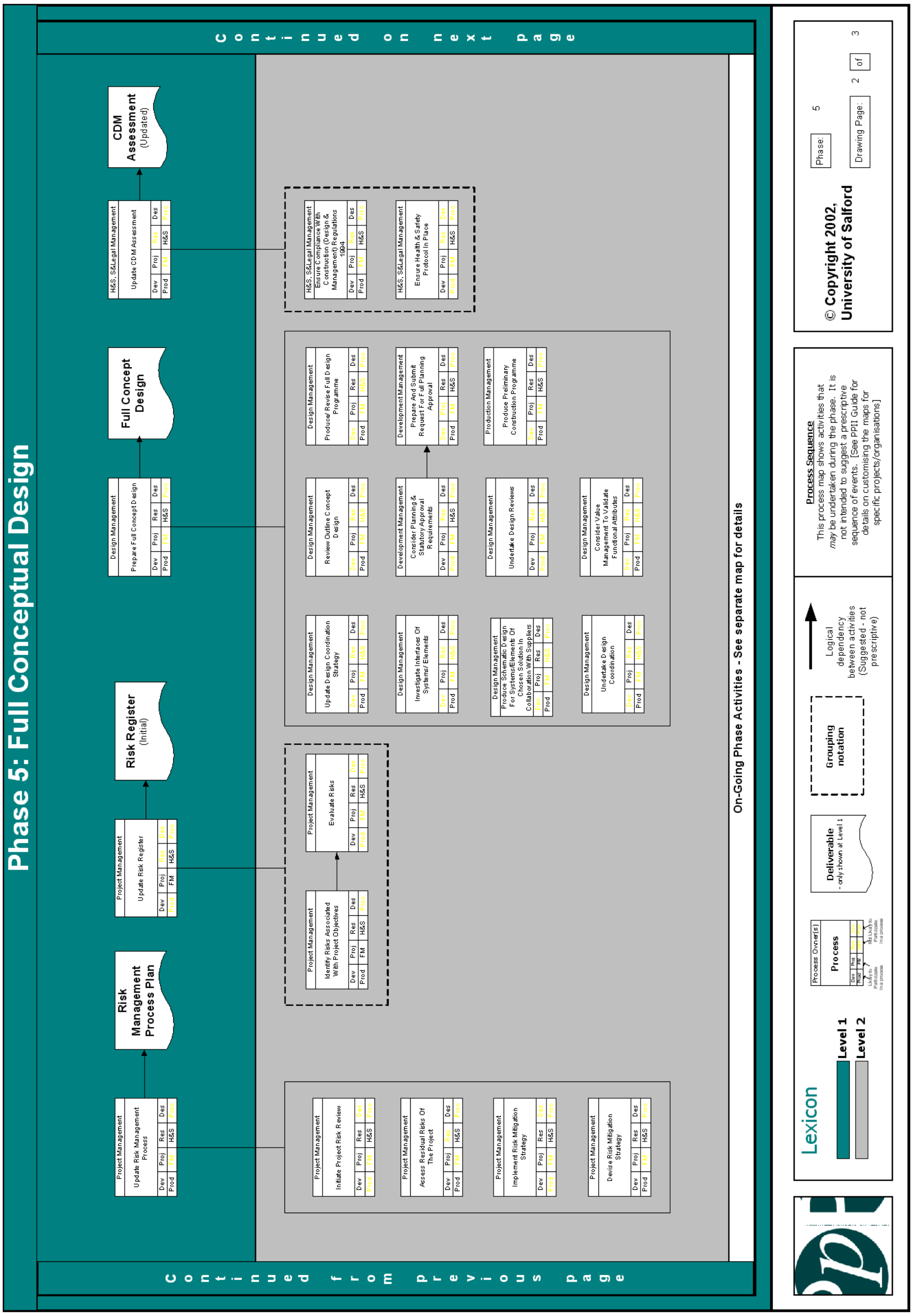
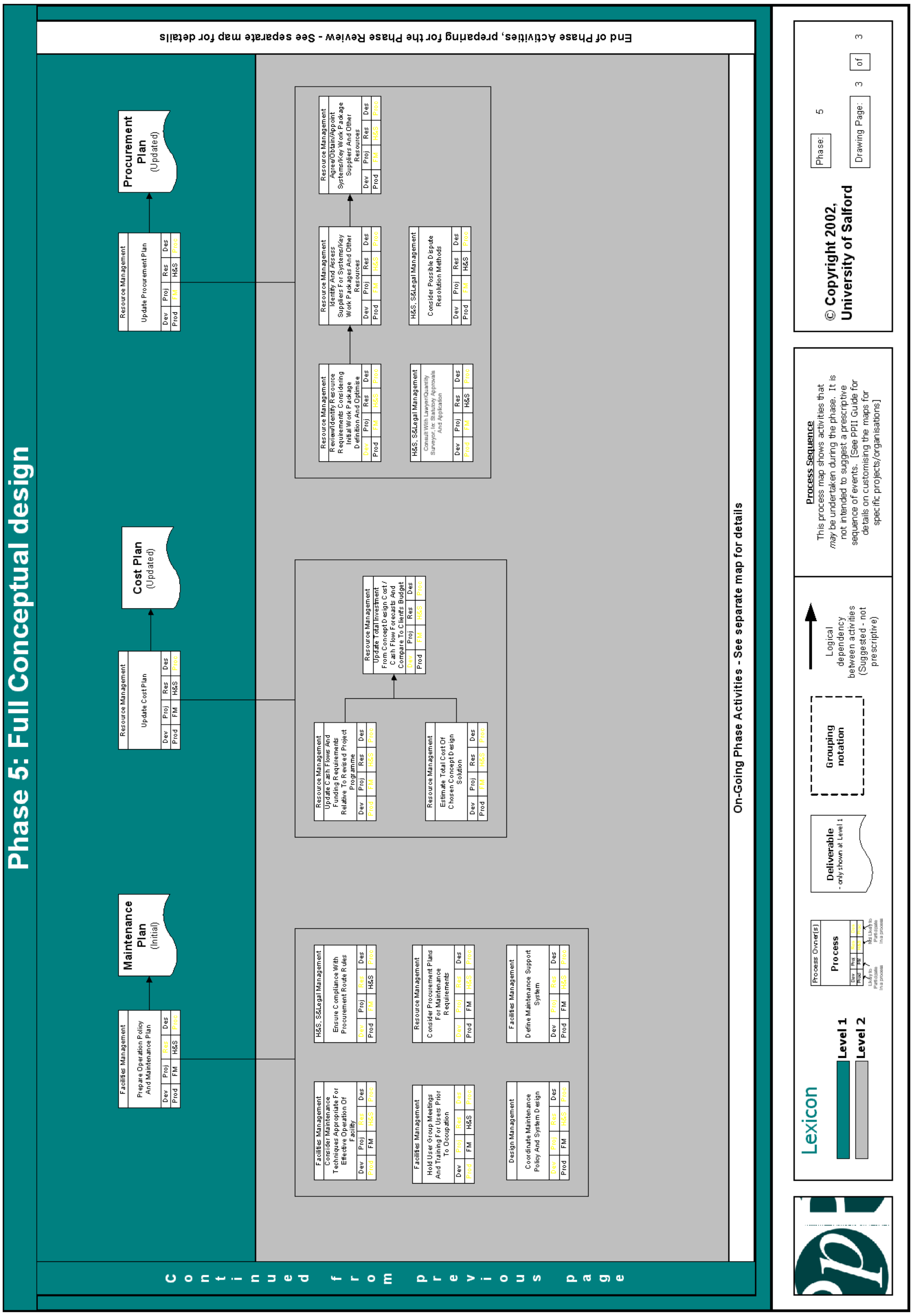
Phase: 5
Drawing Page: 1 of 3


Phase 5: Full Conceptual Design
Risk Management Process Plan
Risk Register (Initial)
Full Concept Design
CDM Assessment (Updated)
On-Going Phase Activities - See separate map for details
Continued from previous page
Continued on next page
Lexicon
Level 1
Level 2
Deliverable
Grouping notation
Logical dependency between activities (Suggested - not prescriptive)
Process Sequence
© Copyright 2002, University of Salford
Phase: 5
Drawing Page: 2 of 3


Phase 5: Full Conceptual design
End of Phase Activities, preparing for the Phase Review - See separate map for details
On-Going Phase Activities - See separate map for details
Continued from previous page
Maintenance Plan (Initial)
Cost Plan (Updated)
Procurement Plan (Updated)
Facilities Management
Prepare Operation Policy And Maintenance Plan
Resource Management
Update Cost Plan
Resource Management
Update Procurement Plan
Lexicon
Level 1
Level 2
Process
Deliverable
Grouping notation
Logical dependency between activities (Suggested - not prescriptive)
Process Sequence
This process map shows activities that may be undertaken during the phase. It is not intended to suggest a prescriptive sequence of events. [See PPI Guide for details on customising the maps for specific projects/organisations]
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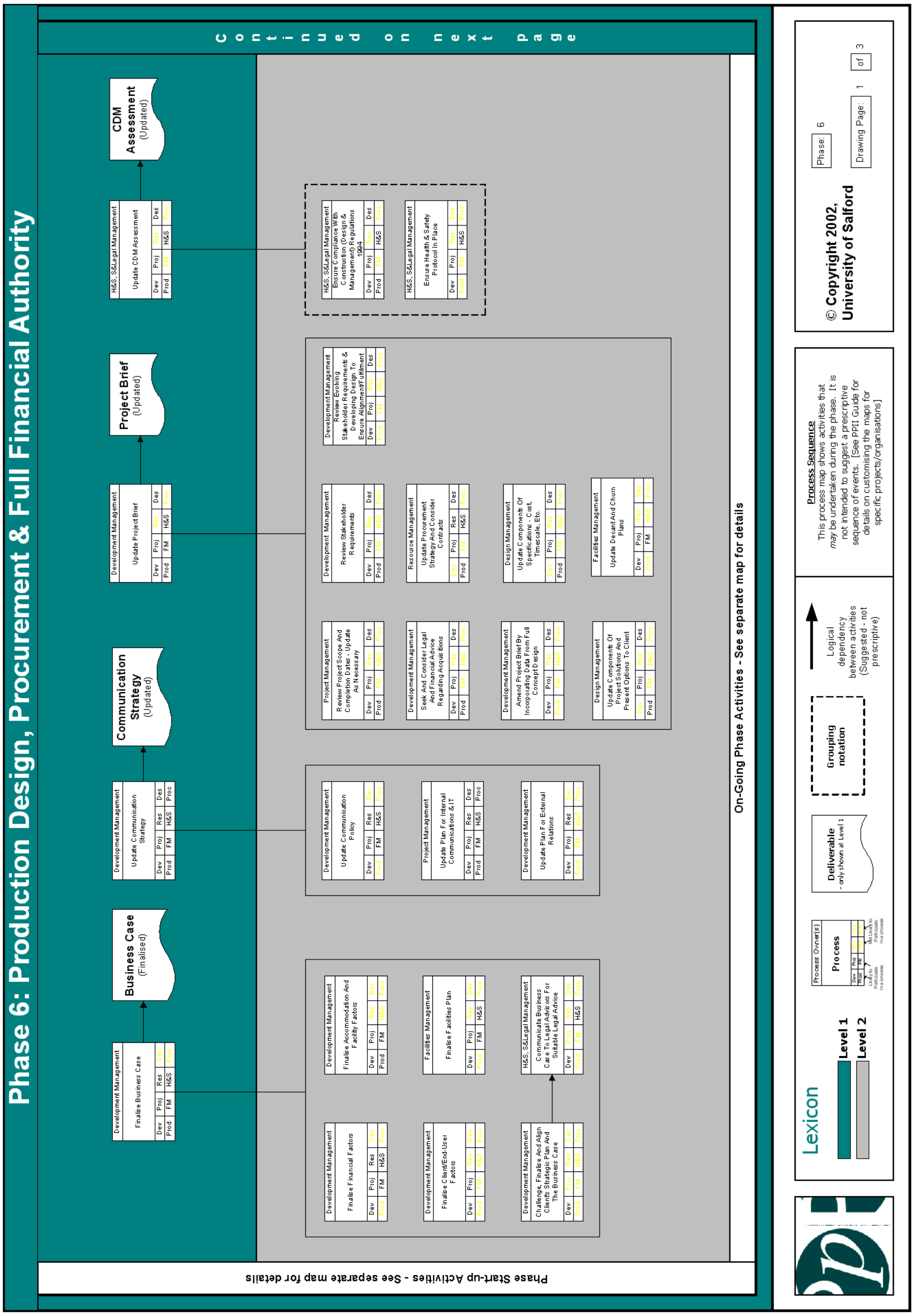
Phase: 5
Drawing Page: 3 of 3


Phase 6: Production Design, Procurement & Full Financial Authority
Business Case (Finalised)
Communication Strategy (Updated)
Project Brief (Updated)
CDM Assessment (Updated)
Continued on next page
On-Going Phase Activities - See separate map for details
Phase Start-up Activities - See separate map for details
Lexicon
Level 1
Level 2
Process
Deliverable
Grouping notation
Logical dependency between activities (Suggested - not prescriptive)
Process Sequence
This process map shows activities that may be undertaken during the phase. It is not intended to suggest a prescriptive sequence of events. [See PPII Guide for details on customising the maps for specific projects/organisations]
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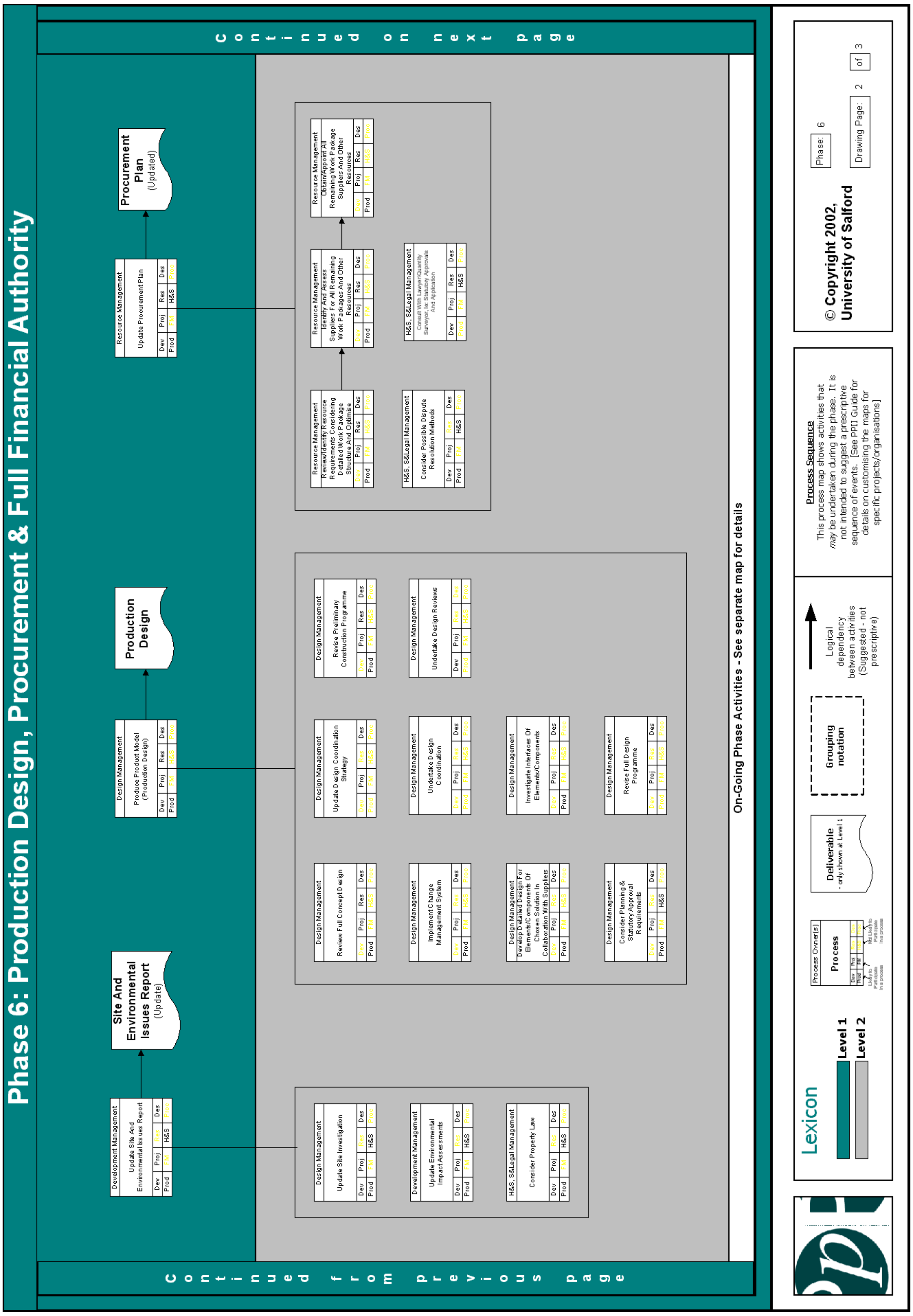
Phase: 6
Drawing Page: 1 of 3



Phase 6: Production Design, Procurement & Full Financial Authority
Continued from previous page
Continued on next page
Development Management
Update Site And Environmental Issues Report
Site And Environmental Issues Report (Update)
Design Management
Produce Product Model (Production Design)
Production Design
Resource Management
Update Procurement Plan
Procurement Plan (Updated)
Design Management
Update Site Investigation
Development Management
Update Environmental Impact Assessments
H&S, S&Legal Management
Consider Property Law
Design Management
Review Full Concept Design
Design Management
Implement Change Management System
Design Management
Develop Detailed Design For Elements/Components Of Chosen Solution In Collaboration With Suppliers
Design Management
Consider Planning & Statutory Approval Requirements
Design Management
Update Design Coordination Strategy
Design Management
Undertake Design Coordination
Design Management
Investigate Interfaces Of Elements/Components
Design Management
Revise Full Design Programme
Design Management
Revise Preliminary Construction Programme
Design Management
Undertake Design Reviews
Resource Management
Review/Identify Resource Requirements Considering Detailed Work Package Structure And Optimise
Resource Management
Identify And Assess Suppliers For All Remaining Work Packages And Other Resources
Resource Management
Obtain/Appoint All Remaining Work Package Suppliers And Other Resources
H&S, S&Legal Management
Consider Possible Dispute Resolution Methods
H&S, S&Legal Management
Dev
Prod
Proj
Res
Des
H&S
On-Going Phase Activities - See separate map for details
Lexicon
Level 1
Level 2
Process Owner(s)
Process
Deliverable
- only shown at Level 1
Grouping notation
Logical dependency between activities (Suggested - not prescriptive)
Process Sequence
This process map shows activities that may be undertaken during the phase. It is not intended to suggest a prescriptive sequence of events. [See PPI Guide for details on customising the maps for specific projects/organisations]
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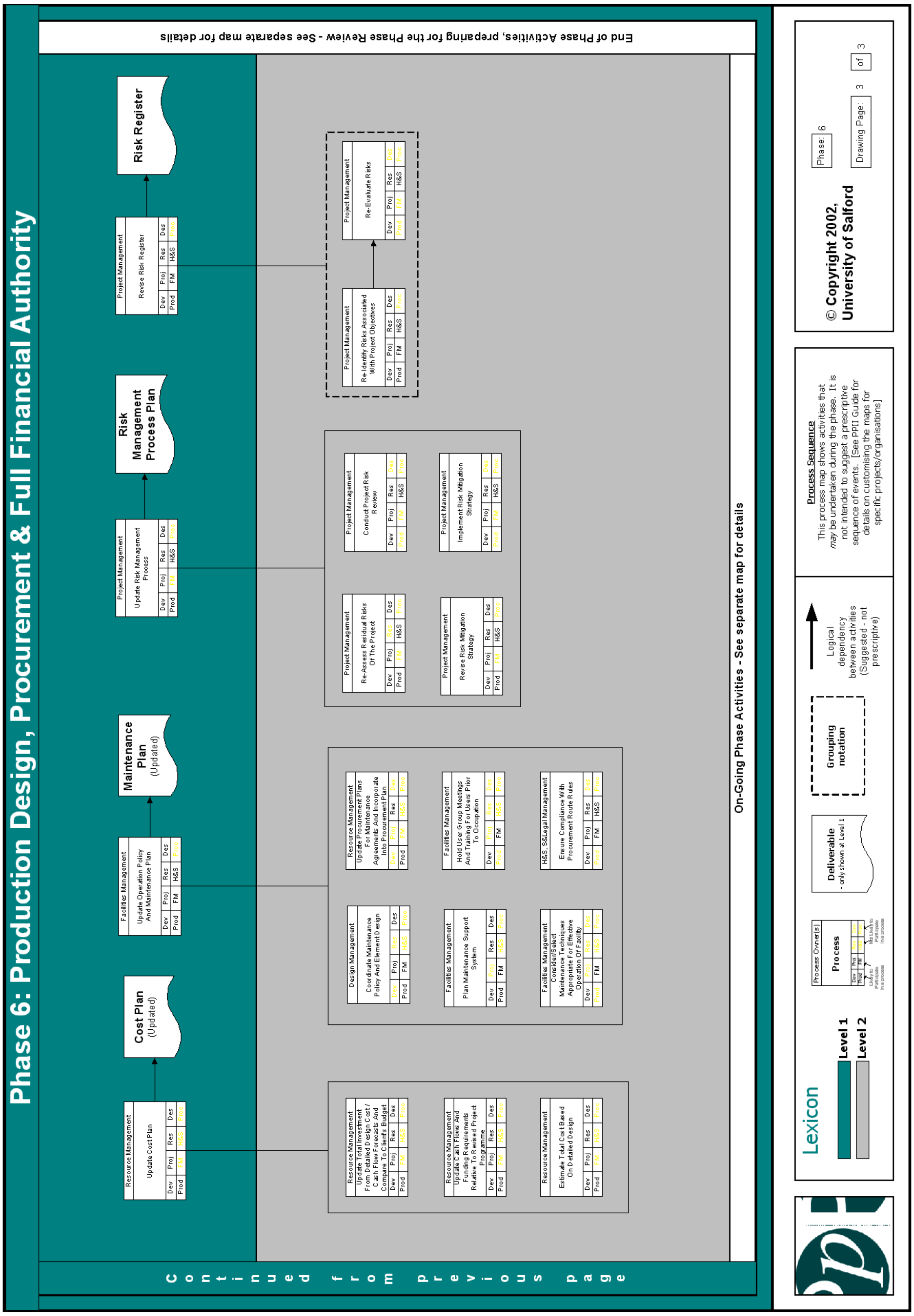
Phase: 6
Drawing Page: 2 of 3



Phase 6: Production Design, Procurement & Full Financial Authority
End of Phase Activities, preparing for the Phase Review - See separate map for details
On-Going Phase Activities - See separate map for details
Continued from previous page
Cost Plan (Updated)
Maintenance Plan (Updated)
Risk Management Process Plan
Risk Register
Resource Management
Update Cost Plan
Facilities Management
Update Operation Policy And Maintenance Plan
Project Management
Update Risk Management Process
Project Management
Revise Risk Register
Resource Management
Update Total Investment From Detailed Design Cost / Cash Flow Forecasts And Compare To Client's Budget
Resource Management
Update Cash Flows And Funding Requirements Relative To Revised Project Programme
Resource Management
Estimate Total Cost Based On Detailed Design
Design Management
Coordinate Maintenance Policy And Element Design
Facilities Management
Plan Maintenance Support System
Facilities Management
Consider/Select Maintenance Techniques Appropriate For Effective Operation Of Facility
Resource Management
Update Procurement Plans For Maintenance Agreements And Incorporate Into Procurement Plan
Facilities Management
Hold User Group Meetings And Training For Users Prior To Occupation
H&S, S&Legal Management
Ensure Compliance With Procurement Route Rules
Project Management
Re-Assess Residual Risks Of The Project
Project Management
Revise Risk Mitigation Strategy
Project Management
Conduct Project Risk Review
Project Management
Implement Risk Mitigation Strategy
Project Management
Re-Identify Risks Associated With Project Objectives
Project Management
Re-Evaluate Risks
Dev
Proj
Res
Des
Prod
FM
H&S
Lexicon
Level 1
Level 2
Process Owner(s)
Process
Deliverable
Grouping notation
Logical dependency between activities (Suggested - not prescriptive)
Process Sequence
This process map shows activities that may be undertaken during the phase. It is not intended to suggest a prescriptive sequence of events. [See PPII Guide for details on customising the maps for specific projects/organisations]
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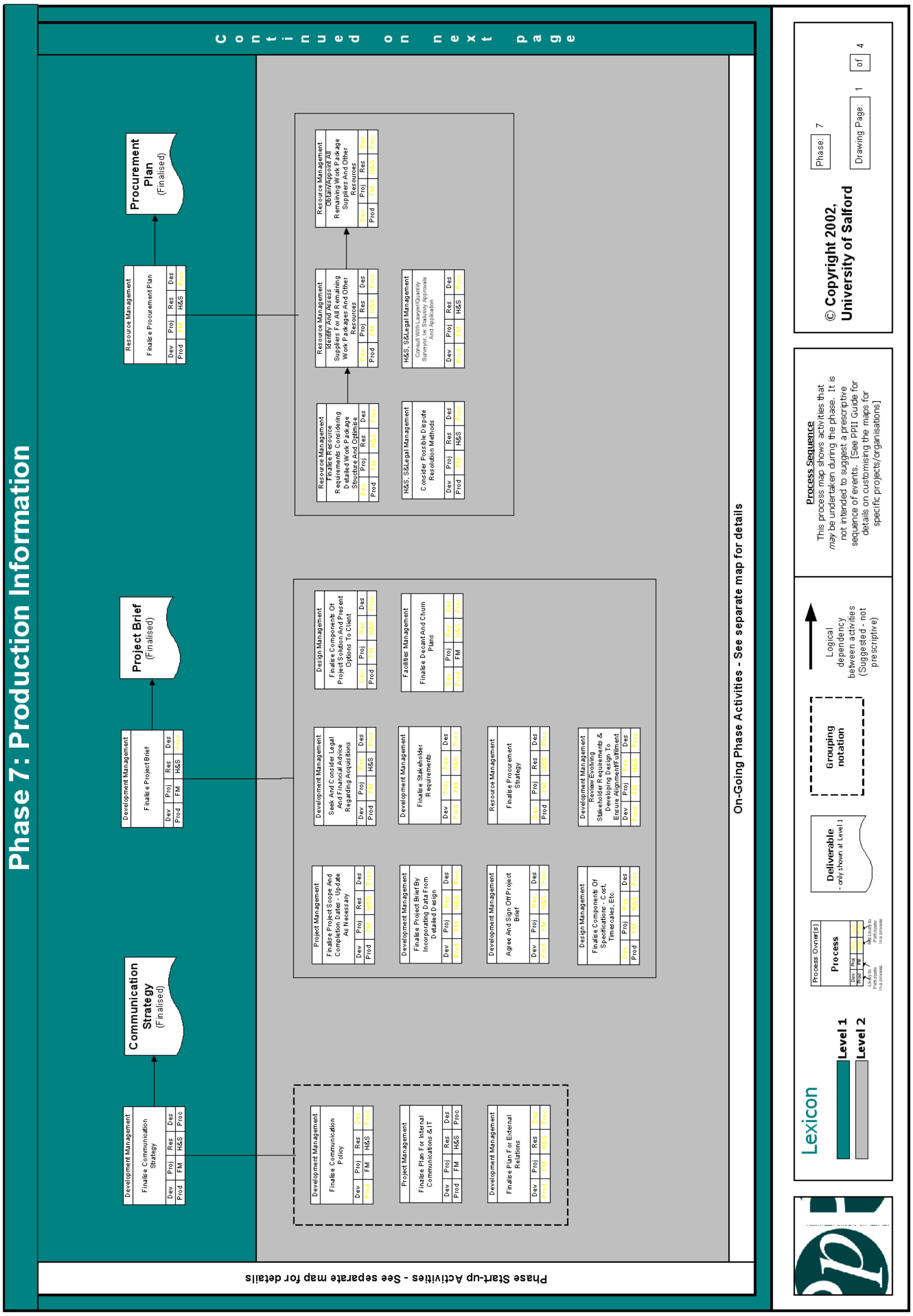
Phase: 6
Drawing Page: 3 of 3


Phase 7: Production Information
Communication Strategy (Finalised)
Project Brief (Finalised)
Procurement Plan (Finalised)
On-Going Phase Activities - See separate map for details
Phase Start-up Activities - See separate map for details
Continued on next page
Lexicon
Level 1
Level 2
Process
Deliverable
Grouping notation
Logical dependency between activities (Suggested - not prescriptive)
Process Sequence
This process map shows activities that may be undertaken during the phase. It is not intended to suggest a prescriptive sequence of events. [See PPII Guide for details on customising the maps for specific projects/organisations]
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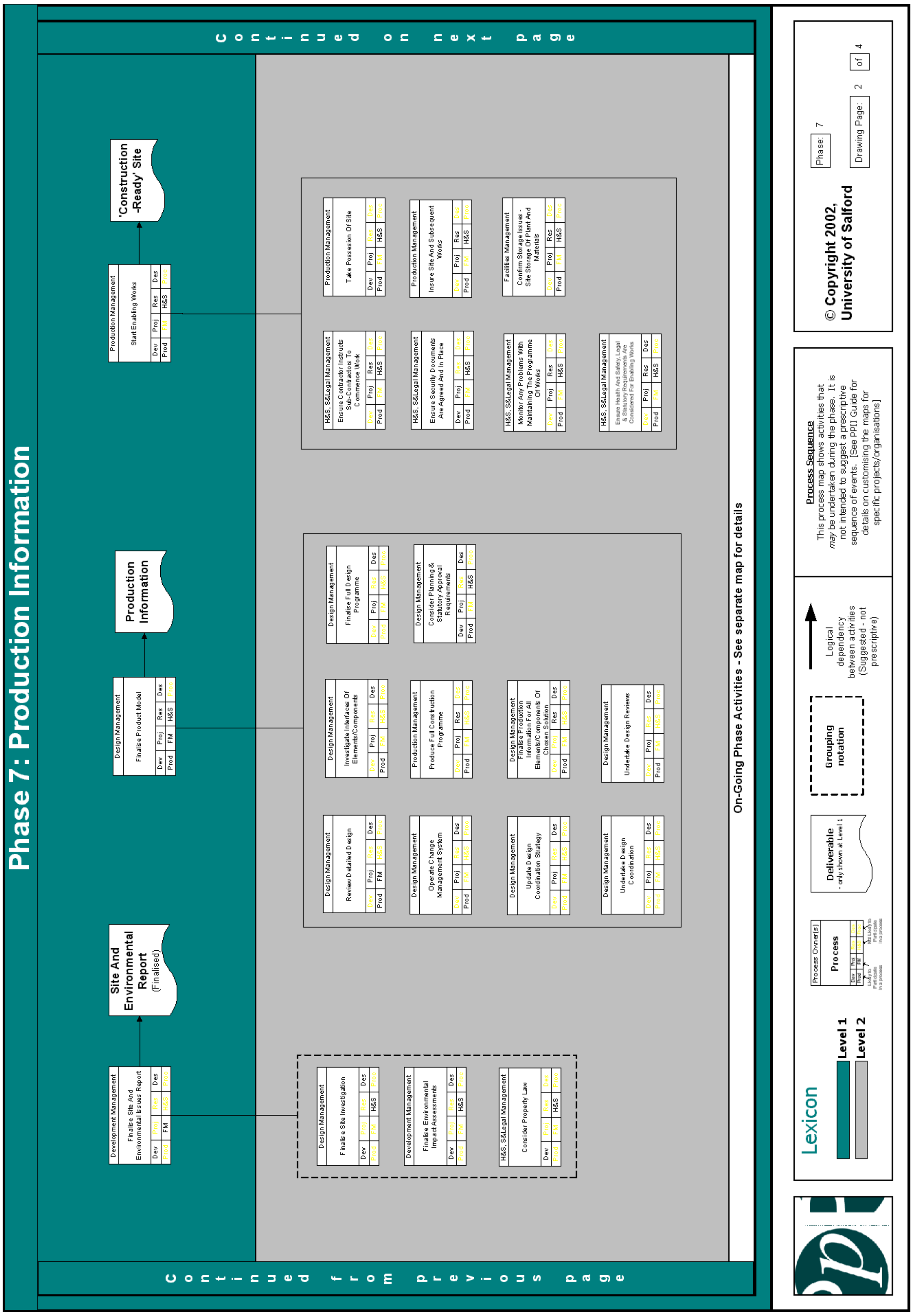
Phase: 7
Drawing Page: 1 of 4


