SIMULATING THE IMPLEMENTATION OF TECHNOLOGICAL INNOVATIONS IN CONSTRUCTION

By

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THESIS CONTENTS

ABSTRACT

Introducing new technologies or innovative processes can enhance construction efficiency and enable organisations to achieve objectives of lowering costs, continuous improvement and competitive advantage. New ideas have to show significant benefits before they are accepted. Despite of the differences between the construction and manufacturing industries, opportunities are still available to learn from manufacturing approaches to innovation.

A fundamental challenge facing construction innovation is the way that construction organisations plan and control the implementation of innovation where many projects do not fulfil their time and cost objectives. Management should not only improve techniques for planning and scheduling but also allow managers to assess and simulate the anticipated performance resulting from innovation. According to this assessment, managers would be more able and perhaps more ready to accept new processes/products or iterate the implementation process until a satisfactory level of performance has been achieved. Intangible benefits offered by advanced construction technologies are hard to quantify using traditional economic analysis techniques. This could result in the rejection of a potentially profitable idea. Benefits to be gained from improvements in operational efficiency are measured by cost and time-savings and increasing productivity. These benefits, in addition to intangible benefits, need to be measured and quantified.

Simulating the implementation process of innovation has not been addressed, although many models have been developed to describe the innovation process in construction which considered implementation as a sequential process incorporating iterations. Existing models attempt to describe the content of each innovation implementation stage, but do not specify the outcomes of the activities within each stage or how managers could simulate these activities. On the other hand, several models have been developed to help managers assess the value of new technologies. These models have not considered innovation as a dynamic process and have not dealt with the implementation phase from a planning perspective.

The characteristics of construction innovations emphasise that traditional planning techniques need to be developed to more effectively support the implementation process of innovative projects. The literature review undertaken as part of this research highlighted the limitations of traditional planning tools when used on innovative projects. The proposed tool should simulate the nature of experimentation, iteration and refinement activities considering the 'influence information' affecting these projects and the 'performance indicators' to assess the implementation process of innovation. This technique deals with the various uncertain outcomes inherent in innovative projects, define all situations of a particular innovation, plan the implementation activities and improve the ability to manipulate uncertain events.

This research aims to simulate the implementation of innovation. The developed simulation tool can fill the gap of fostering innovation in construction where the most important characteristics of construction innovation, high level of uncertainty and iterative nature of its activities, can be simulated and monitored effectively.

The objectives of the research are to: study the innovation process in construction and identify its planning and monitoring stages; examine the existing decision support systems used to assess innovations; and simulate the implementation stage of innovation considering the influence information and the methods of assessment.

To achieve these objectives the following steps are offered:

- propose a systematic approach for the innovation implementation phase;
- develop a technique for simulating the influence information of this phase;
- develop a technique to simulate the implementation assessment;
- develop a technique to identify loops of iterative tasks of innovation;
- integrate the above techniques in a user-friendly computer package for planning purposes; and
- validate the proposed techniques and package.

After establishing the research aim and objectives, semi-structured interviews were held with industry professionals involved in innovative construction projects. Data required for the simulation tool were collected from two projects and a third project was used for the purpose of validation. The interview structure was developed to identify: the main information that influence the implementation of innovation; the implementation stages; performance indicators used to assess implementation; and the planning tools used to control the process.

This research introduces an IT simulation tool (Implementing inNOVations In Construction Engineering Technologies - INOVICET) that simulates the implementation of innovation in construction. The tool describes the information affecting innovative projects. The tool takes into account the results of the implementation phase of innovation and uses measurement techniques suitable for dealing with uncertain environments.

The proposed simulation tool comprises four techniques: Monte Carlo technique to simulate the influence information on the innovation implementation phase; a planning tool to simulate the implementation phase of innovation; a Fuzzy Logic approach to simulate the innovation performance; and the Dependency Structure Matrix (DSM) to simulate the iteration inherent in the implementation phase. Decision-maker preferences are used to run and analyse the output of the simulation tool.

The programme produced by the simulation tool provides a systematic methodology for implementing an innovative project. This was endorsed by the case study's project team. The application highlighted that INOVICET represented the innovative project activities clearly and could be used as a checklist for the project phases to monitor the planned activities. The main conclusion of the study was that INOVICET may be applied to any project with minor adjustments to fit the specific nature of each project.

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CHAPTER 1

INTRODUCTION

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INTRODUCTION

1.1 Background to the research

Innovation is a key factor for any industry wishing to develop new markets or introduce new ideas to improve productivity. The organisational objectives of lowering costs, achieving continuous improvement and gaining competitive advantage can be achieved by introducing new technologies that enhance the quality of the product and increase construction efficiency. "The ability of firms to be competitive is heavily dependent on the development and effective utilisation of technological innovations" (Yates 1994). Innovative approaches may help many existing construction problems, such as poor productivity, difficulties with international competition and poor business performance. There are also many opportunities to innovate even if there are no apparent problems facing organisations' technological or business processes. However, the process of innovation can involve risks which need to be assessed and managed to capitalise on innovative products and processes, and it is critical that the whole process of innovation is effectively managed.

The Technology Foresight Panel on Construction (1995) reported that the UK's construction industry had fallen behind many other developed nations and the industry needed action to be more competitive and to strengthen it. The British Property Federation's (1997) survey of major UK clients revealed that more than a third of major clients are dissatisfied with consultants' performance in design and innovation. Egan (1998) also highlighted that the construction industry needs to be more innovative, integrate project processes and continuously innovate and learn from previous experience. Product development requires detailed knowledge of clients' aspirations and effective processes for innovating and learning through objective measurement of completed projects (Egan 1998).

Hinks et al (1997) investigated the maturation of organisational capability in construction and emphasised that continuous process improvement is achieved by using quantitative feedback from the process and piloting innovative ideas and technologies.

New ideas have to show significant benefits before they are generally accepted. Construction innovation may be the: development of new construction methods or design; application or extension of methods or techniques originally developed to meet other requirements; development and application of new equipment or tools; or scaled-up or refined existing methods. Through Total Quality Management, the most recent improvements have been incremental, involving small refinements over a period. However, the need to achieve significant step changes, that are often achieved as the result of innovation, has been addressed (Lansley, 1996).

Technological innovation often results from integrated efforts that consider the whole process such as producing materials, design, manufacturing and marketing. This integration is essential for large-scale Research and Development (R&D) efforts. Technological innovation is not necessarily based on scientific or structured R&D but often on cumulative and routine improvements which are crucial to technological advancement. Organisations require 'specific mechanisms' to transfer any successful results of an innovation to other projects. In construction, these mechanisms do not generally exist.

Noori (1990) reported that there is general agreement among researchers and developers that:

- technology advancement is inevitable;
- the innovation process is necessary for any industry's survival;
- implementation of any new technology carries considerable risks which are not easy to quantify;
- the advent of new technology will create a greater need for co-operation among business, government and labour; and
- the costs, benefits and values of technology will have to be continually re-examined by firms in particular and by society in general.

Managing technological change and the resulting challenges to strategic, economic, financial, material and human resources can be considered as management objectives. New technology can be used to link engineering, science and management disciplines to address planning, development and implementation of technological capabilities to shape and accomplish the strategic and operational objectives of an organisation.

The process of innovation in developing countries faces more problems than those stated earlier. Ofori (1994) emphasised that the technological lag, shortage of resources and inadequate R&D make the change more difficult for these countries. There are also many cultural barriers to innovation and lack of training within the workforce.

The innovation process in manufacturing has been analysed at many different organisational levels. Due to the significant differences between the construction and manufacturing industries in terms of the characteristics of constructed products, the inherent technological constraints and the nature of the supply chain, it is often very difficult and perhaps inappropriate to adopt manufacturing approaches to innovations without considering these differences in detail.

Tatum (1989) stated that the construction industry is responsive to demand, strongly externally influenced, highly fragmented, project-based, geographically focused, served by many suppliers and highly competitive. Construction operations are dependent on unique designs, scattered on remote sites, constantly reconfigured and performed under highly variable environmental conditions. The large scale (in terms of both physical size and expense) is related to the long-term nature of the construction product which adds to the conservatism found in construction practices. The lower level of continuous education for construction workforce, when compared to other industries, also slows down the spread of new practices (Schumacher et al 1998).

The number of decisions per US $ of work in construction is high compared with manufacturing, as outlined by Betts and Ofori (1994). This situation is often influenced by the unique features of construction projects, complex communication systems for projects, and continuous reassessment of risks.

Many characteristics have been identified to differentiate between constructed products and manufactured products. These are considered to some extent as barriers to implementing innovations in many construction fields, for example those detailed below and recorded by Nam and Tatum (1988), Betts and Ofori (1992) and Schumacher et al (1998).

1) Immobility.

Construction products are immobile structures and facilities. Although ships are heavy, durable, complex and costly products, shipbuilding is not classified as construction since ships are movable, (the US Department of Commerce Bureau of the Census 1984). For the same reason, data regarding mobile homes and travel-trailers are included in the manufacturing rather than in construction. This places limitations on mass production (the most effective manufacturing characteristic) but encourages standardisation to increase productivity and product quality. Each product has to be designed and produced to meet the requirements of a particular site and owners' need. Although there are some successful trails in the field of modularization and automation in limited areas of construction, the use of mass production systems in construction will not be realised in the near future. Heavy lifting equipment and high transportation costs also compound the problem.

2) Complexity.

The degree of complexity relates to site conditions, structure composition, individual tastes of owners and designers and diverse types of materials, equipment and their combinations, often requires a high degree of specialisation to handle these various aspects.

3) Durability.

Constructed products must resist the forces of nature over an extended period of time. As a consequence, construction materials and products are often bulky and heavy which can restrict the development of construction technology for many important applications.

4) High cost.

The high costs of constructed products can cause technological conservatism within designers and builders. Even a reasonably testable model of a constructed product is very costly. It can also lead to high risks associated with any construction innovation that is implemented without the full test of product.

5) High degree of social responsibility.

Concern for public safety and health, and the growing awareness of environmental issues can also result in more conservatism in design and specification.

6) Regional variation

Most construction companies compete in regional markets and special capabilities are required to shift into another region. This regionalism may drive companies to foster innovations to gain competitive advantage within their region, but it may also limit investment in other regions which is considered a factor towards innovating.

Innovation and diffusion are both kinds of change to the status quo, however, construction resists most attempts to change, as stated below.

> *"A major assumption of the diffusion theories is that a potential adopter is an individual or a group that lines up to make an S-shaped diffusion curve. However, if the adopter is not an individual or a group, but rather a system in which every actor acknowledges that others have heterogeneous goals, this system may regard an innovation as a force that upsets the equilibrium state. Changes in this system through the rapid diffusion of innovations are difficult" (Nam and Tatum 1988).*

Therefore, the status quo of construction is described by the term 'locked system'. The concept of a locked system explains why construction innovation that is technologically superior does not often follow diffusion theories as anticipated by economists or engineers. The system participants include various owners, craft unions, local governments that enforce obsolete building codes, and many interest groups and coalitions that have stakes in construction technology development. The dynamics and friction among the participants slow the rate of innovation and are too complex to be realistically measured in quantitative terms.

Despite the above mentioned differences, a number of lessons can be learnt from the manufacturing sector with regards to the implementation and practical use of a 'process view' within the construction industry (Cooper et al 1998). The manufacturing area of New Product Development (NPD) relates closely to construction. NPD concentrates on the development of an idea, need or client requirement. Cooper et al (1998) listed the similarities found between the two industries for NPD which include:

- a project can be initiated internally or by direct and/or indirect contact with the customers;
- product development requires different specialists' and functions' participation;
- the successful building or product can only be achieved if all external and internal resources are utilised and co-ordinated effectively; and
- the building or product is handed over to the customer/client and provisions are made for future support.

These similarities do not overcome the barrier that the NPD activities in manufacturing are co-ordinated, managed and controlled using the framework of NPD process while ad hoc methods are still governing the construction achievement in this area.

Barriers to innovation, in addition to the inherent risk of applying an innovation, slow the process of introducing new technologies in construction. Many construction decisions, for example risk management and innovation decisions, are qualitative and subjective in nature and thus need heuristic approaches to be analysed and simulated. Risk, competitiveness and intangible benefits that have strategic significance for a given organisation require more appropriate methods of analysis that can not be provided by traditional approaches.

Several attempts have been made to model the innovation process. However, none of these address and simulate the special characteristics of the implementation phase. A fundamental challenge facing construction innovation is the way that construction organisations plan and control the implementation of innovation in an industry where most projects do not fulfil their time and cost objectives. Management should not only include improved techniques for planning and scheduling but also allow innovation managers to assess and simulate the anticipated performance. According to this assessment, managers would be more able and perhaps more ready to accept the new process/product or iterate the implementation process for satisfactory performance.

The hypothesis that drove this study was that "Are simulation tools suitable for planning the implementation of innovations in construction?"

1.2 Problem definition and justification

On projects, which have a clearly defined end-objective, all the planning and control activities in the project can be accurately directed to achieve that goal. However, on innovative projects, there is rarely complete knowledge of what the future may bring and there is a very high level of uncertainty. As shown in Figure 1.1, a project may have one start event but may often have several targets or combination of final targets (A or B or AB) which have great uncertainty in their features. Also, there are several alternative scenarios to achieve these targets which include many decision nodes to define the various scenarios and variables that affect the project progress.

A plan only details what should happen, not necessarily what will happen. Budgets only say what costs are expected, not necessarily what it will be. One thing is certain, changes and deviations will arise. Methods have to be implemented to allow changes to take place in a controlled manner and to evaluate the decision nodes that improve the processes of implementation and monitoring. Projects should have a well-defined objective against which progress can be measured and changes assessed. Evaluating the innovation process, especially the implementation stage which includes the changing of innovation into reality, has to date only been partially studied. The implementation stage often includes new types of construction activity characteristics (i.e. experimentation, iteration, and refinement) resulting from any unaccepted performance of some implementation trials or any problems or changes during the implementation.

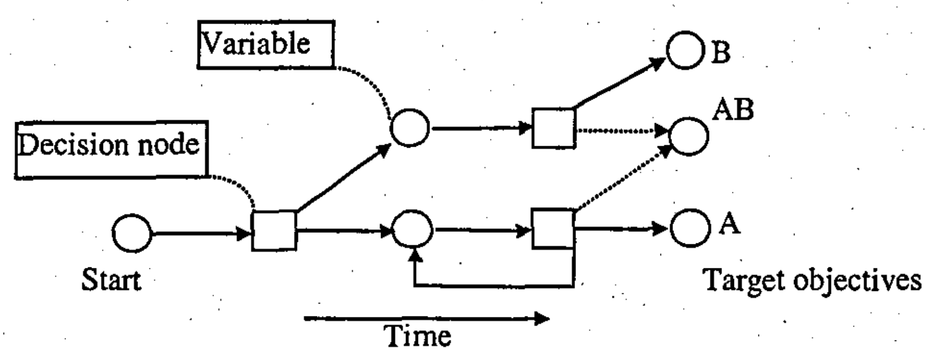

Figure 1.1: The implementation plan of an innovative project

1.3 Aim and Objectives of this research

The aim of this research is to develop a simulation tool that helps construction companies to plan and improve the implementation of innovation. This aim should satisfy the need to investigate a systematic approach which can capture and utilise the expertise of construction planners for estimating project objectives. The research should enhance the accuracy of the implementation plan. Whilst absolute accuracy is impossible to achieve, the opportunity exists to enhance current approaches to determine project goals.

The objectives of the research are to:

- study the innovation process in construction and identify its planning and monitoring stages;

- examine the existing decision support systems used to assess innovations; and
- simulate the implementation stage of innovation considering the influence information and the methods of assessment.

To achieve these objectives the following steps were performed:

1. propose a systematic approach for the innovation implementation phase;
2. develop a technique for simulating the influence information of this phase;
3. develop a technique to simulate the implementation assessment;
4. develop a technique to identify loops of iterative tasks of innovation;
5. integrate the above techniques in a user-friendly computer package for the planning purposes; and
6. validate the targeted techniques and package.

1.4 Research methodology

The methodology pursued during the course of the research programme is outlined in Figure 1.2.

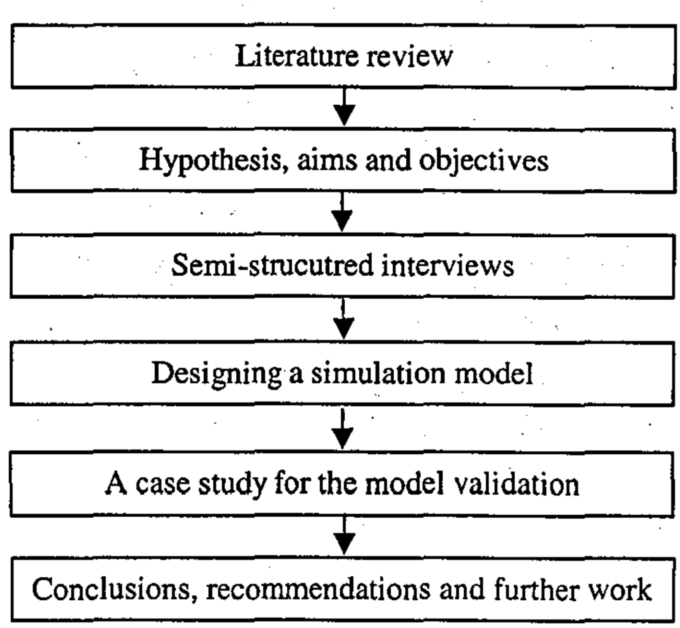

Figure 1.2: The research methodology diagram

The research methodology comprised mainly of the following tasks.

1. A literature review of the related disciplines required for the innovation concept, which included: the nature of innovation; innovation processes; decision-making to innovation adoption; risk and uncertainty assessment; and planning techniques and performance evaluation. This literature resulted in hypothesis, aim and objectives definition.
2. From the defined aim and objectives, a survey of innovative construction projects was undertaken to provide industrial cases supporting the literature review. This survey included 59 construction companies that were ranked by the New Civil Engineer magazine 1998 (Civil Engineering contractors file). Semi-structured interviews were held with construction industry professionals to identify the current practice of managing the innovation process.
3. Investigation of the current decision-making tools and techniques that may suit problem simulation.
4. Building a simulation tool for implementing innovations in construction. Four tools were used: Monte Carlo simulation; project management tool; fuzzy logic approach; and dependency structure matrix. Justification of using each tool is introduced wherever the tool is described.
5. A case study was undertaken to validate the proposed simulation tool.

1.5 Research achievements

The main achievements of the research are:

- identification of the main influence information that affect the innovation process in construction;
- identification of the main performance indicators that could be used to assess an innovative project; and
- development of a simulation tool that simulates this process which can help plan and control the implementation of innovations.

The main conclusion derived from this research has verified the hypothesis that existing simulation tools are unsuitable for planning the innovation implementation while the techniques of the developed simulation tool (which was based on a combination of the Dependency Structure Matrix (DSM), Monte Carlo simulation, and a fuzzy logic approach) will improve this implementation.

The proposed tool is used at the initial stage of a project after deciding to implement an innovation for that project. It is mainly used to simulate and plan the proposed implementation of innovation. The proposed tool requires users to input three sets of data: the planning data of the implementation tasks that include tasks' durations, resources, costs and the required dependencies among them; the stochastic data of the influence information and the fuzzy sets of the performance indicators. The output of the tool includes the deterministic and stochastic results of each loop tasks. The output also includes the fuzzy evaluation of the performance achieved.

The main benefits of using this tool for innovative project include:

1) It may be used by managers throughout the different implementation stages as a checklist to aid managers in identifying the innovation implementation tasks and their relevant information requirements;
2) the DSM can assist managers to identify loops of iterative innovation tasks. Knowing these tasks will enable managers to specify certain estimations of the information that causes iterations;
3) the Monte Carlo simulation results will provide managers with planning schedules and costs for different implementation scenarios;
4) the tool helps managers to decide whether to accept or iterate an innovative process to achieving satisfactory performance. The fuzzy logic approach, which was used to simulate project performance, reflects the nature of simulating innovation performance in linguistic judgements, such as bad or adequate. The fuzzy logic approach also converts qualitative criteria into numerical measures that can simulate an innovation process where mathematical precision is impossible or impractical; and
5) the tool will allow managers to investigate:

- the sensitivity of the subjective estimates of the influence information on the implementation tasks;
- the changes in the performance standard required to accept the innovation;

- the number of iterations to achieve satisfactory performance in terms of time or cost;
- the loop sizes to get the minimum number of dependency estimations;
- the different duration/cost of loop tasks for each iteration;
- the most critical information that influences project implementation; and
- the fuzzy evaluation of project performance to decide on iterated work.

1.6 A guide to the thesis

The thesis comprises nine chapters accompanied by five appendices. A brief summary of each chapter's contents is presented below as is followed by a flow chart of the thesis structure.

Chapter 1: Introduction

This chapter explains the background to the research, aims, objectives, the research methodology and the main achievements of the research.

Chapter 2: Innovation process and implementation

Implementing technological innovation in construction requires understanding the process map of this implementation. Many models have been devised for the innovation process. This chapter reviews the relevant literature regarding the nature of innovation and models of the innovation process in construction. The current practice for innovation process models and the problems encountered during managing innovation are also presented. The chapter proposed project management stages for this research.

Chapter 3: Decision making to innovation (tools and techniques)

The decision to adopt any innovation often requires consideration of many factors that affect the whole supply chain. Not only do cost/benefit factors have to be evaluated, but also the excessive risk/uncertainty factors. Innovation usually has no previous data thus increasing the degree of uncertainty for its application. Several methods of evaluation and assessment of new technologies exist. The value-added concept of a strategic nature replaces the strict return-on-investment evaluation of business ventures of a tactical nature in evaluating the rapid change. Chapter 3 reviews the existing decision making tools that have been used to evaluate new technologies in construction. The chapter concludes by identifying the research techniques to achieve the proposed simulation tool.

Chapter 4: Simulating innovation implementation

The fundamental challenge regarding construction innovation is the planning and control of work. Chapter 4 proposes a simulation tool to describe the innovation implementation in construction. The tool considers the assessment techniques within uncertain environments. The tool components include information affecting innovative projects, project stages and performance indicators to measure the innovation implementation. These components have been linked in a descriptive framework to evaluate the effectiveness of innovation. The chapter also details the research methodology adopted to develop this tool. Data acquisition for building this tool is explained and the tool boundaries are declared.

Chapter 5: Simulating influence information using Monte Carlo technique

Implementing construction innovations, that have many scenarios to be analysed, require decision-makers to use subjective judgements for the likelihood of particular scenarios. The analysis of these problems is complicated by the level of uncertainty because, invariably, the decision-maker may lack control over the consequences of one or more of the scenarios under consideration. The way to deal with these problems is through a structured methodology that puts uncertainties into perspective and takes them into account during the decision making process. Developing a planning tool to manage the innovation process requires testing the process against information influencing its implementation. From the planning point of view, as this information may change the innovative project objectives (i.e. time or cost) from the initial ones, these deviations need to be simulated in a sensible and reliable tool to help managers monitor their plan. In this chapter, the Monte Carlo technique, used to achieve this type of planning, has been presented.