Phase 7: Production Information
Continued from previous page
Continued on next page
Site And Environmental Report (Finalised)
Production Information
'Construction -Ready' Site
On-Going Phase Activities - See separate map for details
Lexicon
Level 1
Level 2
Process
Deliverable
Grouping notation
Logical dependency between activities (Suggested - not prescriptive)
Process Sequence
This process map shows activities that may be undertaken during the phase. It is not intended to suggest a prescriptive sequence of events. [See PPII Guide for details on customising the maps for specific projects/organisations]
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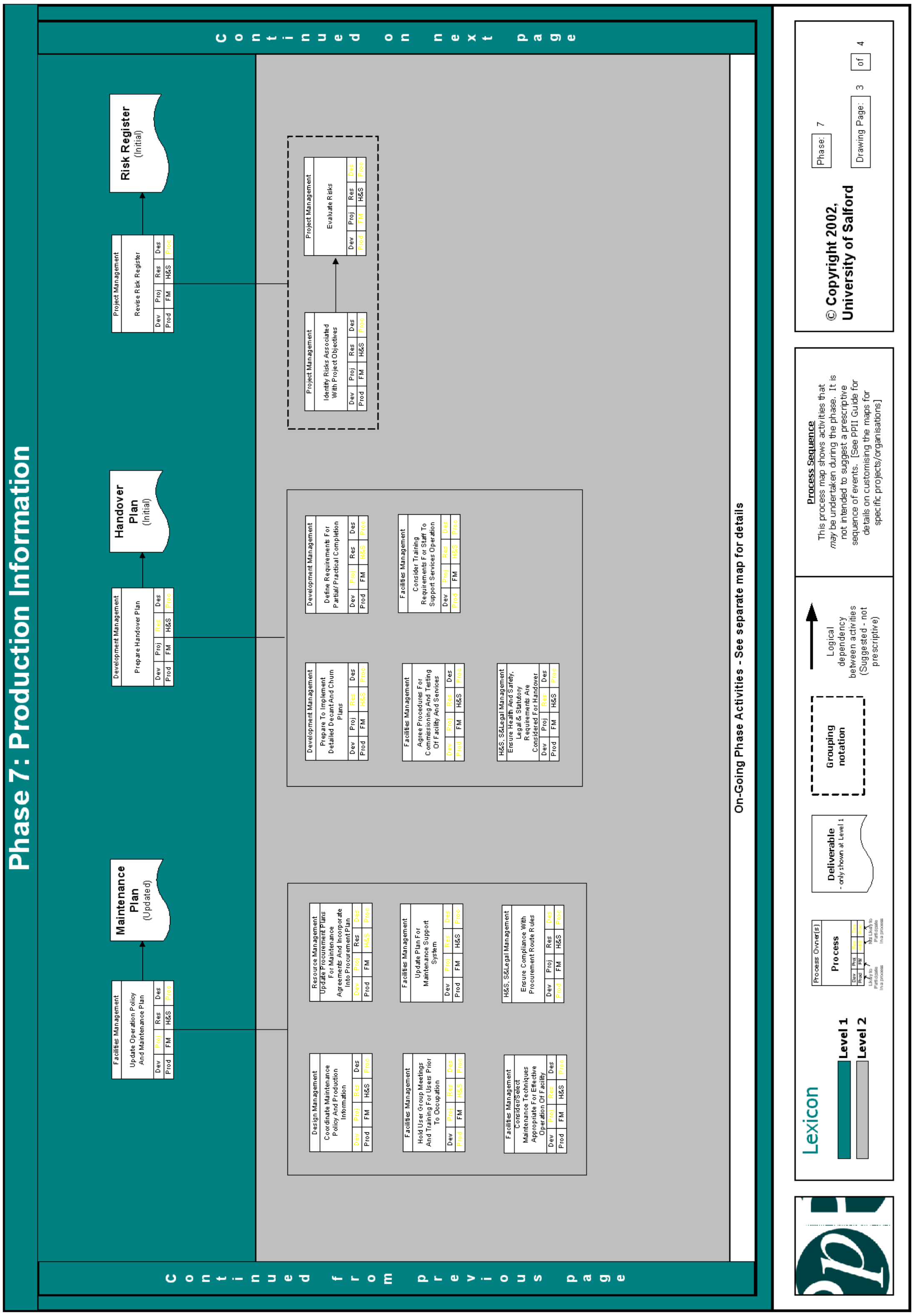
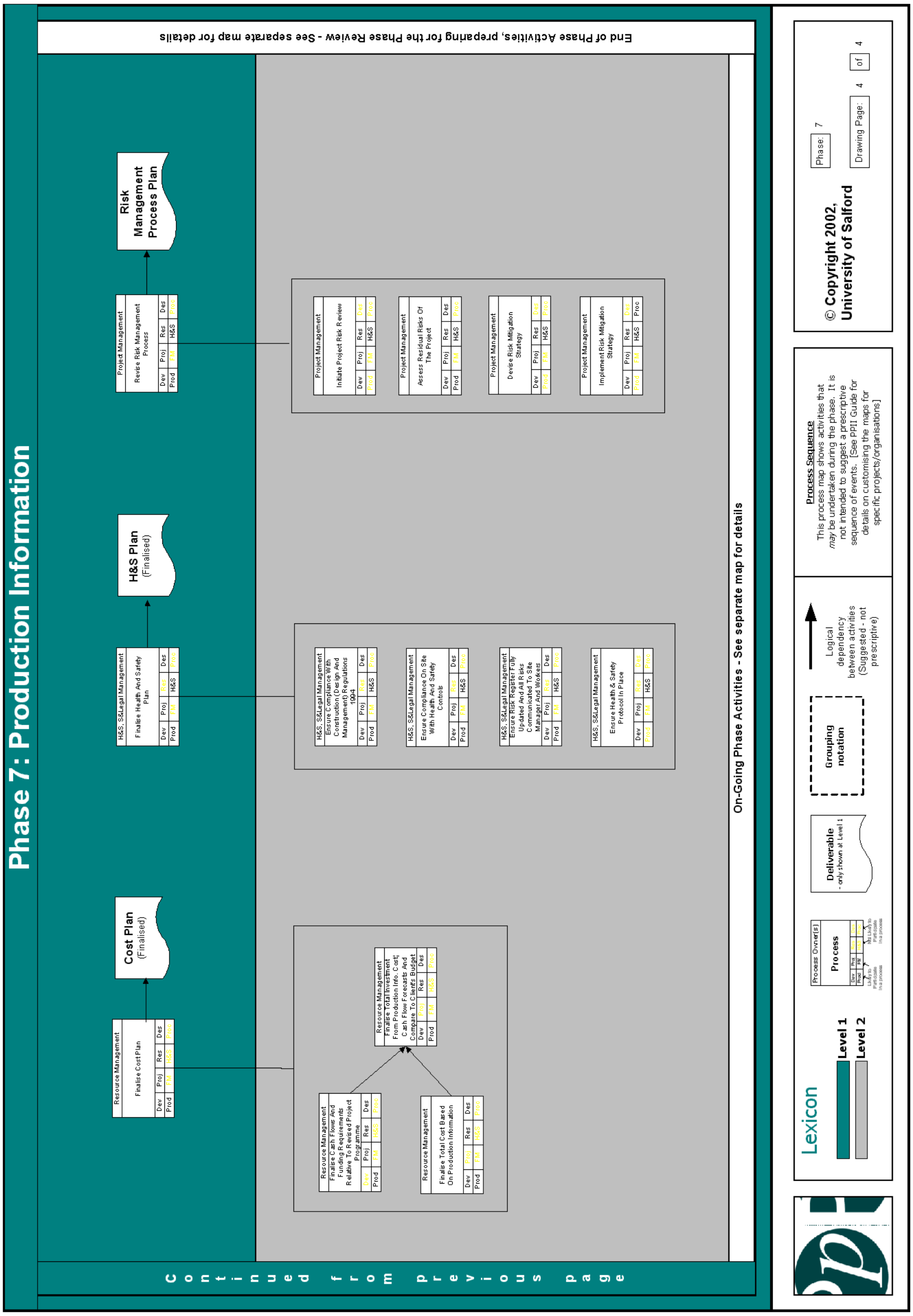
Phase: 7
Drawing Page: 2 of 4


Phase 7: Production Information
Continued from previous page
Continued on next page
Maintenance Plan (Updated)
Handover Plan (Initial)
Risk Register (Initial)
On-Going Phase Activities - See separate map for details
Lexicon
Level 1
Level 2
Process
Deliverable
Grouping notation
Logical dependency between activities (Suggested - not prescriptive)
Process Sequence
© Copyright 2002, University of Salford
Phase: 7
Drawing Page: 3 of 4


Phase 7: Production Information
Continued from previous page
Resource Management
Finalise Cost Plan
Cost Plan (Finalised)
H&S, S&Legal Management
Finalise Health And Safety Plan
H&S Plan (Finalised)
Project Management
Revise Risk Management Process
Risk Management Process Plan
Resource Management
Finalise Cash Flows And Funding Requirements Relative To Revised Project Programme
Resource Management
Finalise Total Cost Based On Production Information
Resource Management
Finalise Total Investment From Production Info. Cost; Cash Flow Forecasts And Compare To Client's Budget
H&S, S&Legal Management
Ensure Compliance With Construction (Design And Management) Regulations 1994
H&S, S&Legal Management
Ensure Compliance On Site With Health And Safety Controls
H&S, S&Legal Management
Ensure Risk Register Fully Updated And All Risks Communicated To Site Manager And Workers
H&S, S&Legal Management
Ensure Health & Safety Protocol In Place
Project Management
Initiate Project Risk Review
Project Management
Assess Residual Risks Of The Project
Project Management
Devise Risk Mitigation Strategy
Project Management
Implement Risk Mitigation Strategy
On-Going Phase Activities - See separate map for details
End of Phase Activities, preparing for the Phase Review - See separate map for details
Lexicon
Level 1
Level 2
Process Owner(s)
Process
Deliverable - only shown at Level 1
Grouping notation
Logical dependency between activities (Suggested - not prescriptive)
Process Sequence
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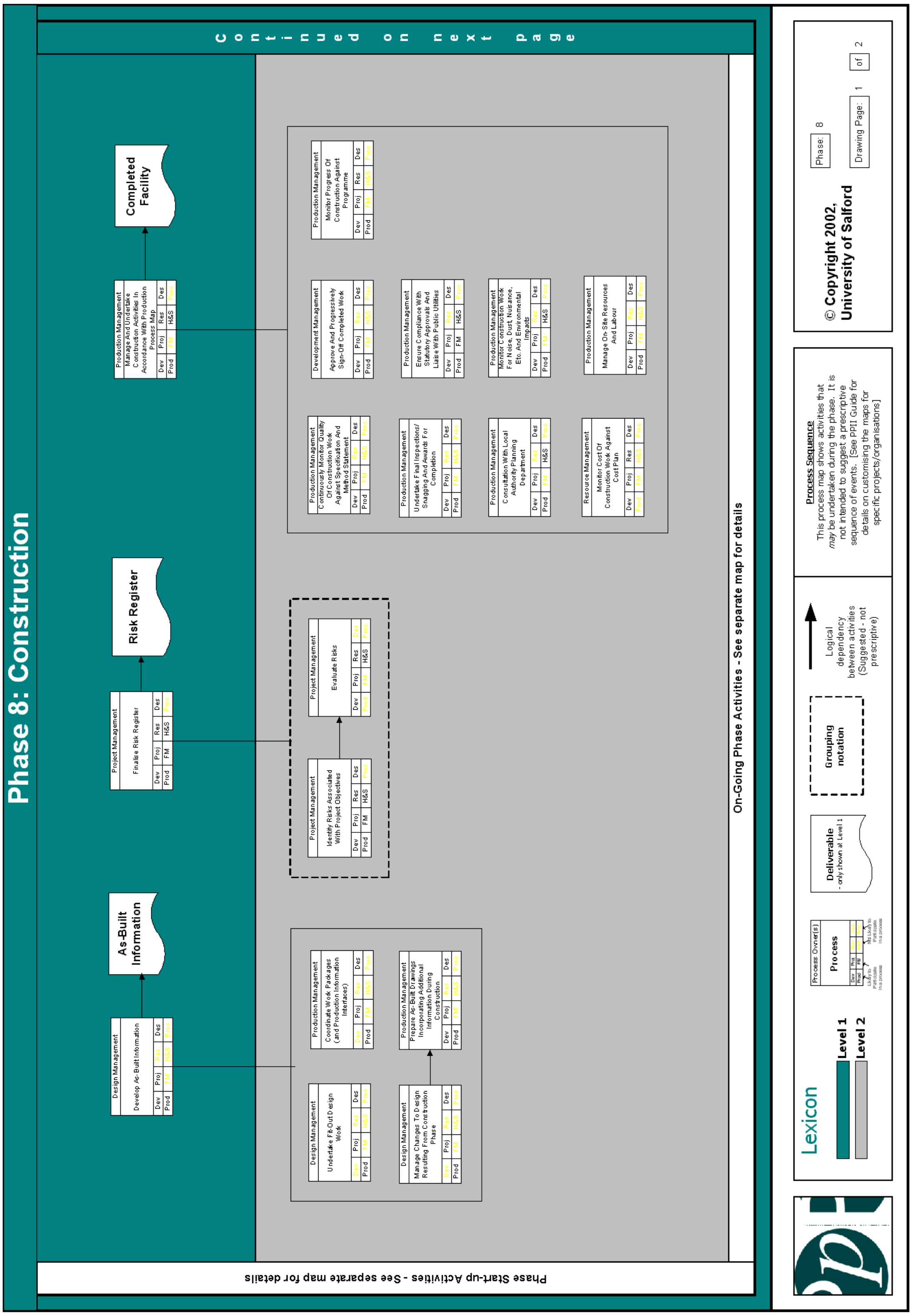
Phase: 7
Drawing Page: 4 of 4



Phase 8: Construction
As-Built Information
Risk Register
Completed Facility
Design Management
Develop As-Built Information
Project Management
Finalise Risk Register
Production Management
Manage And Undertake Construction Activities In Accordance With Production Process Map
Project Management
Identify Risks Associated With Project Objectives
Project Management
Evaluate Risks
Design Management
Undertake Fit-Out Design Work
Design Management
Manage Changes To Design Resulting From Construction Phase
Production Management
Coordinate Work Packages (and Production Information Interfaces)
Production Management
Prepare As-Built Drawings Incorporating Additional Information During Construction
On-Going Phase Activities - See separate map for details
Phase Start-up Activities - See separate map for details
Continued on next page
Lexicon
Level 1
Level 2
Process Owner(s)
Process
Deliverable
Grouping notation
Logical dependency between activities (Suggested - not prescriptive)
Process Sequence
This process map shows activities that may be undertaken during the phase. It is not intended to suggest a prescriptive sequence of events. [See PPII Guide for details on customising the maps for specific projects/organisations]
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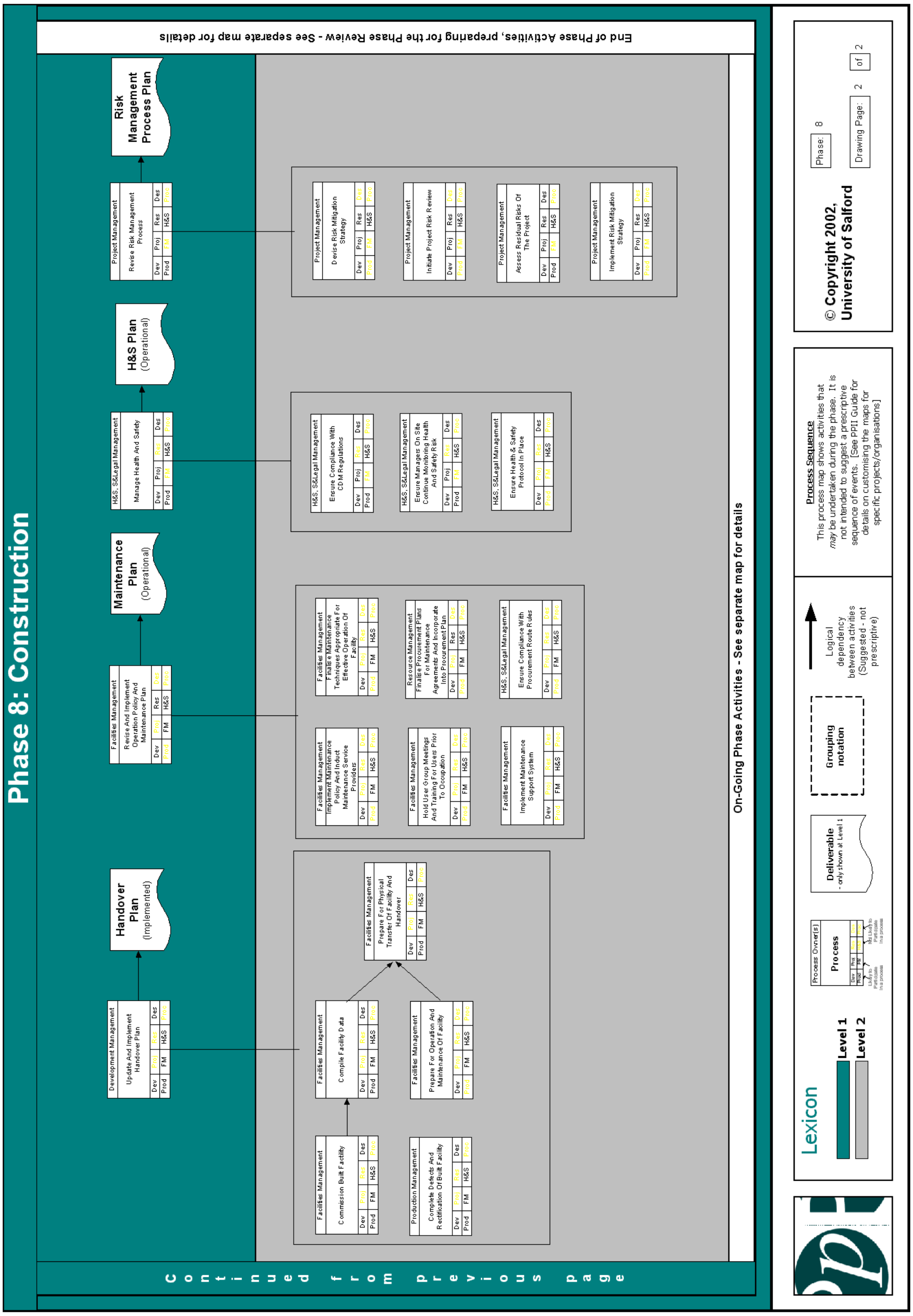
Phase: 8
Drawing Page: 1 of 2


Phase 8: Construction
Handover Plan (Implemented)
Maintenance Plan (Operational)
H&S Plan (Operational)
Risk Management Process Plan
End of Phase Activities, preparing for the Phase Review - See separate map for details
On-Going Phase Activities - See separate map for details
continued from previous page
Lexicon
Level 1
Level 2
Process
Deliverable
Grouping notation
Logical dependency between activities (Suggested - not prescriptive)
Process Sequence
This process map shows activities that may be undertaken during the phase. It is not intended to suggest a prescriptive sequence of events. [See PPI Guide for details on customising the maps for specific projects/organisations]
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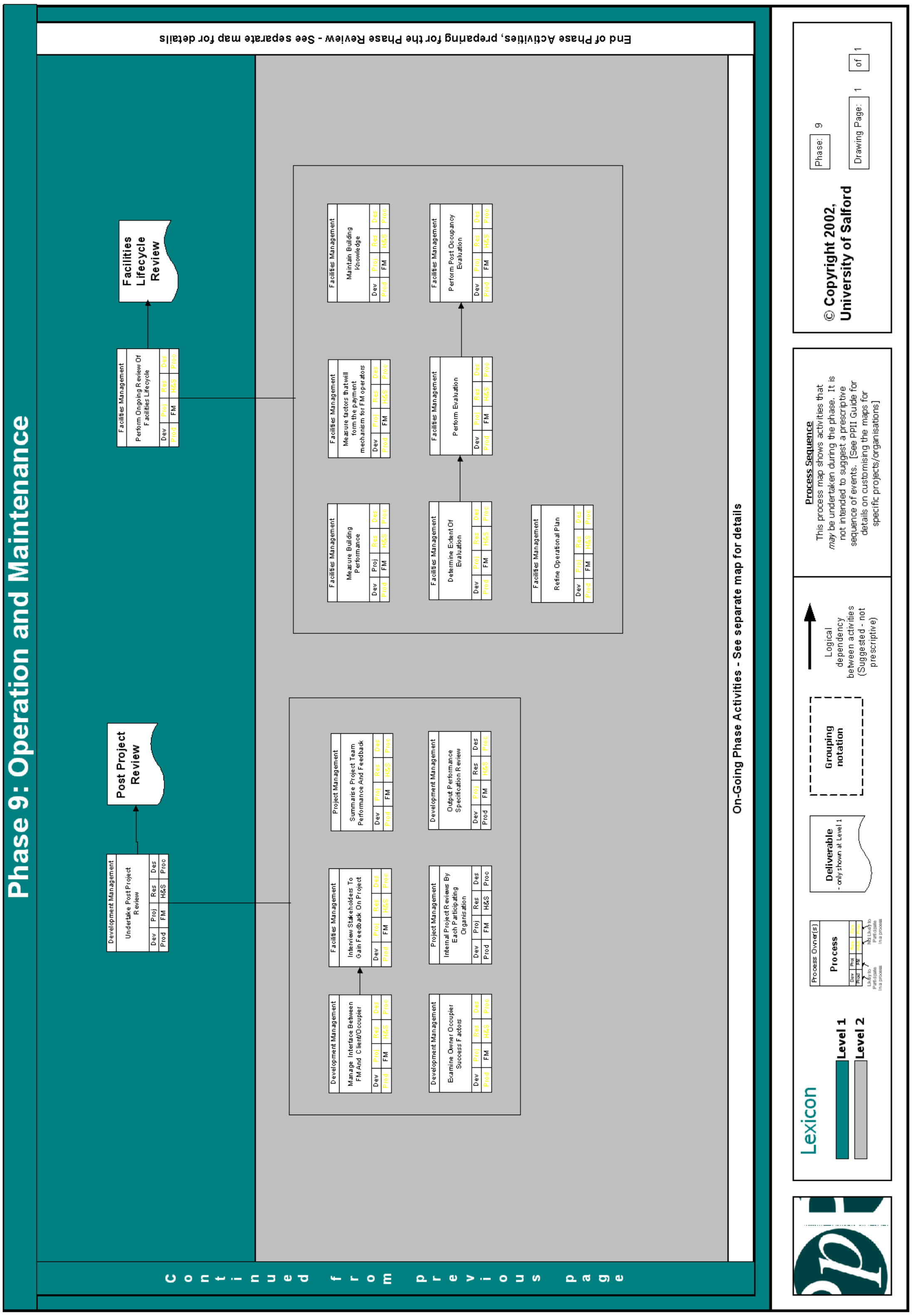
Phase: 8
Drawing Page: 2 of 2


Phase 9: Operation and Maintenance
End of Phase Activities, preparing for the Phase Review - See separate map for details
On-Going Phase Activities - See separate map for details
Continued from previous page
Post Project Review
Facilities Lifecycle Review
Development Management
Undertake Post Project Review
Facilities Management
Perform Ongoing Review Of Facilities Lifecycle
Manage Interface Between FM And Client/Occupier
Interview Stakeholders To Gain Feedback On Project
Summarise Project Team Performance And Feedback
Examine Owner Occupier Success Factors
Internal Project Reviews By Each Participating Organisation
Output Performance Specification Review
Measure Building Performance
Measure factors that will form the payment mechanism for FM operators
Maintain Building Knowledge
Determine Extent Of Evaluation
Perform Evaluation
Perform Post Occupancy Evaluation
Refine Operational Plan
Lexicon
Level 1
Level 2
Process
Process Owner(s)
Deliverable
Grouping notation
Logical dependency between activities (Suggested - not prescriptive)
Process Sequence
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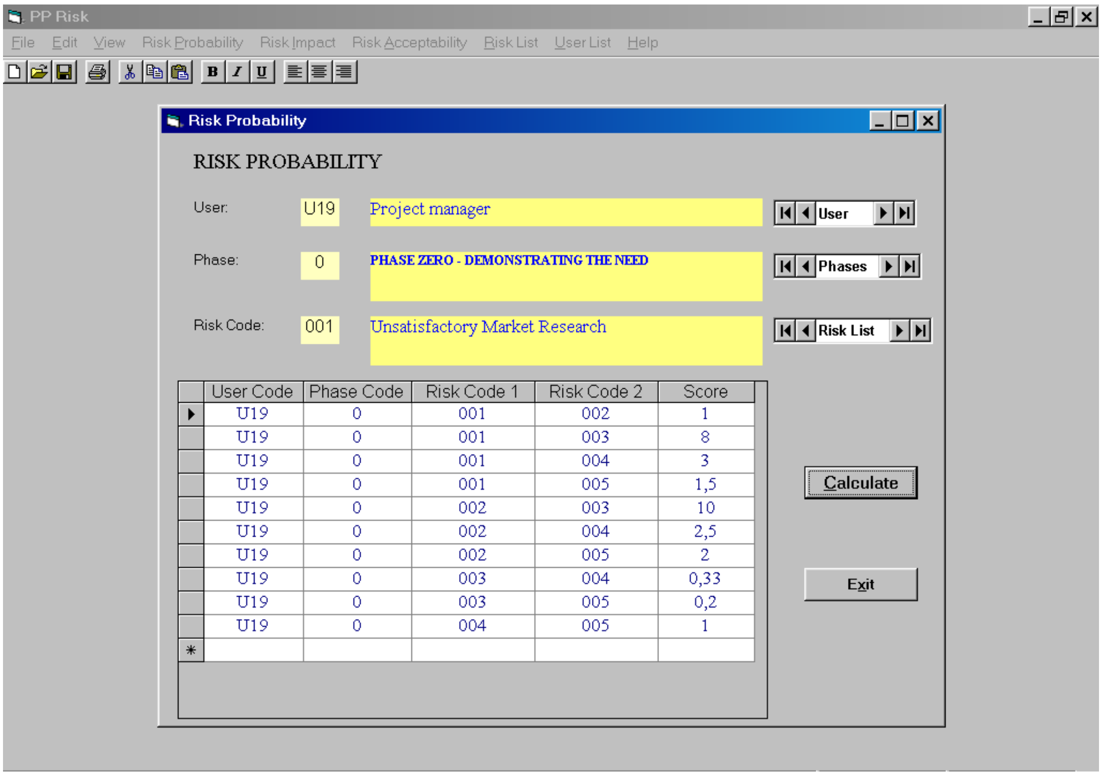
Phase: 9
Drawing Page: 1 of 1