Chapter 6: Simulating innovation performance using a fuzzy logic approach

The decision to accept a particular construction innovation depends on many performance parameters. Translation of an innovative process into performance requirements often results in a vague and imprecise definition of the relevant performance indicators. Simulating innovation performance precludes the probabilistic analysis approach because innovation outputs are considered non-probabilistic results and may be measured in linguistic terms. Consequently, fuzzy models are suitable for simulating innovation performance because of the difficulty in predicting output performance and the impact of unexpected changes on the progress of construction. This chapter reviews some evaluation models that are used to assess "construction performance". The chapter also discusses the reasons for adopting a fuzzy logic approach to simulate performance evaluation. The fuzzy logic approach has been detailed to show how performance can be evaluated. It is concluded that performance evaluation can be enhanced by using non-probabilistic tools and techniques.

Chapter 7: Simulating the iterative nature of the implementation of innovation

A planning methodology is required to overcome the shortcoming of the current planning practice that takes little account of the interdisciplinary, iterative nature of the innovation process with its performance outcome. This leads to a compromised innovation process containing inevitable cycles of rework together with associated time and cost overruns in both design and construction. Chapter 7 presents the principles of the Dependency Structure Matrix (DSM) to simulate iterations resulting from any experimentation or refinement that are always expected in implementing construction innovations. The chapter also discusses the potential application of DSM during planning and control of innovation implementation. It also contains a description of the resulting iterations from an innovation implementation. It concludes that this approach could form the basis of a useful tool for managers to foster innovation in construction organisations.

Chapter 8: Testing and validation of the simulation tool

This chapter describes a detailed case study that was undertaken to evaluate and validate the developed tools.

Chapter 9: Conclusions and recommendations

The main conclusions and recommendations of the research are presented in Chapter 9. Further works of research are also presented.

Chapter (1): Introduction. *This chapter explains the background to the research, aims, objectives, research methodology and main achievements of the research.*

Literature review

Chapter (2): Innovation process and implementation. *This chapter reviews the relevant literature regarding the nature of innovation and models of the innovation process in construction. The current practice for innovation process models and the problems encountered during managing innovation are also presented. The chapter recommends the project management stages that are used for the proposed tool.*

Chapter (3): Decision making to innovation (tools and techniques) *This chapter reviews the existing decision making tools that have been used to evaluate new technologies in construction. The chapter concludes with the research techniques to achieve the proposed simulation tool.*

Chapter (4): Simulating innovation implementation *This chapter describes the simulation of implementing innovations in construction. Data acquisition is explained. Outlines of the proposed simulation tool are declared.*

Structure of the simulation tool

Chapter (5): Simulating influence information using Monte Carlo Technique *In this chapter, the Monte Carlo technique that has been used to simulate the influence information on the innovation process is presented.*

Chapter (6): Simulating innovation performance using a fuzzy logic approach *The technique used to model performance assessment of the implementation phase of innovation is described in this chapter. The running procedure of this technique is illustrated.*

Chapter (7): Simulating the iterative nature of the implementation of innovation *This chapter contains description of the iterations resulting from an innovation implementation. It also introduces the DSM technique adopted to simulate this iterative process.*

Chapter (8): Testing and validation of the simulation tool *This chapter describes a detailed case study that was undertaken to evaluate and validate the developed tools.*

Chapter (9): Conclusions and recommendations *The main conclusions of the research and recommendations for further research are presented in this chapter.*

CHAPTER 2

INNOVATION PROCESS MODELS

CHAPTER 2

INNOVATION PROCESS MODELS

2.1 Introduction

Evolution is a natural process - any industrial sector will suffer if it resists evolution and fails to develop and change. Effective management is required in developing technological innovations that result in competitive advantage, new markets and improved productivity. Construction organisations need to develop specific characteristics if they are to stimulate new technology and overcome the expected barriers to innovation in order to achieve the desired competitive advantage. Exploitation of competitive advantage through strategic positioning is also required. It is insufficient and often dangerous to only react to events or problems after they have occurred. The adopted strategy should aim to influence the future. Innovative technology carries considerable unknown risks and creates a greater need for co-operation among businesses, government and individuals. Existing methods of construction already have well established schedules and costs, consequently innovation needs to prove its acceptability regarding the planning objectives of schedule and cost. Once the technology has been used successfully on several projects, it becomes more readily accepted. In construction, the acceptance of any innovation often only comes after very significant advantage has been achieved and demonstrated on several projects (MacLeod et al., 1998).

This chapter reviews the developed models of innovation processes and the current models of planning innovative projects. Recognition of the meaning of the term 'innovation' is essential to understand the innovation process. This is in addition to recognising that the surrounding environment heavily influences the degree of innovation.

2.2 Innovation definition and recognition

2.2.1 Definitions

Derived from the Latin word NOVUS, or new, the term 'innovation' has a number of related meanings. Innovation is an idea, practice, or material artifact perceived to be new by the relevant unit of adoption (Tornatzky, 1983). It is alternatively defined as 'the introduction of something new' or 'a new idea or device' (Arditi et al 1997). Innovate means 'bring in new methods, ideas, etc.' (Oxford Dictionary 2000).

Several studies distinguish between product and process innovation. Tatum et al (1989) reported that "innovation" is the first use of a technology within a construction firm. "Invention" is the process by which a new idea is discovered or created and "process innovations" are advances in technology that enable a greater output per unit of input. "Process innovation" is an improvement in construction methods designed to accomplish usual construction operations or to improve the efficiency of a standard operation. However, "Product innovation" is an innovation that produces a qualitatively superior product.

Nam and Tatum (1989) defined "product innovation" in construction as the process through which new ideas turn into a new component of a constructed product that has economic, functional or technological value.

Freeman (1989) defined "innovations" as nontrivial improvements in products, processes and systems that are actually used and are novel to the organisations developing and/or using them.

Farid et al (1993) differentiated between creativity and innovation as creativity forms something from nothing while innovation shapes that something into products and services.

Laborde and Sanvido (1994) defined "new technology" as a product or process that a company has not previously used in their construction operation. "Innovation" is seeking, recognising and implementing a new technology to improve the functions a company is performing. What may be considered to be a new technology to one company, may not be considered by other companies.

Innovation takes place when practices are so new that the set pattern of traditional and accepted technical and business processes is replaced by a new approach requiring deliberate and informed action and control (Lansley, 1996). In construction, innovation is not a straightforward matter and is difficult to recognise, record and apply. Most innovation takes place through small refinements over long periods of time after creating better understanding, reliability and confidence in the new approach. However, the cumulative benefits can be considerable when realised together. Innovation often requires considerable investment in equipment and in superior business skills as well as a confident view of the market.

Innovations that cause change can be classified into three groups: incremental; radical; and revolutionary. Incremental innovation is represented as the gradual process making steady improvements in a product or process. Radical innovation introduces totally new products or processes over relatively short periods of time. Revolutionary innovation causes significant economic changes. Arditi et al (1997) reported that incremental innovation is considerably more common than both radical and revolutionary innovations. Many of the minor modifications that take place in feeder industries, such as the construction equipment industry, often occur incrementally over years.

Tatum (1986) reported that there are some contrasting views regarding the processes of innovation which include:

- discontinuous series of major breaks or a continuous stream of change;
- "technology push" versus "demand pull" as major change forces; and
- scientific discovery preceding technological innovation or following advanced application.

Competitive performance usually depends not simply on success with a single innovation, but success with a sequence of innovations and post-innovation improvements. This approach involves a shift in perspective from treating innovation as isolated and discrete events to treating innovations as an evolving flow of developments in a technological agenda. After the introduction of a radical change, organisations do need a period of stability to learn new methods and subsequently continue to raise their performance.

Innovations in design and construction of large scale facilities pose different problems than in the manufacture of a product (Slaughter, 1998). The scale of the facilities often influences the degree to which an innovation can be tested at full scale before use. Slaughter and Shimizu (2000) analysed the relationship of an innovation to its context for large, complex and multi-system facilities of long span and multi-segmental bridges. The results of analysis differ significantly from manufacturing-based activities where the system aspect of the design and construction of complex built facilities reveals potential interaction among innovations. The nature of this interaction was system, actualising and complementary links. The timely identification of these links and the appropriation of resources could significantly decrease the time required to implement the set of linked innovations successfully.

As previously mentioned, the aim of this research is to simulate the implementation of a new process or method to the project team using a planning tool to ensure effective monitoring and control. The project team, consequently, has to deal with a lack of information including the achievable performance after implementation. Implementation is a stage of the innovation process that converts the concept of innovation into reality. Derived from the above definitions, this research adopts a broad definition of innovation which is 'developing and implementing a new process or product that the project team has not previously dealt with'. This definition accommodates the proposed methodology that manipulates procedures of implementing processes/products that a company has no experience with. Derived from this definition, an innovative project can be defined as 'a project that has a new process or product that the project team has not previously dealt with'. This results in increasing the level of uncertainty and often the work being iterated to achieve satisfactory performance.

A new process could be implemented according to a standard procedure that may simulate the innovation process as most of the innovation process models propose, presented later in this Chapter. This means that a standard procedure can be used to ensure running the innovative project regardless the detailed tasks of the implemented innovative project. This procedure should consider the above mentioned characteristics of innovative projects (i.e. high level of uncertainty and experiment, refinement and iterations). Accordingly, a standard procedure has been adopted in this research to simulate the innovative project phases.

2.2.2 Recognition

The environment that affects the development of new technologies has been studied in several ways. Many factors and attributes have been recorded that influence the innovation process and the adoption of new technologies. Rogers (1983) proposed five attributes of a new technology that are related to its adoption:

- "relative advantage" that is, the degree to which the innovation is perceived as better than the technology it replaces, including technical performance, cost, risk or other attributes;
- "compatibility" with values, norms and operations;
- "complexity" that is, the difficulty in understanding and using the technology; and
- "observability" refers to the ability to observe the performance of the new technology, and
- "Trainability" refers to test on a limited basis the performance of the new technology.

Laborde and Sanvido (1994) presented factors that influence the innovation process such as the company size, the innovation type and the breadth of application of the innovation. Company size is a factor but not necessarily a barrier to innovation. "Innovation" may be small or large. Breadth of the innovation application may be on a specific project or company-wide. Large firms are more able to afford the new investment for innovation and tolerate the risk of adoption, whereas smaller firms are more likely to value technology and have less complex decision-making processes. In many cases, innovation comes from smaller or new firms other than from large or older firms.

O'Connor and Davis (1988) classified the drivers of construction innovation into: needs for ad hoc focused studies; needs for work-around solutions to actual problems; and risk-management solutions to potential field problems.

The rate of innovation in an industry is dependent on many interrelated factors, and the rate of innovation in some sectors plays a significant role in the production of innovation used by other sectors (Arditi et al 1997). The dynamic interactions among strategic decisions, marketing policies, production practices, regulations imposed by the government, and research and development priorities also affect the degree of innovation.

Betts and Ofori (1994) explained that the five forces of positioning an organisation in relation to market forces particularly through exploiting industry changes are buyer power, supplier power, threat of new entrants, product substitution and jockeying for position among industry members.

Pries and Janszen (1995) investigated the level of innovation in the construction industry during the period (1945-1992) for about 290 building innovations. Market demand for product improvements was found to be a relatively unimportant motive. Throughout the period studied, the primary motive for innovation was to improve productivity (75 per cent) and only 25 per cent of innovation were in response to special market demands.

Mitropoulos and Tatum (2000) studied eight cases of adoption of CAD and Electronic Data Interchange (EDI) technologies. The analysis of each individual case focused on two sets of factors: the driving forces that initiated the adoption process and the organisational characteristics that influenced the decision to adopt. Competitive advantage, process problem, technological opportunity and external requirements were described as the major drivers for process innovation in this analysis.

Gann (2000) presented four factors that have to be considered in determining success for innovation in project-based firms, these factors are:

1. the need to develop new capabilities to deliver integrated systems solutions and services to enhance the value they provide to clients;
2. the need to implement new mechanisms for managing learning processes and knowledge within their businesses;
3. the need to develop a better understanding of the changing balance between general and specialist skills; and
4. the need to improve their capabilities in managing innovation and technology if they are to build reputations for technical excellence that set them apart from more traditional players.

Gann also identified particular skills for firms to innovate which are: strong leadership; competent interdisciplinary people capable of working in teams; and an appropriate infrastructure to support implementation. Firms can improve their performance through the use of new technologies by employing innovation directors, technology managers, gatekeepers and facilitators to co-ordinate the use of existing and often latent technical know-how.

Winch (2000) defined innovativeness – '*the extent to which the design of the organisation facilitates or inhibits innovation*' – as one of the principal themes in the management of innovation. Winch also offered some propositions to organisations as follows:

Relatively uninnovative project organisations will feature:

- tall hierarchy;
- clear divisions of labour and precise definitions of roles;
- reliance upon procedures for the co-ordination of work; and
- low commitment to work and colleagues.

Relatively innovative project organisations will feature:

- flat organisation;
- ambiguous and overlapping role responsibilities;

- reliance upon strong project leaders for co-ordination of work; and
- high commitment to work and colleagues.

While the above section outlined some aspects of the environment fostering innovation in organisations, the following section outlines modelling the innovation process in the organisations.

2.2.3 Modelling the implementation of technological innovation

Implementing technological innovation in construction requires understanding the process map for this implementation. Many models have been devised to represent the innovation process. The review of innovation process models revealed that some of these models act as an overview of the process, containing very few details especially in the way of the implementation. They may incorporate descriptions of factors that influence the process such as organisational structure, innovation culture and management. On the other hand, some other models analyse standard construction processes and systems, and then assess the impacts of innovations on them. Later models look more deeply into implementation and the required deliverables. Some of these models focus on the main phases of the construction projects and others on the site-level tasks.

Studying these models improves the understanding of the importance of effective innovation management to ensure the smooth running of the projects within budget and time constraints. Models to simulate innovation implementation should consider the effect of experimentation, iteration and refinement of activities that are reliant on volatile information in implementing innovative projects. The following sections review the above mentioned process models.

2.3 Innovation process

Understanding how innovation takes place and how the process is implemented requires studying a series of subjects. Among these are assessment of the effectiveness of the current implementation strategies in the construction area. It also includes identification of: the key success factors for implementation; the characteristics of an environment that nurtures innovation; the barriers to innovation; and the recommended actions to remove these barriers. Implementing innovation is usually proceeded by a change in many organisational or technical rules, changes in management personnel, assessing quality or new service capabilities. Implementing change successfully requires a conducted plan as required for constructing a major project. Milestones should be set, activities, responsibilities and due dates should be established. However, for innovation to take place, an environment that stimulates or encourages new ideas must be created, which remains the responsibility of management. From the literature of this research, the characteristics of the innovation process can be summarised as chaotic, individually motivated, opportunistic, customer-responsive, tumultuous, interactive and iterative in its development.

In manufacturing, several models have been developed to specify the process of innovation such as Zaltman et al (1973), Hage (1980), Gardiner and Rothwell (1985), Partridge (1987), and Voss (1988). Drawing on these models, Winch (1994) developed a generic model for the implementation of advanced manufacturing technologies. Winch stated that any proposed model of change should be capable of adaptation and re-adaptation to the case under study without losing its conceptual integrity. This suggests that generic models should not be over-refined, but clear in specification and plausible in application. The first stage in Winch's model is the evaluation of the new technology, both technically and financially. The evaluation process is the 'Justification' by which the bidding for funds takes place. The outcome of this stage is the 'Adoption' decision on whether to proceed with the implementation. It lays down the criteria by which the success, or otherwise, of the implementation will be assessed. A number of organisational processes have been addressed in this stage which include:

- creating a strategic vision through which the technology is evaluated both in the context of the existing production strategy and in terms of external opportunities and threats posed by the technology;
- the promotion of commitment and competence amongst those that will use the system; and
- generating broad and informed political support.

The second stage is the installation and commissioning of the new technology. During this stage, the commitment of those immediately involved with the system is usually gained, and workers are trained to operate the system. The configuration of the new systems should start during this stage and may be organised on a participative basis. Relationships with the vendors of the technology will also be at their most important. The intended outcome is technical success in the sense that the performance of the technology as laid down in the specification at the evaluation stage is met or surpassed.

The third and final stage is the 'Consolidation'. During this stage, the organisation makes adaptations in its internal structure and process so that the performance of the system can be improved. If necessary, a system management section is established to ensure its routine operation. There may also be a further configuration of the technology so that it complements the organisational context. The intended outcome is business success in that the objectives laid down at the evaluation stage are either met or surpassed, or that sufficient unforeseen benefits are reaped to counterbalance any disappointments with the original aims.

In construction, many models have been developed to describe the innovation process. These models illustrated the main steps of the innovation process in construction, how it can be implemented and the required elements of innovative organisation. A review of these models is provided in the following sections.

2.4 Innovation process models

2.4.1 Innovation process in construction organisations and projects

Tatum (1987) defined the major elements of the innovation process in construction firms, as shown in Figure 2.1. This includes extensive feedback and iteration. Tatum et al (1989) represented this process on construction projects as shown in Figure 2.2. Both models outlined the drivers to innovations and the organisational culture required to foster innovation. They identified the major forces and opportunities for innovation in construction that included market and competitive demands, entrepreneurial opportunities, strategic focus, regulatory requirements, and new technologies from other industrial sectors. Individual project objectives, performance requirements (such as cost or schedule challenges) or technical demands to accomplish operations that exceed current technologies are also forces driving innovation.

Tatum emphasised that new construction technologies are affected by new approaches from other industries, which may be modified to suit construction or to improve the existing technologies. Outside suppliers have also been considered valuable sources of developing new technologies.

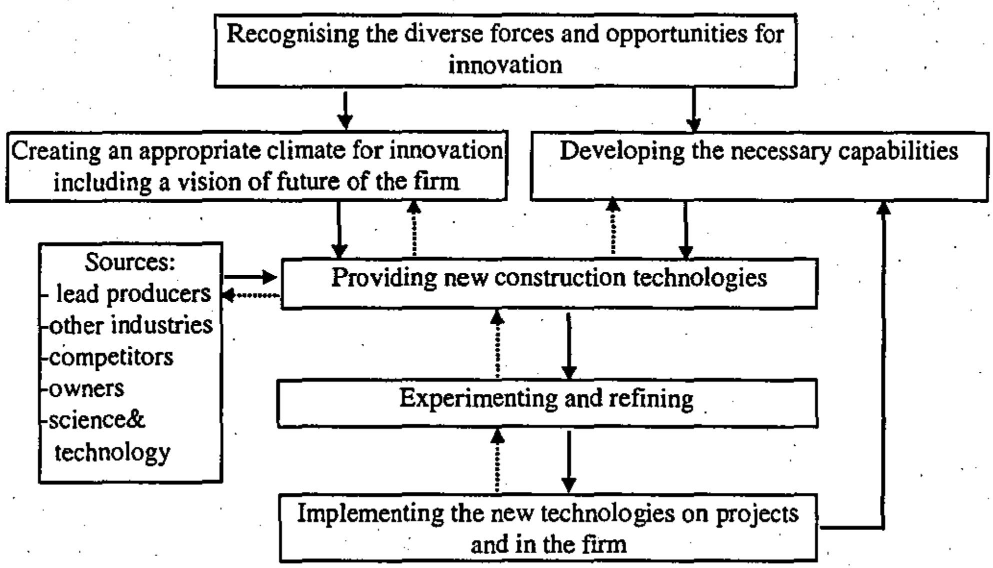

Figure 2.1: Innovation in construction organisation (Tatum 1987)

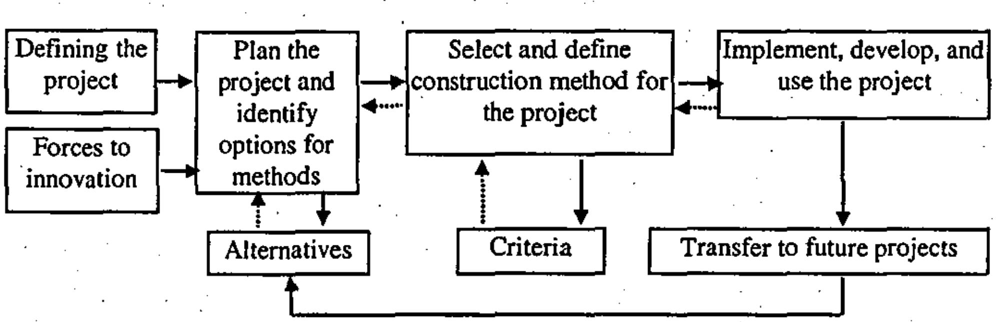

Figure 2.2: Innovation on construction project (Tatum et al 1989)

The model illustrated that experimentation and refinement are required for the innovation process. The implementation stage also needs resources, financial support, and time for a champion to put across all factors of the innovation including benefits. Feedback and iteration may change any inherent processes completely, refine the present idea or make more experimentation.

Tatum's model identified Champions as "Individuals who expend the energy and take the risks necessary to make innovations happen". Although these champions are not easily identified within construction firms, line managers may assume this role in many organisations, but the role of innovation Champion is likely to take second place in the face of operational problems or marketing opportunities. The organisational structure, the organisational environment and the role of key individuals in the organisation were considered the main factors that define the success of innovation.

2.4.2 Technology–Transfer model

Another innovation process model, the Technology–Transfer (T^2) model, was presented by De la Garza and Mitropoulos (1991). It focused on the transmission of a new technology to individuals or organisations that ultimately leads to its adoption. It was based on documented case studies of the adoption of Expert System (ES) technology in construction. This process included problem identification, research and development, field demonstration, product/system authorisation and product/system application.

This model differentiated between adopting innovation through individual or organisational decisions. An individual, who adopts a new technology, makes the actions of knowledge, persuasion, decision, implementation and confirmation. While through an organisation, it is more complex because decision making and implementation are the responsibilities of different groups.

The (T^2) process implementation in an organisation has the following three stages.

1. Initiation, where a technology gatekeeper, who links between the organisation and the sources of technology, identifies and evaluates new technology.

2. Decision, where Champions convey innovation to the senior management who decides whether to adopt or reject technology. A well-planed technology adoption process ideally requires that two types of Champions be present, namely; the Technical Champion, who endorses the technology until its successful implementation and assumes the technical risk; and the Executive Champion, who supports the technology from the top and allocates resources to the technical Champion.
3. Implementation, where fitting the technology to the desired application is implemented. Modification for either the technology or the company's structure may be required to fit each other. The technology is put into regular use to be an organisation routine.

T^2 process model for ES technology within an organisation has been expanded to outline the stages, flow, and factors affecting the T^2 of expert systems, Figure 2.3. The process can take either a top-down or a bottom-up approach depending if senior management initiates the technology-transfer process. De la Garza and Mitropoulos (1992) concluded that the main factors that affect the T^2 process are the senior management's attitude toward technology, the organisational environment, the position of the gatekeeper, the organisational technological capabilities and the state of maturity of the ES technology. The model T^2 provided a framework that can be used by other engineering disciplines for analysing the transfer of other innovative technologies and the adoption of corporate policies requiring change to the status quo.

Ofori (1994) emphasised technology transfer for developing countries as a technological capability area for these countries to build an innovation process programme. Technology transfer may be implemented on a specific project or on a larger scale. The change resulting from technology transfer requires a country-specific approach with a sound overall policy infrastructure within which technology transfer should be planned and continually monitored with preferably measurable targets and success factors. Successful transferred technologies should support and promote technological self-reliance and appropriateness to the recipients' needs and resources. Integration of the transferred technology into the existing systems could improve and upgrade other technologies and stimulate activities in other sectors of the economy. Transfer mode should match between the complexity of the technology and the capability of the recipients to gain the expected improvement and contribution of labour productivity and corporate/industry efficiency. Significant human resource development programmes and some building regulations may need revision for this system of technology transfer.

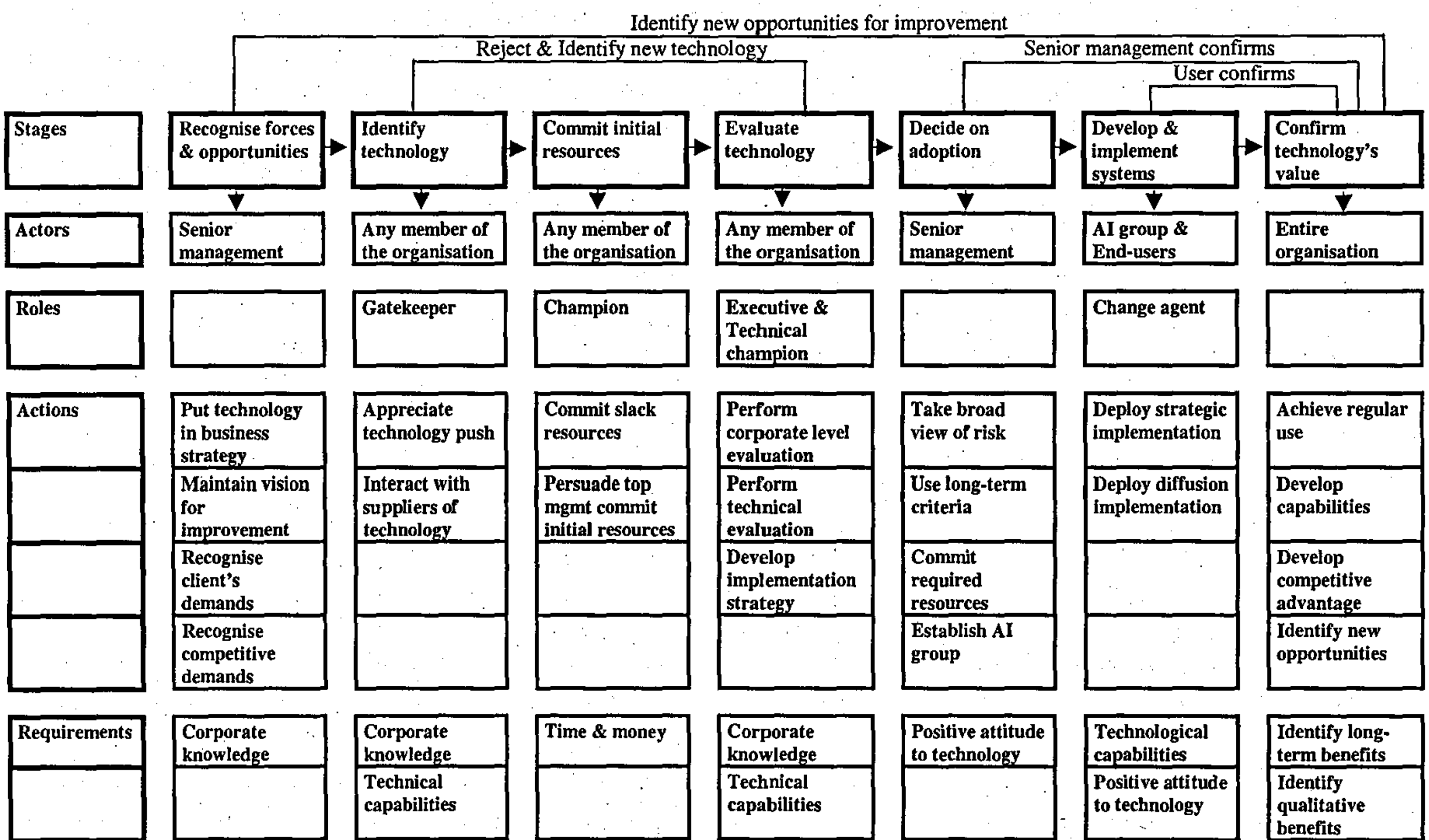

Figure 2.3: Actor, roles actions, and requirements of T² process (De La Garza and Mitropoulos 1992)

Problems of construction technology transfer may be summarised as:

- unwillingness of the transfer partners to nurture potential competitors;
- time, cost and managerial implications of transfer on a project;
- lack of understanding of what is to be transferred; recipients' and clients' suspicion of the usefulness of technologies transferred; and
- ineffectiveness of previous transfer; and difficulty of measuring effectiveness.

2.4.3 Innovation in small and large companies

Laborde and Sanvido (1994) introduced a detailed model that suits small and large companies. This model divided the process into identification, evaluation, implementation and feedback, as illustrated in Figure 2.4.

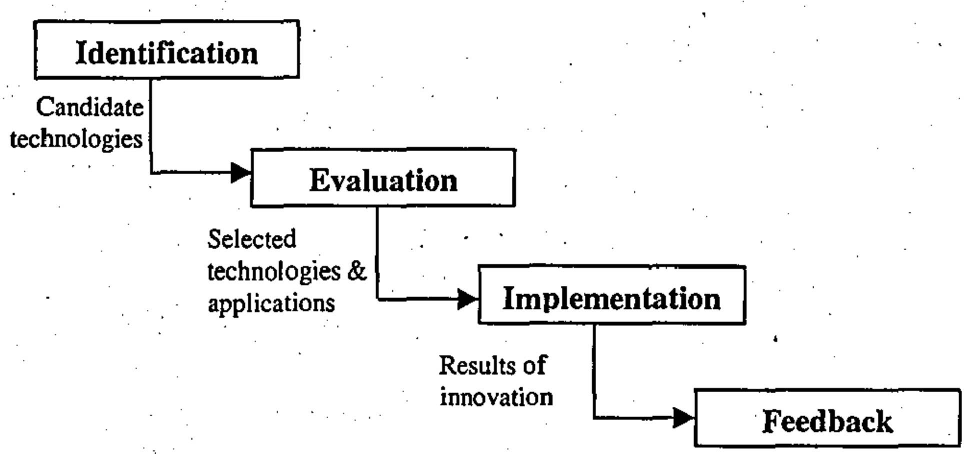

Figure 2.4: Innovation model for contractors (Laborde and Sanvido 1994)

Identification includes motivation to innovate, sources of innovation and technology identification. On a project basis, the motivation may be to solve a problem. On a company-wide basis, it may be to improve business practice, to keep the company competitive in the marketplace or to be recognised as a leader in the industry. The sources of innovation were identified as supplies such as product manufacturers, software developers, subcontractors, the contractor's competition, construction research organisations and universities, employees and formal in-house development efforts.

On a project basis, the project team members are the primary source of proposing innovations. The team should be involved early in the design phase to consider several alternatives, where the search for innovations should be considered from all project teams. The work processes, training and costs related to the new technologies should be outlined in this stage. On a company-wide basis, a 'Director of development' should be appointed who has detailed knowledge of the company goals and has the facilities to evaluate innovations. In a smaller company, it could be the task of an officer in the company. All project managers should at some point hold this position, through a rotation system.

Evaluation is the second stage of this model. It requires the same steps for both project and company-wide bases. The director of development or the project manager analyses the benefits versus the costs of the alternatives using the criteria:

- innovation consistency with the company/project strategy;
- initial innovation cost;
- development/adaptation time;
- consequence of innovation on other departments;
- payback period, future projects benefit, the needed training, and the impact on project schedule and budget;
- cost savings over conventional methods;
- difficulty of implementation; and
- quality and safety aspects of the innovation.

The successful implementation, the third stage, is mainly to:

- choose a small project for less risk;
- choose a competent project team;
- involve the architect and the owner as soon as possible;
- provide the necessary resources;
- train the team members;
- invest time in planning (specially when trying something new);

- hold regular review meetings; and
- document as much as possible.

Feedback, the final step, includes the following tasks:

- compile all documentation and analyse the final results. Evaluate the overall project performance as influenced by the new technology;
- make recommendations for the future projects;
- reward team members regardless of success or failure; and
- disseminate the information to other projects.

Laborde and Sanvido (1994) presented a detailed approach to clarify this model for the small and large contractors.

2.4.4 Overcoming pitfalls in the innovation process

Kraft (1997) suggested the following five straightforward steps to ease understanding of an innovative idea for those who are not familiar with it and to overcome the pitfalls that can disrupt the process.

1) Fully understand the idea. The questions that arise when a new idea is presented should be expected and answered. Also, the validity of the new idea must be measured. A good selling point is that the idea serves a human need as well as, or better than, other available alternatives.
2) Plan the process. The key components of the planning process are developing the message, identifying the target groups and selecting the appropriate venues. A good consensus-building plan should include a scope of work, a schedule and an estimate of resources.
3) Develop awareness with participation of the target groups.
4) Educate the target groups with a suitable program to increase the chances of idea acceptance. Providing a detailed description of the development process to these groups, feedback and involvement are important in this step.
5) Secure commitment of the target groups. The objective of this step is converting the target groups into stakeholders. The key to getting a buy-in by the target

groups is to get them involved early and keep them involved throughout the process.

2.4.5 Innovations in the design stage

MacLeod et al (1998) suggested 'SIGMA' as an innovation process model in the design stage. This model was divided into five phases as below.

S: Specify the requirement of the design that include the needs and constraints of the target innovation and regular check output against it.

I: Identify relevant information that includes codes of practice, design guides, case studies, failure cases and so on.

G: Generate candidate design solutions. The brainstorming carried out in groups serves as a powerful approach to generate new ideas. The innovative environments give the required experience for the individuals to get good performance in innovative design.

M: Make an assessment of the solutions and choose the one to be used. This may expend time and cost for the design process but it will be more beneficial for the total construction process.

A: Arrange the task to be tackled, that is, draw up a programme of work. The low degree of certainty in planning of innovative work may cause problems for this phase as well as the complex real interaction of innovative activities.

A formal approach to requirements and the corresponding checklist for successful innovative designs are important especially for construction designs where there is no opportunity to test prototypes.

2.4.6 Innovation in construction automation

Boles et al (1995) suggested a model to develop construction automation as an innovation process. It comprised the following six phases.

- Phase 1: Identification of the potential problems. Interviews and brainstorming sessions with experts in the field are necessary.
- Phase 2 (subjective filters): Identification of those problems that are common to:

the research program managers (who wish to fund a project to solve a specific problem); end users (who wish to have devices that are practical, easy to use, and improve performance); and technology sources (such as scientific laboratories).

- Phase 3 (objective filters): A conceptual design or design of the pathfinder, where pathfinder refers to a partially functional laboratory device used for experimentation, plus technical and economic feasibility studies. This phase is quantitative and includes technological and economical risk analyses.
- Phase 4: The pathfinder development and testing phase that involves designing and building a laboratory test platform where candidate technologies can be compared. This phase is where technological options are investigated, for incorporation into the prototype, and performance estimates from the previous phase are adjusted to experimental results.
- Phase 5: Prototype development and field testing to verify performance measures, (Prototype refers to a fully functional and field-demonstrable devices).
- Phase 6: Manufacturing, training and field implementation for the applications that successfully pass each of the previous phases.

2.4.7 Innovations in standard construction processes

Slaughter (1999) developed a set of specific system models to represent the detailed tasks of standard construction processes. The models were developed through computer-based dynamic process simulation. The library of models, which was provided by this approach to simulate specific construction systems, includes structural steel, cast-in place concrete, glass/metal curtain-wall, pre-cast concrete panels, HVAC, electrical wiring, plumbing, fire protection, gypsum board interior walls/ceiling, suspended ceilings and occupied multi-storey building. For example, Figure 2.5 gives the flow diagram of the model sub-process is structural steel erection for placing individual structural members. These models were used to analyse impacts of related innovations on such flow diagrams. The outcome from these models includes estimates of daily progress, overall duration, resource-based costs and exposure of workers to dangerous conditions for each system.

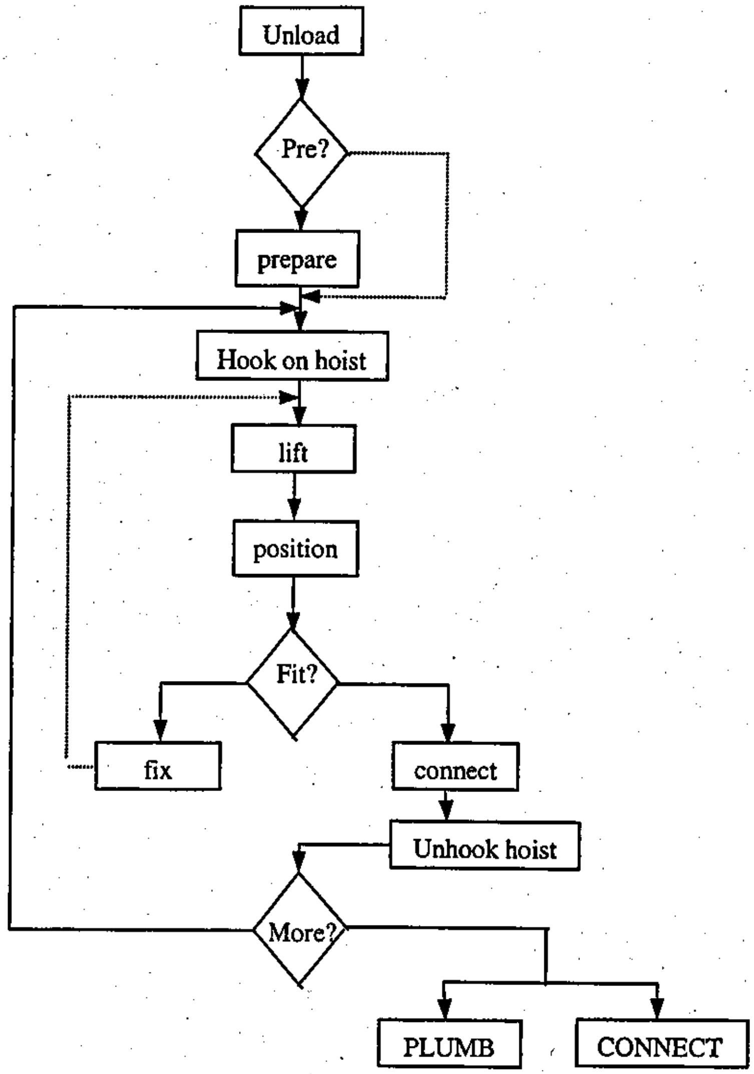

Figure 2.5: Example of process flow for structural steel erection (Slaughter 1999)

2.4.8 A general procedure for construction projects

Another valuable model was introduced by Sheath et al (1996). It was termed as "Process Protocol". Although this model does not target innovations in its methodology, it provides a general procedure for any construction project. It covers the whole life of a project from recognition of a need to the operation and maintenance of the finished facility considering both the business and technical point of view (Kagioglou et al, 1998). The Process Protocol has been adopted by the Latham inspired CRISP (Construction Research and Innovation Strategy Panel) committee as a basis for its activities in terms of promoting process thinking in the construction industry (Cooper et al 1998). A high level checklist (the Process Protocol phases) was provided to ensure that all aspects of a project are identified and managed effectively, as shown in Table 2.1 column a. The model provides a structured set of sub-processes termed "activity zones" that achieve the project objectives (Table 2.1 column b). It also lists "project deliverables", Table 2.1 column c, which represent project and process information required for each project phase.

Soft and hard gates are involved between phases to ensure that major decisions are assessed and evaluated. A soft gate implies that decisions are approved conditionally. Hard gates indicate firm and final decisions regarding whether or not to proceed to the next phase within the process. This model examines the process at an overview level in terms of its stages. An IT map has been introduced by Aouad et al (1998) which can be considered as a support tool for the process protocol. This IT map supports the widely known themes within the computer integrated sector: simulation (e.g. "what if", project simulation, economic appraisal), visualisation (e.g. VR, 3D); intelligence (e.g. artificial intelligence, KBS, NN, case-based reasoning); communications (e.g. EDI, Internet); integration (e.g. integrated database) and IT support (e.g. CAD, project planning, cost control). To help the industry to adopt and implement the Process Protocol, the Process Protocol Toolkit was developed which aims to assist the creation of the process model, manage the process information of the project, and address the problems raised throughout the lifecycle of a construction project (Wu et al, 2000). Fleming et al (2000) presented the development of the sub process maps of the Activity zones of the original high level map of the Process Protocol. Appendix A gives more description of process protocol's terms and the required deliverables for each project phase.

Table 2.1 Process Protocol Elements

a (project phases)	b (activity zones)	c (project deliverables)
Phase 0 Demonstrating the need	Development Management	Stakeholder list
Phase 1 Conception of need	Resources Management	Statement of Need
Phase 2 Outline feasibility	Design Management	Business Case
Phase 3 Substantive feasibility study - outline financial authority	Facilities Management	Project Execution Plan
Phase 4 Outline conceptual design	Health & Safety, Statutory and Legal Management	Process Execution Plan
Phase 5 Full conceptual design	Project Management	Performance management report
Phase 6 Coordination design, procurement and full financial authority	Process Management	Communications strategy
Phase 7 Production information	Production Management	Procurement plan
Phase 8 Construction	Change Management	CDM assessment
Phase 9 Operation and Maintenance		Project brief
		Design brief
		Concept design plan
		Outline concept design
		Full concept design
		Product model
		Cost plan
		Maintenance plan
		Production process map
		Handover plan

2.5 Summary and conclusion

Many models have been developed to describe the innovation process and there are many similarities between them. Models, such as those of Tatum (1987), Tatum et al (1989), De La Garza and Mitropoulos (1991), Laborde and Sanvido (1994), Kraft (1997), MacLeod et al. (1998), Boles et al (1995), and Slaughter (1999) tried to model several stages of the construction process. These models described the innovation process: for both construction firms and projects; in technology transfer; for small or large companies; for overcoming the pitfalls in the process; in the design stage; in construction automation; in standard construction process; and for the general procedure of a construction project. These models highlighted the characteristics and requirements of an innovative process to improve or discover the most suitable scheme. Some of them focused on specific construction processes and others were generic.

Implementing construction innovation has been considered as a sequence process incorporated iterations. The climate encouraging innovation was analysed to include informality, intensive involvement of all parties and organisational flexibility. To create a climate conducive to innovation, people and their interactions, time, space, location and information flows should be managed. This climate should expect some failure and any problems associated with failure should not be linked with poor management. Special linkages for both internal co-ordinations with functional groups and external co-ordination with suppliers and owner are also required.

The above mentioned models show that although many attempts have been made to model the innovation process and innovation has been analysed at many levels (organisational or project site), planning and simulating the implementation stage of an innovation has not been addressed. Any stage model is an analytic device to segment a flow of activity through time. Transition between stages ought to be meaningfully specifiable. Many of the mentioned models attempt to describe the content of each stage, but do not specify the outcomes of the activities within each stage and how managers simulate these activities using tools and techniques.

Based on the literature reviewed and the studied technological innovative cases in construction, the proposed simulation tool aims to fill this gap. The first step was to specify the basic process that can be used to describe the implementation activities. Therefore, the proposed simulation tool adopts the above process protocol. The process protocol can be considered as a comprehensive generic model for construction projects' implementation that makes the protocol as a basic procedure for projects' analyses. This research incorporates the effect of implementing innovation based on the detailed phases of the protocol. The research objectives include studying the effect of the high level of uncertainty inherent in innovative projects on the standard construction phases. These objectives also include simulating the effect of unacceptable performance on the innovation implementation.

The technique applied to simulate innovation implementation analyses the impact of influence information on the process conditions (the process protocol phases and deliverables) in their planning terms (time and cost). The results of this simulation are linked directly to an assessment approach for the performance of each process phase. According to the assessment, managers can define the relationships between each process phase, its performance and its succeeding phase. Also, managers can decide if the process phase is accepted or the work should be re-done to achieve satisfactory performance. The latter decision describes the iteration accompanying implementing innovations in construction. To develop the proposed simulation tool, the existing tools and techniques used for assessing new technologies and innovations, were comprehensively reviewed in Chapter 3.

CHAPTER 3

DECISION-MAKING FOR INNOVATION (TOOLS AND TECHNIQUES)

CHAPTER 3

DECISION-MAKING FOR INNOVATION

(Tools and Techniques)

3.1 Introduction

The decision to adopt any innovation often involves consideration of many factors that can affect the whole industry. Not only cost/benefit factors have to be evaluated, but also the excessive risk/uncertainty factors. Innovation usually has no previous completed data and this increases the degree of uncertainty for its application. However, several methods of evaluation and assessment of new technologies already exist. The value-added concept of a strategic nature replaces the strict return-on–investment evaluation of business ventures of a tactical nature in evaluating rapid changes.

Decisions with high long-term effect and of an innovative nature may be costly to implement, particularly in the face of significant uncertainty. Vickers (1965) described a "decision" as "the set of mental readinesses to distinguish some aspects of the situation rather than others, based on observation, communication and previous experience". An alternative way of describing a "decision" is through the concept of schema, defined as "the knowledge structure or set of expectations that an individual draws upon to guide interpretation, inference and action in any particular situation", Boland et al. (1990).

A decision problem is assigned when a mismatch between the expectations and the actualities is defined. A causal chain linking the problematic situation to events and actions is established by the decision-makers using their knowledge and theories to reach personal actions that affect this gap. This gap is often first identified in terms of performance, such as poor quality. The root causes of this expected poor performance should be defined such as the problem of poor quality is due to inadequate testing of products resulting from no standard testing procedures being available. This indicates what direction a decision-maker needs to look for possible action to close the gap. Many questions should be answered by the decision-maker such as: why a response is necessary; how a set of possible actions can solve the problem; how a course of these actions may be selected; does achieving innovation solve the problem; and how to evaluate this innovation.