APPENDIX 3: The set of SQL commands for creating the database

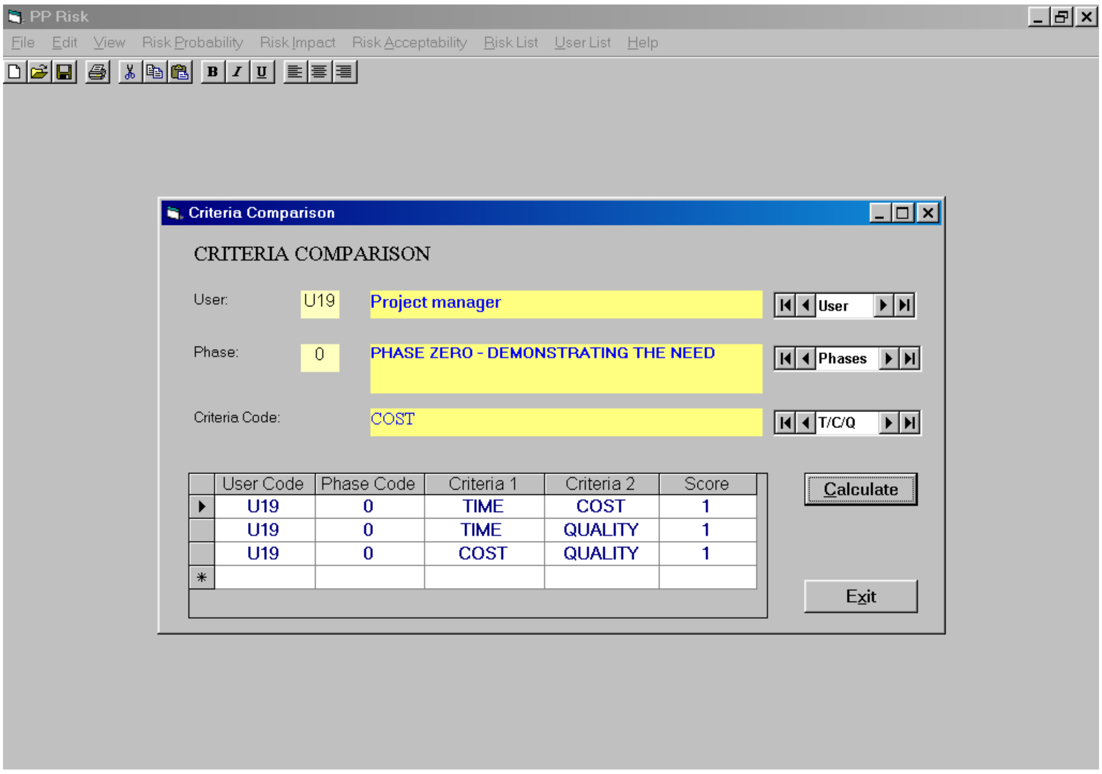
```
CREATE TABLE Phases
  (PhaseCode TEXT(1) CONSTRAINT PKPhaseCode PRIMARY KEY,
   PhaseName TEXT(100));
CREATE TABLE RiskList
  (PhaseCode TEXT(1) CONSTRAINT FKPhaseCode REFERENCES
    Phases(PhaseCode),
   RiskCode TEXT(3),
   RiskName TEXT(100),
   CONSTRAINT PKRiskCode PRIMARY KEY(PhaseCode,RiskCode));
CREATE TABLE User
  (UserCode TEXT(10) CONSTRAINT PKUserCode PRIMARY KEY,
   Name TEXT(30),
   Title TEXT(20),
   Position TEXT(50));
CREATE TABLE TCQ
  (TCQCode TEXT(10) CONSTRAINT PKTCQCode PRIMARY KEY);
CREATE TABLE Criteria
  (UserCode TEXT(10) CONSTRAINT FKUserCriteria REFERENCES
    User(UserCode),
   PhaseCode TEXT(1) CONSTRAINT FKPhaseCriteria REFERENCES
    Phases(PhaseCode),
   TCQCode1 TEXT(10) CONSTRAINT FKTCQCode1 REFERENCES TCQ(TCQCode),
   TCQCode2 TEXT(10) CONSTRAINT FKTCQCode2 REFERENCES TCQ(TCQCode),
   Score Double);
CREATE TABLE Probability
  (UserCode TEXT(10) CONSTRAINT FKUserProbability REFERENCES
    User(UserCode),
   PhaseCode TEXT(1) CONSTRAINT FKPhaseProbability REFERENCES
    Phases(PhaseCode),
   RiskCode1 TEXT(3) CONSTRAINT FKProbabilityCode1 REFERENCES
    RiskList(RiskCode),
   RiskCode2 TEXT(3) CONSTRAINT FKProbabilityCode2 REFERENCES
    RiskList(RiskCode),
   Score Double);
CREATE TABLE ImpactTime
  (UserCode TEXT(10) CONSTRAINT FKUserTime REFERENCES
    User(UserCode),
   PhaseCode TEXT(1) CONSTRAINT FKPhaseTime REFERENCES
    Phases(PhaseCode),
```

```
   RiskCode1 TEXT(3) CONSTRAINT FKTimeCode1 REFERENCES
    RiskList(RiskCode),
   RiskCode2 TEXT(3) CONSTRAINT FKTimeCode2 REFERENCES
    RiskList(RiskCode),
   Score Double);
CREATE TABLE ImpactCost
  (UserCode TEXT(10) CONSTRAINT FKUserCost REFERENCES
    User(UserCode),
   PhaseCode TEXT(1) CONSTRAINT FKPhaseCost REFERENCES
    Phases(PhaseCode),
   RiskCode1 TEXT(3) CONSTRAINT FKCostCode1 REFERENCES
    RiskList(RiskCode),
   RiskCode2 TEXT(3) CONSTRAINT FKCostCode2 REFERENCES
    RiskList(RiskCode),
   Score Double);
CREATE TABLE ImpactQuality
  (UserCode TEXT(10) CONSTRAINT FKUserQuality REFERENCES
    User(UserCode),
   PhaseCode TEXT(1) CONSTRAINT FKPhaseQuality REFERENCES
    Phases(PhaseCode),
   RiskCode1 TEXT(3) CONSTRAINT FKQualityCode1 REFERENCES
    RiskList(RiskCode),
   RiskCode2 TEXT(3) CONSTRAINT FKQualityCode2 REFERENCES
    RiskList(RiskCode),
   Score Double);
```

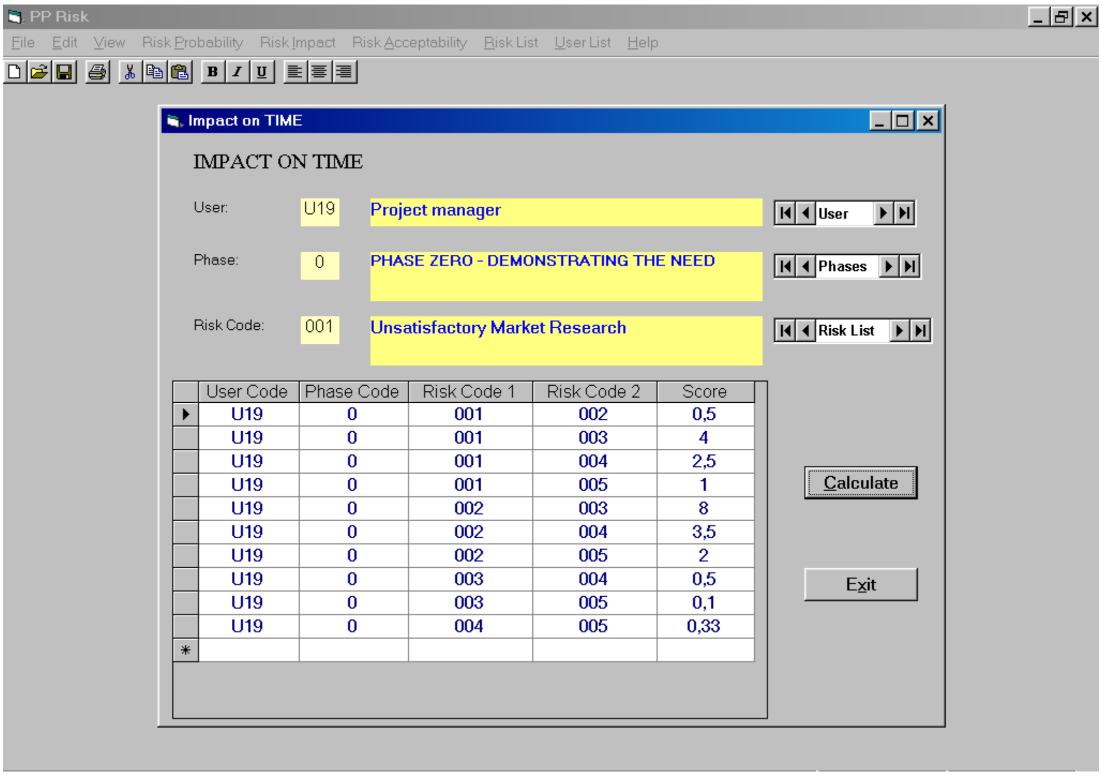
APPENDIX 4: Application of the Process Driven Risk Management Framework



Phase 0: Risk probability - comparative matrix

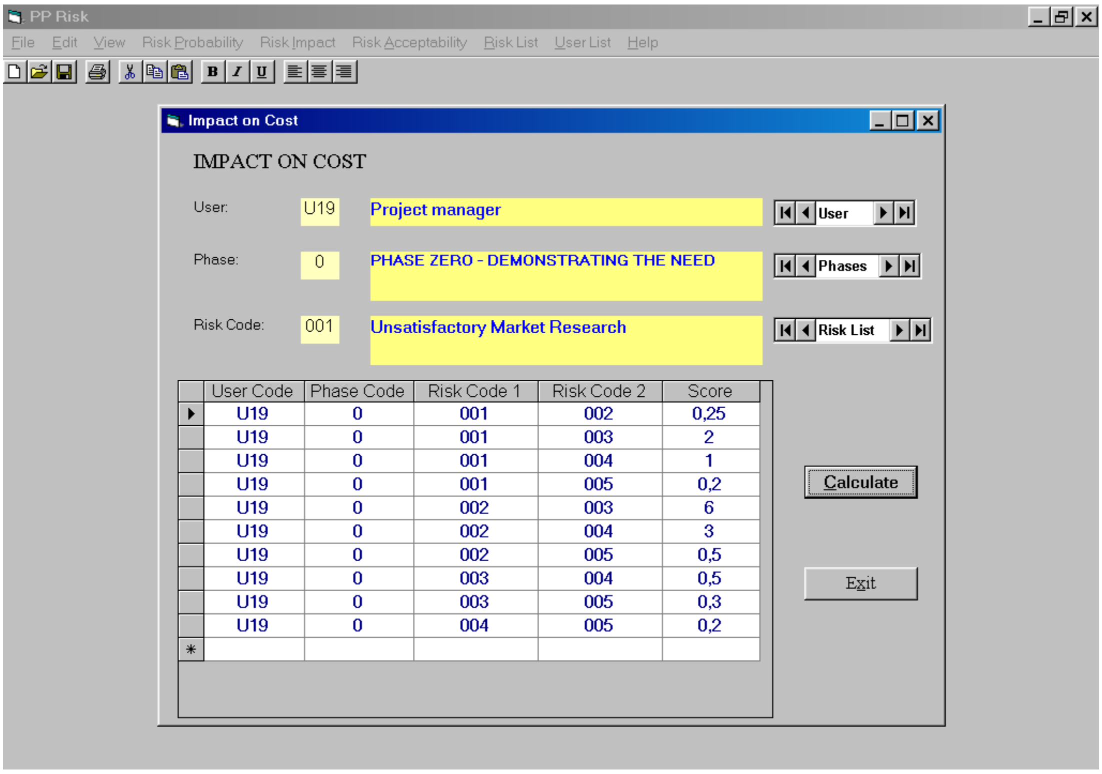


Phase 0: Criteria comparison - comparative matrix



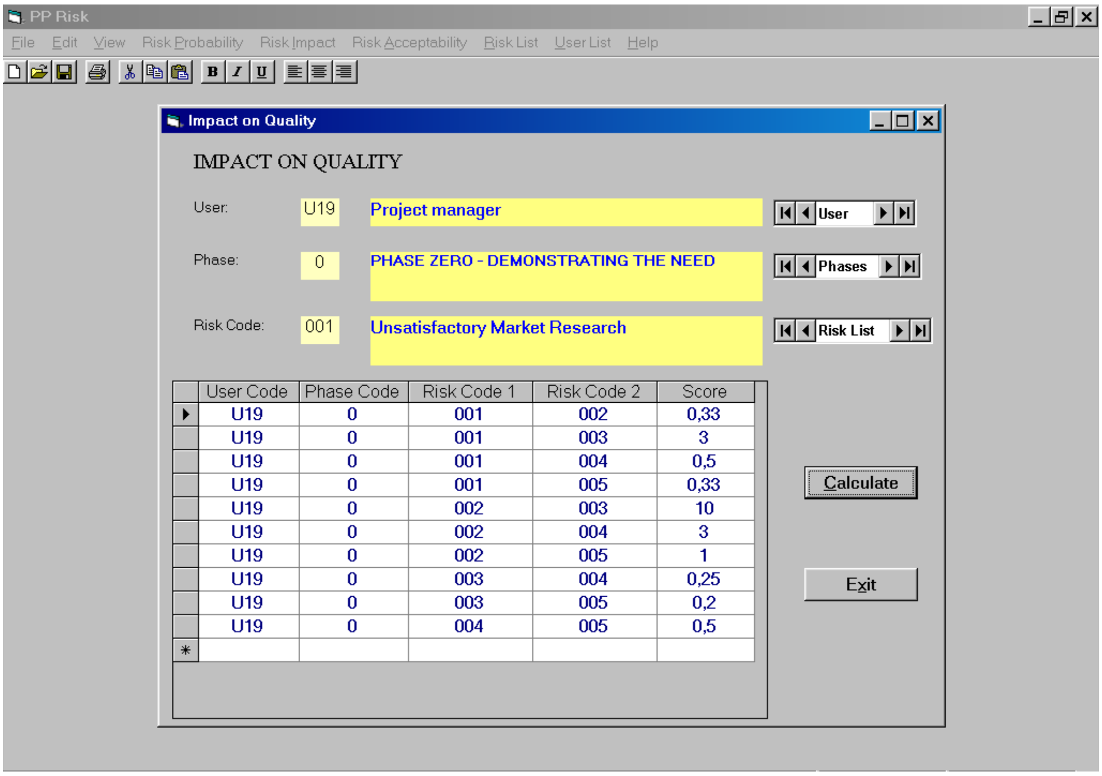
User Code	Phase Code	Risk Code 1	Risk Code 2	Score
U19	0	001	002	0,5
U19	0	001	003	4
U19	0	001	004	2,5
U19	0	001	005	1
U19	0	002	003	8
U19	0	002	004	3,5
U19	0	002	005	2
U19	0	003	004	0,5
U19	0	003	005	0,1
U19	0	004	005	0,33

Phase 0: Impact on TIME - comparative matrix

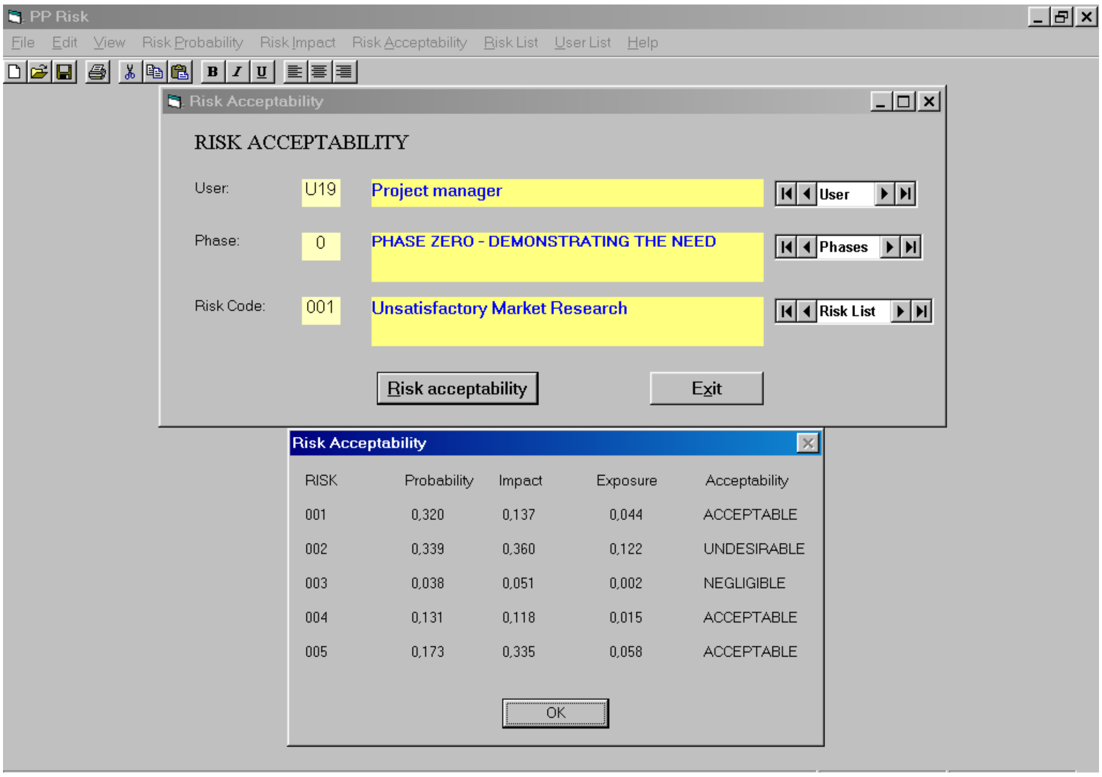


User Code	Phase Code	Risk Code 1	Risk Code 2	Score
U19	0	001	002	0,25
U19	0	001	003	2
U19	0	001	004	1
U19	0	001	005	0,2
U19	0	002	003	6
U19	0	002	004	3
U19	0	002	005	0,5
U19	0	003	004	0,5
U19	0	003	005	0,3
U19	0	004	005	0,2

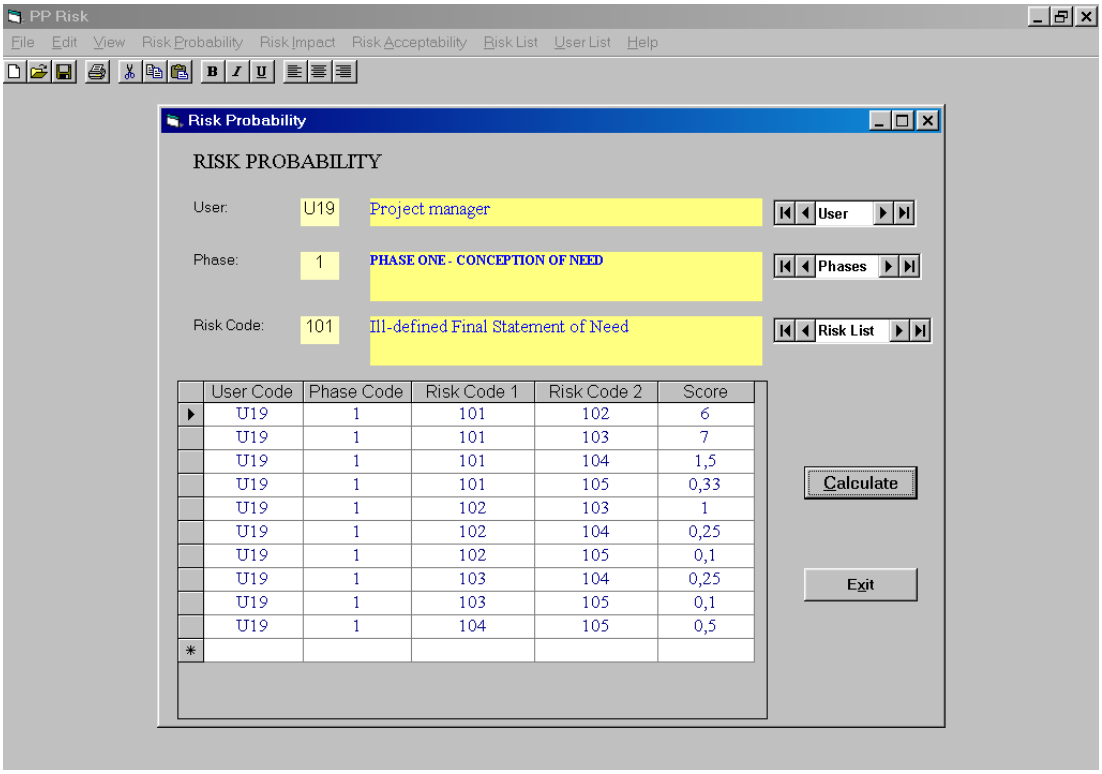
Phase 0: Impact on COST - comparative matrix



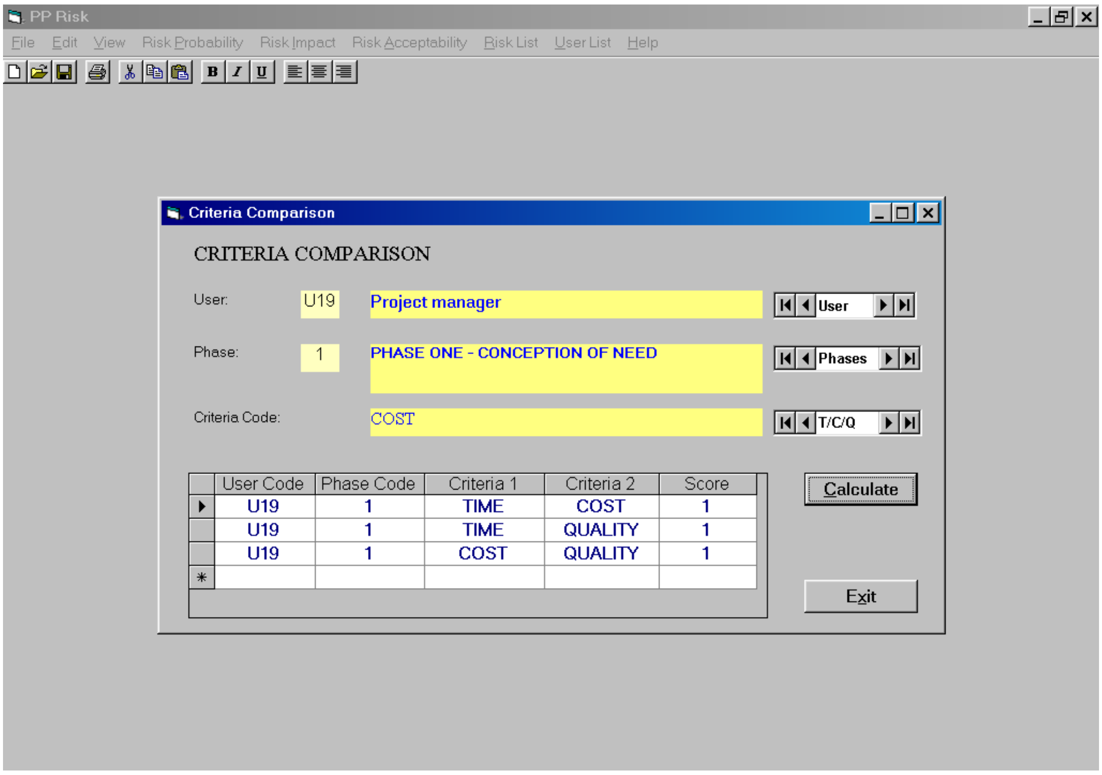
Phase 0: Impact on QUALITY - comparative matrix



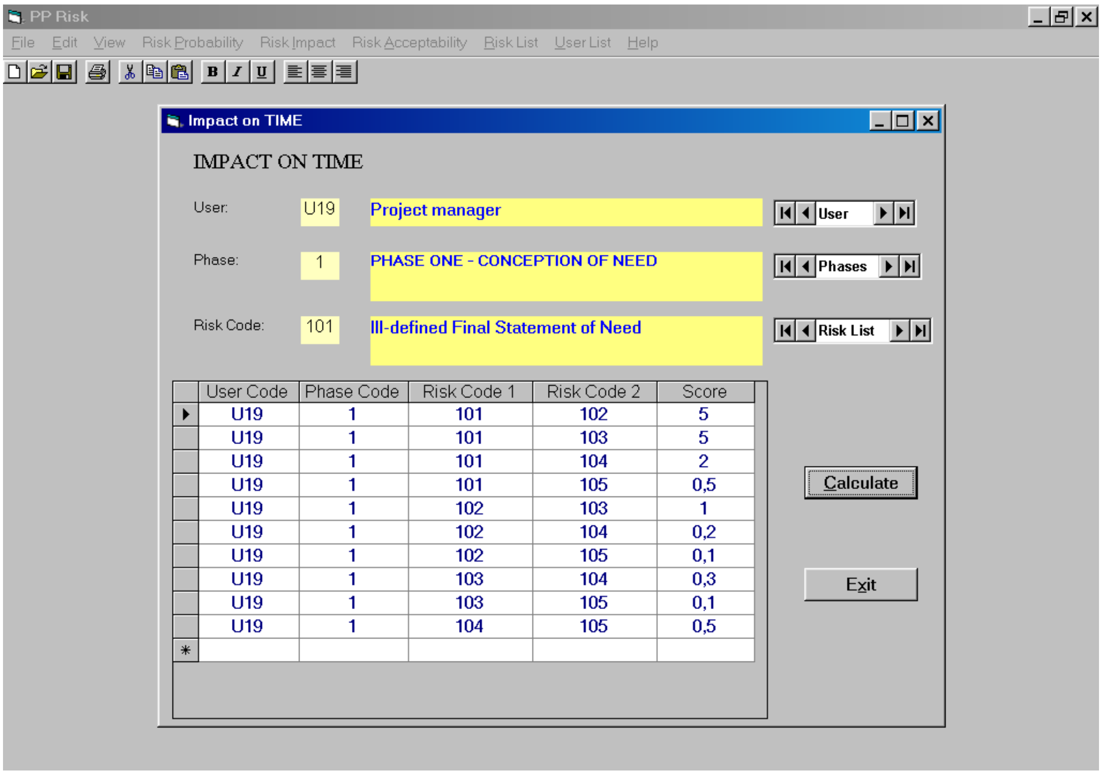
Phase 0: Risk exposure and risk acceptability obtained by PP-Risk



Phase 1: Risk probability - comparative matrix

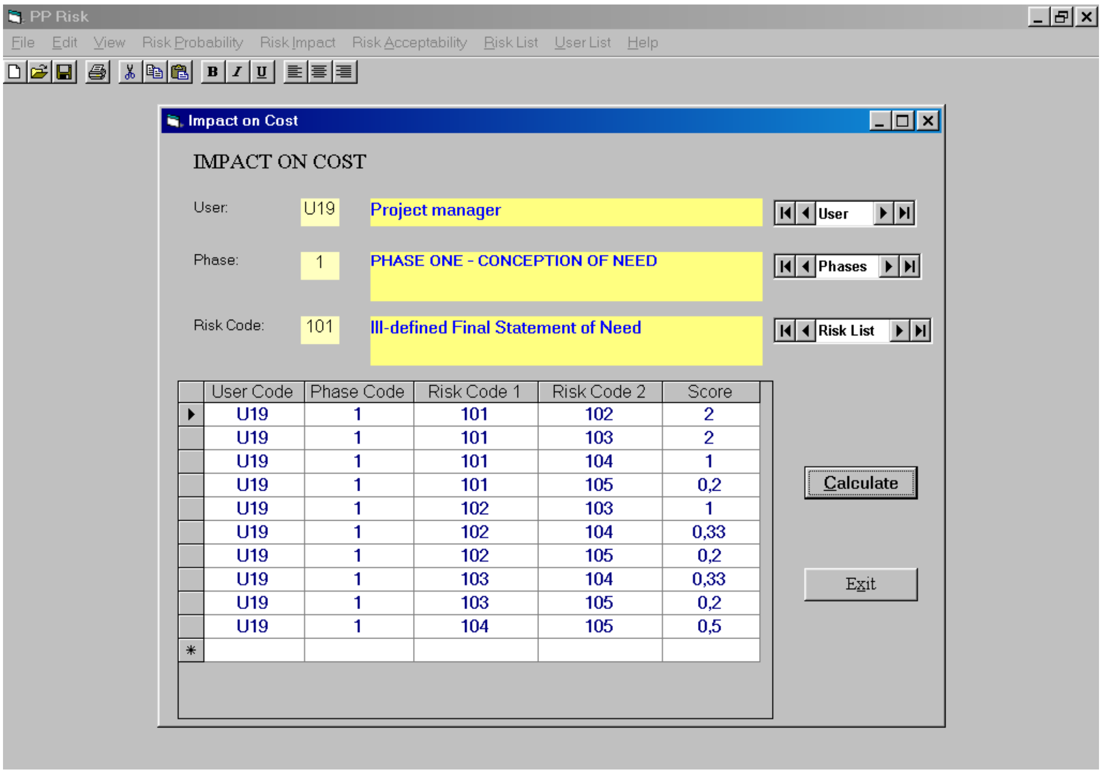


Phase 1: Criteria comparison - comparative matrix



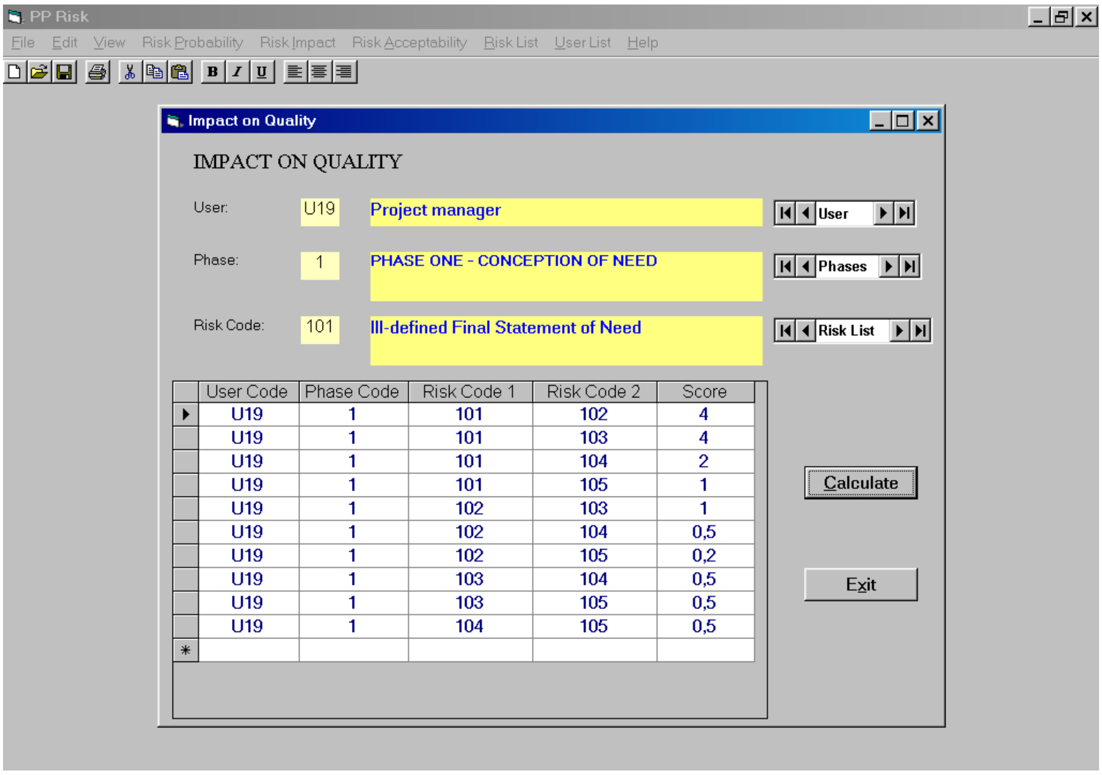
User Code	Phase Code	Risk Code 1	Risk Code 2	Score
U19	1	101	102	5
U19	1	101	103	5
U19	1	101	104	2
U19	1	101	105	0,5
U19	1	102	103	1
U19	1	102	104	0,2
U19	1	102	105	0,1
U19	1	103	104	0,3
U19	1	103	105	0,1
U19	1	104	105	0,5

Phase 1: Impact on TIME - comparative matrix

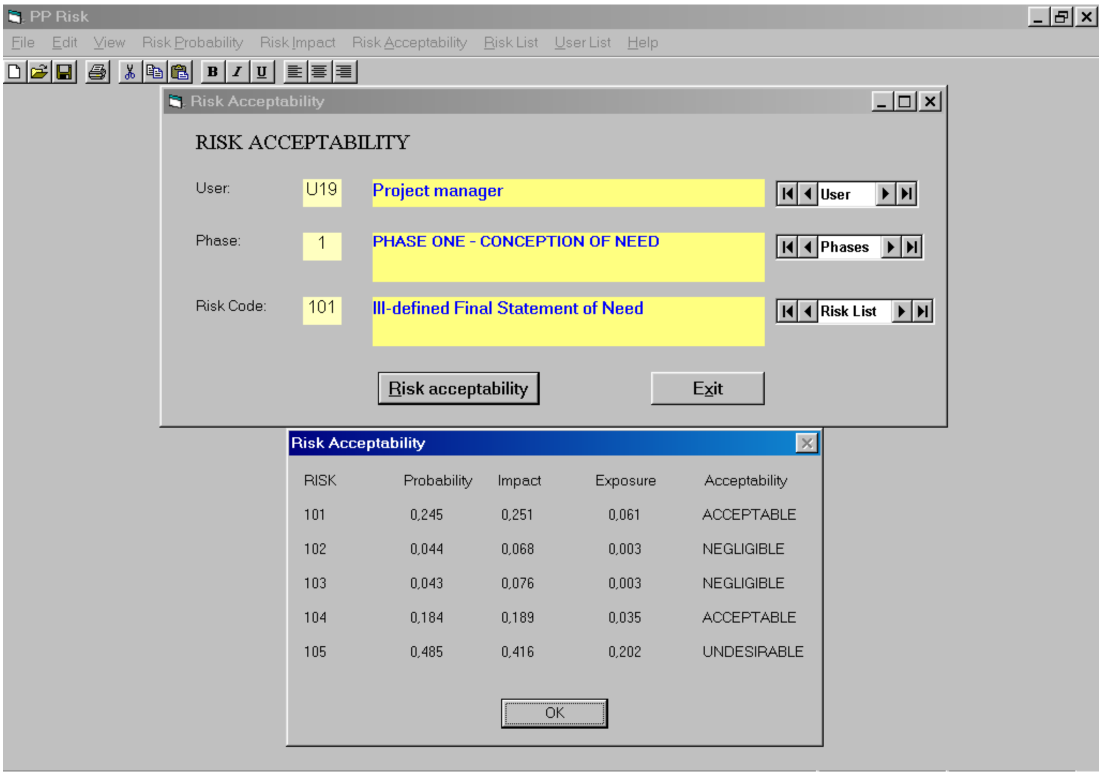


User Code	Phase Code	Risk Code 1	Risk Code 2	Score
U19	1	101	102	2
U19	1	101	103	2
U19	1	101	104	1
U19	1	101	105	0,2
U19	1	102	103	1
U19	1	102	104	0,33
U19	1	102	105	0,2
U19	1	103	104	0,33
U19	1	103	105	0,2
U19	1	104	105	0,5

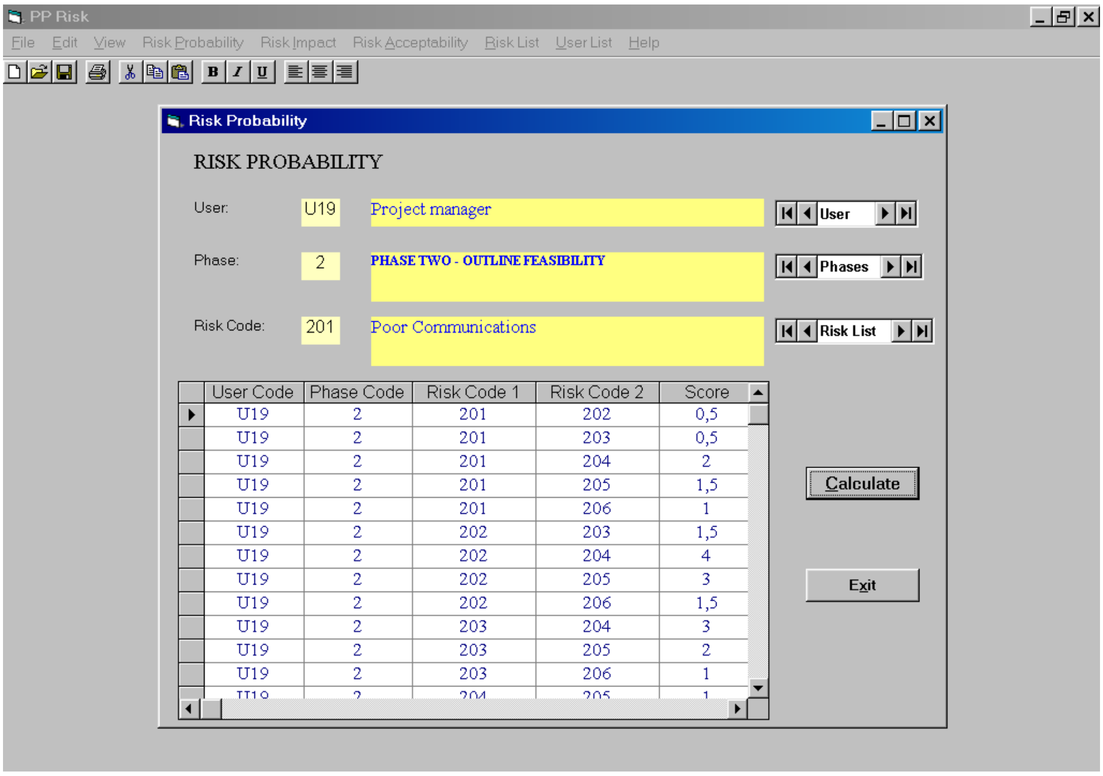
Phase 1: Impact on COST - comparative matrix



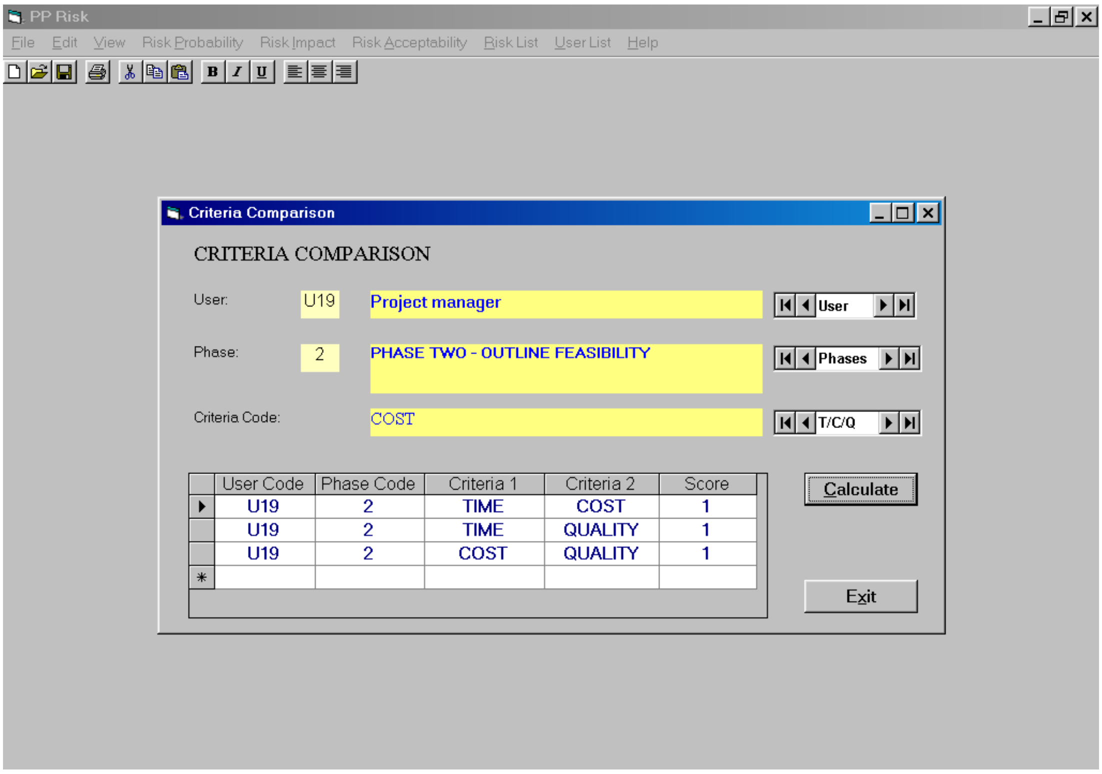
Phase 1: Impact on QUALITY - comparative matrix



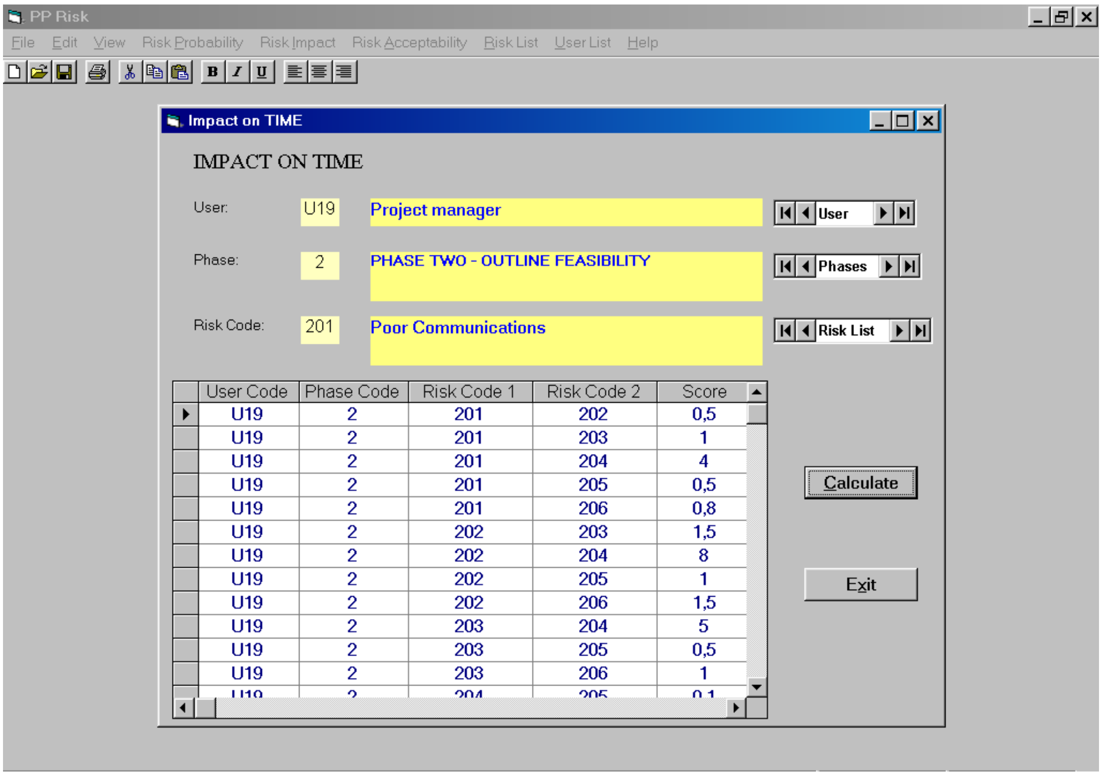
Phase 1: Risk exposure and risk acceptability obtained by PP-Risk



Phase 2: Risk probability - comparative matrix

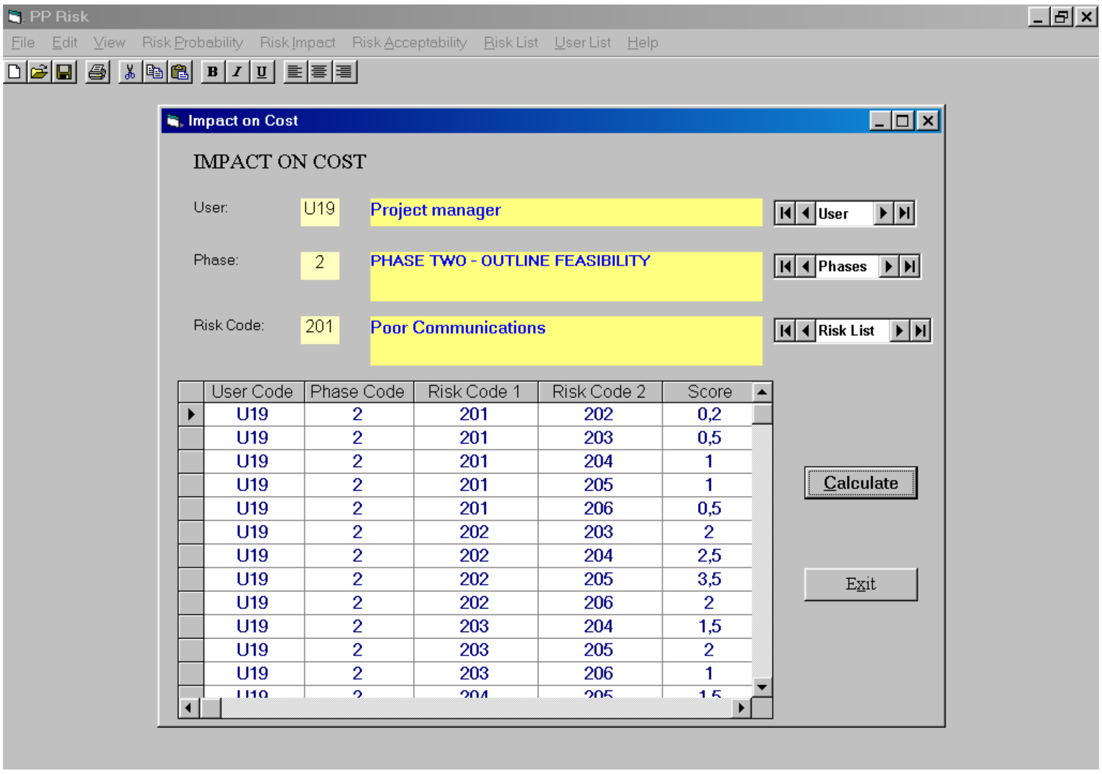


Phase 2: Criteria comparison - comparative matrix



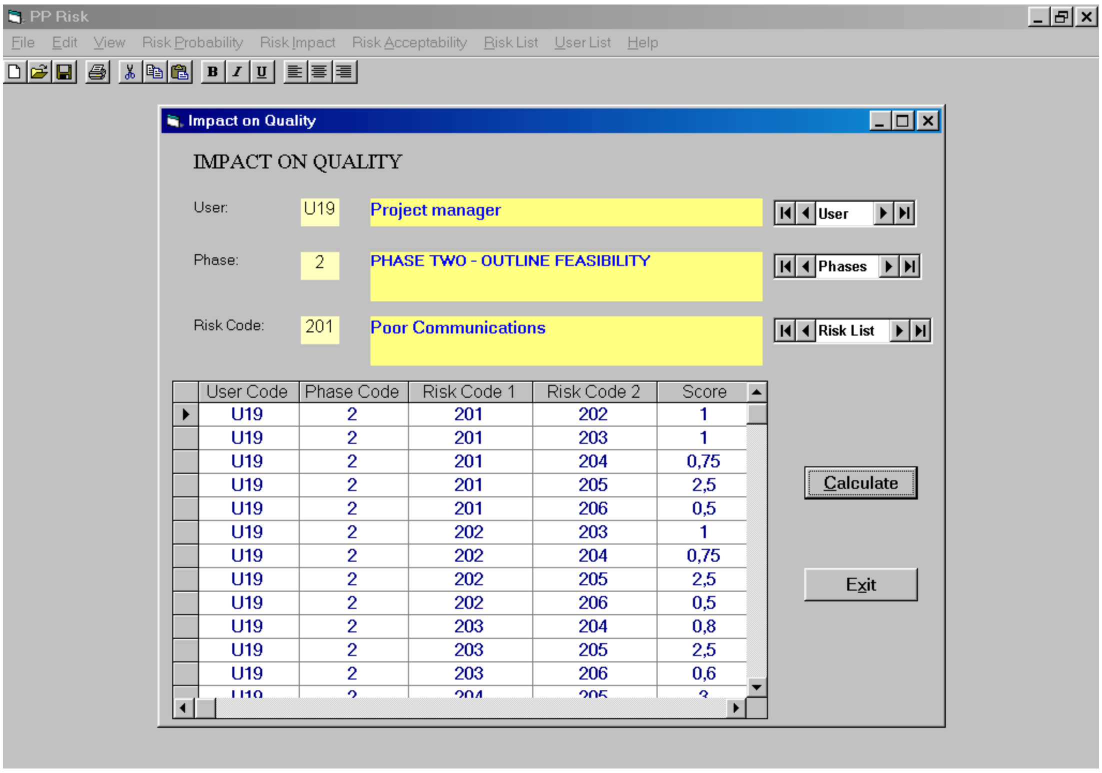
User Code	Phase Code	Risk Code 1	Risk Code 2	Score
U19	2	201	202	0,5
U19	2	201	203	1
U19	2	201	204	4
U19	2	201	205	0,5
U19	2	201	206	0,8
U19	2	202	203	1,5
U19	2	202	204	8
U19	2	202	205	1
U19	2	202	206	1,5
U19	2	203	204	5
U19	2	203	205	0,5
U19	2	203	206	1
U19	2	204	205	0,1

Phase 2: Impact on TIME - comparative matrix

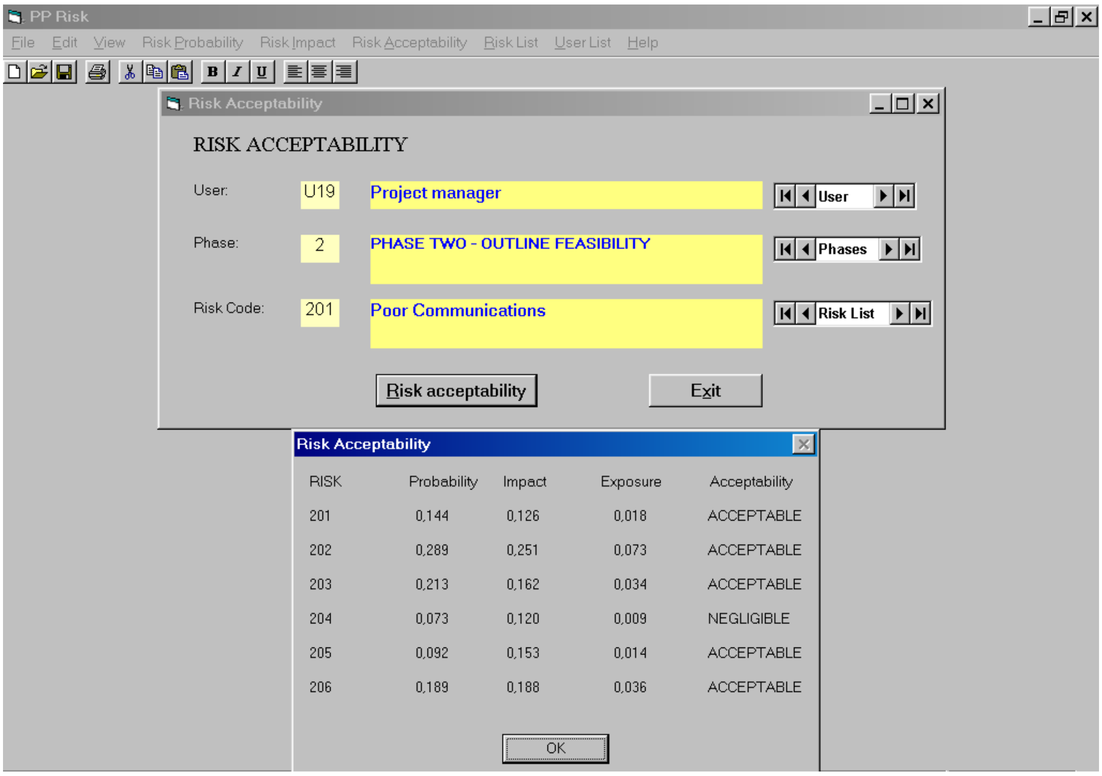


User Code	Phase Code	Risk Code 1	Risk Code 2	Score
U19	2	201	202	0,2
U19	2	201	203	0,5
U19	2	201	204	1
U19	2	201	205	1
U19	2	201	206	0,5
U19	2	202	203	2
U19	2	202	204	2,5
U19	2	202	205	3,5
U19	2	202	206	2
U19	2	203	204	1,5
U19	2	203	205	2
U19	2	203	206	1
U19	2	204	205	1,5

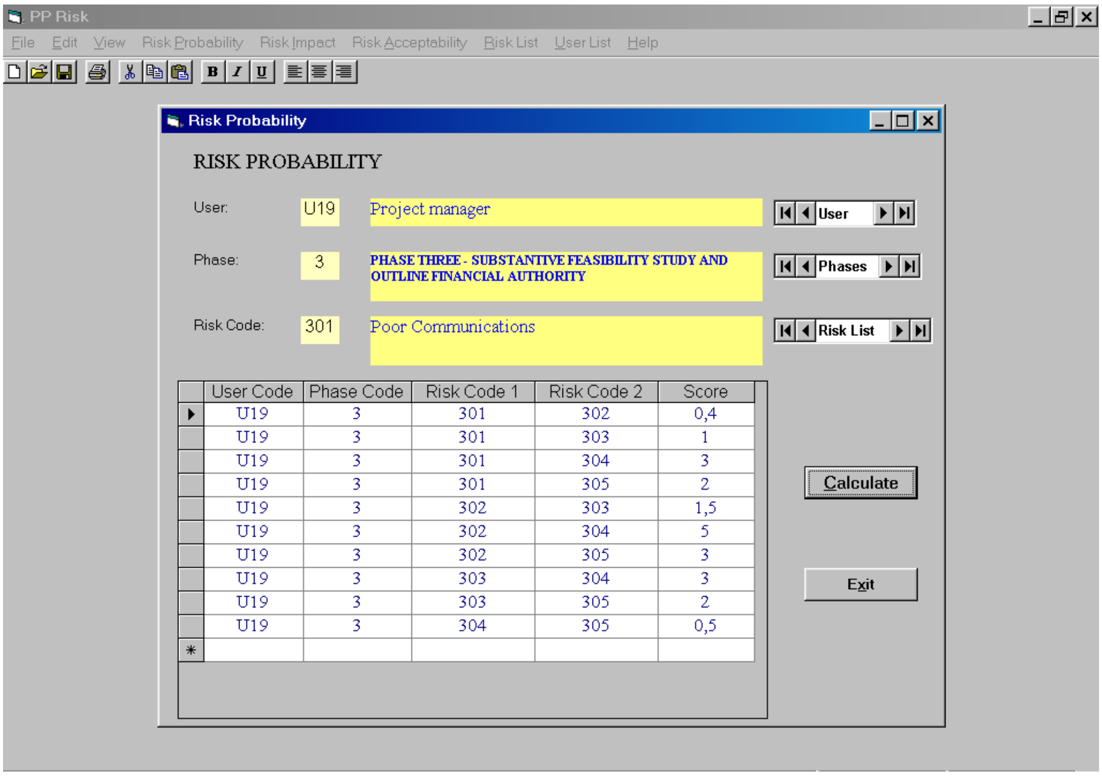
Phase 2: Impact on COST - comparative matrix



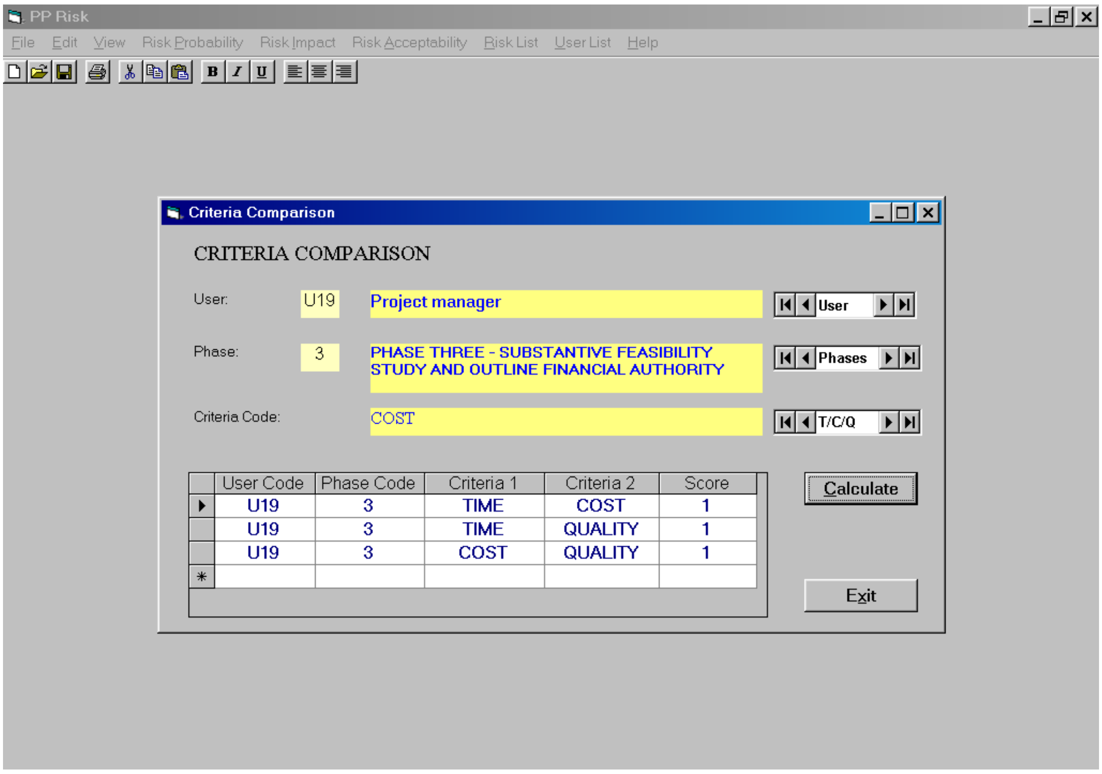
Phase 2: Impact on QUALITY - comparative matrix



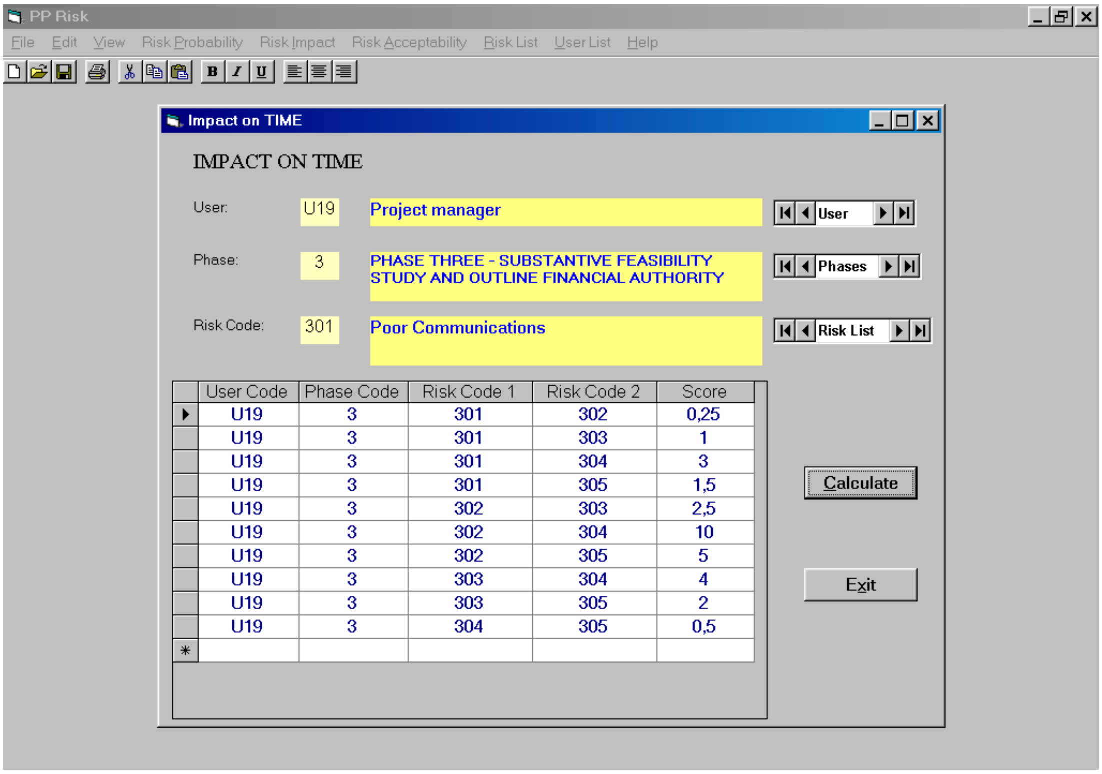
Phase 2: Risk exposure and risk acceptability obtained by PP-Risk



Phase 3: Risk probability - comparative matrix

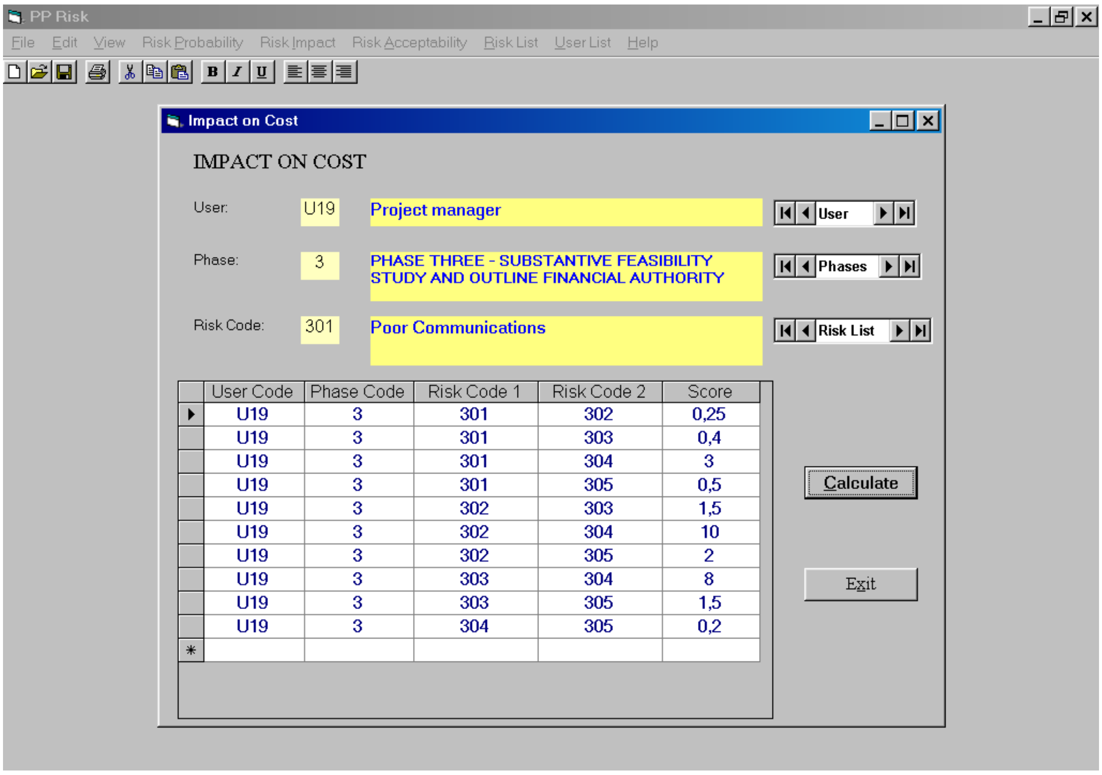


Phase 3: Criteria comparison - comparative matrix



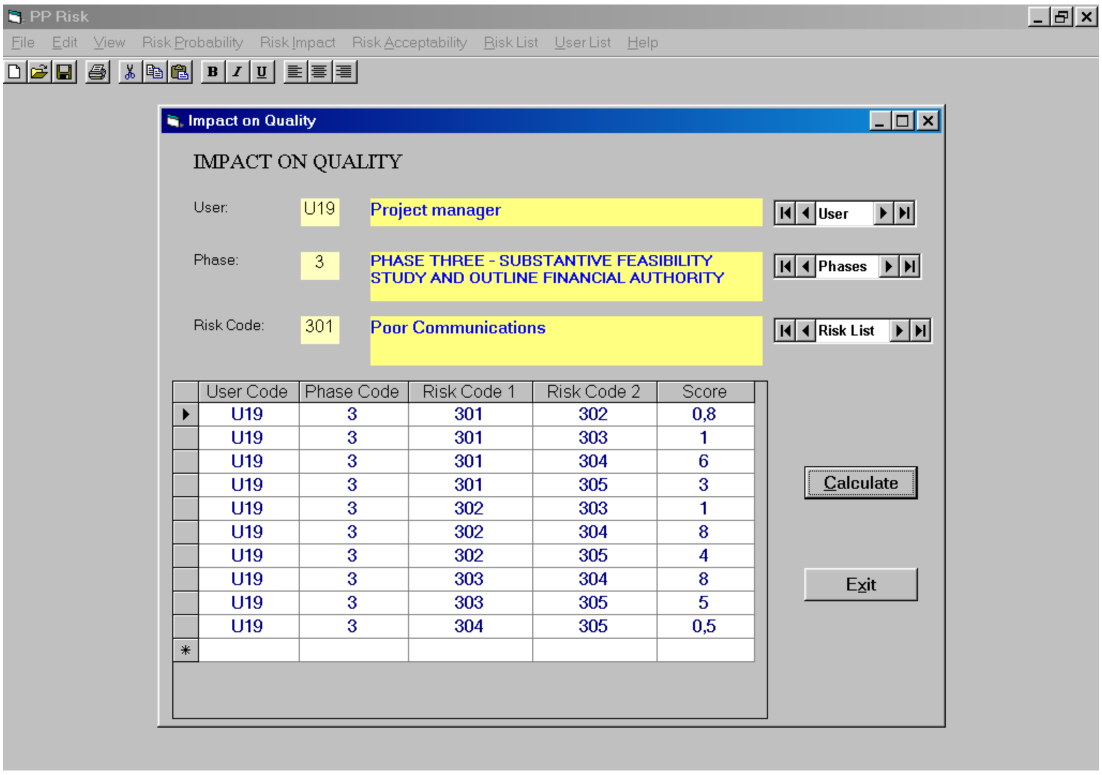
User Code	Phase Code	Risk Code 1	Risk Code 2	Score
U19	3	301	302	0,25
U19	3	301	303	1
U19	3	301	304	3
U19	3	301	305	1,5
U19	3	302	303	2,5
U19	3	302	304	10
U19	3	302	305	5
U19	3	303	304	4
U19	3	303	305	2
U19	3	304	305	0,5