Heijden (1994) put the following cognitive demands on decision-makers to enable the achievement of a successful decision: perception of the environment, sense-making through theory building, information gathering, extrapolation of the theory through causal reasoning, problem definition, creation/invention of action options, making commitments.

Wright and Ayton (1994) highlighted the continuous change of problem definition over time and gave the following characteristics to this dynamic definition:

- problem formulations are not stable, even during the decision-making episode;
- the presence of more data leads to higher levels of problem formulation;
- experienced managers display problem redefinition as frequently as novices;
- coming to a final choice is more akin to a process of weaving schemas than making lists of options or cycling through previous ideas; and
- schemas are continuously re-invented up to the moment of final choice.

The difference between the institutional/organisational decision-making and the individual decision-making comes from the requirement of a degree of consensus among a group of people or stakeholders. A process of building enough consensus is required to ensure that no key stakeholders exercise their effective power of veto and to compromise on values, expectations and options.

In this chapter, the decision analysis structure will be reviewed. Then the decision-making tools and techniques that have been used to assess implementing new technologies will be presented. The chapter concludes by identifying the techniques required to simulate innovation implementation in construction.

3.2 Decision analysis

In decision analysis, a problem is decomposed into elements small enough to be analysed. The possible events, decisions, uncertainties, expected outcomes and the relationships among them are then represented in a form of model. By determining the value of each possible group of events and estimating the probability of uncertain outcomes, decision-makers can evaluate intermediate points in the model and identify the sequence that will lead to the optimal results. Decision analysis is structured by the:

- formal tools of decision theory, probability theory and mathematical modelling;
- accumulated research findings in the area of behavioural judgement and decision-making; and
- skilled judgement of analysts and subject experts.

Typical sources of complexity within decision analysis, as listed by Keeney (1982) include:

- multiple objectives, not all of which can be achieved;
- difficulty in identifying good alternatives;
- the importance of intangible factors;
- long-time horizons with effects extending far into the future;
- many groups being affected and concerns for equity;
- risk and uncertainty from many sources including the actions of others, changes in priorities over time and lack of data or inherent unpredictability;
- risks to health and safety;
- need for expert knowledge from multiple disciplines;
- multiple decision makers and stakeholders;
- significant value trade-offs;
- attitudes toward risk taking; and
- decisions being sequential, earlier ones conditioning those that follows.

Russell (1992) introduced a hierarchical process for developing decision support systems of construction management related problems such as evaluation of new construction technologies. Eight levels were ordered from simple/small to difficult/large models as presented below.

1. Financial model that incorporate financial parameters to control the operation at any one time.
2. Linear model where decision criteria are subjectively weighted and rated by a decision-maker and combined into a single measure.
3. Linear model incorporating multiple ratings that adds the corresponding probabilities for the multiple ratings of a given criterion and measures the imprecision and uncertainty associated with the process.
4. Multi-attribute utility model that develop a method to combine qualitative and quantitative decisions criteria that are aggregated to arrive at an expected utility where risk, uncertainty, and the decision-maker's preferences are modelled and considered.
5. Fuzzy set model which is a method to model qualitative criteria by determining the degree of membership to a set via membership functions that are elicited from a decision- maker and combined into an aggregate measure.
6. Statistical model to evaluate quantitatively criteria relevant in decision-making techniques such as least squares regression of logistic regression where a dependent variable and independent variable exist. Discriminate and factor analyses are other techniques relevant to decision modelling.
7. Knowledge-based expert system model which is a methodology to combine qualitative and quantitative criteria in the form of heuristics rules.
8. Hybrid model which is a method that integrates any of the described decision and modelling techniques.

Mathematical programming (such as linear programming) and deterministic or stochastic simulation were also used for decision-making problems. Motivating innovation requires definition, classification and assessment of the existing technology methods and processes, consequently, the following sections review the existing tools and techniques in two approaches, classification analysis models and decision support systems.

3.3 Classification Analysis Models

Architectural, engineering and construction professionals need useful information to make shifts in strategy and culture needed for effective implementation of innovation. Classification or discriminant analysis can be used for solving multi-attribute problems. Discriminant analysis and classification are multivariate techniques concerned with separating distinct sets of objects (or observations) and allocating new objects (or observations) to previously defined groups. Discriminant analysis is exploratory in nature and is often used on a one-time basis in order to investigate observed differences when causal relationships are not well understood. Classification procedures are less exploratory in the sense that they lead to well-defined rules, which can be used to optimally assign a new object to the labelled classes. These two methods are not appropriate when the decision-maker may not know the value of a certain attribute and may not have past data as each problem is different (Murtaza et al, 1993).

On this basis and to support technological advancement, Tatum (1988) developed a conceptual framework for construction technology to understand the components of construction technology and the ways in which they differ for different construction operations. This framework included:

- material and permanent equipment resources (e.g., concrete, a steel beam, an elevator, etc.);
- construction applied resources (information, skills, equipment, tools, general conditions, space, energy, and time);
- construction process (construction methods and construction tasks); and
- project requirements and constraints of site (project objectives, regulatory requirements, contractor's capabilities, and area resource availability and practices).

Several attributes were defined for each framework element. These attributes had a rating system on a scale to assess the framework elements. The elements and the attributes of the classification provided a tool to measure technological change and analyse specific operations for potential improvement, compare construction operations and be used as a research tool.

Another classification system, the Advanced Building Technologies ABT Matrix system, was suggested by Ioannou and Carr (1988). It was an information database that relates technologies to building systems and vice versa. The database included the identification and documentation of the benefits, advantages and the limitations of promising technologies that are applicable to the enclosure and structural systems of commercial and light industrial buildings. The specific focus was on technologies that apply to the system of floor, roof, structure, wall and miscellaneous which were not directly related to these mentioned systems.

Ioannou and Liu (1993) originated an "Advanced Construction Technology System" (ACTS) from a consensus that the construction industry needs a more structured and systematic means for the identification of innovative technologies that would speed up the process of technology transfer and promote efficiency and effectiveness. The project was an industry-wide effort to identify, compile and disseminate information on emerging construction technologies in selected areas that merit priority. ACTS is a computer database for classification, documentation, storage and retrieval of information about emerging construction technologies. It was a custom Microsoft Windows' application, classification and keyword files and the technology information stored in its database. The system included 397 technologies that relate to civil, architectural, electrical, instrumentation, mechanical, and piping systems. The technology documentation format was originally based on the one developed for the Advanced Building Technology (ABT) Matrix (Ioannou and Carr 1988). Technologies in ACTS were combinations of resources, methods, and environmental requirements and constraints that produce a construction product.

3.4 Decision Support Systems

This section discusses the application of decision systems in adopting innovations in construction. One main reason that slows the process of introducing new technologies to the construction industry is the inherent risk of applying a new unproven device or technique. Risk, competitiveness and other intangible benefits offered by an advanced construction technology are hard to measure, quantify and represent using traditional economic analysis techniques. The high initial cost required for the implementation of a new technology may result in rejection of a potentially profitable alternative when using traditional Net Present Value (NPV) analysis.

According to Wakeman (1997), project development moves from the debate to action level where decision-makers deal with four potential barriers to success, namely, technical, financial, institutional and public/perceptual. A decision support tool that enables managers to successfully implement construction innovations in a structured way should help to formalise innovative activities and overcome these barriers. One of the commonly used methods in decision analysis is the weighting factor method. Examples of these tools will be presented in the following sections.

3.4.1 Impact-Assessment model

Chang et al (1988) built an impact-assessment model to prioritise identified innovative technologies that have the greatest potential of revenue or performance benefit to a studied construction program. The model used three assessment factors. An impact factor was generated based on the cost and volume of construction represented in the studied program. Using the impact factor, the technologies identified through the forecasting exercise can be ranked from most to least potential impact and thus is used to prioritise further detailed evaluation efforts.

Scalar factors were also generated to deal with the cost/benefits of using the new technology as further qualifiers for decisions regarding technologies that have the highest evaluation priorities. The new technology might save money and provide a better quality product; this is what the cost-benefit-rating factor indicates. The benefit determination might contain a qualitative judgement based on construction technology experience. Due to the relative newness of the technology and its level of implementation and incorporation into standard construction practices, there is a certain degree of risk.

A risk assessment factor was designed to recognise the differences of various levels of innovation based on a proposed risk classification. A technology that is used widely will have less risk associated with it than that is still on the drawing board. A series of questions was developed to provide the risk classification. The proposed assessment would not provide a single numeric value used to judge the technologies' impact potential, but it enabled an individual, with construction expertise using some weights for his/her judgement, to make a proper decision on which technologies to evaluate.

3.4.2 Overall Assessment Factor (OAF) model

Lutz et al (1990) developed a comprehensive evaluation system for assessing the expected overall utilisation of a new building technology. This system had three-phases. The first was the technical assessment phase, which described the technical performance of all building systems in terms of eight attributes: structural serviceability, fire safety, habitability, durability, practicability, compatibility, maintainability and architectural function. These attributes could be broken down into numerous sub-attributes related to a particular building system. The evaluator might compare the performance of the technical sub-attributes with the owner requirements and code criteria. Performance of the technical sub-attribute was assigned by six assumption ratings according to the owner requirements. A weighting factor should be determined first by polling a large sample of experts to rate the relative importance of technical sub-attributes for each of the above eight technical attributes for each building system. Then, the attribute score was determined and the technical assessment factor (TAF) was calculated. This factor indicates the expected performance of this technology related to owner requirements and code criteria.

The second phase was determination of the savings assessment factor (SAF). SAF is the estimated life cycle costs and the potential savings or loss of the new technology compared to the existing technology.

The third phase was the risk assessment. The risk assessment factor (RAF) is a measurement by experts to the probability of success that the new technology would perform as required. The OAF model used a list of ten evolutionary steps for the technology development to forcast the probability of success for the new technology. The overall assessment factor OAF is then calculated by multiplying TAF, SAF and RAF according to which the decision maker can decide on using the new technology.

3.4.3 Technology Impact Factor (TIF) model

Skibniewski (1991) introduced a data management system for construction technologies that could be retrieved to: provide the maximum improvement in quality and cost performance on projects; aid in forecasting and identifying innovative building technologies; evaluate technologies with the greatest potential applications; and plan implementation of the appropriate technologies into standard construction practice.

The system used a technology impact assessment to identify innovative technologies based on their impact on relevant construction projects. The greater provided cost or performance benefit to the relevant construction programme, the higher the priority ranking of the technology. The impact assessment comprises the following two separate factors.

1. A technology impact factor (TIF) is determined by multiplying (% relevant building programme), (% building cost affected by the system) and (% of system affected by technology). These calculations are performed for each technology considered for implementation. If a technology affects a large percentage of a complete building system, it has a high relative impact factor.

2. The other factors are the scalar factors for the cost, benefit and risk of using each technology. These are applied in a procedure similar to that adopted in the earlier impact assessment model. The results of TIF develop a prioritised list of technologies.

3.4.4 Product/process assessment model

To assess the total technological dimension of a new production system, both product and process should be considered. Trinh and Sharif (1996) prepared a list of suggested attributes for assessing product and process complexity. Product attributes could be measured by a set of key attributes, such as the performance function, the achievable accuracy or its physical size and weight. Process attributes might include the construction speed. These attributes are used to compare the level of advancement of competitive products/processes. The technological complexity of a construction process can be considered as the technological requirements that the construction process must meet to convert effectively a particular design (with specifications) into an actual product. No definite relationship between product and process complexity could be asserted which means in comparative evaluations of competitive products, the degree of technological requirements in design and in production for a particular product might not be at the same level of complexity. An assessment using a simple ranking of technological complexity for a number of products/processes can be arrived at by estimating the summation of multiplication of the normalised attribute value of each product/process and the weighting of this attribute for the all number of attributes characterising the complexity of a product/process. The larger the value of this summation, the higher is the complexity of the product/process.

To determine the weighting of all attributes and quantify the values of qualitative attributes, Trinh and Sharif used the Analytical Hierarchy Process (AHP) multi-criteria analysis which will be illustrated next.

3.4.5 Analytical Hierarchy Process (AHP)

Skibniewski and Chao (1992) stressed the importance of the intuitive judgements of a decision-maker as well as the consistency of alternatives' comparison in the decision-making process to adopt new technologies. The AHP approach, initiated by Saaty (1980), agrees well with the behaviour of a decision-maker that builds judgements on knowledge and experience. It organises tangible and intangible factors in a systematic manner and provides a structured relatively simple solution to the decision-making problems related to new construction technology implementation. In general, the AHP solution process is as follows.

1. A complex problem is decomposed into a hierarchy with enough levels including all attribute elements to reflect goals and concerns of the decision-maker.

2. Elements are compared in a systematic manner using the same scale to measure their relative importance, and the overall priorities among the elements within the hierarchy are established.
3. The relative standing of each alternative with respect to each criterion element in the hierarchy is determined using the same scale.
4. The overall score for each alternative can then be aggregated, and the sensitivity analysis can be performed to see the effect of change in the initial priority setting, while the consistency of comparison can be measured using Saaty (1980) consistency-ratio.

The characteristics of decision-making problems in new construction technologies always involve risk factors and intangible benefits that affect the evaluation result. The AHP approach addresses this problem well.

Skibniewski and Chao (1992) introduced an AHP model that included overall assessment at 'level 1'. 'Benefit Factors' and 'Cost Factors' were at 'level 2' which grouped favourable and unfavourable factors, respectively, reflecting the decision maker's general criteria for evaluation. Starting from 'level 3', the criteria were gradually specified and divided into more specific evaluation attributes through several intermediate levels depending on the technology under evaluation and the decision maker's perception of the problem. These criteria might be operational benefits, NPV, quality improvement or initial investment. The alternative solutions occupy the lowest level.

A pair-wise comparison of each level elements were made regarding their relative importance with respect to or impact on, the elements at the adjacent upper level. These comparisons constructed a square comparison matrix (n*n matrix), where n is the number of elements in a group on one level. The comparison is based on the rate of importance on a scale of 1-9, suggested by Saaty (1980), while a value of 1 shows equal importance for two attributes, a larger value indicates a greater importance for one attribute or alternative over another. Saaty (1980) concluded, through a mathematical proof and extensive experiments, that the normalised eigenvalues of the comparison matrix can represent consistently the relative strengths of its elements in aggregating a final evaluation.

The model evaluated alternatives according to a comparison of the relative strength of one alternative over another with respect to each tangible or intangible criterion, based on the decision-maker's knowledge and experience.

To use this method effectively for evaluating technology innovations, good communication is required to collect and co-ordinate the opinions from various functions such as finances, operations, technical development, marketing and safety. The management's intuitive judgement and perception of the problem is the major source of priority setting for evaluation criteria.

A development of this technique was introduced by AbouRizk et al (1994). The basic emphasis of this development was on the quantitative analysis of the risk factors involved in construction innovation and their impact on various company objectives for each given technology alternative. The development included:

1. identification of the alternative technological options to be included (A1, A2, ..., Ak);
2. definition of the criteria to be used in the analysis (C1, C2, ..., Cn); and
3. definition of the risk factors associated with the various alternatives (R1, R2, ..., Rm). Then the relative importance of the criteria and the importance of the risk factors relative to the criteria could be determined.

The same process is repeated to evaluate the relative effect of risk factors on the alternatives resulting in a weight matrix. Then the aggregation of a score from the whole process for each alternative could be performed. This process is different from the previous AHP model of Skibniewski and Chao (1992) in:

- putting the risk factors as a separate factor linking the alternative and the criteria,
- expanding the matrix for more alternatives, risks and criteria, and
- developing a computer program to ease the complex calculations.

3.4.6 Simulation technique

Based on the role of 'champions', which is crucial to the successful implementation of most innovations, Schumacher, T. et al (1998) developed a training simulation tool to enhance the innovative capacity of these champions in mature organisations. This tool includes a method to build interaction with information sources to achieve innovation and to solve problems that may arise during the innovation process. The simulation is conducted in an eight-hour training class that combines role play, decision making, interaction with the simulation software and small group discussion.

3.4.7 Innovation Acceptability model using Neural Network (NN)

A Neural Network based approach, which incorporated the AHP method, was proposed by Chao and Skibniewski (1995) for predicting the adoption potential or acceptability of a new construction technology. It was assumed that a user makes a rational choice between the two technologies according to their relative performance strengths weighted by his/her personal judgement. The acceptability of a new technology was defined as the proportion using a new technology for a defined operation instead of a base technology. This model was designed considering that the judgmental weight provided for each performance factor by a user does not change with a different technology being evaluated.

This approach can be described in a sequence as:

1. identifying technology performance factors (cost, risk, flexibility, manoeuvrability, etc.);
2. selecting a technology to serve as the conventional (base) technology on which an acceptability estimate is based;
3. producing performance characteristic vectors for alternative technologies using the AHP method, which would be used as input to a NN model. For training of NN as supervised approach, the technology acceptability for the training sets was conducted by a survey with a group of users familiar with existing technologies to collect their choices between the new and the base technology. So, the technology performance vector formed the input, and the corresponding approval from the users formed the output; and

4. determining acceptability of alternative technologies using the proposed NN model.

3.5 Summary and conclusion

The long-term strategic benefits to be gained from construction innovation demonstrate the need for effective decision support tools that facilitate the innovation process and monitor its implementation. In general, multi-criteria' decision-making problems can be solved by using mathematical programming, simulation, decision analysis, or artificial intelligence/expert systems.

Not all decisions are straightforward and many involve complex problems, which require detailed analysis if the best solution is to be determined. Decision analysis takes its scope not just from the comparative evaluation of alternatives, but the entire process that leads to complete description of the problem structure. This includes generating alternatives, modelling their probable impact, and assessing the preferences of individual decision-makers.

Techniques used to assess the performance of new technologies have started to shift away from the strict return-on–investment evaluation, which can be seen as tactical in nature, to value-added concepts of a strategic nature. Intangible benefits offered by advanced construction technologies are hard to quantify using traditional economic analysis techniques and this may result in the rejection of a potentially profitable idea. Benefits to be gained from improvements in operational efficiency are measured by cost and time-savings and increasing productivity. These benefits, in addition to intangible benefits, need to be measured and quantified as indicators of achieving innovations and to provide an assessment of its implementation.

The innovation process should be simulated to simplify monitoring of the implementation and documenting problems that occur during the implementation phase. The assessment process of adopting innovations is not just a choice among alternatives as comprehensively described in the previous models to adopt new technology.

The decision to implement innovations in construction requires decision-makers to provide subjective estimates due to insufficient information regarding the values of the influence factors on this implementation.

Although several models have been developed to help managers assess new technology, such as those mentioned in this chapter, the process of innovation implementation has received less attention. These models have not considered innovation as a dynamic process and have not dealt with the implementation phase from the planning view. The simulation tool proposed in this research targets simulating this implementation phase and assessing its effectiveness. The implementation phase includes several steps at which decisions should be analysed to react the changeable information.

The characteristics of construction innovation emphasise that traditional planning techniques need to be developed to support more effectively the implementation progress of innovative projects. The proposed simulation technique should consider the nature of experimentation, iteration and refinement activities considering the 'influence information' affecting these projects and the 'performance indicators' to assess the implementation process of innovation. This technique should deal with the various uncertain outcomes inherent in innovative projects, define all situations of a particular innovation, plan the innovation activities and improve the ability to manipulate uncertain events. The proposed simulation tool can fill the gap of fostering innovation in construction where the most important characteristics of construction innovation, a high level of uncertainty and the iterative nature of its activities, can be simulated and monitored. Chapter 4 describes the components of the proposed simulation tool and the rest of this thesis details how this tool works.

CHAPTER 4

SIMULATING THE IMPLEMENTATION OF INNOVATION

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4.1 Introduction

A fundamental challenge to the construction industry regarding innovation is the planning and control of work. Implementing technological innovations in construction requires an understanding of process maps for the implementation of innovation. Many models have been devised for the innovation process, see Chapter 2. The reviewed innovation process models revealed that some models provide an overview of the process, containing very little in the way of implementation. Other models analyse standard construction processes and systems, and assess the impact of introducing innovation. The later models look deeply at the methods of implementation and the deliverables required for each implementation stage. Some models focused on the main phases of construction projects and others on site level tasks.

Decision support techniques and tools developed to assess new technologies (see Chapter 3) focus mainly on evaluating alternative technologies, with very little attention being paid to the implementation phase. This does not help achieve effective innovation management which aims to ensure the smooth running of innovative projects under controlled budgets and time.

Simulating the innovation implementation should consider the effect of experimentation, iteration and refinement of activities that are reliant on volatile information. This chapter introduces a simulation tool that deals with the effectiveness of the innovation implementation phase. It includes the structure of this simulation tool, data collection, interview results and the simulation techniques of this tool. The proposed simulation tool identifies iterations within the innovation process and schedules activities according to the decision-maker's preference for the performance assessment. As IT will play a major role in developing and adopting new processes (Aouad et al 1998), the Chapter also presents the IT tools suggested for the proposed simulation.

4.2 Project implementation

Projects having clearly defined end-objectives with traditional and accepted construction processes can easily be planned and controlled. The project activities will be then directed to achieve project objectives. Figure 4.1 illustrates how the paths of the final product can be completed for the whole project. The sequential processes to perform these paths can be planned, as well.

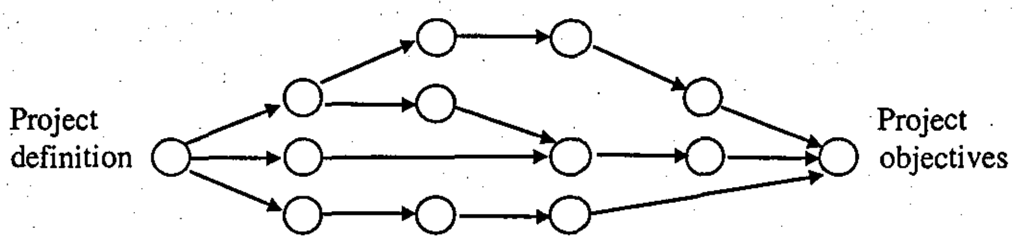

Figure 4.1: Sequential process for traditional project

Most innovative projects in construction have a high degree of uncertainty and incomplete knowledge of what the future may bring. Planning an innovative project often shows what should happen, not necessarily what will happen. The budget may only detail what costs are expected but not what they actually will be. One thing is certain, changes and deviations will arise. The problem with the traditional planning process is that companies can not realistically simulate or accurately quantify the actual savings in time and cost that will be made through innovation.

Aspects that differentiate innovative projects from traditional ones include more initial problems, longer preparation time, higher cost, more training and changes in management tools. The inherent uncertainty associated with innovative projects often requires several iterations to complete a certain task or group of tasks. Refinement or experimentation is required before final acceptance of the product. This iterative process is not normally a characteristic of a non-innovative project.

In addition to the fact that many of the potential benefits associated with an improved process can only be realised with significant IT support, methods have to be implemented to allow changes to take place in a controlled fashion. There should be well-defined objectives against which progress can be measured and changes be assessed. Simulation should address scheduling techniques that consider iterative (loops) progressing.