Phase 3: Impact on TIME - comparative matrix

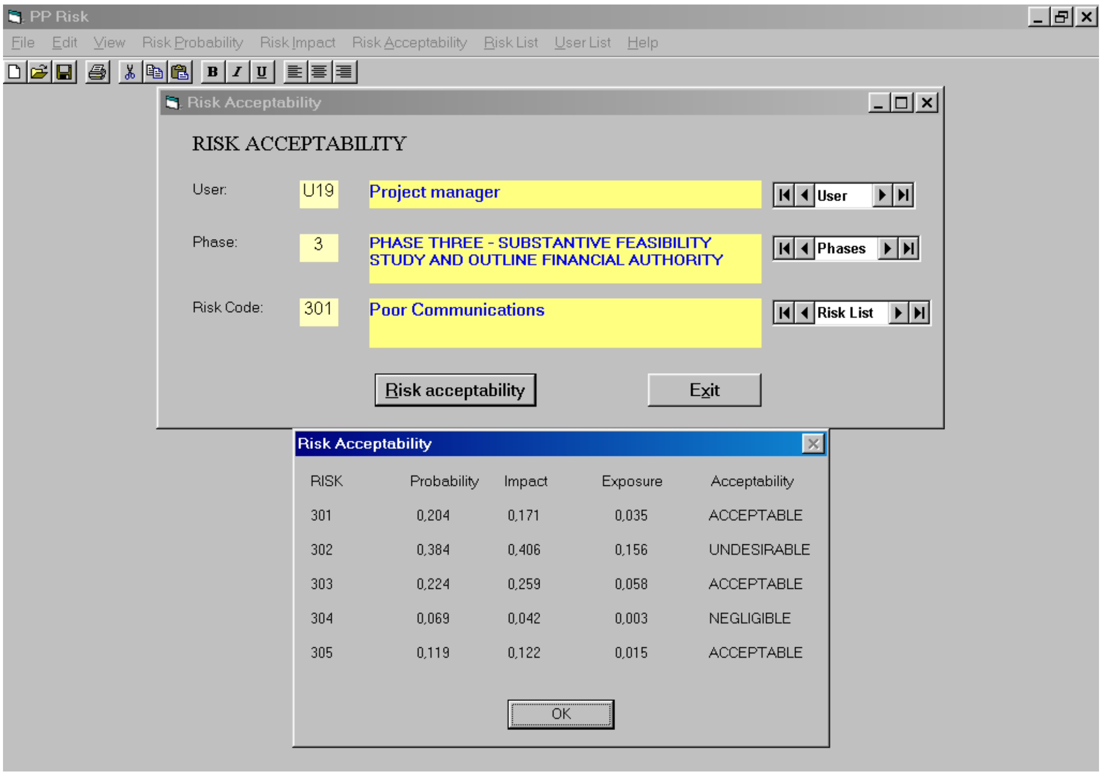


User Code	Phase Code	Risk Code 1	Risk Code 2	Score
U19	3	301	302	0,25
U19	3	301	303	0,4
U19	3	301	304	3
U19	3	301	305	0,5
U19	3	302	303	1,5
U19	3	302	304	10
U19	3	302	305	2
U19	3	303	304	8
U19	3	303	305	1,5
U19	3	304	305	0,2

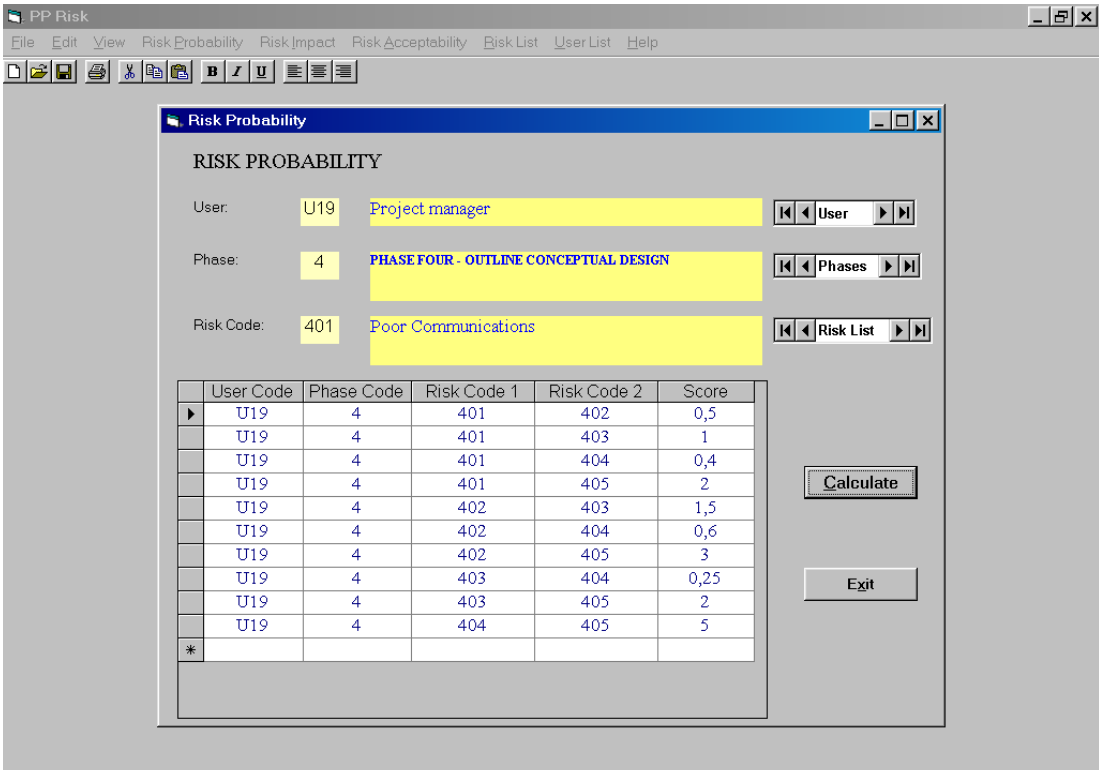
Phase 3: Impact on COST - comparative matrix



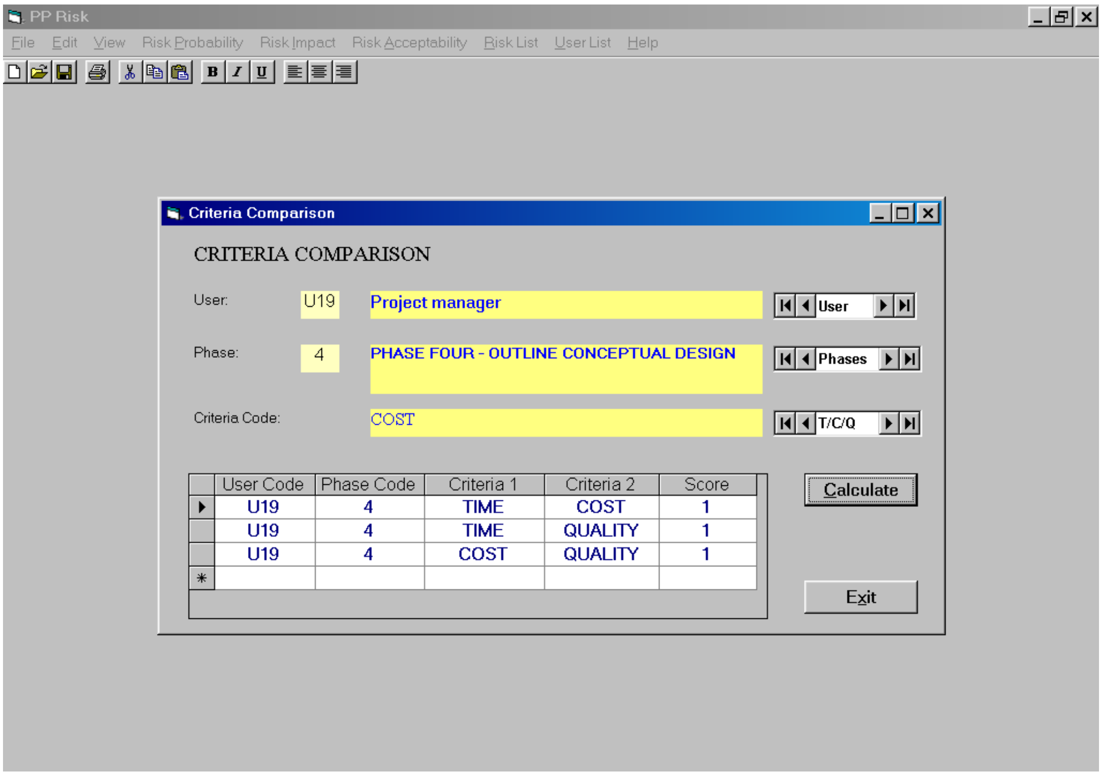
Phase 3: Impact on QUALITY - comparative matrix



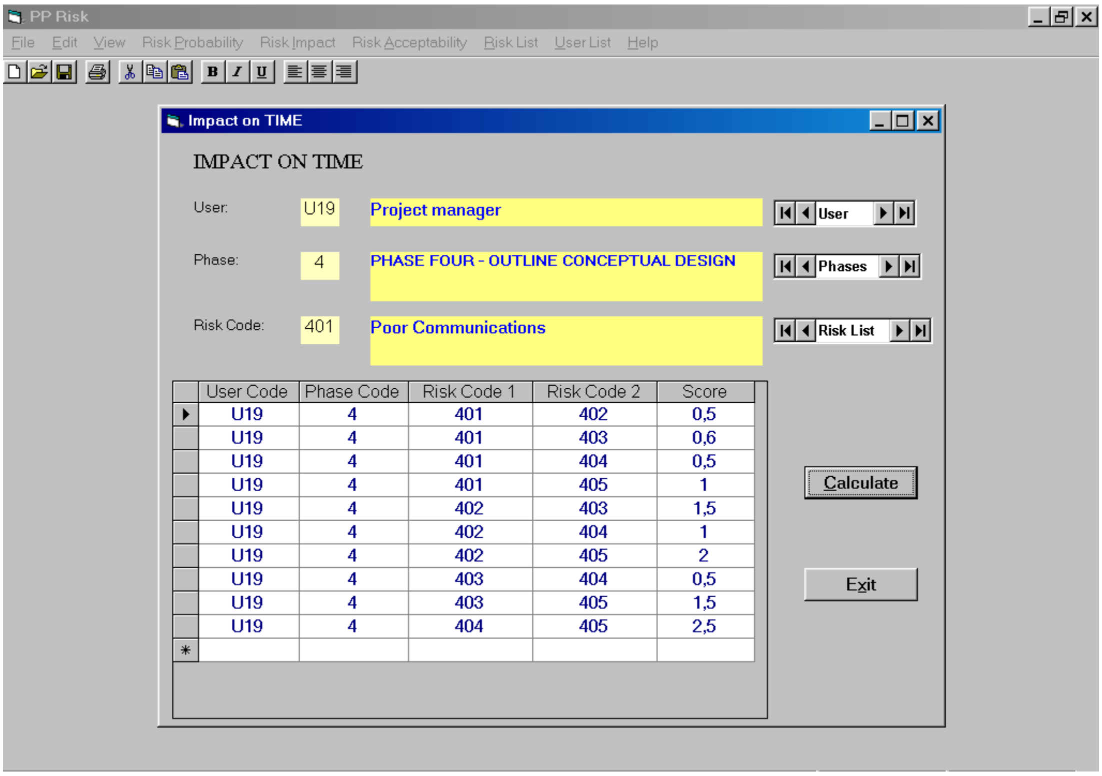
Phase 3: Risk exposure and risk acceptability obtained by PP-Risk



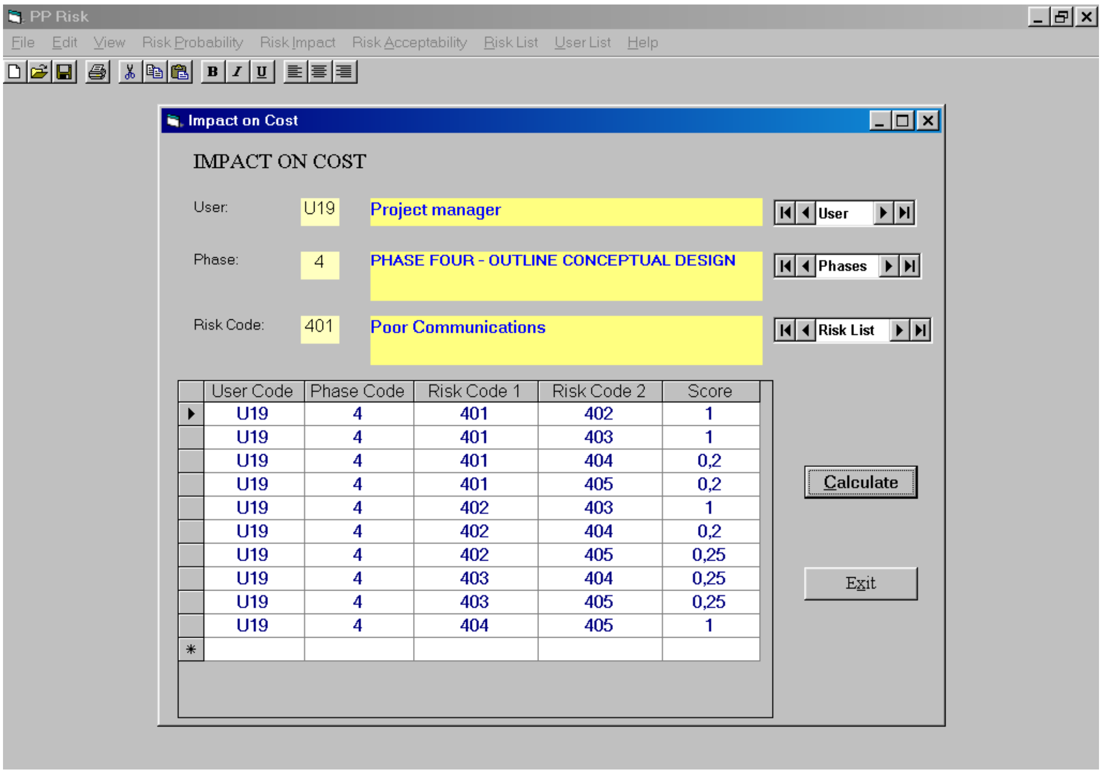
Phase 4: Risk probability - comparative matrix



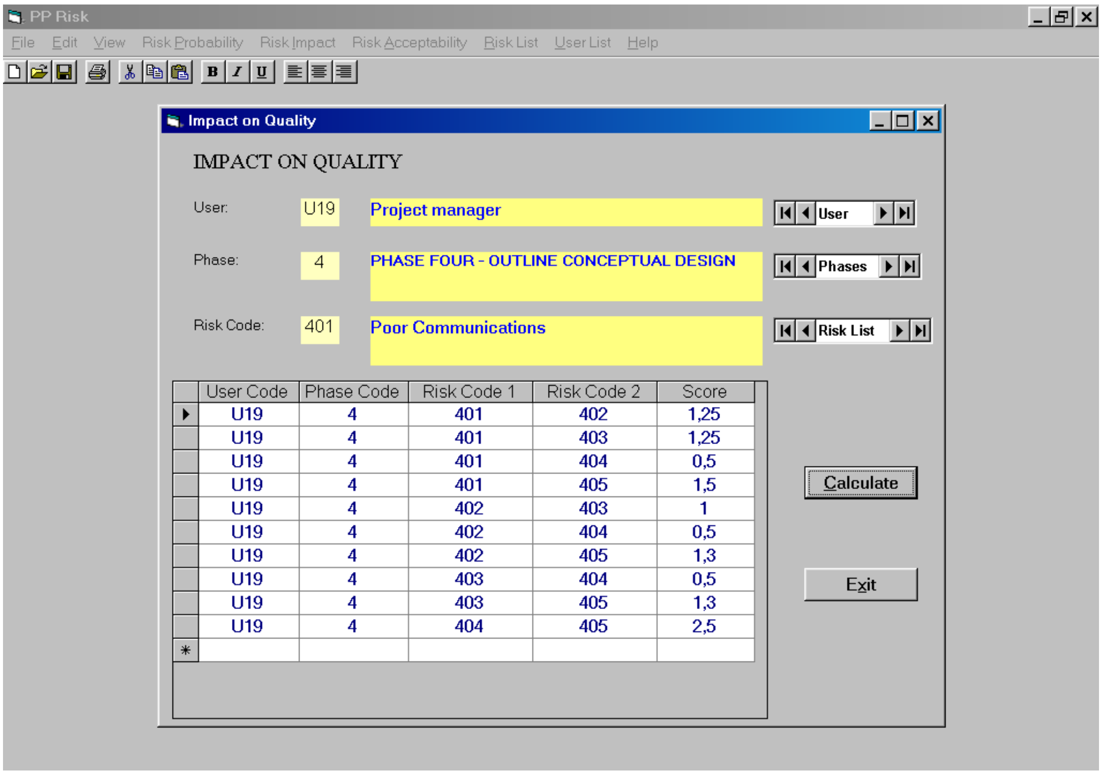
Phase 4: Criteria comparison - comparative matrix



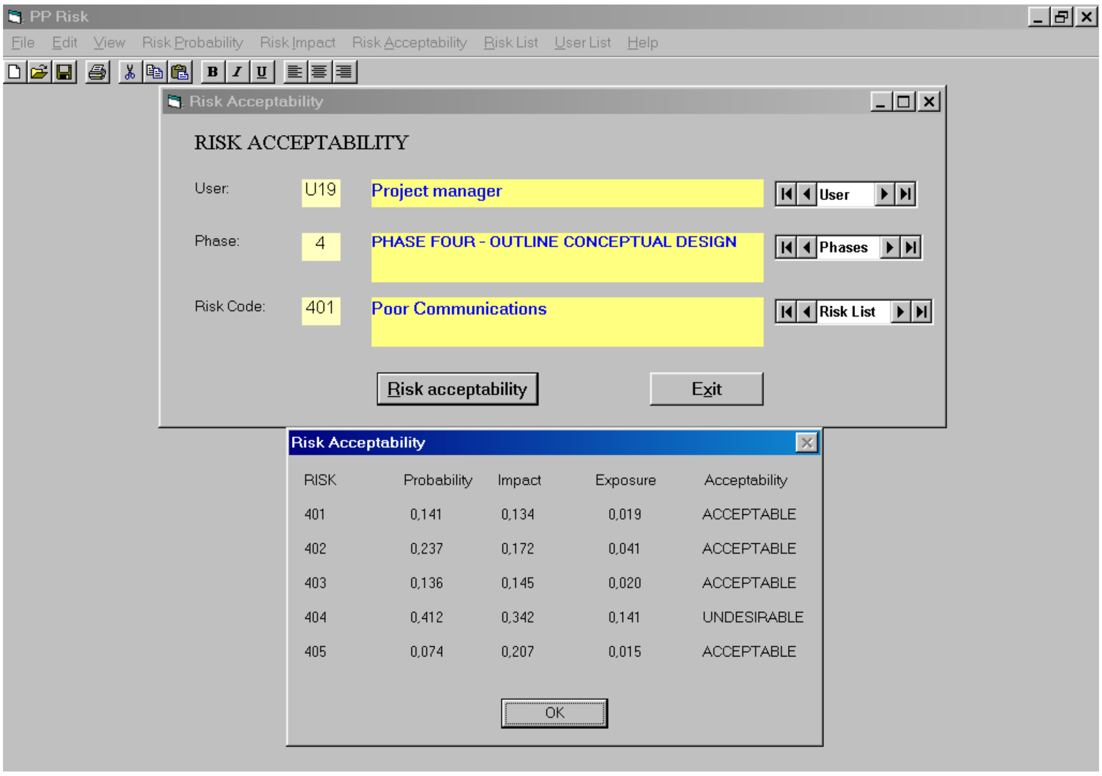
Phase 4: Impact on TIME - comparative matrix



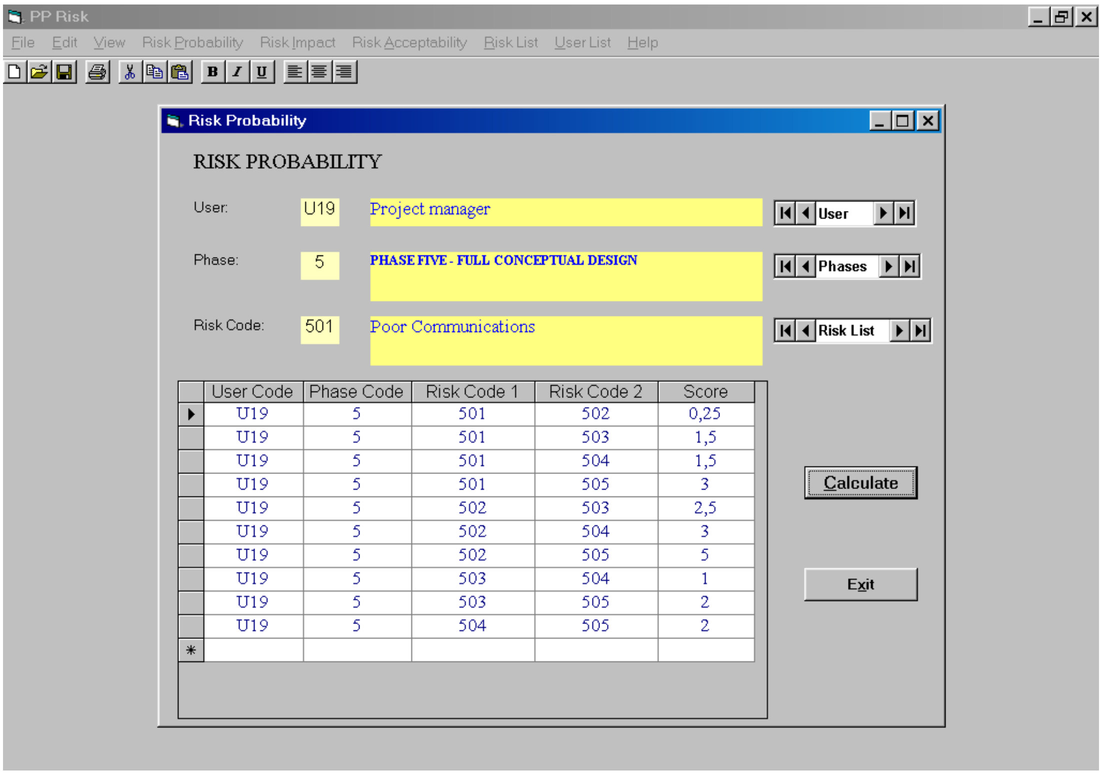
Phase 4: Impact on COST - comparative matrix



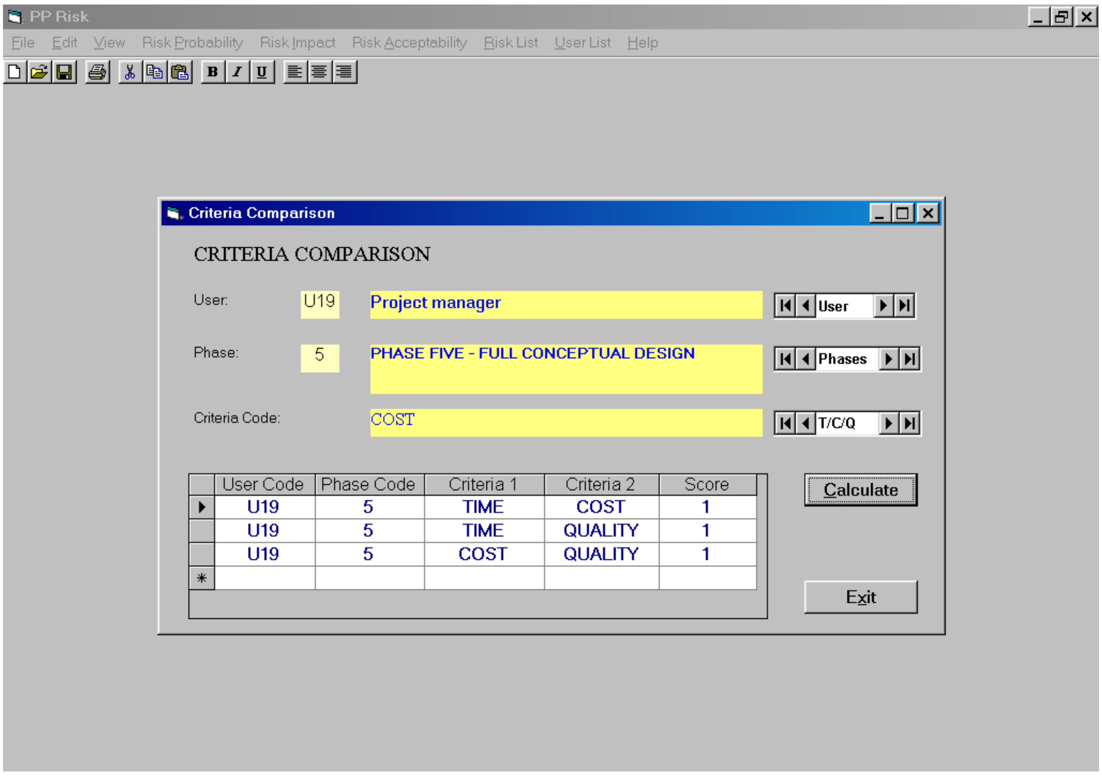
Phase 4: Impact on QUALITY - comparative matrix



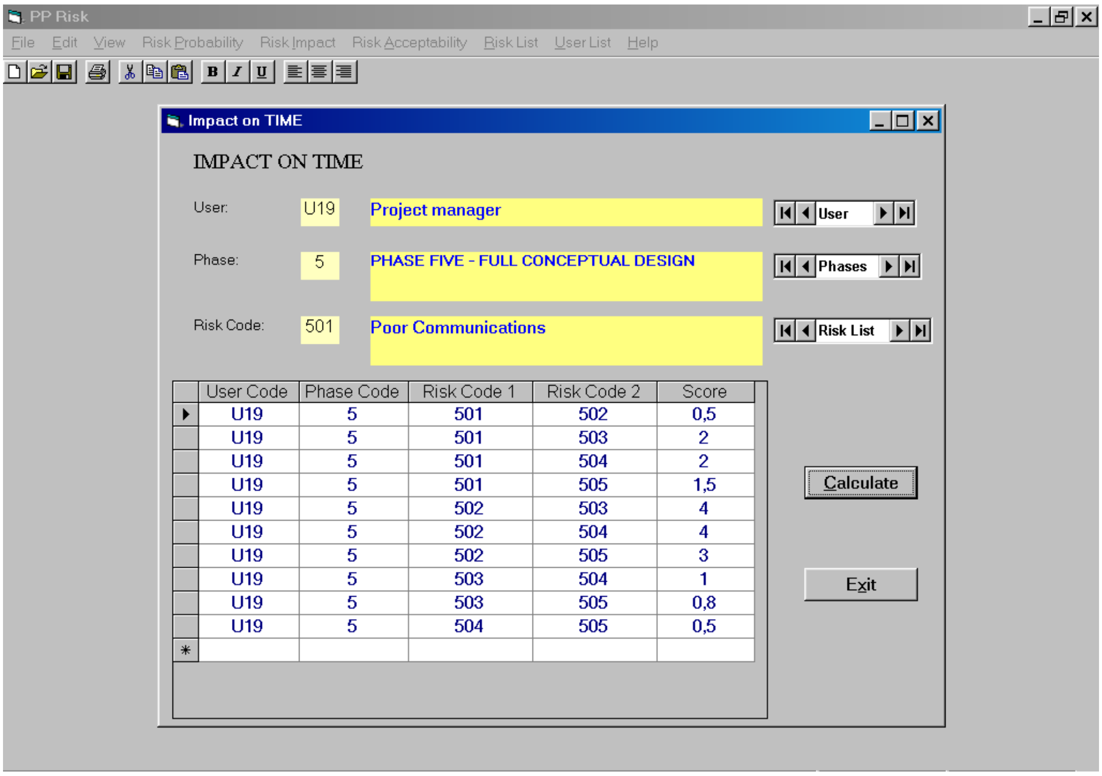
Phase 4: Risk exposure and risk acceptability obtained by PP-Risk