4.3 Process of innovative projects

The process of paths to achieve an end objective, as shown in Figure 4.2, could not be put in the same sequential phases as traditional projects. The project may have one start event but may often have several targets or combination of final targets (A or B or AB) which have considerable uncertainties in their features. Also, the project may follow several alternative scenarios to achieve these targets, indicated by decision nodes. The innovative project may often break down into sets of planned activities to perform one stage of innovation with uncertain performance of this stage towards achieving the final product. After each set of activities, there is a decision node at which analysis of the implemented work and performance evaluation is required. The decision node may contain several options; accept, modify, re-test, re-produce, reject and use another process, or reject and stop the all process of innovation. This phase includes new types of construction activity characteristics (i.e. experimentation, iteration, and refinement).

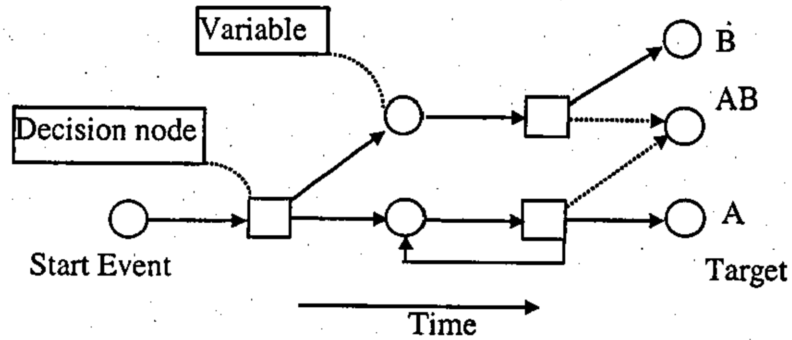

Figure 4.2: Process of an innovative project

The problem of simulating the implementation phase involves deciding whether or not to accept the product of a construction process. If the process is faulty, it should be rejected, and vice versa. Reliable performance indicators should be employed to help ascertain the process's condition, as shown in Figure 4.3 where influence information indicates what affects the process condition when deciding to adopt an innovative process.

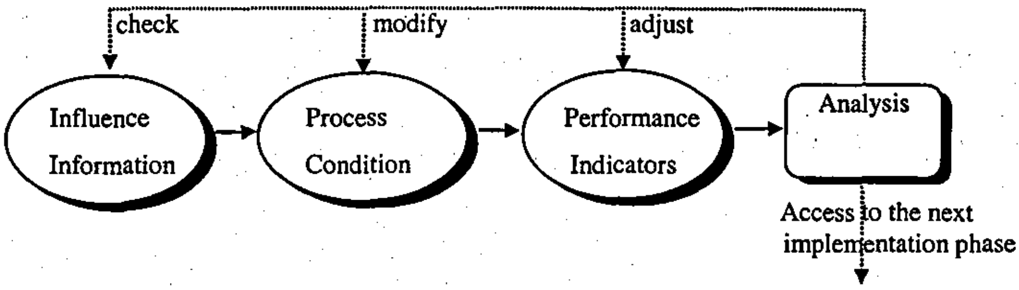

Figure 4.3: Phase of innovation implementation

The direction of the arrow indicates the direction of influence. Probabilities of the process perfection are dependent on the actual status of the process. Even though the process condition influences the performance indicators, the measurement of the performance indicators is known before the true process condition is determined. In this situation, the timing of the nodes should be opposite from the direction of the arrow. The decision node 'Analysis' is therefore added and is based on the measurement results. The arrow from 'Performance Indicators' to 'Analysis' indicates that the measurement result is known before the decision to access or iterate is made. The true condition of the process is then learned. According to the results of this 'Analysis', the decision maker can select any of the shown alternatives; check the 'Influence Information', modify the 'Process Conditions', adjust the 'Performance Indicators' or access to the next implementation phase.

It can be concluded from the above that the implementation process of an innovation can be interpreted by the relationships between some evidence and a hypothesis. The evidence is usually the result of some test or forecast, and the hypothesis concerns the presence or absence of a specific underlying condition. There is a need to represent the probability of obtaining evidence that correctly or incorrectly matches the hypothesis. It is a measure of the accuracy of the forecast. A decision is also required to represent the probability of the hypothesis being true or false given a certain piece of evidence.

If the four components of the implementation problem, illustrated in Figure 4.3, are represented as one state, the implementation process of innovation can be a recursively-defined system with a finite number of states. Simulating changes of these states over time can simulate the real development of innovation implementation. A directed graph called a 'state-transition diagram', developed from the probability theory, can describe this type of simulation as shown in the Figure 4.4.

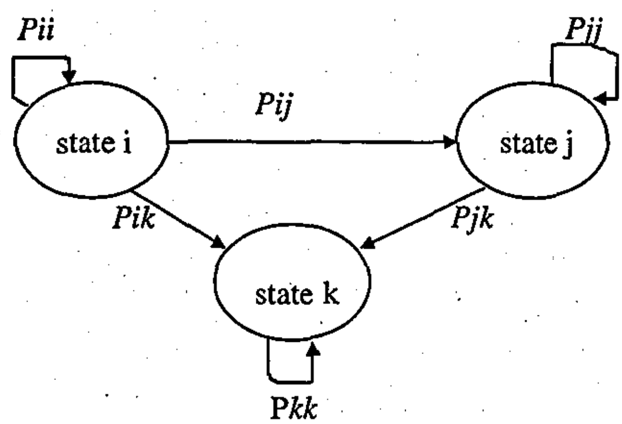

Figure 4.4: State-transition diagram

The arrows represent transitions. As time progresses, transitions take place from one stage to the next. Arrows that are drawn to and from the same state represent the possibility of remaining in that state for the succeeding stage. The transition may be represented by transition probabilities Pij from state i to state j. The transition probabilities for exiting a particular state and the probability of remaining in that state, at a particular stage must sum to 1.0. Transition probabilities may remain the same for all states, as shown Figure 4.4, or may have probability distributions.

This simulation must have values that answer the question, 'what is the value of being in a particular state at a particular time?' For this purpose, 'value' can be broadly defined. For example, it can denote the cost or the time spent in each state, or any measure of effectiveness.

4.4 Research Methodology

The methodology adopted for this research aims to investigate the issue of implementing innovations in construction and testing the simulation tool described above. A number of techniques have been used which included literature reviews, interviews with construction professionals and a case study.

The literature review undertaken for this research highlighted the limitation of existing planning tools for innovative projects. The two common approaches of collecting data for theory testing are questionnaires and interviews. Question administration is the main difference between these approaches. While they are self-administered for a questionnaire, the researcher administers them for the interview. For this research, the interview approach was adopted because it provides the opportunity to investigate many details that might not be included or might be missed through a questionnaire, depending on the experience of the interviewees especially for this research where different practical disciplines are required to be addressed. After setting the research aim and objectives, specific semi-structured interviews were held with industrial professionals involved in innovative construction projects. These projects were: the development of a satellite positioning system for piling rig positioning; and the development of a new continuous flight auger instrumentation system, both were Balfour Beatty Stent Somercotes projects. A case study was selected to validate the developed simulation tool which was the development of a GPS tracking/ work instruction/ recording system for road maintenance and was a Balfour Beatty Raynesway project (see details of the validation in Chapter 8). The purpose of the interviews was to present the research objectives, the proposed methodology, the structure of the simulation tool and the contribution that this research would make to improving the management of the innovation process. The interviewees confirmed that they expected the benefits to be drawn from the research would reflect the need of industry practitioners for tools to improve the management of innovative projects. Collecting data from on-going or completed projects was challenging for several reasons. No formal data were recorded for many of the on-going innovative projects and there were many difficulties encountered in meeting all projects' partners of the completed projects due to them moving to other regions. The interview structure was developed to identify: the main information that influences the innovation process; the implementation stages; performance indicators used to assess this implementation and the planning tools used to control this process (The interview structure is presented in Appendix B).

The case study is the preferred methodology to examine contemporary events in which the relevant behaviours cannot be manipulated (Yin, 1994). As implementing innovations is compatible with this situation, the approach of the case study is proposed to test and validate the simulation tool of this research, see Chapter 8 of this thesis. The following sections introduce the results of the interviews conducted to achieve the adopted methodology.

4.5 Interview results

It was observed, and confirmed by the interviewees, that the process of introducing new technologies to the construction industry is slow compared with other industries. Capital intensiveness, complex legal responsibilities, resistance to change, the fragmented nature of the industry, labour-relations issues, safety considerations, regulations and standard building codes were commonly cited as major barriers to innovation in construction.

Creativity and innovation is affected by personal blocks, perceptual blocks (function of the professional's viewpoint), organisational blocks and cultural blocks (dictated by the society and the environment), but these blocks can be overcome.

The following is a condensed overview of key points extracted from the interviews, which in turn, were followed by reviewing relevant literature available.

4.5.1 Organisation culture

Organisations should create and maintain an innovation culture and seek input from all members in selecting the ideas that show the highest potential for successful innovations. For acceptable and successful innovations, the organisation's employees must overcome the traditional preference for consistent, comfortable, and predictable tasks. This innovation culture makes all members of the firm initiate ideas towards new technologies so that an organisation can gain more opportunities for improvement. The organisation must have a strategic plan and a set of objectives to provide creative employees with a sense of direction and to integrate their innovative activities into an overall pattern that is meaningful to the organisation.

Innovative improvements may be generated by individuals at all levels within an organisation. Thus, empowerment allows decisions to be made at the most appropriate level in an organisation. Decentralisation and informal decision making encourage empowerment and enhance the team culture. Specialists in engineering, equipment, operations and management should informally co-ordinate through this team culture and are thus able to react quickly to changing project demands.

Effective information flow within the project team is essential to identify and resolve problems resulting from new technologies. Individual and organisational communication should provide the information necessary for the decision-makers to develop the production.

4.5.2 Individual roles in an organisation

The role of individuals encouraged by an innovation champion is critical to keeping an organisation in tune to the technological advancement of the era. Two approaches could be defined to explain this role. The top-down approach, where a senior manager initiates the innovation process by performing the role of a gatekeeper. The Gatekeeper is an individual who monitors any improved technologies used by other companies. In the other bottom-up approach, the technology is introduced by an individual who does not belong to the senior management group (De la Garza and Mitropoulos 1991).

Winistorfer (1996) highlighted the role of four key categories of individuals whose attitudes are associated with the success of an innovation, as detailed below.

- Technical Innovator: the "inventor" or individual most responsible for technical innovation.
- Business Innovator: the project manager or individual who is responsible within the organisation for the overall project.
- Chief Executive: the director or individual who is formally the head of the organisation.
- Product Champion: any individual making a significant contribution to an innovation' s progression through an organisation.

These categories do not always exist in construction organisations although the roles might all be embodied in a single individual. As it is difficult to adequately categorise the roles played by some key individuals in terms of the champion types, the role of an Integration Champion, someone who facilitates inter-organisational co-operation and learning, may ease this function (Nam and Tatum 1992a). The concept of an Integration Champion may be incorporated into a contractual arrangement especially where constructed products become more complex and need sophisticated new technology and more specialists.

4.5.3 Organisation desire and capability

Innovation has been used by: governments to upgrade the construction industry; companies to enhance their competitiveness; and professional institutions and trade associations to extend the scope of their member's activities.

Strong and unbiased management commitment to selecting technologies that best support project goals could be considered as one of an organisation's capabilities. An organisation's capability can be strengthened by: the designer's data bank of technology; effective information flow within the project team to identify and resolve problems resulting from new technologies; and the organisational or public consensus to support changes resulting from adopting innovations. The ability of an organisation to recognise the value of new external information, assimilate it, and apply it to commercial ends is critical to its innovative capabilities and performance.

Designers are often reluctant to innovate in the construction process, fearing that contractors will either refrain from bidding or will submit high bid prices. A strong information framework to develop construction technologies could overcome this problem. This framework should link designer sources of information with contractors' capabilities and trends.

Lansley (1996) reported that workforce skills, as an organisational capability, are critical to the adoption of new technologies. Knowledge Development is, therefore, essential to innovation for both senior managers and the workforce.

It was argued that stability of employees for a period of time reduces training costs and focuses experience, but on the other hand the lack of varied experience also produces a lack of creativity, flexibility and lower attitudes to innovation.

Kraft (1997) studied some new project ideas that would have required a change in organisation or public behaviour. The designers of these projects never built an organisational or a public consensus to support these changes. A consensus-building process was built to note some pitfalls that deal with planning these innovative ideas which included:

1. the idea was not well thought out;
2. the consensus-building process was not well planned;
3. the idea was sold to the wrong group;
4. the designer forgot to convince fellow professionals;
5. the plan or designer conveyed the wrong message;
6. the backers didn't use an appropriate venue for courting public opinion;
7. the idea was not properly communicated;
8. the focus was on selling the messenger rather than the message;
9. the backers did not keep the message simple and easy to understand;
10. the message had a negative tone; and
11. the backers lost control of the process.

4.5.4 Problems cause innovations

Problems are uncertain things that cannot be resolved with immediate applications of technology, so problems make innovations. Unusual demands from owners, site and weather problems, constraints on schedule or budget, and contractors' seeking of cost saving are common causes of problems. "Problems are not always clear and cannot be solved one by one, often they are all vexingly mingled together" (Nam and Tatum, 1989 pg. 517-534).

4.5.5 Owner demand

Innovation motivates owners to discover new needs. The characteristics of owner's demands can be generalised as "the demands for a facility that is safe and meet economic, functional, and aesthetic criteria" (Nam and Tatum, 1992b, pg. 507-524).

As barriers to innovation, owners may not tolerate any unnecessary risk or potential liability caused by using a new technology. Many may be unwilling to spend the additional resources required to prove that the new technology meets their own criteria as well as those of the building codes. They would not allow technology that is controversial and thus could cause market resistance. As owners of innovative construction projects often make changes to the project design and during implementation, they could show their commitment by sharing a high portion of risk. The more owner participation, the lower the risk burden.

According to Winistorfer (1996) as government agencies (as owners) receive their funding from legislatures, not from users' groups, they have a low tendency to foster innovations.

4.5.6 Integration of design and construction

Co-operation between the designer and the contractor increases the chance of product innovation. The low degree of integration between design and production functions in the fragmented construction industry is a major factor limiting the size and rate of innovation. Contractors' and suppliers' technological capabilities motivate or restrict the designer, so favourable contractual arrangements with financial incentives for both parties lead to the fostering of innovation. Integration of key functional activities, such as research and development, marketing and production, fosters developing new products and bringing them to the market.

Construction innovation is often the result of a team effort. Team members must have a willingness to assume risks, an opportunity to communicate freely and a common encompassing goal yielding a sense that everyone is a part of building the innovative idea. Some non-contractual means of project integration are important for achieving innovation (Nam and Tatum, 1992a). These means include owner's involvement and leadership, establishment of long-term business relationships between organisations even with building code authorities, employing integration champions and the professionalism of project participants. Owners, designers, and contractors should each seek to identify situations that provide the opportunity for non-contractual integration.

4.5.7 Financial resources

Construction is often a project-based business. Each project targets the owner's needs at the lowest possible cost and schedule. Developing an innovative product or process, unless the project conditions demand it, conflicts with these conditions. Rosenfeld (1994) considered that capital intensiveness makes the risk-aware decision-makers invest in structures built through well-tested designs, materials and methods, rather than in innovative ways. The large initial capital often results in the rejection of innovation regardless of the strategic point of view of using investment appraisal techniques.

4.5.8 Codes and regulations

Construction is closely regulated through codes. This regulation can affect innovation through not only the selection of specific technologies but also how they are used. Codes and regulations may significantly increase construction costs and reduce innovations.

Codes and regulations are written to establish minimum standards of quality and performance in a specific area. The codes are written in general terms and interpreted by local officials for specific applications. If the local officials do not have the technical expertise and are unwilling to consult experts, the code interpretation may restrict the adoption of new technologies by potential innovators (Cushman et al, 1992).

However, Arditi et al (1997) argued that regulations act as a catalyst for innovations, improve products and processes and lead to cost reductions. As an example, environmental regulations to reduce noise, which impose performance criteria, represent a demand-pull force acting on the construction equipment industry.

Whatever the effect of codes and regulations, changing them is irregular, not easy and requires several partners to be consulted. These partners include subcontractors who are mostly small and most vulnerable to the technological changes, labour unions that usually try to prevent the introduction of labour-saving technologies, and local bureaucracy that is conservative in nature as far as public safety and public health are concerned. It needs great effort from all of the local political authorities and may lead to other effects on the construction operations.

4.5.9 Procurement procedures

The imbalance between risk and profit, which often gives the prime benefits from successful innovations to the owner and failure of innovative concepts to the contractors or the designers, discourages innovations. Moreover the contractors often carry the liability for fixing the faults and the designers have to spend time and money on the corrective actions and suffer from damage to their reputation. Rosenfeld (1994) argued the legal responsibilities of designers and managers makes them conservative towards applying new methods. Consequently, traditional procurement methods often constitute a barrier to innovation. The greater use of design/build contract has encouraged designers to be more innovative (MacLeod et al, 1998).

4.5.10 Risk and uncertainties

Risk inherent in applying new techniques and legal liabilities resulting from possible failure often prohibit construction organisations to innovate. "The more rapid the rate of technological change, the more resources committed. As a result, the risk is usually larger" (Skibniewski and Chao, 1992, pg. 577-593). To be a successful innovator, management must accept the risk that is inherent in any innovative process.

4.5.11 Construction market and industry

As construction companies are dependent on the electronics, mechanical, and chemical sectors for technical system innovations, understanding the nature of innovative activities in these sectors is important. The construction industry structure involves a very large number of small firms, organised in temporary coalition to address specific projects and a highly fragmented and casual workforce. This is an obstacle to progress innovation (Technology Foresight Panel on Construction, 1995).

The extensive, unstable, highly fragmented and geographically dispersed construction market creates an uncertain climate for investment in innovation, especially for small companies which lack capital (Slaughter, 1993). Many conditions and requirements are unique to each construction project and many technologies are not reused. Thus, low-cost technologies are often favoured.

4.5.12 Planning tools and techniques

Despite the differences highlighted between innovative and non-innovative construction projects, no special tools or techniques were specified for planning innovative projects as indicated by the interviewees and also from the literature. This may cause uncontrolled progress of the times and costs of an innovative project. The previous sections discussed the considerable amount of information that has to be included in order to simulate innovative projects. Innovations do not usually have complete sets of data from previous projects to build off and this increases the degree of uncertainty in planning the innovative projects. This uncertainty is compounded by the special characteristics of the innovative project activities (i.e. experimentation, iteration and refinement). This research aims to develop a simulation tool to facilitate the management and control of innovation implementation. The following sections describe the proposed tool to deal with such problem.

4.6 The proposed simulation tool

Implementing inNOVations In Construction Engineering Technologies has been studied to introduce the simulation tool **INOVICET**. This tool is built on the interview results, reviewed case studies (detailed in Appendix C) and the structure of the simulation tool stated earlier. Figure 4.5 illustrates the tool components and techniques. Each technique will be justified and illustrated in its relevant chapter. The tool procedure is described in Figure 4.6.

INOVICET comprises four techniques: the Dependency Structure Matrix (DSM) to simulate the iteration inherent in the implementation phase; Monte Carlo technique to simulate the influence information on the innovation implementation phase; a fuzzy logic approach to simulate the innovation performance; and a planning tool to simulate the implementation phase of innovation. Decision-maker preference is involved to run and analyse the output of the compound tool.

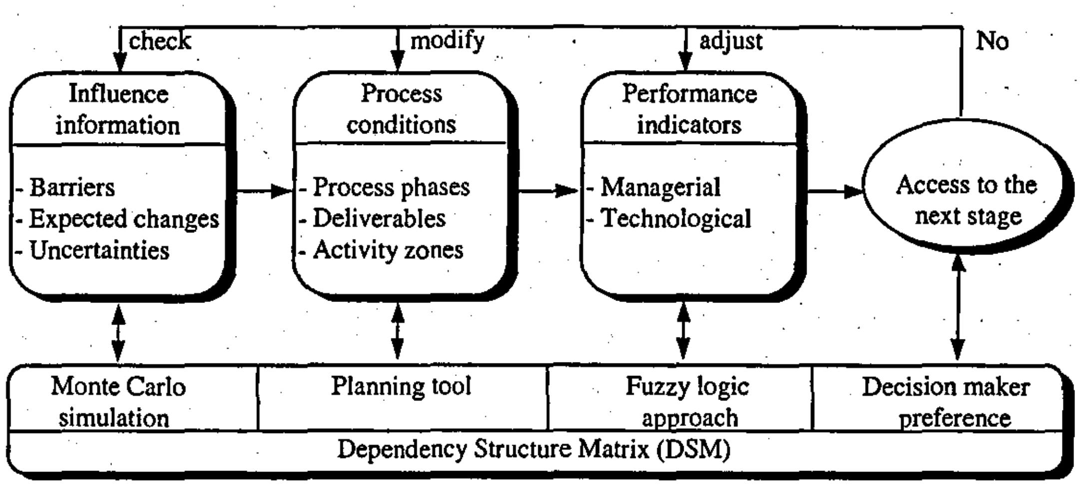

Figure 4.5: Structure of the simulation tool for innovation implementation stages

Data used to build the simulation tool 'INOVICET' was based on literature, interview results and case studies. INOVICET was validated by a case study, see Chapter 8. The collected data are demonstrated in the following sections.

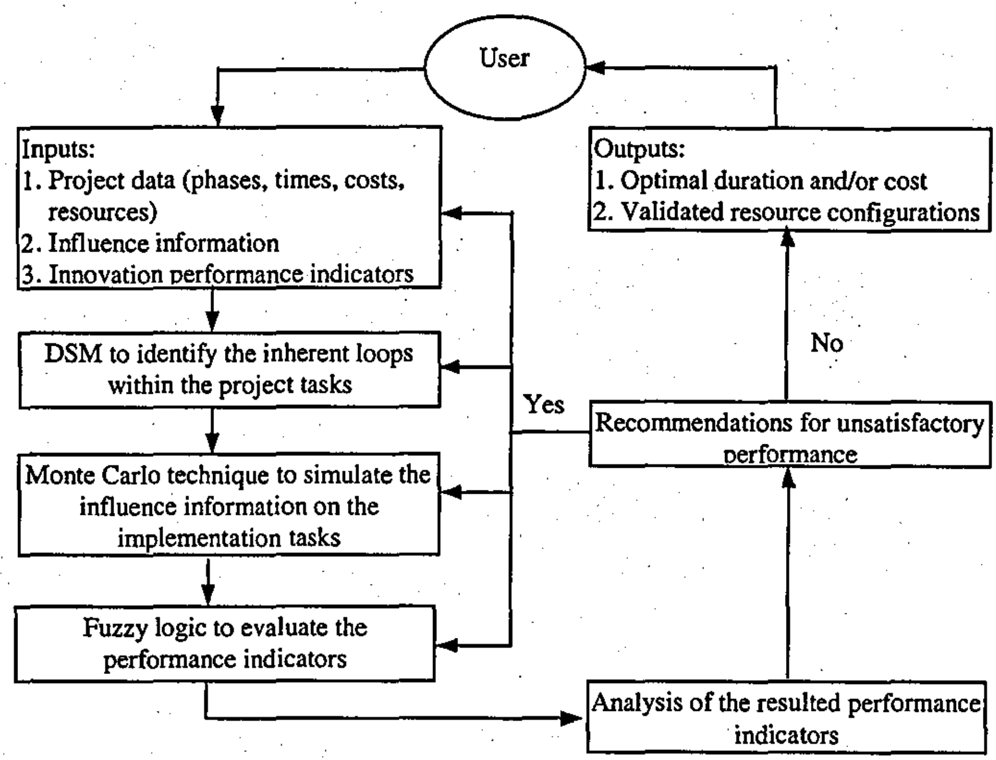

Figure 4.6: INOVICET procedure and techniques

4.6.1 The influence information

As previously illustrated in Chapter 2, the innovation process starts by identifying innovation objectives and its driving forces. Objectives may include higher turnover, higher profits, higher productivity, quality improvement, increased durability or cost reduction. The forces driving innovation can be on a project or strategic basis. These forces include problems that cannot be solved by current technology, owner demands that are not only for safe and economic products but also for more functional facilities and aesthetic criteria, market changes or the strategic needs of organisations. High standard of regulatory demands may cause design and construction teams to innovate to fulfil these regulations. Changes in the construction environment, any related science, engineering, industry and society may have a significant effect on the construction industry if these are to be adopted. Support of strong research and development programs can achieve the strategic goal of gaining a more significant business market share. On the bases of business objectives, innovation may not be established for a whole project, but may be included in only some types of activities or even in one activity.

The INOVICET simulation tool defines "Influence Information" as any aspect of knowledge, which affects the decision to move to the next phase of implementation. This has been decomposed into barriers, changes and uncertainties. Barriers may result in schedule and cost growth. Managers should consider the probable barriers to innovation, estimate the effects on the implementation plan and take actions to overcome these barriers. The expected changes and deviations through innovative projects are often more than on non-innovative projects. Sources of uncertainty during construction innovation can arise from the physical characteristics of the process, defective design and work, funding sources, and environmental risk and safety. Table 4.1 identifies these information proposed by this tool.

Apart from determining and defining the influence information, some formulating criteria should be assigned to monitor innovation progress. These are defined in the INOVICET as 'performance indicators'.

4.6.2 Performance indicators

It is difficult to generalise how a new technology will affect productivity, profitability or other aspects of a construction company's business. Performance measurement could be carried out by grouping the achieved performance for each implementation phase. Performance indicators for innovation objectives were categorised for this research according to managerial and technological aspects.

Performance measurements should be incorporated to confirm the result of an implementation phase. Benefits can be gained from both improvements in operational efficiency and competitive position of the firm. Efficiency benefits result from the cost and time savings and productivity increase. These savings may come from automation of complex tasks, improved utilisation of human resources and organisational expertise, and increased control and integration of operations.

Competitive advantages (organisational effectiveness) result from the improved product quality and price, the additional services and the improved technological image to the clients.

Table 4.1: Influence information

Barriers	Expected changes
Codes	The priority attached to the project
Reaction of other construction partners	Functional requirements due to the type of building
Labour relations issues	Funding and resources made available
Organisation culture	Owner's view
Individual roles in the organisation	Operational requirements
Level of design/construction integration	Project aesthetics
Safety considerations	Market circumstances
Economic and political conditions	Level of complexity of the project
Capital intensiveness	
Resistance to change	
Fragmented nature of the industry	
Workforce skills	
Company size (capability of implementation)	
Governmental regulations	
Environmental and social constraints	
Procurement procedures	
Uncertainties	
Economic sources	Capability sources
Yield (financial returns)	Damage to existing utility construction lines
Costs (financial estimates)	Safety risks
Time (how long it takes)	Productivity decline (learning curve)
Training requirements	Practicality of design and buildability
Availability of human resources	Technological function risk
Contractual claims	
Market changes	Political and social sources
	Contractual and tendering methods
Physical sources	Environmental risks
Substructure conditions	Government rules and regulatory bodies
Weather conditions	

The tangible (quantifiable) benefits of new technology can be accounted for using traditional justification techniques. The justification process includes the potential savings in costs or time. The analysis of performance should not be limited to the tangible benefits. The increasing complexity of integrated technology makes measuring the intangible (qualitative) benefits of the new technology more difficult. The compound measuring of tangible and intangible benefit factors changes the basis of decision making from numerical formulas to intuitive judgements. The list shown in Table 4.2 summarises new technology indicators that may help in innovation assessment. It also demonstrates the technological benefits of innovation that have been concluded from the reviewed innovation cases in construction. Every innovation has its own indicators that should be clearly and regularly measured. Objective measures should be used as widely as possible to overcome bias in measurements of subjective measures. This measurement of innovation performance may iterate with the innovation objectives and the actual progress of the project.

Table 4.2: Performance Indicators

Managerial performance indicators	
TANGIBLE	**INTANGIBLE**
Profit	New function
Turnover	More expertise
Productivity	Efficiency
Quality (longer useful life, accuracy)	Effectiveness
Less material costs	Less errors
Less required jobs	Lower risk
Reduction of unit construction cost	Job satisfaction
Reduced workload	Service
Reduction of times	Work safety
Increased market share	Increase distinctive capabilities
Reduced training and supervision	Retention of a competitive advantage
	Reduced materials handling
	Synergy with other equipment
	Ability to respond quickly to future technology
	Level of environmental disruption
Technological performance indicators	
Structural serviceability	Speed of construction work
Practicability	Reduced floor space requirements
Fire safety	Increased utilisation of manpower and equipment
Compatibility	Reduced tooling, utilities and production control
Habitability	Reliability (concerning the probability of failure)
Maintainability	Flexibility
Durability	Improved product quality (reduced inspection)
Architectural function	Impact of new technology on other processes

4.6.3 Process conditions

INOVICET defines "Process Conditions" as the implementation plan required to achieve the proposed innovation. This plan should be developed totally at the initial stage of the project and should include all the project phases. This plan should include the basic procedures required to complete the project. These procedures require certain deliverables to ensure the completion of each process phase. This is compatible with the procedures provided by the "process protocol" adopted by this research to simulate the implementation phase of innovation, see Chapter 2 and Appendix A for details of this protocol.

Each phase has the characteristics of a typical construction project in addition to the iterative nature of an innovative project. The iterative nature may be applied to a complete phase or to individual activities.

4.7 Proposed simulation techniques

In general, multi-criteria decision problem solutions can be summarised as mathematical programming, financial models, multi-attribute utility models, decision analysis, simulation models, knowledge-based expert system models or artificial neural network techniques (see Chapter 3 for applications of these techniques in evaluating new technologies in construction).

Mathematical programming and financial models are suitable for a small number of quantitative variables involved in decision making problems. Decision theory requires that the decision-maker has full information about the values of all the selection factors and provides subjective estimates and rates for each alternative. The subjective weighting factors need to be tested periodically to ensure that they are realistic and balanced.

Knowledge-based expert systems (KBES) are concerned with decision making in complex systems where experience and heuristic knowledge is of great importance. Modelling a certain situation in the form of IF .... THEN rules as those used in Expert Systems is not sufficient to provide performance similar to the human expert since any lack of required data will stop the reasoning session. Situations that comprise of a large number of interrelated attributes that must be considered in parallel are very difficult to model since construction experts might fail to explain why or how they arrive at decisions (Adeli, 1988).

Implementing innovations in construction requires many scenarios to be analysed and decision-makers may use subjective judgements for the likelihood of particular scenarios. The analysis is complicated by uncertainties because decision-makers often lack control over the consequences of the scenarios under consideration. A structured methodology is required to improve the analysis of these scenarios taking account of the uncertainties and the expected iterated work.

Simulation models provide a schematic and analytical framework needed for the study of construction processes and the development of construction operations. It is an appropriate alternative where the complexity of a process or system makes mathematical modelling unfeasible.

Those simulating construction processes, such as innovation, should consider deterministic or stochastic simulation. Deterministic simulations consider systems whose components behave predictably. An example of this type of systems is traditional project management. Stochastic simulations consider systems whose components behave in a way which can not be completely predicted. This fits well with the characteristics of the innovation process. The stochastic process simulation uses mathematical models to study systems that are characterised by the occurrence of random events. It provides full statistical information about the performance of system criterion. The expected behaviour of the system and the probability that the system behaviour may be significantly different can be determined. As Monte Carlo Simulation is a popular technique for this type of simulation, it will be adopted in the next stage of this research to simulate the effect of the influence information on the stages of innovation implementation.

Simulating innovation performance precludes the probabilistic analysis approach because innovation outputs are considered to be non-probabilistic results. In addition, the innovation outputs may be measured in linguistic terms. Subjective judgements and their capabilities in expressing estimator's plans are critical to adoption of the simulation technique. Subjective judgements about a unique event assume the application of a heuristic rule. This heuristic rule assumes that the probability of an event is derived from how easy it is to construct a scenario that leads to the event. This probability of events changes with time, where the probability of a correct action after an unaccepted trial of implementation increases for the next trial due to the learned experience and corrections. Therefore, fuzzy models are more suitable for simulating innovation performance. The fuzzy logic approach is useful in the absence of adequate information, expresses the qualitative terms of performance measures and expresses the linguistic judgements expected for evaluating the innovation performance such as bad, adequate, and excellent.

Planning of the innovation process, however, requires not only an estimation of the information that affects the process, but also of the performance accompanying this process that has to be redone until a satisfactory outcome occurs. The special feature of this type of planning is the interdependency of the process and its results. While the results are dependent on the process, the process could not be approved until these results are obtained. Thus, it may require iterations to complete the implementation phases, see Figure 4.6. This makes traditional network analysis tools inappropriate for planning innovation because they give no account of this interdependency. INOVICET was devised to overcome these limitations by adopting the Dependency Structure Matrix (DSM) tool to simulate the detailed innovation process. DSM is a powerful tool that could be used to demonstrate interdependent tasks, identify iterative tasks and plan engineering's works based on a required number of iterations. This technique can be used to simulate the innovation process. An example is given in Figure 4.7 to illustrate how the proposed techniques work.

4.8 Summary and Conclusion

Schedule growth on innovative projects has been shown to be due to changes or defective results. Simulating a particular implementation scenario is complicated by large amount of information and uncertainties where the decision-maker lacks control over the consequences of one or more of the scenarios under consideration.

A structured methodology based on subjective judgements, that puts the information and uncertainties into perspective and then takes them into account in the decision process, is one way to deal with these problems.

This chapter presented a simulation tool that describes the information affecting innovative projects. The tool considers the results of the implementation phase of innovation and the measurement techniques within uncertain environments. Simulating innovative projects is affected by the information driving innovation, the expected/unexpected changes and the performance indicators to measure the innovation implementation. These components have been linked to build the tool 'INOVICET' that simulates the implementation phase of innovation, and evaluate its effectiveness. The chapter includes the structure of the simulation tool, data collection, interview results and the tool techniques.

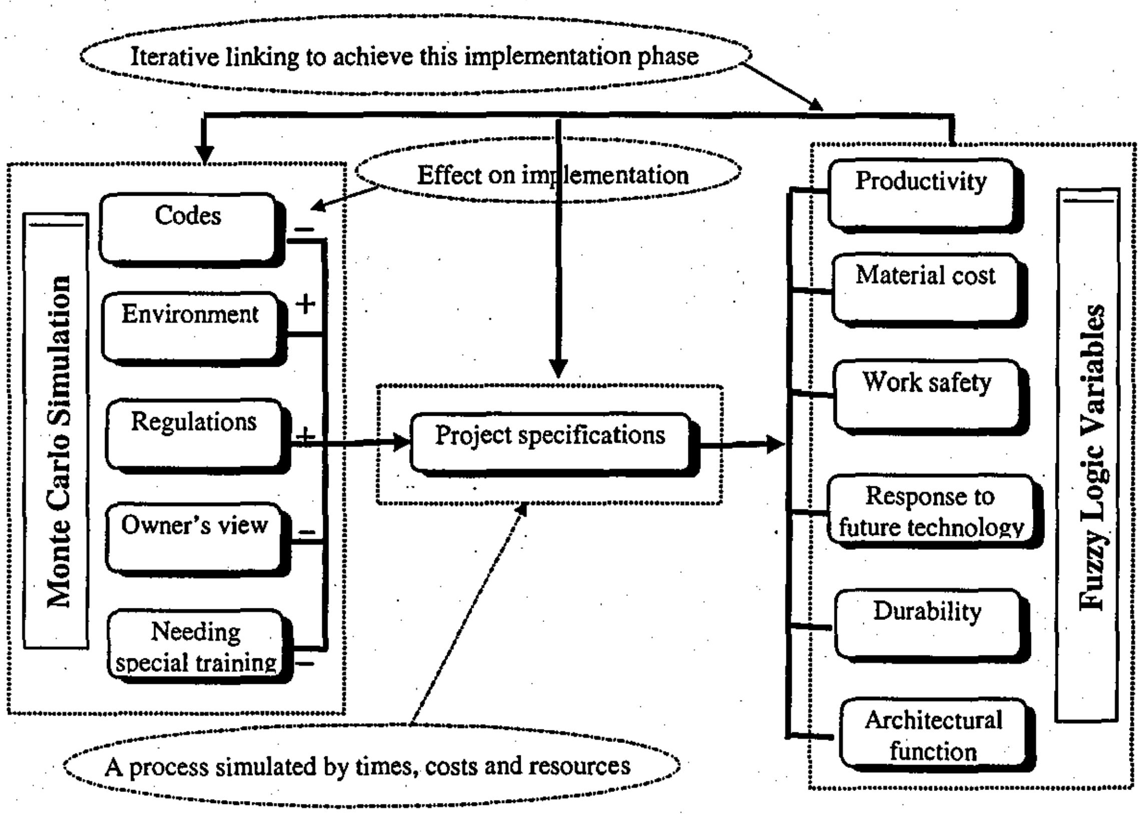

Figure 4.7: An illustrated example for INOVICET

INOVICET comprises four techniques:

- Monte Carlo technique to simulate the influence information on the innovation implementation phase;
- a planning tool to simulate the implementation phase of innovation;
- a fuzzy logic approach to simulate the innovation performance; and

- the Dependency Structure Matrix (DSM) to simulate the iteration inherent in the implementation phase.

Decision-maker preference is involved to run and analyse the output of the compound tool. The following chapters demonstrate each technique and its application in the INOVICET tool.

CHAPTER 5

SIMULATING THE INFLUENCE INFORMATION USING MONTE CARLO TECHNIQUE

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5.1 Introduction

Simulating the implementation of innovation, as previously discussed in Chapter 4, highlighted the influence information that affects the innovation process in construction. Developing a simulation tool to plan the implementation requires testing this process against information that influences its implementation. A planning tool has been designed for this research to simulate innovation implementation based on the process protocol phases (see Chapter 2 for details of these phases). This tool has been developed to simulate the influence information on the implementation of the innovation process. From the planning point of view, as this information may alter the innovative project objectives (i.e. time or cost) from the initial ones, there is a need to simulate these deviations in a sensible and reliable tool to help managers monitor their plans. The proposed simulation will change the planning type from deterministic planning to probabilistic one. In this chapter, the simulation technique developed to achieve this type of planning will be introduced.

5.2 Simulation

Implementing innovations in construction requires many scenarios to be analysed where decision-makers may use subjective judgements for the likelihood of particular scenarios. This analysis is complicated by uncertainties because, invariably, the decision-maker may lack control over the consequences of one or more of the scenarios under consideration. A structured methodology, that puts uncertainties into perspective and then takes them into account in the decision-making process, is a way to deal with these problems.

Simulation involves the use of a model to represent the essential characteristics of a reality, either a system or a process (Fellows and Liu 1997). Simulation, as defined by

Byron (1984), is an activity whereby conclusions can be drawn about the behaviour of a given system by studying the behaviour of a corresponding model whose relationships are the same as those of the original system. Pidd (1992) oriented the simulation definition towards 'computer simulation' as the process where the analyst builds a model of the system of interest, writes computer programs which embody the model and uses a computer to initiate the system's behaviour when subject to a variety of operating policies. Thus, the most desirable policy may be selected. Simulation as defined by Lewis and Orav (1989), is a controlled statistical sampling technique performed on a digital computer, that is used in conjunction with a model, to obtain approximate answers for questions about complex, multi-factor probabilistic problems. Simulation, as a concept, provides the schematic and analytical framework needed for the study of construction processes as developing new processes requires the existing processes to be better understood. As concluded by Touran (1990), simulation is an appropriate alternative where the complexity of a process or system makes mathematical modelling (such as linear programming or zero-one programming) infeasible. Generally, simulation is a dynamic process in which a model provides a basis for experimentation. The experimentation process is used to iterate systematically towards an acceptable solution by repeatedly observing the performance of the model for different specific sets of conditions. An appropriate result is then selected from the set of outcomes that is obtained. The most beneficial aspect of simulation is the capability it offers for experimenting different scenarios on a representation of a real system, but not on the system itself. Simulation also provides an indication of the risk associated with a particular system as well as a measure of expected system performance.

For the purpose of simulating construction processes, such as innovation in construction, two main considerations have to be taken into account namely; deterministic or stochastic simulation and discrete or continuous change. The deterministic simulation is the system's components whose behaviour is completely predictable. An example of this system is the traditional planning tools. A stochastic simulation is the system's components whose behaviour can not be completely predictable which fits well with the characteristics of innovation process information. The stochastic process simulation refers to using mathematical models to study systems that are characterised by the occurrence of random events. It provides full statistical information about a system performance criterion. So, the expected system behaviour and the probability that the system behaviour may significantly be different can be found.

The main difference between discrete and continuous change is that the former deals only with variables that are not changed during the simulation process while the latter allows continuous change for the variables' values during the simulation run. These changes could be represented by differential equations that, theoretically, allow variables to be computed at any period of time. On the basis that an innovative task is completed at a discrete point of time, then the discrete event simulation is the one that will be considered in this research. Many discrete event stochastic simulation models have been developed in the field of construction such as those used to schedule construction activities and simulate repetitive cyclic construction operations.

Apart from the fact that the Monte Carlo method is the most popular technique of the stochastic process simulation, it has a considerable edge in computational efficiency over other methods of approximation as the size of the problem (the number of the studied factors) increases (Fishman, 1996). Therefore, the Monte Carlo method will be adopted in this research. The Monte Carlo method provides approximate solutions to a variety of mathematical problems by performing statistical sampling experiments on a computer.

A very simple procedure of the Monte Carlo method applied to the problem of simulating uncertainty effect on a project progress is shown in Figure 5.1. A probability distribution function is allocated for every influence information. This function simulates the effect of this information on a project phase time or cost. A range of estimates can affect the project phases' time or cost by increasing or decreasing the initial duration/cost estimate of that project phase/task. This range of estimates has a probability distribution function that can be assigned according to the data available for each variable. However, the data available for each variable in construction projects are not often sufficient to fit with sophisticated distributions. A number of profiles are possible, but simple ones are advocated in the absence of statistical data. For example, triangular distribution can be approximated to a normal distribution. Trapezoidal or rectangular distributions are useful in representing situations where there is no evidence that one particular estimate value is any more likely than another within the prescribed range. During simulation, each variable will have a random estimate from this range and then each project task's duration/cost will be changed according to this estimate. After running the project management tool (developed for the proposed model), the schedule and cost analysis for this iteration can be determined. The output of the simulation runs gives the cumulative distribution function for the project objectives (time or cost). Using this output, decision-makers can determine the probability of a project time or cost.

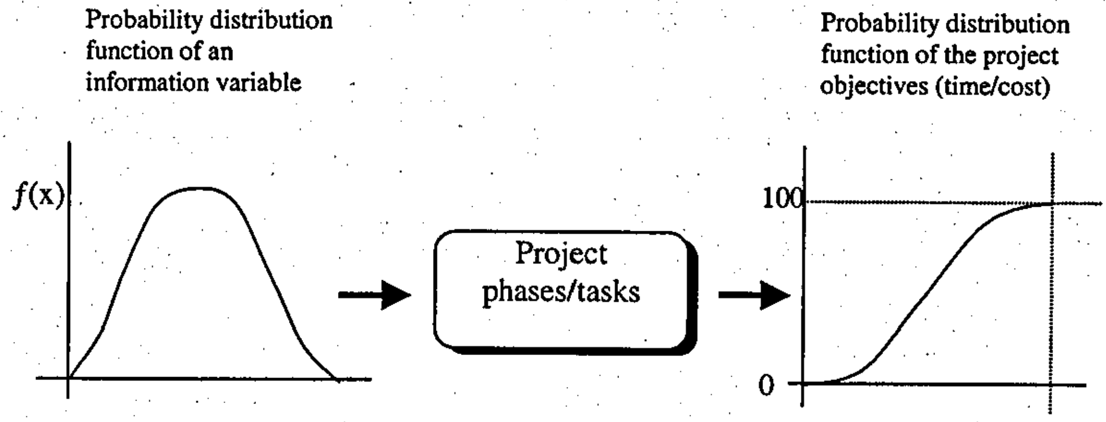

Figure 5.1: Monte Carlo Simulation procedure

The following sections describe the basic elements necessary to perform a simulation experiment on a digital computer for the innovation implementation tasks and variables.

5.3 Basic elements for simulating the influence information

As briefly described above, some basic elements of the Monte Carlo simulation need to be discussed to deal with discrete event simulation for non-repetitive events, as assumed for simulating the implementation of innovations in construction, which are:

- Probability and subjectivity; and
- Decision analysis.

5.3.1 Probability and subjectivity

Probability is taken as representing the observer's degree of belief that the system will adopt a certain state. In decision theory terms, P(Oj) represents the decision maker's degree of belief in Oj being the state that will occur; the stronger his belief, the greater is P(Oj). Different people have different beliefs, thus, different observers and different decision-makers may assign different probabilities to the same event. Probability is, therefore, personal; it belongs to the observer. It is subjective, not objective. Although we may interpret P(Oj) as quantifying a personal degree of belief, we are not at liberty to call it a probability, at least among mathematicians, unless we have shown that it combines with other subjective probabilities according to Kolmogorov's laws (French, 1988). So, the decision-maker should organise his/her beliefs in such a way that it is possible to represent those beliefs by probabilities. The subjective view represents the system observer's degree of belief that a system will adopt a particular state. Subjective probability has a personal, non-objective meaning.