Phase 5: Risk probability - comparative matrix

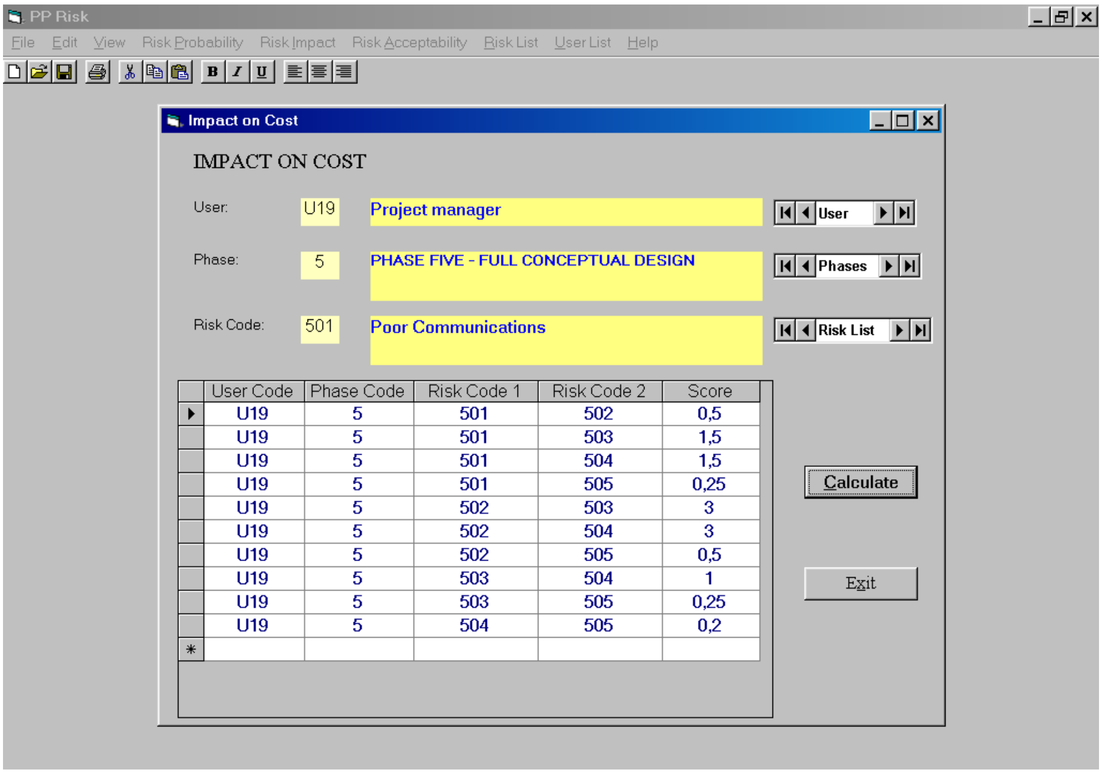


Phase 5: Criteria comparison - comparative matrix



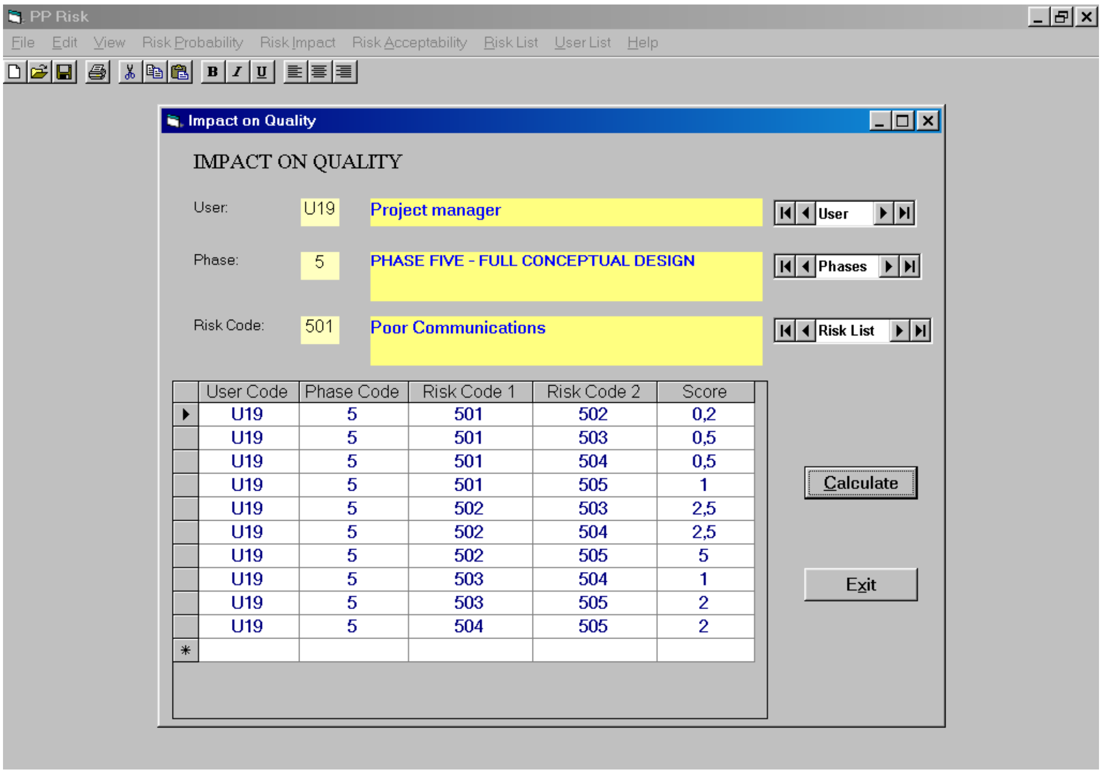
User Code	Phase Code	Risk Code 1	Risk Code 2	Score
U19	5	501	502	0,5
U19	5	501	503	2
U19	5	501	504	2
U19	5	501	505	1,5
U19	5	502	503	4
U19	5	502	504	4
U19	5	502	505	3
U19	5	503	504	1
U19	5	503	505	0,8
U19	5	504	505	0,5

Phase 5: Impact on TIME - comparative matrix

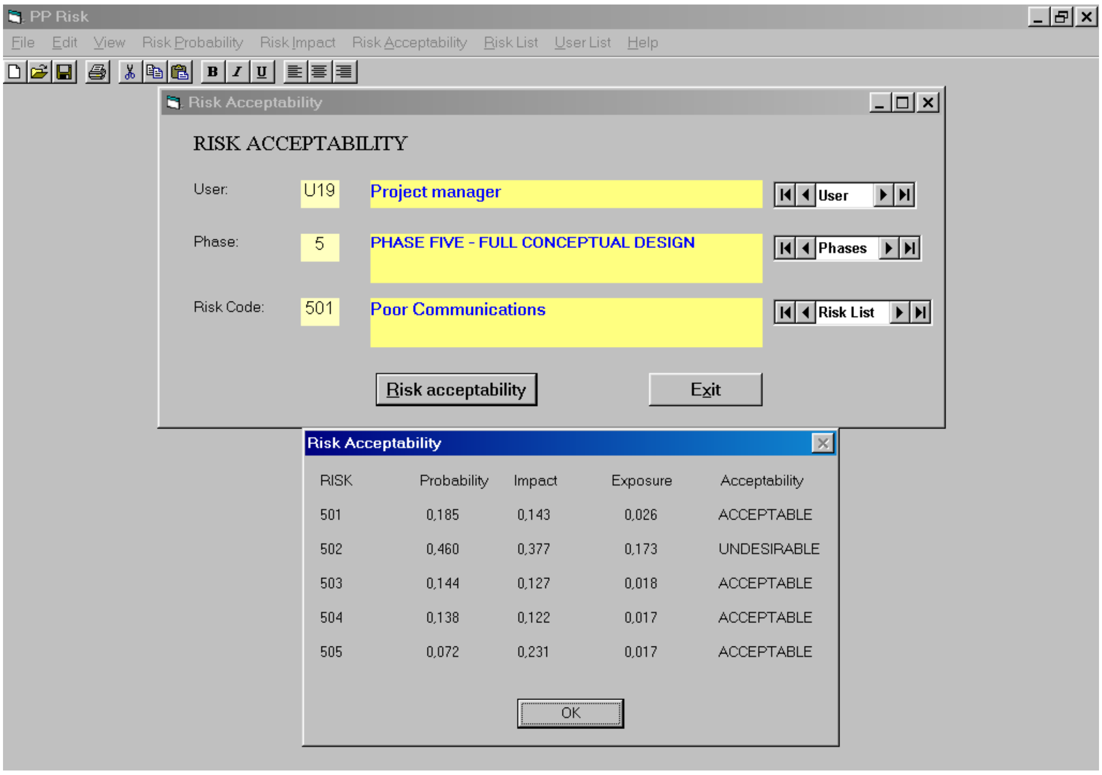


User Code	Phase Code	Risk Code 1	Risk Code 2	Score
U19	5	501	502	0,5
U19	5	501	503	1,5
U19	5	501	504	1,5
U19	5	501	505	0,25
U19	5	502	503	3
U19	5	502	504	3
U19	5	502	505	0,5
U19	5	503	504	1
U19	5	503	505	0,25
U19	5	504	505	0,2

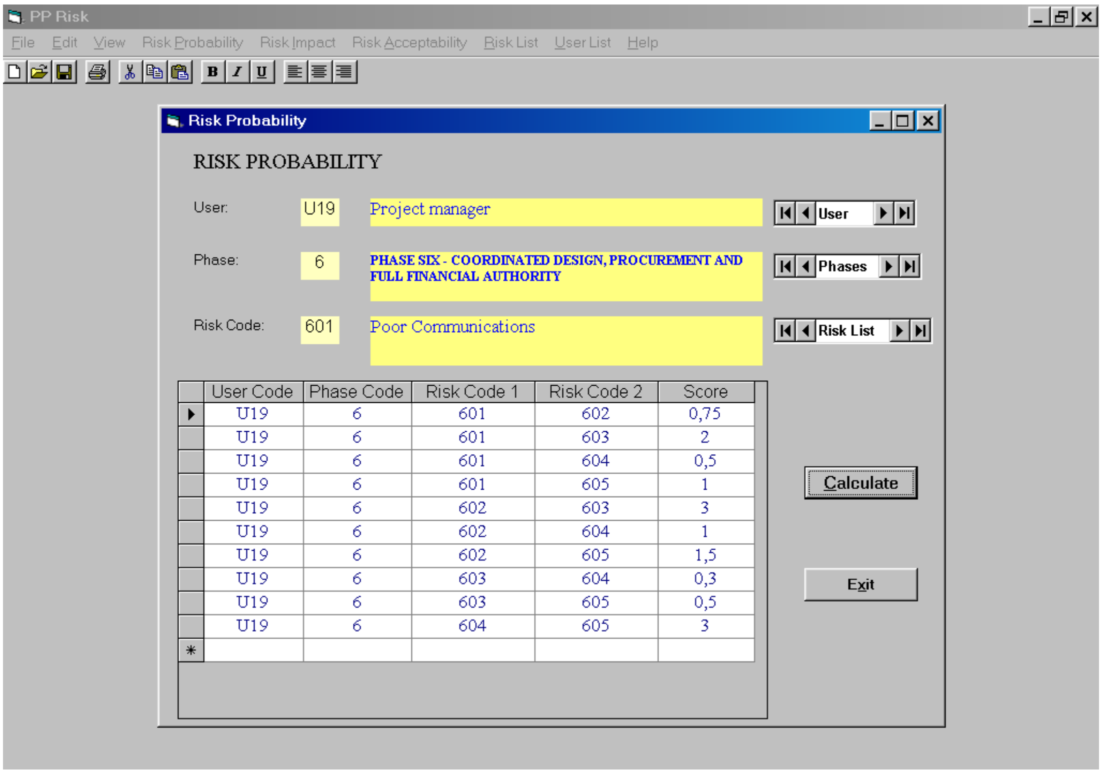
Phase 5: Impact on COST - comparative matrix



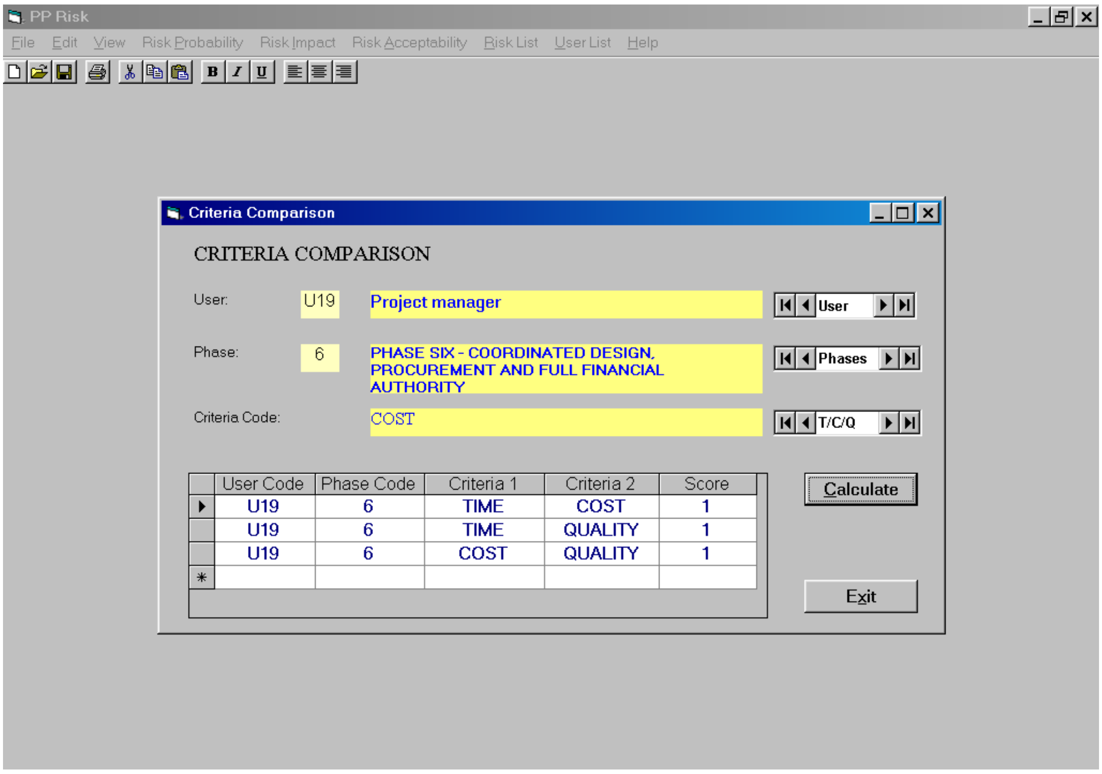
Phase 5: Impact on QUALITY - comparative matrix



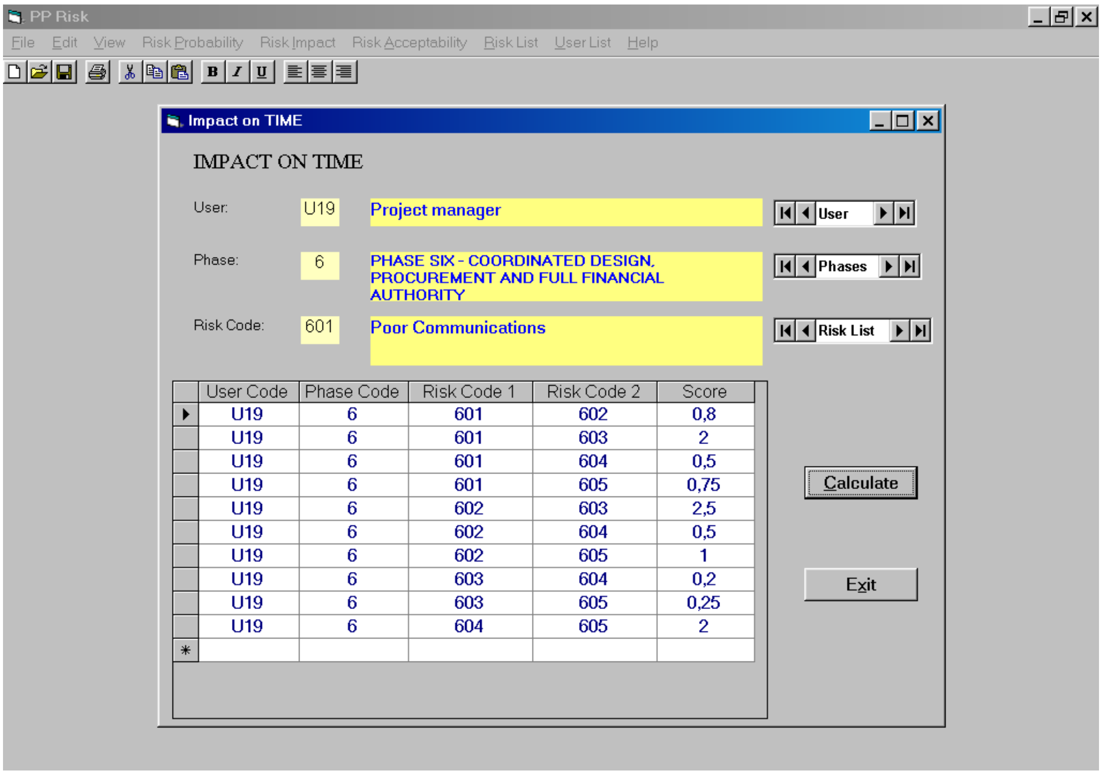
Phase 5: Risk exposure and risk acceptability obtained by PP-Risk



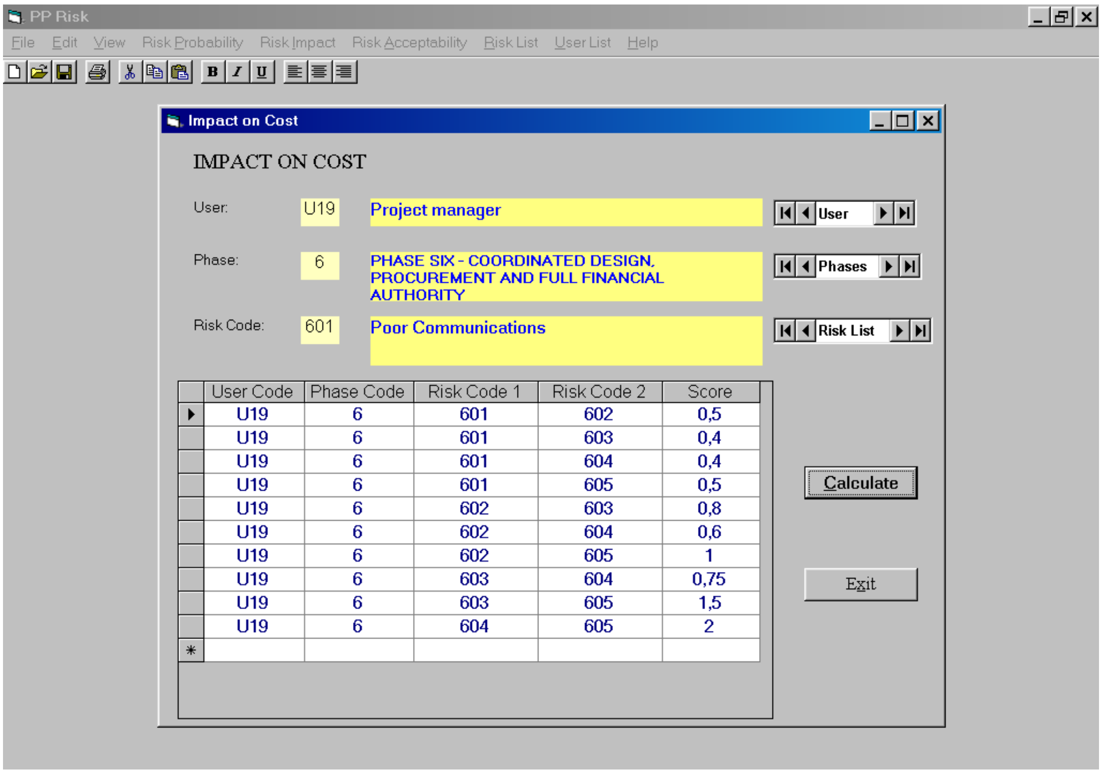
Phase 6: Risk probability - comparative matrix



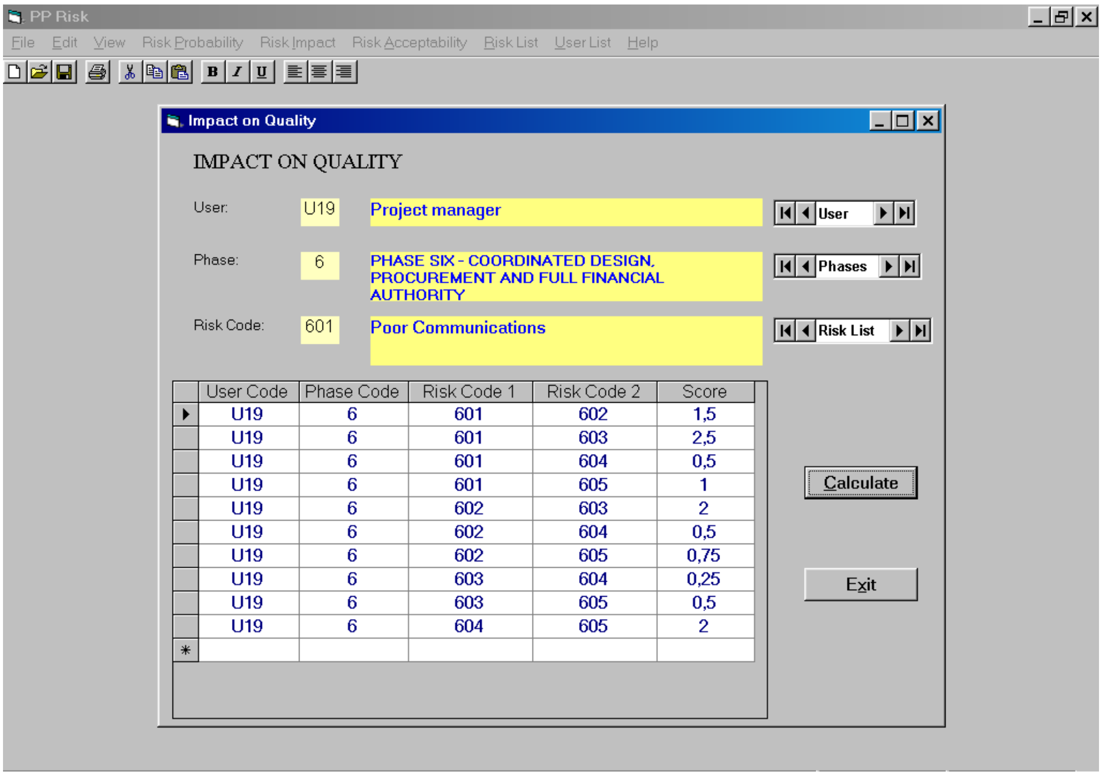
Phase 6: Criteria comparison - comparative matrix



Phase 6: Impact on TIME - comparative matrix

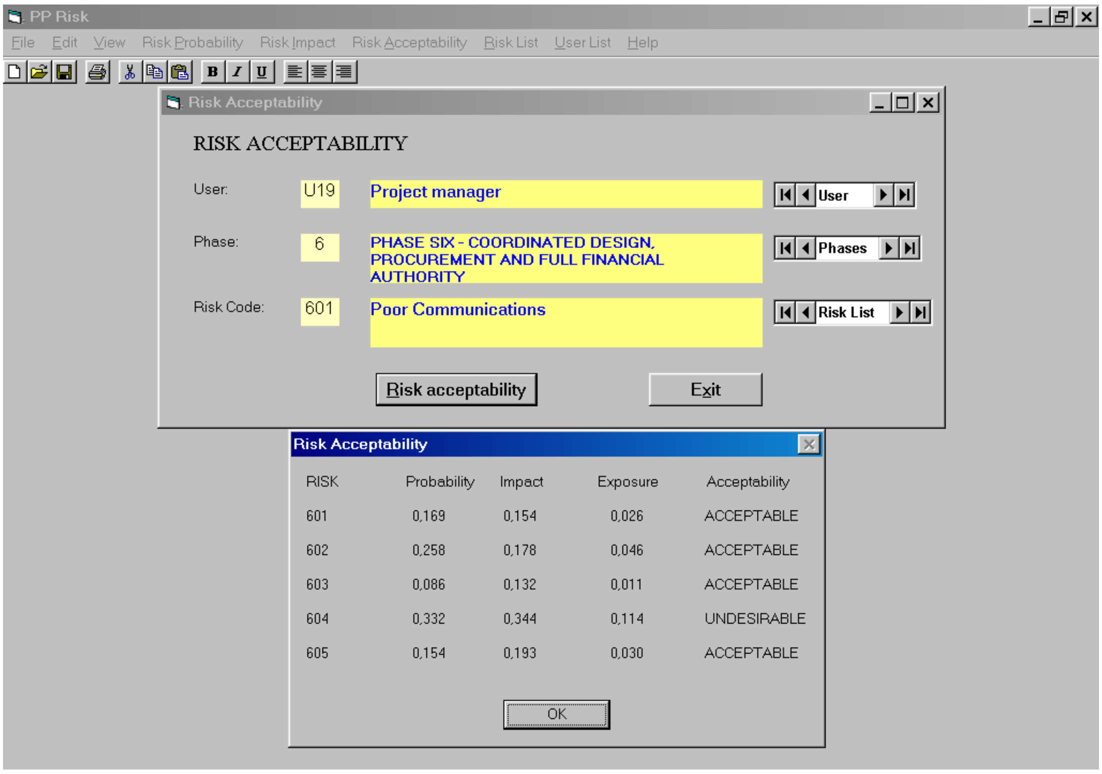


Phase 6: Impact on COST - comparative matrix



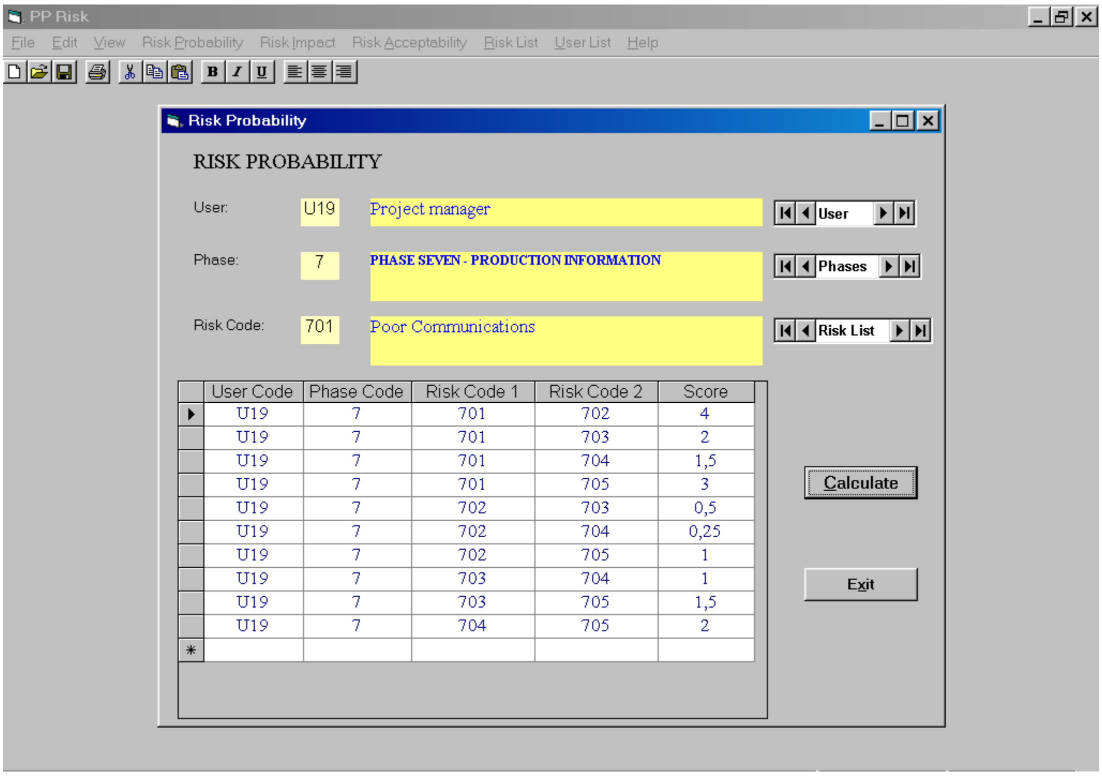
User Code	Phase Code	Risk Code 1	Risk Code 2	Score
U19	6	601	602	1,5
U19	6	601	603	2,5
U19	6	601	604	0,5
U19	6	601	605	1
U19	6	602	603	2
U19	6	602	604	0,5
U19	6	602	605	0,75
U19	6	603	604	0,25
U19	6	603	605	0,5
U19	6	604	605	2

Phase 6: Impact on QUALITY - comparative matrix

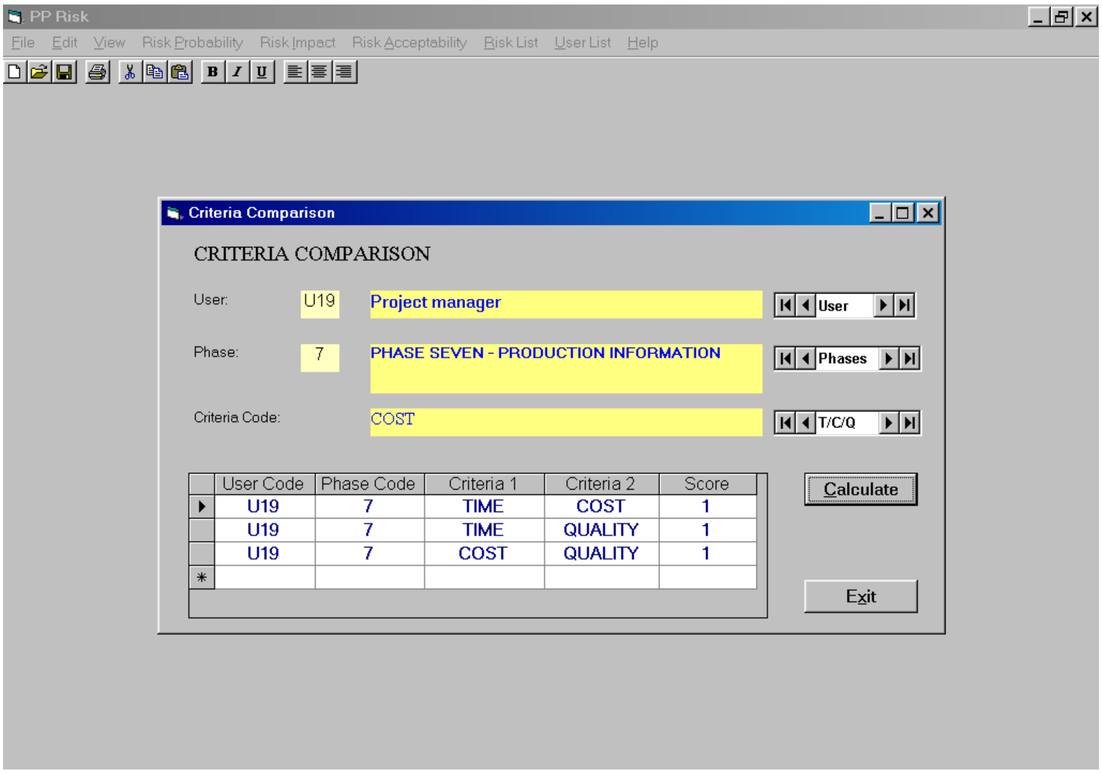


RISK	Probability	Impact	Exposure	Acceptability
601	0,169	0,154	0,026	ACCEPTABLE
602	0,258	0,178	0,046	ACCEPTABLE
603	0,086	0,132	0,011	ACCEPTABLE
604	0,332	0,344	0,114	UNDESIRABLE
605	0,154	0,193	0,030	ACCEPTABLE