Subjective probability is a discipline to measure uncertainties about an event considering the knowledge base at the measurement time (Lindley, 1994). In other words, it reflects the decision-maker's belief about uncertain event. Changing knowledge might change the uncertainty measure.

Ferrell (1994) emphasised that subjective probability provides a normative framework for the representation and updating of beliefs. The probability of a hypothesis is conditional on one or more items required to identify information relevant to the problem at hand. The identification of an item of evidence influences the degree of belief in a hypothesis.

To emphasise the distinction between the frequentist and subjective approaches, consider the probability 'P'. To a frequentist, 'P' is the long-run relative frequency with which the person being observed chooses object 'A' when repeatedly offered the choice between 'A' and 'B'. To a subjectivist, 'P' represents the observer's degree of belief that the person will select 'A' in a choice between 'A' and 'B'. Note that a frequentist must conceive of a sequence of choices, whereas a subjectivist need only imagine the person being offered the choice once. The frequentist approach cannot be used to encode the uncertainty present in the majority of decision problems such as implementing innovations. Decisions are made almost invariably in unique circumstances that may not arise again. Thus, the frequentist approach is quite inappropriate to the decision analysis needs of this research. The subjective view of probability does fulfil these needs in decision analysis. The application of subjective probabilities within decision analysis gets its importance because an uncertainty that cannot be resolved cannot affect the consequence of a decision.

5.3.2 Decision analysis

Decision analysis takes its scope not only just from the comparative evaluation of decision alternatives, but also from the entire process leading up to it of structuring the problem, generating alternatives, modelling their probable impact and assessing the preferences of the decision-makers. The objective of the analysis is not to select an optimum alternative that must be chosen, but to provide insight about the problem and to promote creativity in dealing with it and commitment to the alternative finally selected.

Decision analysis is not always highly dependent on probabilities, other aspects of the problem being more critical. But, in many cases subjective probability judgements and their quality are extremely important. Decision analysis quality depends upon the process being comprehensive, having a sound theoretical basis and being carefully and systematically applied. The same reliance on the procedural guarantee of quality carries over to subjective probability within decision analysis. Concerning the theoretical basis, probability, as a mathematical construct, is well grounded, but there is considerable debate about the philosophical and psychological status of subjective probability. Scarcely anyone would reject it and abstain from probabilistic modelling if no other source of information about uncertainty were available. However, because of its ambiguity there should be an especially strong emphasis in decision analysis on the careful and systematic application of a comprehensive subjective probability elicitation process. Probability changes with time, where the probability of a correct action after one trial is less than after the second trial due to learned experience and corrections.

Nevertheless, subjective probability is a way to deal with uncertainty at any stage of the decision analysis process as a mean of quantifying uncertainties in the models that relate alternatives to possible consequences. Quantification enables the computation of a probability distribution over those consequences for each alternative. Alternatives may be rejected or accepted for further analysis on the basis of the subjective probability of standard system efficiency and effectiveness. During the course of an analysis, the decision-maker may gather information that causes him to revise his beliefs, and consequently, his/her subjective estimate. Due to insufficient data of such type of modelling, decision analysts may tend to use the simplest functions to express his/her beliefs about uncertainties such as, using linear probability functions than sophisticated functions (normal, beta, ...etc)

5.4 Monte Carlo Simulation (Main steps)

This section illustrates the main steps of the Monte Carlo simulation that are used to conduct experiments of the stochastic process simulation. These steps are as follows.

1. Estimate a range of values for each variable affecting the considered system (in our case, the considered system is the project time/cost) and determine the most suitable probability distribution function for each variable. This range consists mainly of two values. The minimum value that expresses the minimum impact of this variable on the project time or cost. This impact is considered as a percentage of the original estimate of time/cost of the task time/cost. For example, a minimum value of 10 per cent means the time or cost of the tasks affected by this variable will be reduced at most by 10 per cent while a maximum value will increase the task duration or cost by its percentage.
2. Generate the cumulative frequency function for the distribution function of the variable, which can be obtained by the inverse probability method or any other method.
3. Select a value for each variable from its cumulative distribution using a random number (RN).

4. Compute the desired objective function of the random variables (which is the project time or cost of the proposed simulation tool determined by a developed project management tool for this research).
5. Repeat steps 1 and 2 for N-times, using successive and independent streams of uniform random numbers, to get N-realisations of the desired function. The 'N-times' is determined where steady results are achieved (i.e. where more iterations do not affect the results).
6. Estimate the desired mean and standard deviation of the objective function.

Figure 5.2 illustrates an example of using the simulation sampling technique in the proposed simulation tool of a triangular probability distribution function for the 'x' variable.

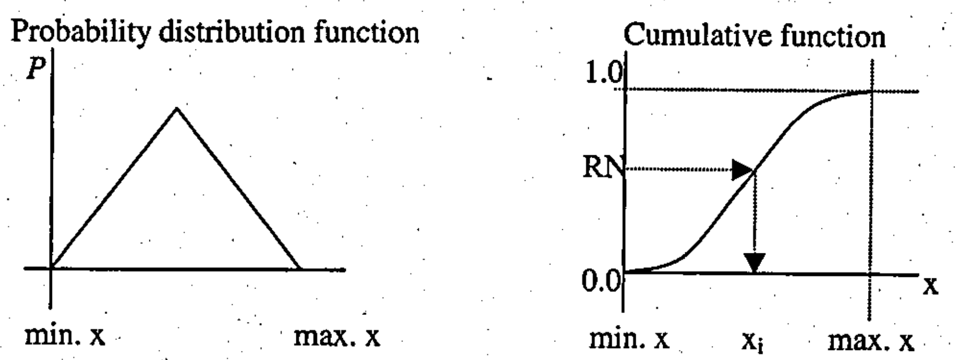

Figure 5.2: Simulation sampling technique

5.5 Monte Carlo technique in the proposed simulation tool

5.5.1 Probability Distribution functions

A random variable is whose values have more than one possible value that can not be predicted with certainty at the time of decision making. For each possible value of the random variable there is an associated likelihood of occurrence.

Random variables are sometimes called stochastic variables to denote the fact that the likelihood of the values occurring is stochastic or probabilistic in nature. On the other hand, if the value of a variable is known or can be predicted with certainty at the time of decision making the variable is called a deterministic variable.

The probability distribution is the graphical representation of the range and the likelihood of occurrence of a random variable. It can be discrete or continuous, depending on the nature of the random variable. If the distribution can be represented by a function, this function is called the probability density function.

Every distribution can be expressed in an equivalent graphical form called the Cumulative Frequency Distribution. A cumulative frequency point expresses the summation of all the previous probability values of the variable to this point.

There are a great number of distributions that are in common use. Each distribution has some features, and is used to describe a variable according to the data available for that variable and with some tests for these data to fit the suitable distribution.

Each random variable has a range of values and can be represented by a probability distribution function. Consequently, the user specifies a type of distribution for each variable by his/her subjective judgement. A difficult situation occurs when the analyst wishes to define a distribution for a random variable but has no data available and has no idea what the shape of the distribution is, or should be. In these cases the analyst needs first to try at least the range of values - a minimum value and a maximum value. Next the analyst needs to determine if any value or a range of values within the limits might be more likely to occur than other values. If the answer is yes, the analyst may then wish to represent the variable as a triangular distribution. If not, a uniform distribution may be suitable. If the most likely estimate for the random variable does not exceed a certain probability value (P), then the weighted triangular distribution can be used.

Some distributions are recommended for representing construction project variables by many models such as those of Van Slyke (1963), Van Tetterdo (1971), Newendorp (1975), Morris (1982) and Willis (1986). These distributions include:

- the uniform distribution which has a range of values and all values have the same probability of occurrence;
- the triangular distribution which has a three possible values for the probability occurrence (the minimum, maximum, and the most likely estimates);
- the weighted triangular distribution which is considered as a special case of the triangular one with the assumption of the probability of the most likely estimate not exceeding a certain value; and
- the discrete distribution has the likelihood of occurrence of the random variable as a discrete value.

5.5.2 Random Numbers (RN)

Random Numbers can be generated using a computer source of pseudo-random numbers. Pseudo-random numbers generation is an algorithm which produces a fixed and deterministic sequence numbers that can at best be called "Pseudo-Random" if the output behaves, according to statistical tests, like a truly random sequence. Pseudo-Random numbers are uniformly distributed within the unit interval (0,1) with equal likelihood. Uniformly distribution random number provides a basis for generating the random varieties required in a wide variety of realistic simulation problems.

It is not correct to use the same random number to sample all distributions on a specific pass. The reason for this is that using the same random number would automatically imply fixed values for all variables (all values will be near their upper or lower limits).

5.5.3 Number of iterations

Crandall (1977) selected five networks for empirical testing to determine the impact of varying the number of iterations during simulation upon the generated time distribution, the criticality of individual activities, and the most likely critical paths. A simulation was performed on each of the five networks varying the number of iterations from 250 to 8000. Results obtained for each network based on varying the number of iterations during the individual simulations are useful in determining the number of iterations to utilise when processing networks by the Monte Carlo technique.

Statistical comparisons of the simulated distributions as a function of the number of iterations indicate that the data generated at 500 iterations were adequate to forecast the desired probabilities of project completion even though the densities were not sufficient to clearly define the actual time distribution. But, it was desired to test the ability to forecast the probability that a given activity would be critical and which paths would be critical. Therefore, Crandall concluded that the 1000 iteration simulation is adequate to determine the relative degree of individual activity criticality.

5.5.4 Dealing with correlation

In practice, numerous interrelationships and dependencies exist among a system's variables. These dependencies may be included in the simulation by means of explicit equations linking the relevant variables.

For any deterministic analysis, each variable estimate is made with complete knowledge of the values attributed to all other variables in the model. For stochastic simulation based on multiple runs, however, it is possible that the expert may allow (consciously or subconsciously) for relationships between the probability distributions that have been selected for the system variables.

It may be, for example, that high values of one variable will tend to be associated with high values of another. Then independent sampling from the prescribed distributions will not fully reflect management's expectations, and consequently, sets of conditional probability distributions are required. A simulation procedure that takes account of such relationships must be based on conditional sampling. Many approaches have been developed to deal with this problem. A popular one was reported by Van Gelder (1967). This approach worked with random numbers and is called 'Markovian Correlation'. This approach assumes that correlating two RNs means two sample values of variables, which use these random numbers, will be correlated.

RNs are chosen independently using RN generators. However, to correlate two random numbers, modification of the second RN somewhat in relation to the first is required. An acceptable formula to achieve this is found by 'Markovian Correlation' in the following expression:

$$\underline{RN_2} = RN_2 + a\,(RN_1 - RN_2)$$

where: RN_1 = first random number drawn

RN_2 = second random number drawn (independently)

$\underline{RN_2}$ = corrected second random number drawn (correlated)

a = weighting factor

This formula corrects the second (independent) random number RN with a proportion (a) of the difference between the first random number and the second one. The effect of the factor (a) is easily recognised. If (a) = 0 then the formula maintains the original independent second random number RN_2 which means no correlation. If a =1 then the second random number is replaced by the first which means full correlation. Somewhere, if the factor (a) has the values $0<a<1$, it obviously obtains partial correlation. Therefore, if the amount of correlation (r) is known or predefined, and after relating (r) to a value of (a), the correlated values for the variables could be determined.

5.6 Summary and conclusions

Towards achieving the research aim (i.e. developing a simulation tool that helps construction companies to simulate the implementation phase of innovation) this chapter introduced a main step of this tool. The proposed simulation tool should include a technique to simulate the influence information on the implementation phases. Building this tool required identification of this information (Chapter 4) and subsequently developing a tool to express its impact on the project phases/tasks. The main characteristic of this information is the high level of uncertainty inherent in their effect on an innovative project. This chapter discussed the technique adopted to simulate this information (Monte Carlo technique) and its structure. The chapter also highlighted the principles of subjective estimates of these information impacts which must be considered the base of using this technique. The proposed tool was developed to deliver Monte Carlo simulation in a user friendly interface.

Programme code of the simulation tool is given in Appendix D. The input format of the tool's stochastic data includes a variable name, the activity affected by this variable and the variable impact range (a percentage of the original estimate). The simulation tool has the capability of identifying influence variables on either the time or the cost of a specific activity. The simulation run starts by selecting an influence value for each variable using random numbers. The affected activity's time or cost is then modified according to the selected percentage of the variable. The project objectives (duration and cost) are then determined using the traditional CPM and cash flow analyses. This simulation sequence is repeated for a sufficient number of runs to get steady results (1000 iterations are enough). A typical result is shown for the case study analysis in Chapter 8. The results are used directly with the fuzzy logic approach developed for this research to assess the output performance of the innovative project. Chapter 6 provides more details of this approach.

CHAPTER 6

SIMULATING INNOVATION PERFORMANCE USING A FUZZY LOGIC APPROACH

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6.1 Introduction

The decision to accept a particular innovation in construction depends on many performance parameters. Meeting project goals in accordance with predetermined performance indicators (such as cost, schedule, quality and safety) needs standard monitoring and control techniques that typically involve a comparison of actual to estimated values where corrections are made if significant deviations exist. The problem of developing a systematic project evaluation process has arisen in previous construction related research (Liu and Walker, 1998). Performance assessment needs a comprehensive set of evaluation criteria and the corresponding indicators for such criteria. The problem grows if the evaluation targets an innovative project where a new process challenges traditional and accepted processes. The inherent uncertainty associated with innovation in construction often requires several iterations to obtain a satisfactory performance. Because refinement or experimentation is often required before the final product is accepted, translation of an innovative process into performance requirements often results in a vague and imprecise definition of the relevant performance indicators. Simulating innovation performance precludes the probabilistic analysis approach because innovation outputs are considered non-probabilistic results and may be measured in linguistic terms. Fuzzy logic models are, therefore, more suitable for simulating innovation performance because of the difficulty in predicting the output performance and the impact of unexpected changes on the progress of construction.

The proposed simulation tool mainly utilises uncertainties and iterations of implementing innovations and uses a fuzzy logic approach to evaluate the performance outcomes of this implementation. The adopted methodology includes the following three steps.

1. Review the construction performance criteria, evaluation models and techniques.
2. Study the fuzzy logic approach as a technique to deal with vague and imprecise definition of the relevant performance indicators.
3. Develop a tool that simulates performance evaluation of the innovative projects under the subjective judgement of project managers.

This chapter reviews some evaluation models that are used to assess "construction performance". The chapter also highlights the differences between innovative projects performance and traditional ones, and discusses the reasons for adopting a fuzzy logic approach to simulate performance evaluation. The fuzzy logic approach is then detailed to show how performance can be evaluated. The developed simulation tool enables users to predict outcomes of a specific scenario of an implementation stage. It is concluded that performance evaluation can be enhanced by using non-probabilistic tools and techniques.

6.2 Construction performance measurement

Based on the business point of view, Bititca et al. (1997) defined performance management as a closed loop control system which deploys policy and strategy, and obtains feedback from various levels in order to manage the performance of the system. Performance measurement is also defined by Bititca et al. (1997) as "*the information system which is at the heart of the performance management process and it is of critical importance to the effective and efficient functioning of the performance management system*". Evangelidisz (1992) defined performance measurement as "*the process of determining how successful organisations or individuals have been in attaining their objectives and strategies*".

Performance measurement has become one of the most significant challenges facing the construction industry. The concept that, if the completed project satisfies the client then the project management processes have been successfully performed, has been argued in many ways. Liu and Walker (1998) addressed the elements needed for this type of measurement such as: what constitutes satisfaction; who are the claimants on the project whose feelings of satisfaction are important; what is the relationship between success and satisfaction; and how should these issues inform our judgement of the outcome of construction projects? According to Oglesby et al. (1989), performance is an inclusive term, encompassing four main elements; productivity, safety, timeliness and quality. Performance of both on-site and off-site activities involves additional aspects that were characterised by Sink (1985) as: effectiveness; efficiency; quality; productivity; quality of work life; profitability; and innovation. Koskela (1992) introduced additional measures for construction, namely:

- waste: number of defects, rework, number of design errors and omissions, number of change orders, safety costs, excess consumption of materials, etc;
- value: value of the output to the internal customer;
- cycle time: cycle time of main processes and sub processes; and
- variability: deviations from the target, such as schedule performance.

Non-traditional measures should be considered with the traditional financial ones. Sanger (1998) stressed that financial measures are useful but they measure the past and measure the easily measurable.

As these measures are not common to all construction projects, evaluation models accommodate the most suitable measures for their applications such as the indices that were selected by Wang et al (1998) to evaluate the implementation of automation in construction. These indices were productivity improvement, quality improvement, cost reduction, time saving, personnel injury reduction, manpower savings and environmental pollution improvement.

Specific research has focused on many individual elements in performance evaluation. As an example, statistically based acceptance specifications provide an objective format for measuring product quality. Quality components such as concrete strengths and pavement thickness tied to a quality index have recently been used for bid evaluation. For example, some highway agencies use pavement profile in evaluating bids by contractors. Here, the owner must establish the cost value of profile conformance in terms of cost per unit length (Ellis, 1997). The contractor's fee or profit is contingent upon meeting some other performance measures which include safety, quality, schedule, craft control and environmental awareness. For example, safety measures may account for a certain percentage of the overall performance and may include criteria that have certain allowance levels in terms of monetary values as part of the total bid. If the contractor falls below the performance standard, then a reduction in profit occurs.

Pocock et al. (1996) presented a method for verification of the relationship between the degree of interaction among project teams and the performance indicators such as cost growth, schedule growth and the number of modifications to the design or construction.

An important part of dealing with performance evaluation involves simulating this evaluation in physical tools and methodologies. The following sections give examples of the existing tools for performance measurement of organisational and project level.

6.3 Simulating organisational performance measurement

Neely et al. (1997) suggested the use of a 'performance measure record sheet' to measure 'how' the performance of an organisation was achieved in addition to 'what' the performance was. The sheet elements were derived from research and case studies. The sheet elements included Performance Title, Purpose, Target, Formula, Frequency of measurement, Frequency of review, Who measures, Source of data, Who owns the measure and what they do, Who acts on the data and What they do.

"The construction industry should set itself clear measurable objectives and then give them focus by adopting quantified targets, milestones and performance indicators", Egan (1998). As a response, the Key Performance Indicators (KPI) pack was released by the Department of the Environment, Transport and the Regions, UK (1999). The KPI is an objective measurement tool for comparing company or project performance in key activities of a business. They facilitate comparison and benchmarking against the range of performances currently being achieved across other projects, companies or the rest of industry. The KPI Pack uses ten headline measures, namely: client satisfaction-product; client satisfaction-service; defects; predictability-cost;

predictability-time; profitability; productivity; safety; construction cost and construction time. According to the KPI Working Group report (2000), the 1999 pack omitted the more detailed elements of performance. The report also presented a framework to benchmark activities in order to clarify these details.

Kagioglou et al. (2001) developed the performance measurement process conceptual framework (PMPF) to present a holistic performance management/measurement process framework which includes the input (vision strategy), process (performance management, deployment process and performance measurement) and output (Business performance). PMPF integrates the main themes of performance management in a simple performance measurement relationship matrix-like arrangement. PMPF developed the balanced scorecard (BSC), devised by Harvard Business School Professor R. Kaplan and Renaissance Solutions President D. Norton, by adding the 'project' and 'supplier' perspectives to suit the construction industry.

6.4 Simulating project performance measurement

Several models have been developed to evaluate project performance at site and project level. Some of these models focus on predicting project performance while others focus on measuring. Many of these limit their analysis to a number of measures such as cost, schedule, or productivity. Traditional models have been used to measure non-traditional performance aspects for example those at the site level; work-sampling techniques have been applied to measure different waste categories in construction (Alarcon, 1997).

Kumaraswamy and Thorpe (1996) formulated a proposal to evaluate a project through: hierarchies of general success criteria appropriate to different categories of projects; indicators that evaluate performance against such criteria; and typical ranges of values that such indicators may take in these project categories. Criteria for success were related to cost, quality, time, client satisfaction, project-team satisfaction, technology, and environment, health and safety. Subcriteria could be considered in a particular project category. Indicators were proposed to help quantify the evaluation of criteria and subcriteria (such as unit cost).

Alarcon and Ashley (1996) presented a methodology for modelling project performance that combines experience captured from experts and assessments from the project team into a general performance model for application in individual projects. Project options such as organisational structures, incentive plans and team-building alternatives have been incorporated into the model knowledge base. The model allows management to alter these options and predict expected cost, schedule and other performance measures. Four performance measures were used for the model analysis: cost, schedule, value and effectiveness. The model requires a probability distribution for each performance outcome in addition to a base performance value to measure each performance deviation. If a combined performance measure is required to evaluate the relative overall performance of options or their combination, a trade-off value between one unit of performance and a cost value is required. The outputs of this model are predictive, quantified comparisons of project execution strategies in terms of the outcome measures, and detailed qualitative and quantitative explanations of the causal interactions.

Russell et al. (1997) identified 76 continuous project variables for successful and less-than-successful projects. These variables were used to predict project cost and schedule performance from the start of detailed design through construction completion as standard S-curves. These variables were measured in terms of money or effort hours and could be converted to a percentage (ratio of to-date to plan). The progress of the actual project can be monitored with respect to the S-curve of the cost or schedule of the successful and less-than-successful projects. Hence, engineering judgement can be used to make a decision as to whether corrective action is necessary to keep the track of the project close to the successful path.

A Neural Network Approach was adopted by Chua et al. (1997) to identify the key determining management factors of the budget performance of a construction project. Eight factors were identified covering the areas of the project manager, his/her team, planning and control efforts. The factors were: number of organisational levels between project manager and labour, manager experience on projects of similar technical scope, detailed design complete at the start of construction, constructability programme, project team turnover rate, frequency of budget updates and control system budget. These factors were used as objective measures of the management attributes for project success. Unlike predictive and regression techniques, where a functional relationship between the input factors and project outcome is assumed and tested using the data, this approach does not need to assume any priori functional relationships.

McCabe et al (1998) produced a construction simulation model that was linked to a belief network where performance indices were calculated and analysed. The belief network is a form of artificial intelligence that may be described as a probabilistic-based expert system. Five performance indices were used for simulating the network of a truck loading operation, namely; the queue length index, queue wait time index, customer delay index, server utilisation index and server quantity index. If the performance constraints were not all met, then remedial actions were sent from the belief network back to the simulation module where the resource parameters were modified and the simulation run again.

A more recent research programme developed accurate representations of standard construction means and methods to evaluate the impacts of innovation on these standard methods (Slaughter, 1999). Performance was measured on the basis of the daily progress, overall duration, resource-based costs and exposure of workers to dangerous conditions.