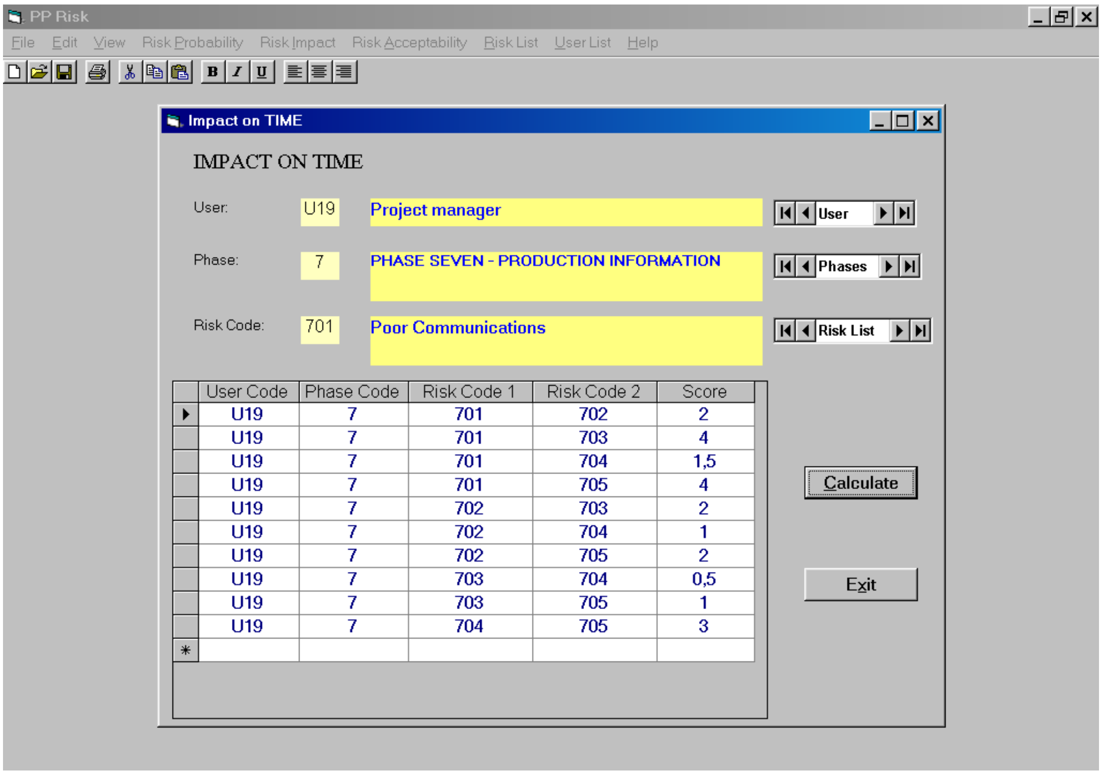
Phase 6: Risk exposure and risk acceptability obtained by PP-Risk



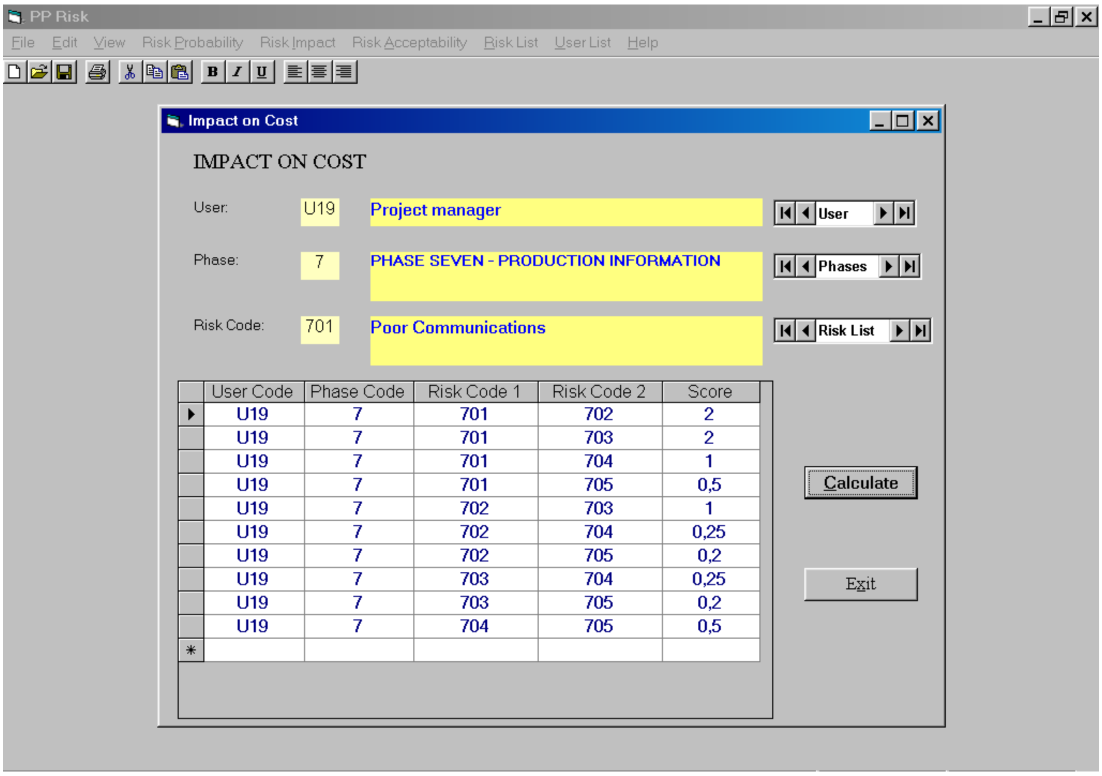
Phase 7: Risk probability - comparative matrix



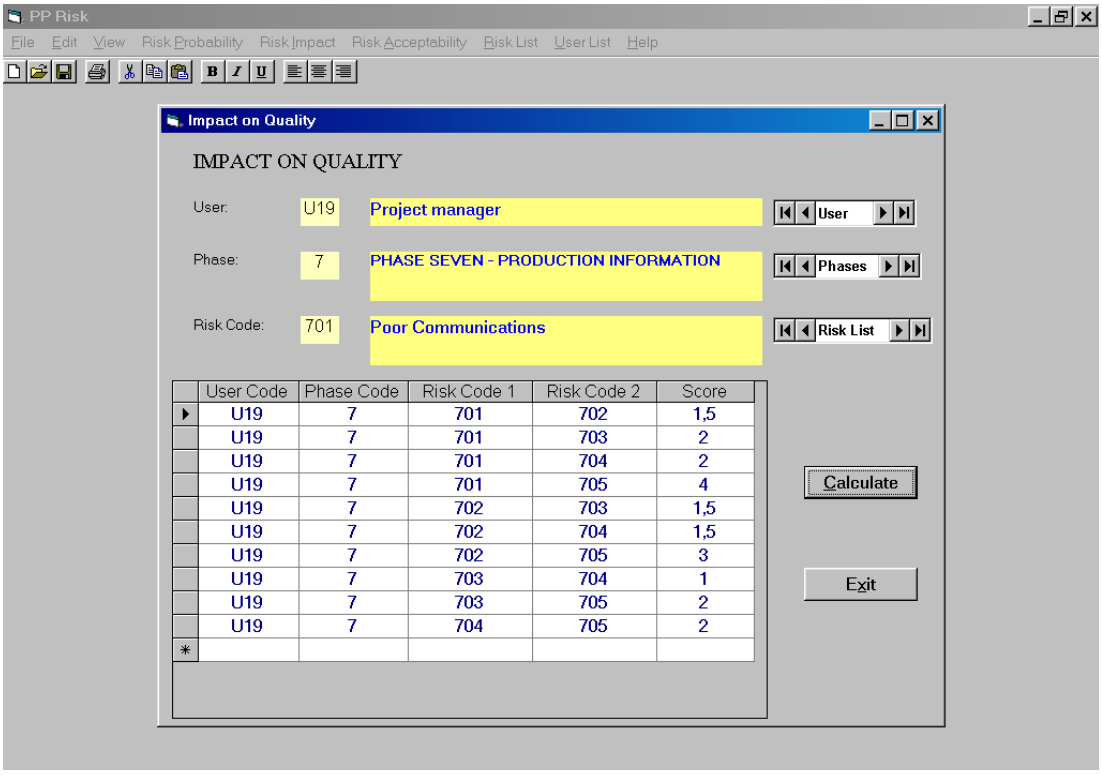
Phase 7: Criteria comparison - comparative matrix



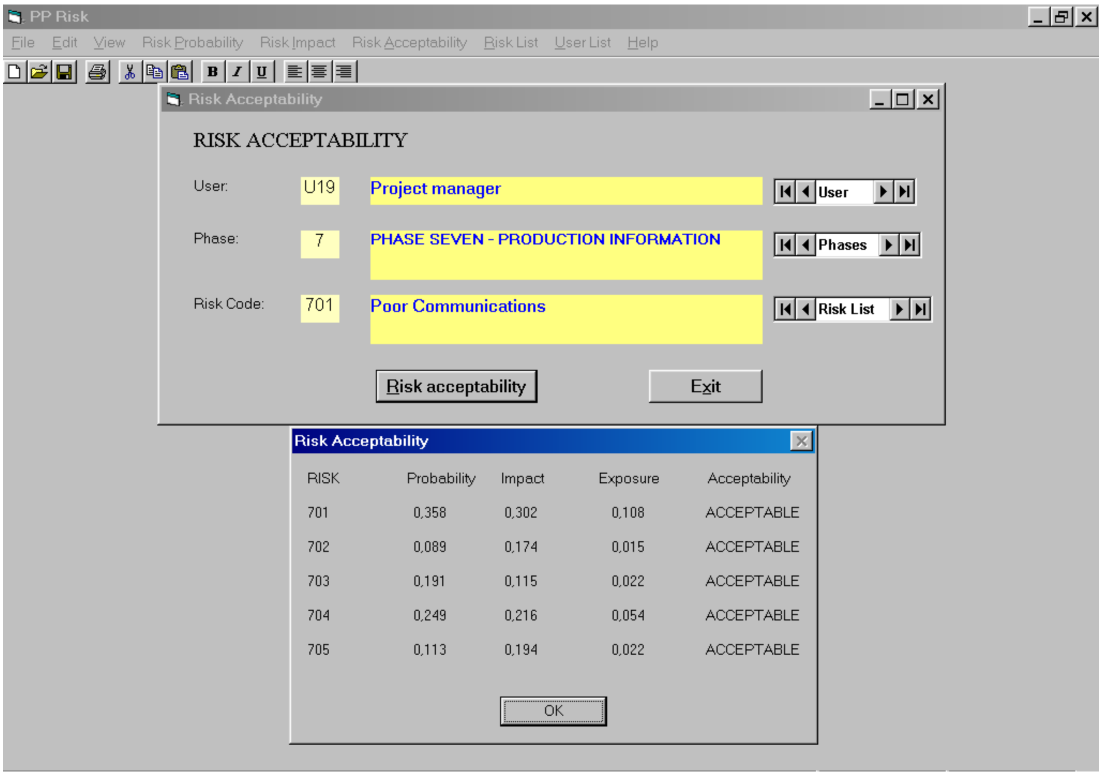
Phase 7: Impact on TIME - comparative matrix



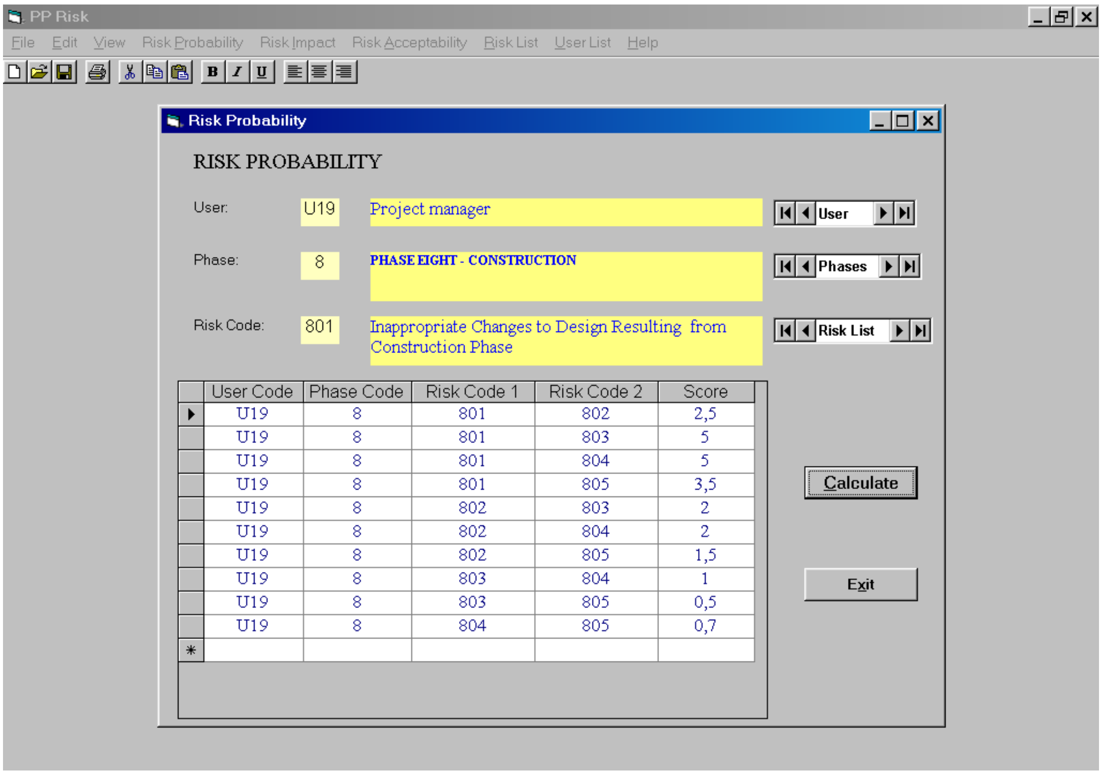
Phase 7: Impact on COST - comparative matrix



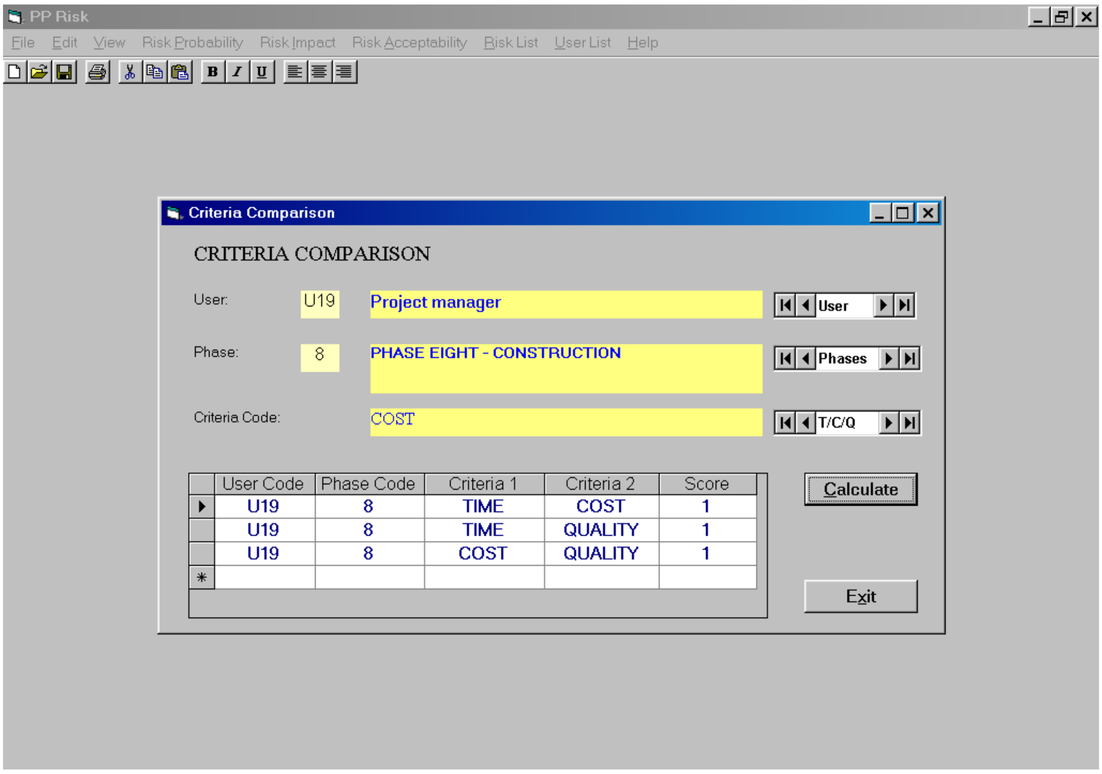
Phase 7: Impact on QUALITY - comparative matrix



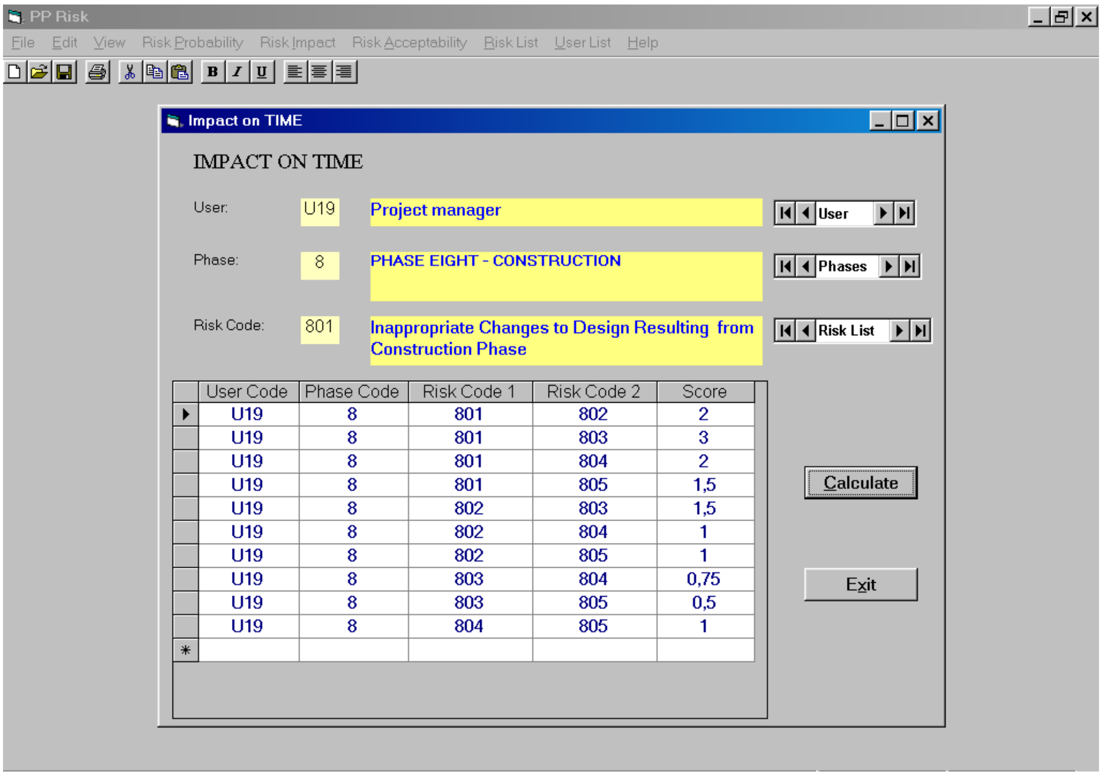
Phase 7: Risk exposure and risk acceptability obtained by PP-Risk



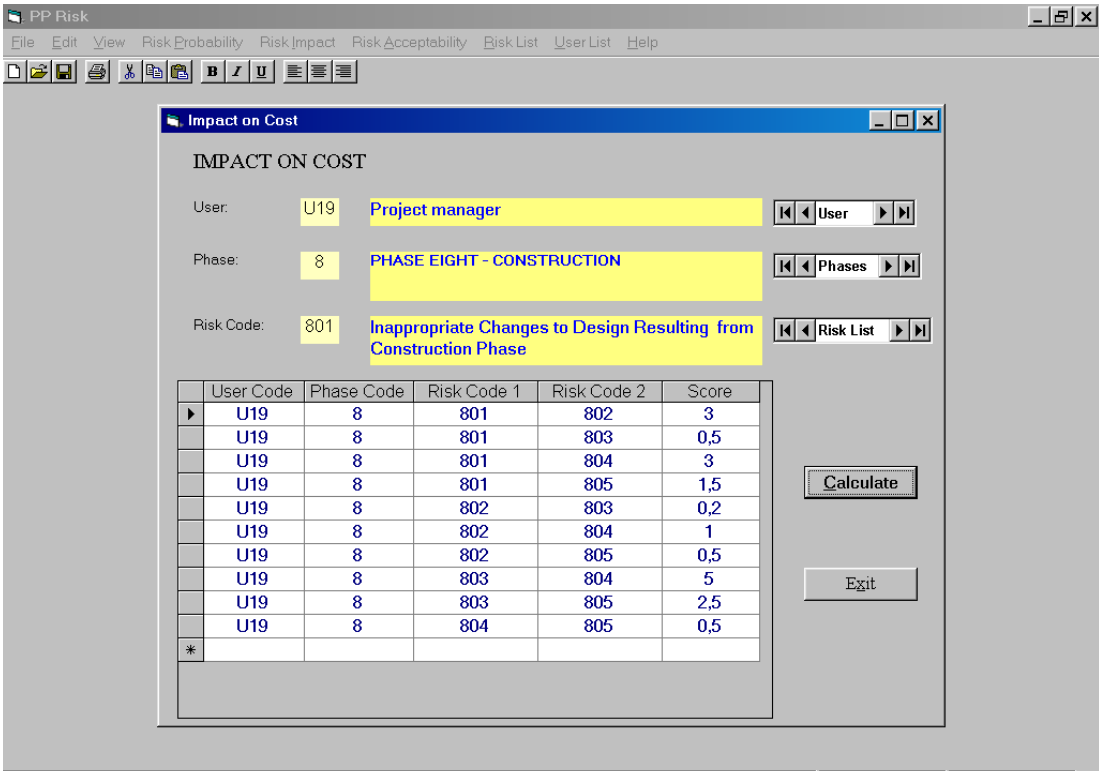
Phase 8: Risk probability - comparative matrix



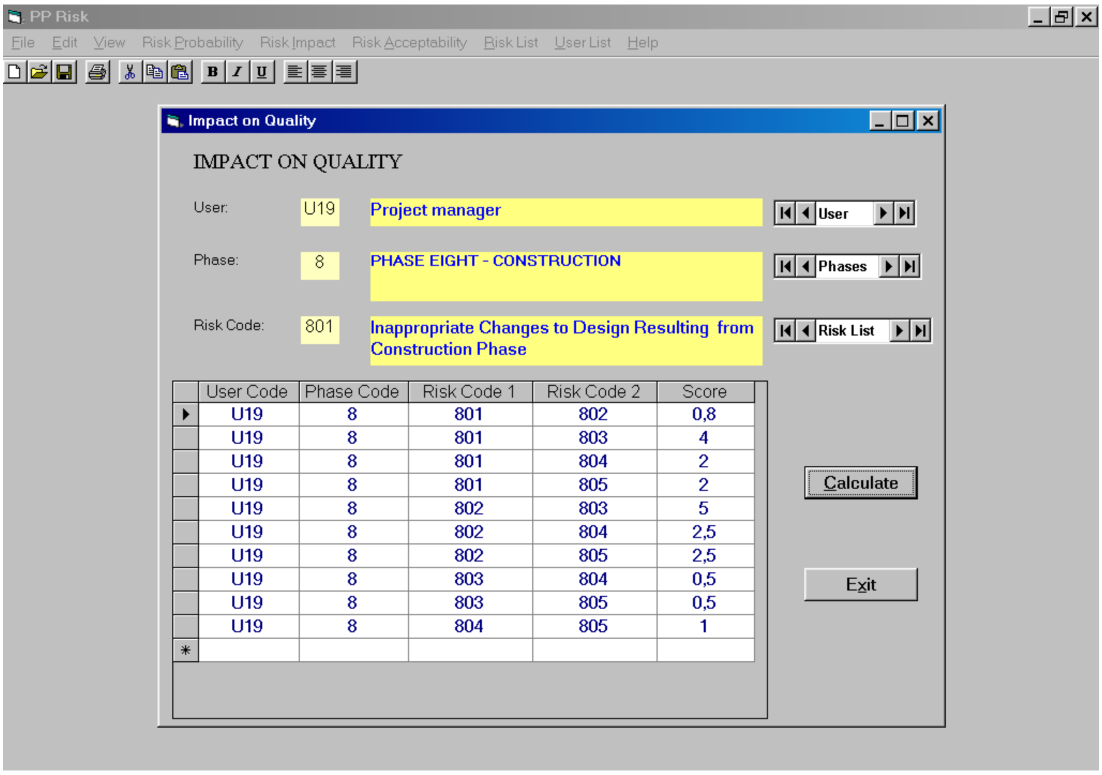
Phase 8: Criteria comparison - comparative matrix



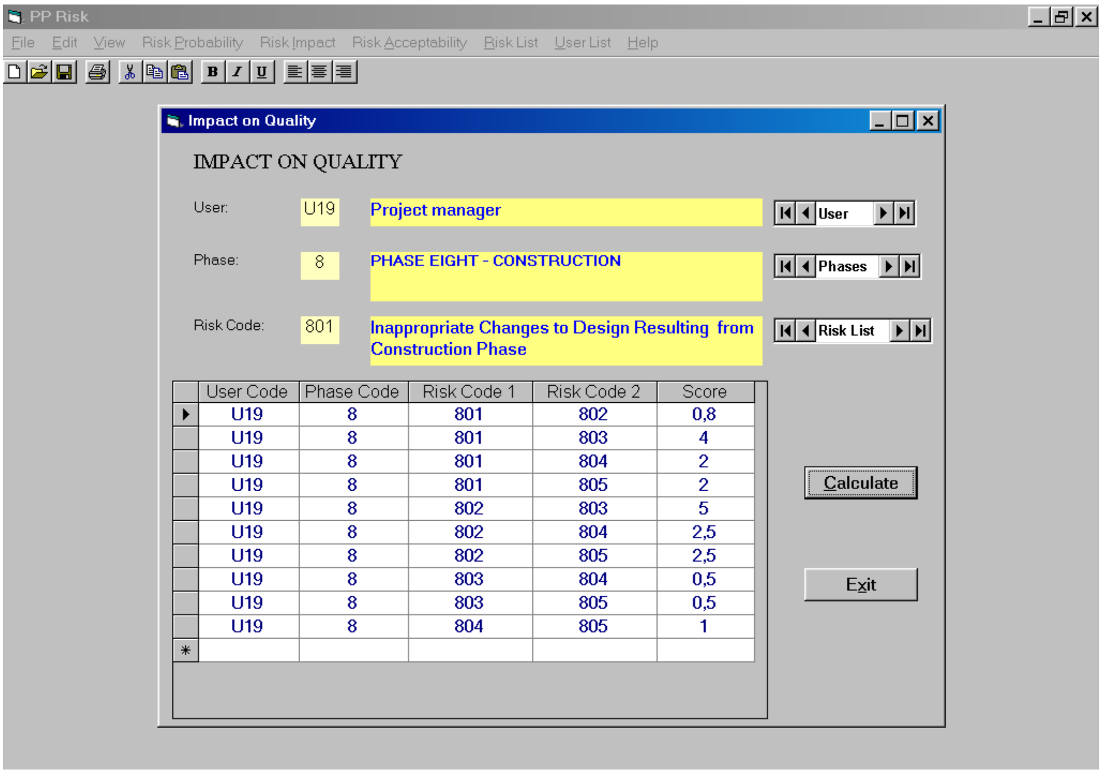
Phase 8: Impact on TIME - comparative matrix



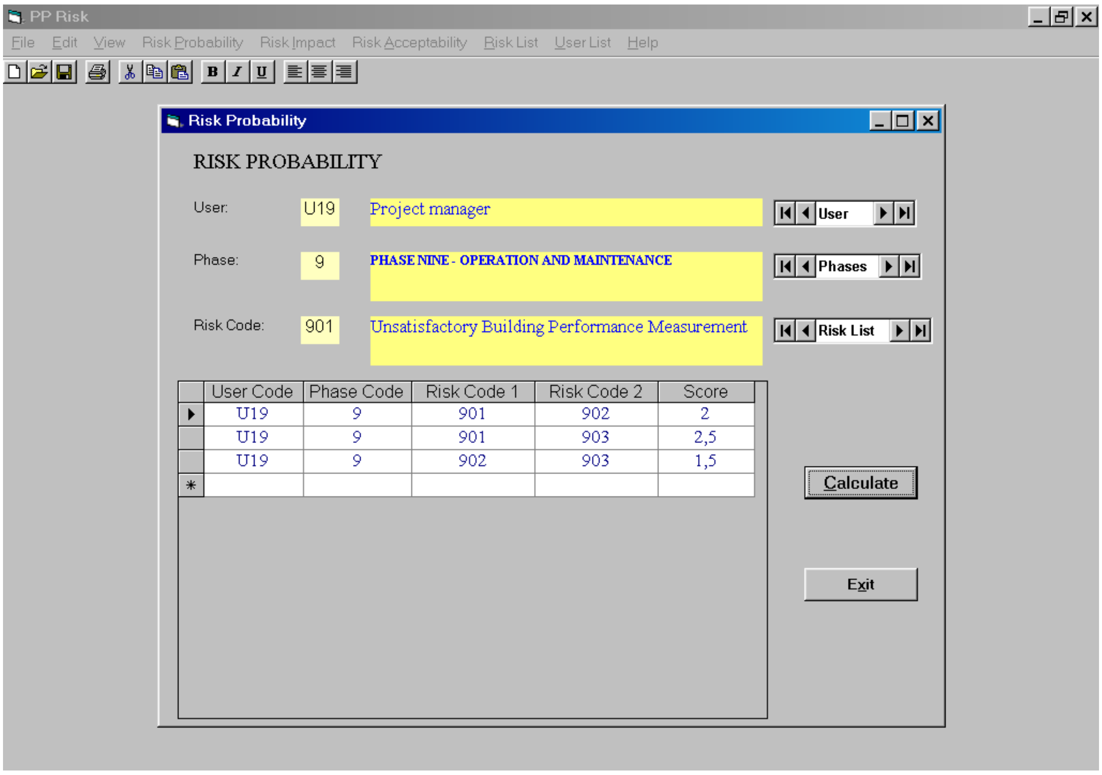
Phase 8: Impact on COST - comparative matrix



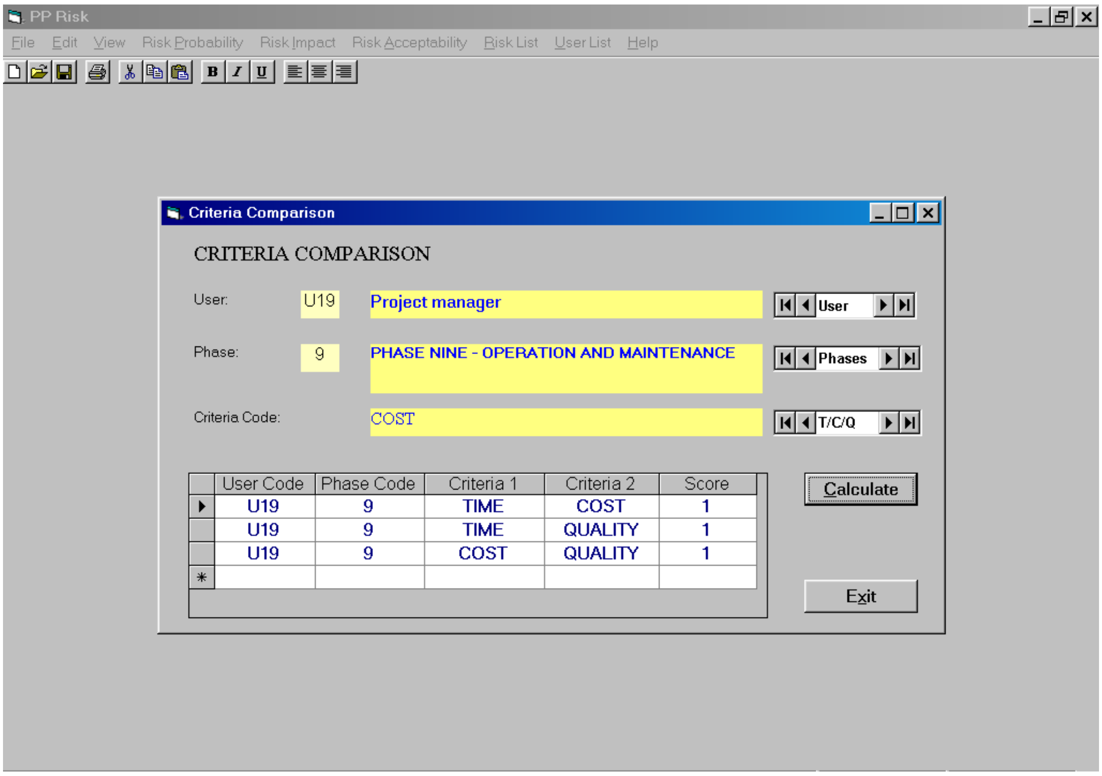
Phase 8: Impact on QUALITY - comparative matrix



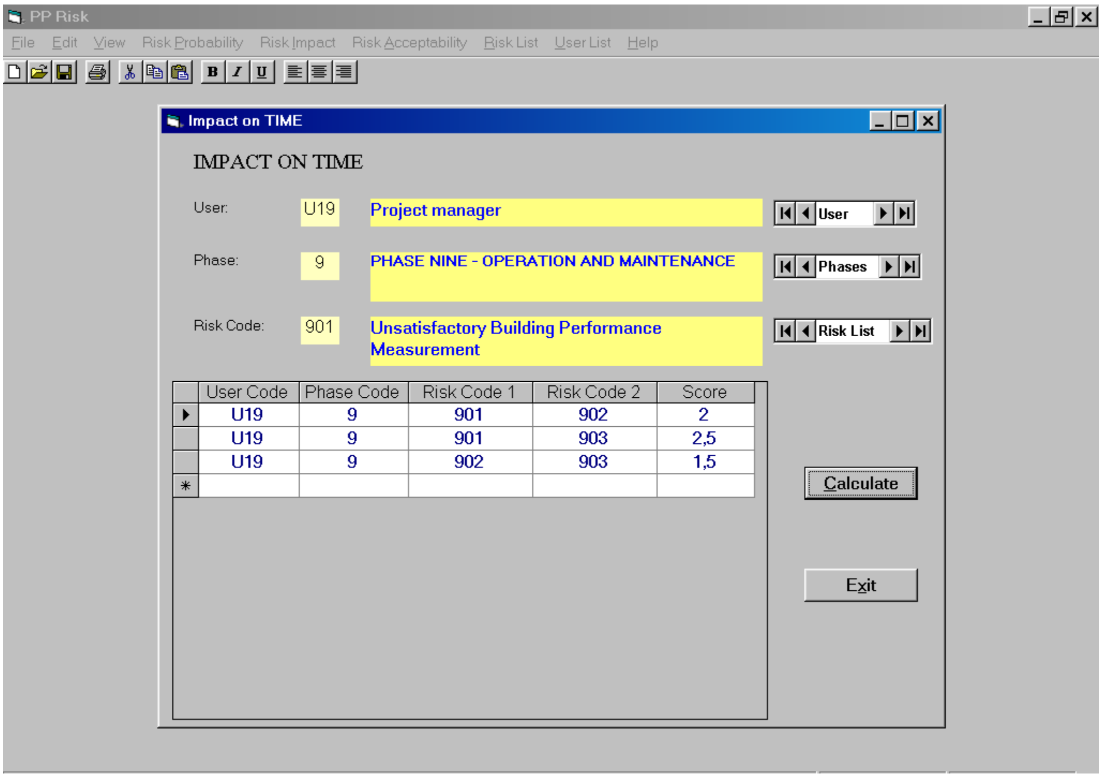
Phase 8: Risk exposure and risk acceptability obtained by PP-Risk



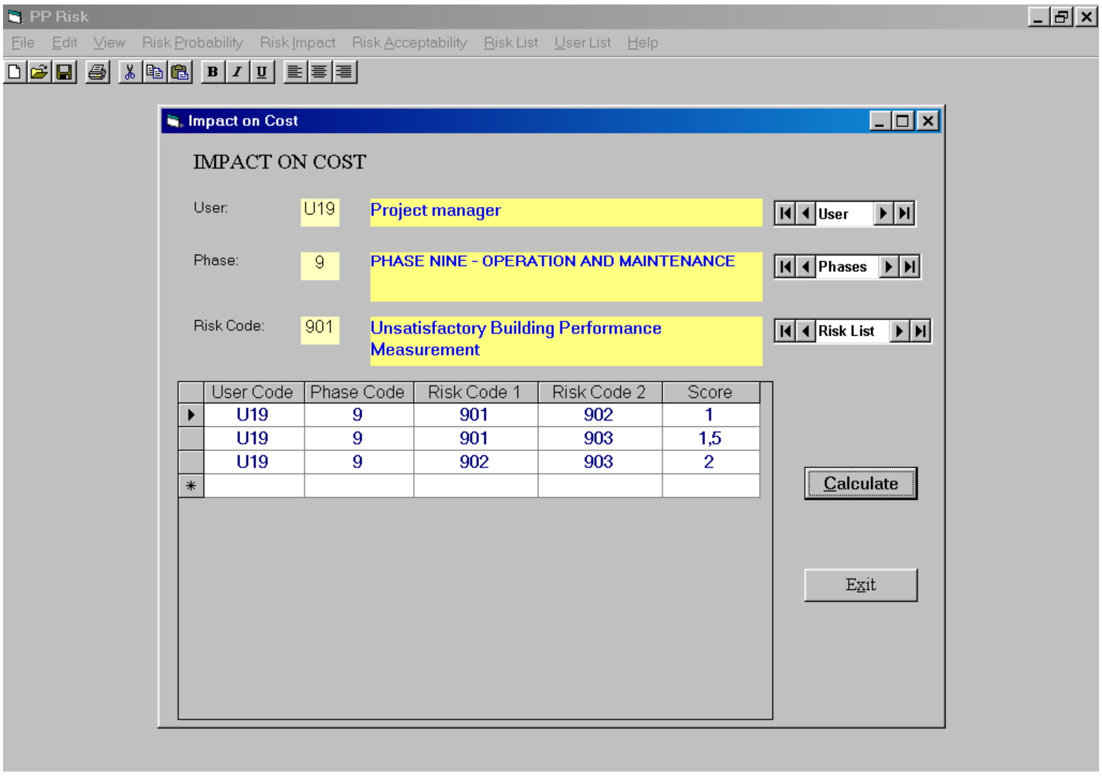
Phase 9: Risk probability - comparative matrix



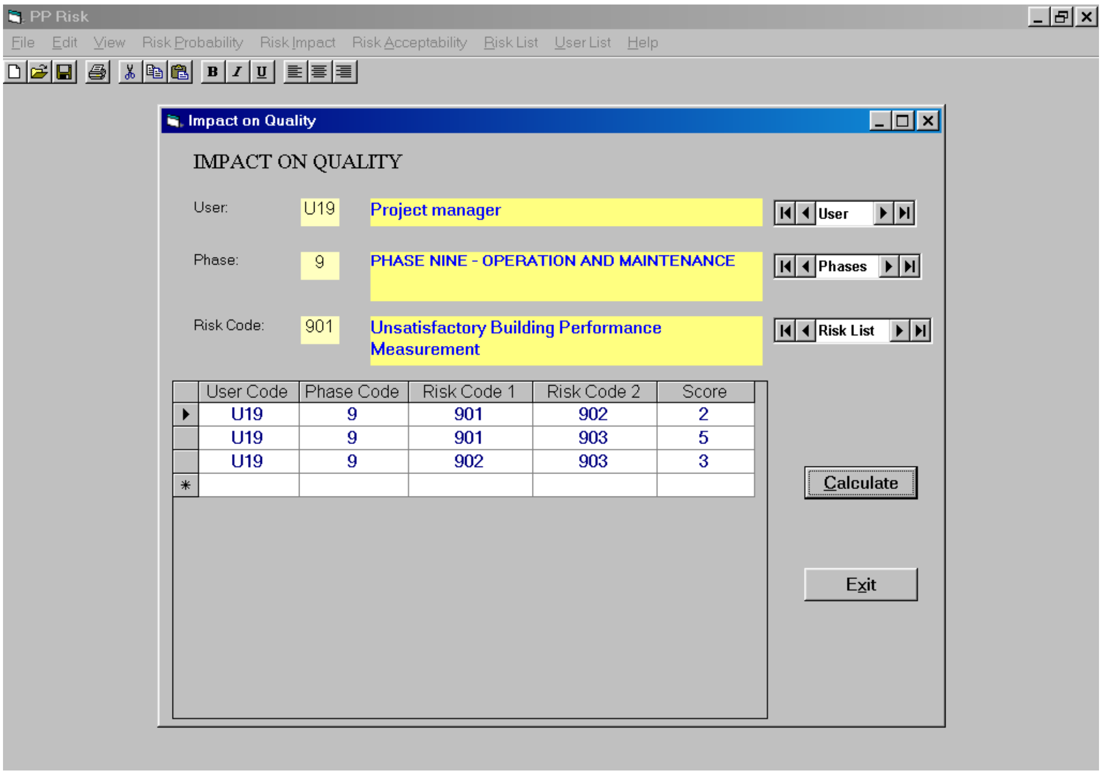
Phase 9: Criteria comparison - comparative matrix



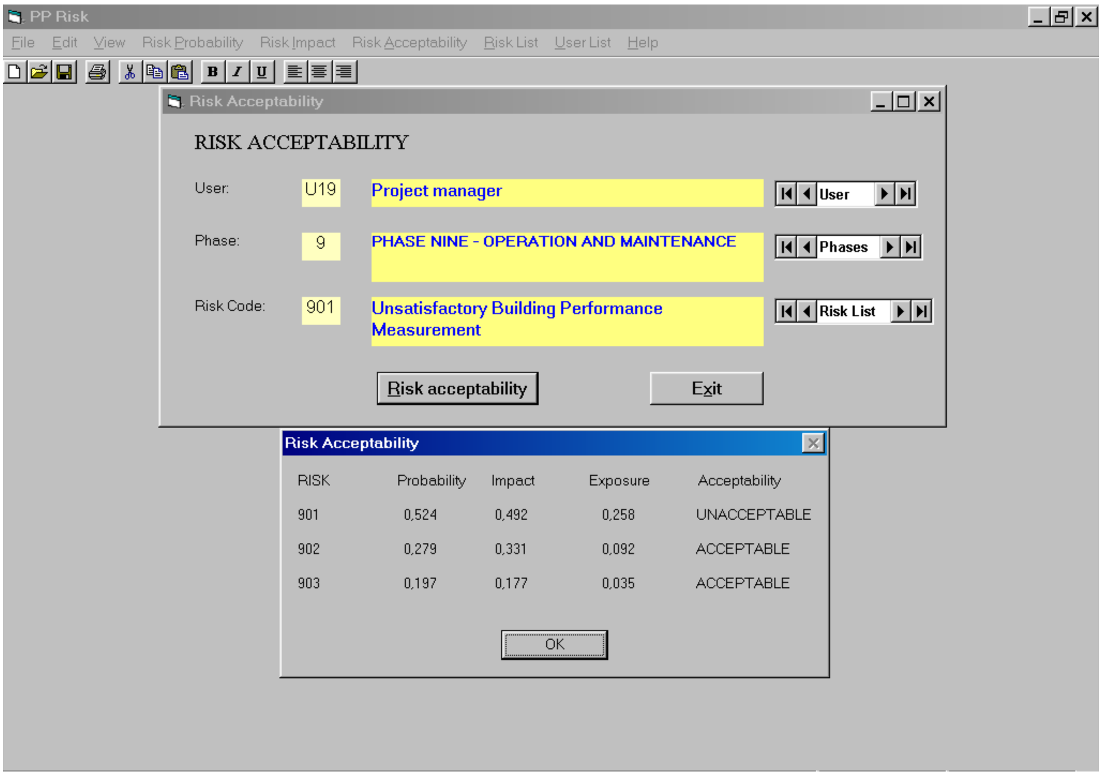
Phase 9: Impact on TIME - comparative matrix



Phase 9: Impact on COST - comparative matrix



Phase 9: Impact on QUALITY - comparative matrix



Phase 9: Risk exposure and risk acceptability obtained by PP-Risk

RISK RESPONSES

PHASE ZERO – DEMONSTRATING THE NEED

Risk 002: Ill-defined Initial Statement of Need. Risk is undesirable. Response methods: Risk sharing and reduction. Responsibility for a possible unfavourable outcome must be defined more precisely, that is, shared out between development, facilities and project managements, and measures taken for their additional training and including new people in management teams. Manage this risk using 51% of the total assets available in this phase, including continuous monitoring and re-examination of the current value of exposure during phase realisation.

Risk 005: Poor Communications. Risk is acceptable. Response method: Risk reduction. Engage additional resources to establish a complete and efficient communication strategy within the management team participating in this project phase. Use 24% of the total assets available in this phase for defining a communication strategy. Continuously monitor cost-effectiveness of investments in improving communications during the realisation of this phase.

Risk 001: Unsatisfactory Market Research. Risk is acceptable. Response method: Risk retention. As the government founded several firms for infrastructure construction, the management team should avail itself of the opportunity (the same owner) of exchanging experiences with other firms that have already constructed similar facilities. No additional funds need be invested for managing this risk and the 19% of the assets available should be used for further personnel training through seminars, study trips and other forms of further education.

Risk 004: No Historical Data Analysis. Risk is acceptable. Response methods: Risk retention. No systematised database about risk sources in earlier similar projects exists so it is impossible to do anything except continuous monitoring. Therefore this risk may be neglected. Still, the 6% assets available should be used for forming and continuously updating the database for this project.

Risk 003: Incomplete Stakeholder List. Risk is negligible. Response methods: No need. This result is expected because the government is the only stakeholder through the firms it founded.

PHASE ONE – CONCEPTION OF NEED

Risk 105: Incomplete Identification of Potential Solution to the Need. Risk is undesirable. Response methods: Risk reduction. Reduce risk by engaging consulting firms and/or independent consultants with the necessary experience in designing similar facilities. This will help design management to propose a sufficient number of potential solutions as the bases for a feasibility study. Manage this risk using 68% of the total assets available in this phase, including continuous monitoring and re-examination of the current value of exposure during phase realisation.

Risk 101: Ill-defined Final Statement of Need. Risk is acceptable. Response method: Risk retention. Form an expert group to review the Final Statement of Need and assess whether the Government's needs, goals and demands have been completely defined. Use 20% of the total assets available in this phase to manage this risk.

Risk 104: Poor Communications. Risk is acceptable. Response method: Risk retention. Include the design management team in the communication chain alongside all the project participants thus far. Continuously monitor and upgrade communications quality and level and communications infrastructure, using 12% of the total assets available in this phase.

Risk 102: Changes in Stakeholder List. Risk is negligible. Response methods: No need. The only stakeholder is the government, that is, the government-founded firm for managing infrastructure facilities. Thus this risk may be disregarded.

Risk 103: Poor Assessment of Stakeholder Impact. Risk is negligible. Response methods: No need. This risk may be disregarded for the same reason as Risk 102.

PHASE TWO – OUTLINE FEASIBILITY

Risk 202: Poor Consideration of Site Investigations. Risk is acceptable. Response methods: Risk reduction. Site investigations results determine excavation and supporting methods. Tunnels are longitudinal structures and it is practically impossible to predict the scope of investigations that will significantly reduce this risk. The risk can only be reduced by placing 42% of the assets available in the hands of geotechnical experts, who will foresee the optimal volume and type of investigations.

Risk 206: Inadequate Cost/Benefit Analysis for Each Option. Risk is acceptable. Response method: Risk reduction. Use 21% of the assets available in this phase on additional feasibility studies for particular methods and approaches to particular solutions, including a cost/benefit analysis for each option.

Risk 203: Poor Consideration of Environmental Impact. Risk is acceptable. Response method: Risk reduction. Reduce risk by additional analysis of measures necessary for quality environmental analysis. Use 9% of the total assets available in this phase to manage this risk.

Risk 201: Poor Communications. Risk is acceptable. Response methods: Risk retention. Continuously monitor and improve quality of communications and the communications infrastructure in accordance with the adopted communications strategy, using 10% of the assets available in this phase.

Risk 205: Unrealistic Completion Dates for Each Option. Risk is acceptable. Response methods: Risk retention. The risk does not have a large exposure and should only be continuously monitored during the realisation of this phase, using 8% of the assets available.

Risk 204: Ill-defined Structure of Funding and Financial Options. Risk is negligible. Response methods: No need. Major government-funded infrastructure projects have a clearly defined funding structure.

PHASE THREE – SUBSTANTIVE FEASIBILITY STUDY & OUTLINE FINANCIAL AUTHORITY

Risk 302: Unsatisfactory Site Investigations. Risk is undesirable. Response methods: Risk reduction. Unsatisfactory site investigations in tunnel construction may lead to an unrealistic assessment of the support system along the tunnel and fundamentally impact the results of feasibility studies. Reduce the risk by engaging a specialised site investigations institution with experience on similar facilities and additionally training geotechnicians in the design management team to supervise site investigations. Manage this risk using 59% of the total assets available in this phase.

Risk 303: Poor Assessment of Environmental Impact. Risk is acceptable. Response method: Risk reduction. Reduce risk by engaging an independent reviewer to assess the existing analysis and to act as consultant in making an appropriate impact analysis. Manage this risk using 22% of the total assets available in this phase.

Risk 301: Poor Communications. Risk is acceptable. Response method: Risk retention. Ensure quality information exchange between building site and research laboratories, and offices for assessing environmental impact and making substantive feasibility studies, with continuous monitoring and improving the adopted communications strategy and renewing the communications infrastructure. Use 13% of the assets available in this phase.

Risk 305: Inadequate Substantive Cost-Benefit Analysis. Risk is acceptable. Response methods: Risk retention. Considering that assets were set aside in the preceding phase to reduce the risk of inadequate cost/benefit analysis for each option, the risk exposure is small so the risk should only be monitored and its current exposure re-examined during the realisation of this phase. Use the 6% assets available to manage the other risks of this phase.

Risk 304: Ill-defined Structure of Funding and Financial Options. Risk is negligible. Response methods: No need. Major government-funded infrastructure projects have a completely defined funding structure for a substantive feasibility study.

PHASE FOUR – OUTLINE CONCEPTUAL DESIGN

Risk 404: Inadequate Evaluation of Outline Conceptual Design Alternatives. Risk is undesirable. Response methods: Risk reduction. Design alternatives in tunnel construction are proposed on the basis of prior investigations and on recommendations drawn from the experiences of tunnel builders under similar conditions. Use 60% of the assets on an independent analysis of the acceptability of the recommendations for each design alternative.

Risk 402: Lack of Site Investigations Update. Risk is acceptable. Response method: Risk retention. The relatively small exposure results from the fact that this tunnel is over 5 km long and that additional investigations cannot cover all the unknowns. Use the 17% assets available to monitor the risk and continuously re-examine its exposure during the realisation of this phase.

Risk 403: Lack of Environmental Impact Assessment Update. Risk is acceptable. Response method: Risk retention. The environmental impact assessment made in the substantive feasibility study is usually sufficient for tunnels so use the 8% assets available for monitoring during the realisation of this phase.

Risk 401: Poor Communications. Risk is acceptable. Response methods: Risk retention. Use the 8% assets and time available for risk monitoring and improving communications strategy and infrastructure.

Risk 405: Inaccurate Total Cost of Chosen Outline Conceptual Design Estimate. Risk is acceptable. Response methods: Risk retention. Due to the impossibility of investigating all the 5 km of the tunnel in detail, it is impossible to exactly anticipate the distribution of the support system and the excavation method so calculation of the total costs is only an outline, which fundamentally decreases its significance. The 6% assets available should be used to additionally train personnel for analysing the costs of this kind of facility.

PHASE FIVE – FULL CONCEPTUAL DESIGN

Risk 502: Poor Schematic Design for Elements of Chosen Solution. Risk is undesirable. Response methods: Risk reduction. This risk strongly dominates Phase 5. To reduce it, engage a specialist institution with significant experience in tunnel design to make the schematic design. Manage this risk using 69% of the total assets available in this phase, including continuous monitoring and re-examination of the current value of exposure during phase realisation.

Risk 505: Poor Communications. Risk is acceptable. Response method: Risk retention. Use the 10% assets and time available for risk monitoring and improving the communications strategy and infrastructure.

Risk 503: Inadequate Maintenance Plan. Risk is acceptable. Response method: Risk retention. The risk exposure is relatively small because maintenance strategy is relatively well defined for tunnels and has been tested on tunnels constructed earlier. This risk may be disregarded and the 7% assets available used for perfecting maintenance management.

Risk 504: Inadequate Health and Safety Plan. Risk is acceptable. Response methods: Risk retention. The risk exposure is relatively small because the health and safety plan used in tunnel construction is detailed and has been tested on tunnels constructed earlier. This risk may be disregarded and the 7% assets available invested in risk monitoring during the realisation of this phase.

Risk 505: Inaccurate Total Cost of Chosen Concept Design Solution Estimate. Risk is acceptable. Response methods: Risk retention. In this phase of tunnel construction the calculation of total costs is only an outline, which fundamentally decreases its significance. The 7% assets available should be used for the further training of staff to analyse the costs of facilities of this kind.

PHASE SIX – COORDINATED DESIGN, PROCUREMENT & FULL FINANCIAL AUTHORITY

Risk 604: Poor contractual strategy. Risk is undesirable. Response methods: Risk sharing and reduction. Use 50% of the assets available in this phase to find the best contracting strategy for all project participants. Pay special attention to choice of contract type and contractor selection method, and ensure that the contract covers risk sharing between investor and contractor, subcontractor, supplier and insurance company.

Risk 602: Poor Detailed Design for Elements of Chosen Solution. Risk is acceptable. Response method: Risk reduction. The risk can be reduced if the detailed design includes work technology and the human and material resources available during tunnel construction. Use 20% of the total assets available in this phase to manage this risk.

Risk 605: Unsatisfactory Potential Suppliers Skills and Inability to Fulfil Requirements. Risk is acceptable. Response method: Risk retention. This risk has relatively small exposure because of positive experiences on tunnels constructed earlier. Use the 13% assets available to continuously monitor and re-examine the current risk exposure during phase realisation.

Risk 601: Poor Communications. Risk is acceptable. Response methods: Risk retention. Include the potential material and equipment supplies and the contractor in the communications chain as effectively as possible, using 11% of the assets available.

Risk 603: Inaccurate Total Cost Based on Detailed Design Estimate. Risk is acceptable. Response methods: Risk retention. Many unknowns encumber the total costs calculation so this risk may be disregarded. Use the 5% assets available for additionally training personnel in costs analysis for facilities of this kind.

PHASE SEVEN – PRODUCTION INFORMATION

Risk 701: Poor Communications. Risk is undesirable. Response methods: Risk reduction. This phase directly precedes construction and all preparations should now be made. Considering that communications between designer, material and equipment supplied and contractor is very important in tunnel construction, invest 49% of the assets available in this phase in communications strategy with continuous monitoring and re-examining of the current value of exposure during phase realisation.

Risk 704: Unsatisfactory Procurement Plan. Risk is acceptable. Response method: Risk reduction. The risk can be reduced by breaking the construction process into work packages down to the smallest details and by additionally adapting the procurement plan to the contractor, his human and mechanical resources and to the possibilities of acquiring material. Manage this risk using 24% of the total assets available in this phase.

Risk 703 Unsatisfactory Maintenance Plan. Risk is acceptable. Response method: Risk retention. The maintenance strategy for tunnels built to date is considered satisfactory. The risk may be disregarded and the 10% assets available used for perfecting facility maintenance management.

Risk 705: Inability to Finalise Total Cost Based on Production Information. Risk is acceptable. Response methods: Risk retention. Any calculation of the cost of tunnel construction before work has begun is imprecise so this risk may be disregarded. Use the 10% assets and time available to additionally train personnel to analyse the costs of facilities of this kind.

Risk 702: Unsatisfactory Health and Safety Plan. Risk is acceptable. Response methods: Risk retention. The Health and Safety Plan for tunnels remains practically the same as in Phase 5. The risk may be disregarded and the 7% assets available invested in monitoring the realisation of this project phase.

PHASE EIGHT – CONSTRUCTION

Risk 801: Inappropriate Changes to Design Resulting from Construction Phase. Risk is undesirable. Response methods: Risk reduction. Because of the differences in predictions and the actual engineering-geological profile of the soil, or because project criteria have not been satisfied, the design management team introduces many changes in the tunnel support system and the excavation methods during work. Reduce the risk of inappropriate changes by engaging consultants to help the design management decide. Manage this risk using 59% of the total assets available in this phase, including continuous monitoring and re-examination of the current value of exposure during phase realisation.

Risk 802: Unsatisfactory Monitoring of Quality of Construction Work. Risk is acceptable. Response method: Risk reduction. Due to incomplete standards and work complexity this risk may be reduced by engaging quality-control experts in tunnel construction who will anticipate all the necessary measures for unquestionable construction quality control and control of realising project requirements. Use 17% of the assets available in this phase to supplement the monitoring programme.

Risk 805: Lack of On-Site Resources And Labour Management. Risk is acceptable. Response method: Risk retention. Prior experience in government-funded tunnel construction has shown that this risk may be disregarded and the 10% assets available used for enhancing project management.

Risk 803: Unsatisfactory Monitoring of Cost of Construction Work. Risk is acceptable. Response methods: Risk retention. Firms that manage infrastructure construction in the name of the government have a well designed system of monitoring costs of construction work. Use the 8% assets available on the further training of monitors.

Risk 804: Unsatisfactory Monitoring of Progress of Construction. Risk is acceptable. Response methods: Risk retention. Firms that manage infrastructure construction in the name of the government have a well designed system of monitoring construction progress. Use the 6% assets available on the further training of monitors.

PHASE NINE – OPERATION & MAINTENANCE

Risk 901: Unsatisfactory Building Performance Measurement. Risk is unacceptable. Risk Response: Risk transfer. Eliminate the risk by contractually transferring it to an institution that will continually measure building performance during the exploitation of the facility. Manage this risk using 67% of the total assets available in this phase.

Risk 902: Lack of Maintenance Strategies Update. Risk is acceptable. Response method: Risk reduction. Reduce the risk by improving maintenance management in the government institution that manages infrastructure facilites. Maintenance strategies should be continuously monitored and improved during the realisation of this phase, for which use 24% of the total assets available.

Risk 903: Lack of Lifecycle Budgetary Requirements Update. Risk is acceptable. Response method: Risk retention. Since tunnels are infrastructure facilities of national interest the lack of lifecycle budgetary requirements update may be disregarded. Use the 9% assets available to respond to the other risks in this phase.

APPENDIX 5: The Questionnaire form used for verification of the framework

1. What do you think about the proposed breakdown of the construction project in 10 phases within 4 stages?
   - Very appropriate
   - Appropriate
   - Generally appropriate
   - Less appropriate
   - Not appropriate

2. How generally satisfied are you with the proposed approach whereby risk management becomes part of the construction process?
   - Very satisfied
   - Satisfied
   - Reasonably satisfied
   - Dissatisfied
   - Very dissatisfied

3. Do you find the proposed framework useful for risk management in construction projects?
   - Very useful
   - Useful
   - Somewhat useful
   - Neutral
   - Not useful

4. What do you think of the proposed key risks in the construction process regardless of the project's type and size?
   - Very acceptable
   - Acceptable
   - Reasonably acceptable
   - Unacceptable

- Very Unacceptable

5. To what extent does using the proposed framework improve your understanding of process in construction?
   - Very much
   - Much
   - Not much
   - Some
   - Not at all

6. Is the proposed framework appropriate for a risk assessment in the stage in which you managed risks?
   - Very appropriate
   - Appropriate
   - Generally appropriate
   - Less appropriate
   - Not appropriate

7. What do you think about the acceptability of AHP for qualitative risk analysis in the decision making process?
   - Very acceptable
   - Acceptable
   - Reasonably acceptable
   - Unacceptable
   - Very Unacceptable

8. How suited is PP-Risk as a Decision Support System for the proposed framework?
   - Very suitable
   - Suitable
   - Somewhat suitable

- Neutral
- Not suitable

9. How satisfied are you with the PP-Risk user interface?
   - Very satisfied
   - Satisfied
   - Reasonably satisfied
   - Dissatisfied
   - Very dissatisfied

10. Assess the benefits of using the proposed framework supported by PP-Risk for process-driven risk management, from the aspect of time, cost and quality management?
    - Significant
    - Major
    - Medium
    - Some
    - Trivial

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