Among the previous performance evaluation models, described above, it is noted that there is a lack in simulating innovation performance. The recent programme of Slaughter (1999) can be considered the most valuable example that deals specifically with innovation performance. From the above, it is noted that all of the performance measures were expressed in quantifiable terms and the measures used were entirely objective. As performance evaluation is a multi-criteria problem and no two organisations or managers will weigh individual measures equally, a model for evaluation must have the flexibility to include the individual organisational objectives in quantitative and qualitative terms. The flexibility required for innovation planning should overcome decision-makers' poor abilities to make realistic probability assessments for the stages of the innovation process. Unresolved uncertainty cannot affect the consequence of a decision, therefore, subjective judgements and their capabilities to express estimator's plans are critical to adoption of the simulation technique. Subjective judgement of a unique event assumes the application of a heuristic rule. This heuristic rule to implement innovations assumes that the probability of an event is derived from how easy it is to construct a scenario that leads to the event. This probability of events changes with time, where probability of correct action after an unaccepted trial of implementation increases for the next trial due to the learned experience and corrections.

The simulation tool developed in this research evaluates the performance outcome of an innovation according to the available information and helps managers decide whether to accept the output or iterate for modifications. The tool uses the Monte Carlo technique to simulate the innovation process's influence information (as described in Chapter 5). Results are then used as input data to a fuzzy logic approach of the innovation's performance outcomes. The fuzzy logic approach is useful in the absence of adequate information and also to express the qualitative terms of performance measures. The main advantage of the fuzzy logic concept is its ability to express linguistic judgements. This fits well with simulating innovation performance where linguistic judgements such as bad or adequate are often used in expressing performance. The proposed simulation tool assumes the possibility of estimating a trade-off value between one unit of performance and a cost value or a time unit to express any performance indicator. In the following section, the concept behind the proposed tool is illustrated and the impact of performance evaluation on running that tool is presented.

6.5 Fuzzy logic concept and applications

The fuzzy logic approach is one of the artificial logic systems that have been developed to simulate linguistic judgements. The fuzzy logic approach, initiated by Zadeh (1965), is useful for uncertainty analysis where probabilistic data are not available. In traditional crisp set theory, elements are either included or excluded from a set, while in fuzzy set theory, elements are described by a function as being a member or non-member of a set. This is called the membership function. Figure 6.1

illustrates the criteria of a membership function in trapezoidal shape. The membership function has a range of values from zero (which indicates non-membership) to one (which indicates full membership), and values in between describe the degrees of partial membership. Membership functions can take various shapes and forms.

6.5.1 Fuzzy membership function

Ross (1995) identified the terms of a fuzzy membership function that include the core, the support and the boundaries. The core of a membership function for a fuzzy set is the region of the universe that has complete membership; $\mu(x) = 1.0$. The support of a membership function for a fuzzy set is the region of the universe that has non-zero membership; $\mu(x) > 0.0$. The boundaries of a membership function for a fuzzy set is the region that has a nonzero membership but not complete membership; $0.0 < \mu(x) < 1.0$. A typical fuzzy set is one whose membership function has at least one element in the universe whose membership value is unity (as described by a triangular shape). However, many operations such as addition, subtraction or multiplication on fuzzy sets result in fuzzy sets that are not typical. Membership functions can be symmetrical or asymmetrical and one-dimensional universes, as shown in Figure 6.1, or n-dimensional universes where curves become surfaces or hyper-surfaces.

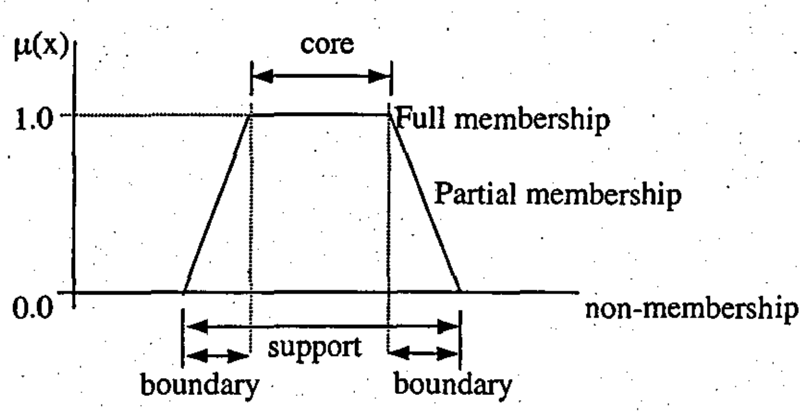


Figure 6.1: The membership function of a fuzzy variable (Trapezoidal shape)

The fuzzy logic approach has been widely applied in construction to represent uncertainties. For example, it was used in: the design/build proposal evaluation process (Paek et al. 1992); the bidding price decision process (Paek et al. 1993); construction activity estimation (Shin 1994); project network analysis (Lorterapong and Moselhi, 1996); and the evaluation of alternative construction technologies (Chao and Skibniewski, 1998).

A group of fuzzy sets can be used to represent a set of variables that in turn represents a set of performance indicators in the proposed simulation tool. Details of this representation are given in the following sections.

6.6 Fuzzy sets of indicators and categories

A fuzzy logic approach to evaluating alternative technologies was introduced by Chao and Skibniewski (1998). The approach was proposed to consolidate the obtained probability distribution of cost (resulting from the Monte Carlo Simulation analysis as a middle ground between the oversimplification of the expected value method and the practical difficulty of the utility theory method) for each alternative technology into a probability-profit-loss vector before evaluation by fuzzy logic. The elements of this vector are defined conceptually in Equations (1) and (2) and are incorporated in Figure 6.2.

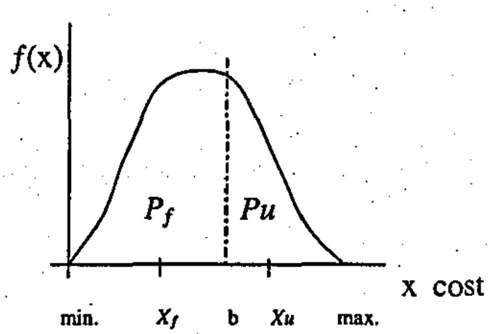


Figure 6.2: Probability density function of cost analysis

$$P_f = \int_0^b f(x)\,dx \quad , \quad X_f = [\int_0^b x\, f(x)\,dx\,] / P_f \quad \text{(1)}$$

$$Pu = \int_b^{+\infty} f(x)\,dx \quad , \quad Xu = [\int_b^{+\infty} x\, f(x)\,dx\,] / P_u \quad \text{(2)}$$

x = cost of operation for using a technology

$f(x)$ = probability density function of cost

b = break-even cost

Where P_f refers to the chance of favourable conditions that result in a profit, and X_f refers to the average cost under such conditions for $x < b$. Pu (= $1 - P_f$) refers to the chance of unfavourable conditions that result in a loss, and Xu refers to the average cost under such conditions for $x > b$.

This approach has been developed in this research to be used as a planning tool and to evaluate the innovation implementation in terms of time and cost performance. The calculation procedure is shown in Figure 6.3.

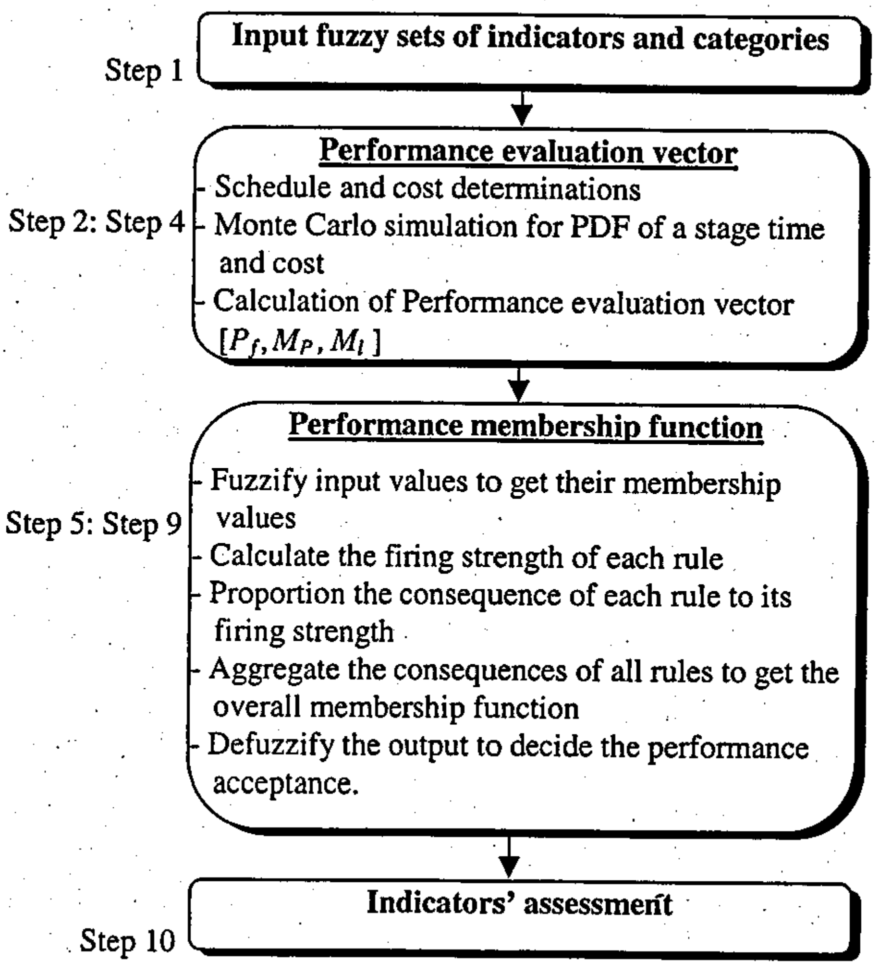


Figure 6.3: Algorithm of fuzzy logic performance evaluation

Measuring performance outcome requires managers to suggest that certain indicators are important (the first step in Figure 6.3). These indicators can be selected from a list introduced by the proposed simulation tool that built on literature and the interview results (see Chapter 4). Each indicator should have a standard that satisfies the project team such as; a cost requirement of "not to exceed" a certain amount of money and quality inspection deviations of "not to exceed" a certain value of units. All the indicator standards should be expressed in terms of cost or time units to suit the structure of the simulation tool. These indicators summarise the overall performance which will be specified as a fuzzy set expressed in Zadeh's notation for discrete fuzzy variable, i.e., $\{\frac{x1}{I1},\frac{x2}{I2},...,\frac{xn}{In}\}$ where x_i are the membership of indicators I_i, $i = 1,\ldots,n$ (n = total number of performance indicators). At least one of x_i should take a value of 1.0. This membership can be represented by the one column fuzzy vector $X = \{x_1, x_2, \ldots, x_n\}$.

The project team is also required to assign the rating categories that these indicators are measured against. The tool proposes these categories as; "Bad" (B), "Inferior" (I), "Adequate" (A), "Superior"(S) or "Excellent" (E). 'B' indicates that the performance outcome (PO) cannot meet the requirements for these criteria, 'I' indicates that PO can only meet the requirements with modifications or lowering the decision-maker standards, 'A' means that PO can meet the minimum acceptance requirements, 'S' means that PO is among the best, and 'E' means that PO is the best available. The linguistic variable "performance outcome" is a fuzzy variable that can be represented by a family of linguistic terms which can be formulated on membership functions having a certain shape and a certain range which are perceived as fit for given conditions. Figure 6.4 illustrates this function in a triangular shape. Overlaps between membership functions always exist to overcome the aspects of the traditional crisp theory of defining an element.

Fuzzy set values for the rating categories should be estimated by the user where at least one takes the value 1.0. Consequently, a one row fuzzy vector is obtained to represent the rating categories; $Y = \{y_1, y_2, y_3, y_4, y_5\}$. The fuzzy relation (R) between fuzzy sets X and Y can be calculated by the Cartesian product (R = X * Y). Then the membership function of the fuzzy relation can be found using Equation 3.

$$\mu_R (x,y) = \mu_{X*Y} (x,y) = \min (\mu_X (x) , \mu_Y (y)) \quad \text{...(3)}$$

This membership function is a relation matrix between the performance indicators (as rows) and the rating categories (as columns). This matrix is used to assess the simulation tool result against each indicator, as will be shown in the tenth step of the simulation tool algorithm (end of section 6.6.2). Given an overall performance *OP'* resulting from the defuzzification (as will be determined in step 9), the fuzzy evaluation of each performance indicator (PI_i) is determined by composition such that shown in Equation 4.

$$OP' * \mu_R (x,y) = PI_i \quad \text{...(4)}$$

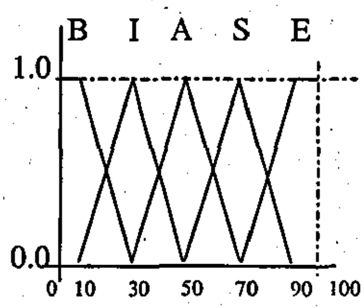


Figure 6.4: Membership functions of the performance outcome

6.6.1 Performance evaluation vector

For the second step of Figure 6.3, the schedule and cost analysis for a set of loop tasks of an innovation implementation stage under ideal conditions of estimation are determined that were resulted from the planning part of the proposed simulation tool (break-even time/cost of Equations (1) and (2)). In the third step, the influence factors that affect the innovation stage are analysed by Monte Carlo simulation, see Chapter 5 for the simulation details, to give the probability density function (PDF) of the stage time or cost. In the fourth step, Equations (1) and (2) obtain [P_f , X_f ,Pu , Xu]. The performance evaluation vector for an innovation stage [P_f, M_P, Pu, M_l] can now be obtained, where $M_P = b - X_f$ is the mean favourable performance for x < b, and $M_l = b - Xu$ is the mean unfavourable performance for x > b. As Pu is redundant of P_f, it can be excluded.

The approximation of an original probability distribution of time/cost by a performance evaluation vector preserves the risk element, while also including the other important element, the possible reward that balances the risk in a decision situation. Thus, the factors that most concern a decision-maker are addressed (Chao and Skibniewski, 1998). This step prepares the input required for the application of the fuzzy logic.

6.6.2 Performance membership function

The fifth step, in Figure 6.3, is to formulate the fuzzy rules for the decision problem using the subjective preference of the decision-maker. Fuzzy logic for decision-making is represented by the form of IF-THEN rules; IF condition 1 AND condition 2 AND...THEN consequence 1 AND consequence 2 AND.... Each condition or consequence in a rule is part of a fuzzy variable. The problem at hand involves three fuzzy input variables:

- the chance of making a favourable performance (FPC);
- the expected favourable performance magnitude (FPM) in favourable conditions; and
- the expected unfavourable performance magnitude (UFPM) in adverse conditions.

The consequence part of a rule is the fuzzy variable of the performance outcome which is set by a pre-determined rules.

A family of fuzzy sets has been formulated for the three fuzzy variables and, for simplicity, each variable was limited to three membership function "Low" (L), "Medium" (M), and "High" (H). The range of values of the three membership functions is determined to cover the expected range of each variable; the maximum chance is one, the maximum and minimum expected FPM or UFPM are calculated according to the results of the Monte Carlo analysis (Figure 6.2). The minimum expected FPM is obtained when the actual implementation of a stage is compatible with the estimation under ideal conditions (i.e. = b – b = 0.0). The maximum expected FPM can be obtained if the actual implementation gives the minimum output of the simulation result (i.e. = minimum value of x), see Figure 6.2. Therefore, the maximum value of FPM = (b – minimum value of x). By the same determination, the minimum and maximum of UFPM can be obtained as (0.0) and (the maximum value of x – b), respectively.

In modelling real-life problems, linear approximations such as the trapezoidal and triangular fuzzy numbers are frequently used (Lorterapong and Moselhi, 1996). The particular shapes and ranges of the membership functions in a fuzzy set family for a fuzzy variable should be derived from the interpretation of individuals and the contexts in which they are considered (Chao and Skibniewski, 1998). Accordingly, triangular shapes were adopted to represent the membership functions (Figure 6.5). However, the important character of the membership function curves for purposes of use in fuzzy operations is the fact that they overlap, Ross (1995). The precise shapes of these curves are not so important in their utility. Rather, it is the approximate placement of the curves on the universe of discourse, the number of curves (partitions) used, and the overlapping character that are the most important ideas.

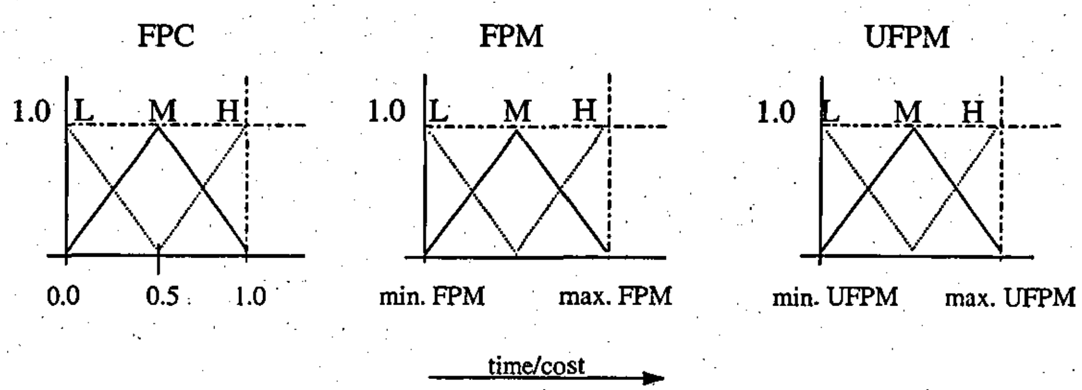


Figure 6.5: Membership functions for the performance evaluation vector

The consequence variable, "performance outcome", has possible linguistic values (B, I, A, S and E) and was defined on a scale of 0 to 100 as the support quantity (Figure

6.4). The consequence function has overlaps and the ranges shown were designed equally. The assigned ranges to the consequence function gives equal weight values for performance evaluation levels.

Since each of these fuzzy variables has three membership functions; L, M, and H, there could be a total of 3^3 (27) different combinations of conditions that affect the performance level. Table 6.1 presents the fuzzy rules formulated for this simulation tool. As an example:

> IF favourable performance chance (FPC) is Medium (M);
> AND favourable performance magnitude (FRM) is Low (L);
> AND unfavourable performance magnitude (UFPM) is High (H); and
> THEN Performance outcome is Bad (B).

Systematic steps were used to determine the membership function (B, I, A, S, and E) associated with the three conditions of each fuzzy rule. For each variable, a score of 1, 2, and 3 was given to the "Low", "Medium", and "High" linguistic terms, respectively, of the FPC and FPM variables. A score of 3, 2, and 1 was given to the "Low", "Medium", and "High" linguistic terms, respectively, of the UFPM. Considering the above example, the three conditions give a total score of 4. This total score is compared to pre-set values of "4 or less, 5, 6, 7, and 8 or more" which relate to the membership functions B, I, A, S, and E, respectively. This process is known as the fuzzy rule inference.

The sixth step of the fuzzy logic performance algorithm (Figure 6.3) is applying the 27 rules so that the firing strength of each rule can be determined. This process is known as fuzzification. Figure 6.6 shows the fuzzification's calculations of the above example rule. The intersection of $[P_f, M_P, M_l]$ with the membership functions provided membership values w1, w2 and w3, respectively. The smallest value of w1, w2, and w3 (the minimum operator) specifies the firing strength of that rule. This method of determining a firing strength of a rule is called the minimum operator which is one of the common methods of fuzzification.

Table 6.1: The fuzzy rules formulated for performance outcome

Rule number	FPC	FPM	UFPM	Performance outcome
1	High	High	High	7=Superior
2	High	High	Medium	8=Excellent
3	High	High	Low	9=Excellent
4	High	Medium	High	6=Adequate
5	High	Medium	Medium	7=Superior
6	High	Medium	Low	8=Excellent
7	High	Low	High	5=Inferior
8	High	Low	Medium	6=Adequate
9	High	Low	Low	7=Superior
10	Medium	High	High	6=Adequate
11	Medium	High	Medium	7=Superior
12	Medium	High	Low	8=Excellent
13	Medium	Medium	High	5=Inferior
14	Medium	Medium	Medium	6=Adequate
15	Medium	Medium	Low	7=Superior
16	Medium	Low	High	4=Bad
17	Medium	Low	Medium	5=Inferior
18	Medium	Low	Low	6=Adequate
19	Low	High	High	5=Inferior
20	Low	High	Medium	6=Adequate
21	Low	High	Low	7=Superior
22	Low	Medium	High	4=Bad
23	Low	Medium	Medium	5=Inferior
24	Low	Medium	Low	6=Adequate
25	Low	Low	High	3=Bad
26	Low	Low	Medium	4=Bad
27	Low	Low	Low	5=Inferior

In the seventh step of Figure 6.3, the smallest value of w1, w2 or w3 resulted from step six is used to truncate the membership function for the output, i.e., it defines the contribution of this rule to the overall output (the shaded area in Figure 6.6). This process is repeated for all rules.

The eighth step of Figure 6.3 applies the union operator (one of the common methods to represent a fuzzy membership function for a fuzzy rules consequences) to aggregate the consequences (Area 1 to Area 27) of the 27 rules to form an overall membership function for the performance outcome.

The ninth step, a defuzzification process, is applied to convert the overall membership function into a crisp (non-fuzzy) value (see Figure 6.7). The centre of area method is one of the most common methods used to defuzzify the overall membership function (Ross, 1995). This crisp value represents the overall performance outcome level (*OP'*) for the assigned innovation stage under the information factors influencing that stage.

Finally, in the tenth step, the decision-maker can decide to accept the performance or iterate the process again for a better performance outcome. This is achieved by executing Equation 4 to get the fuzzy evaluation of each performance indicator's (PI_i) as discussed in step one. The composition of Equation 4 results in identifying each indicator rate, i.e. Bad, Inferior, Adequate, Superior or Excellent.

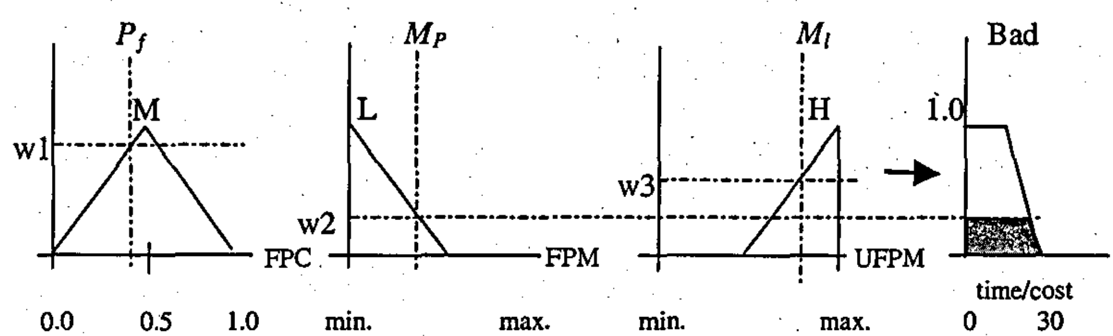


Figure 6.6: Example of fuzzy rule application on performance evaluation vector

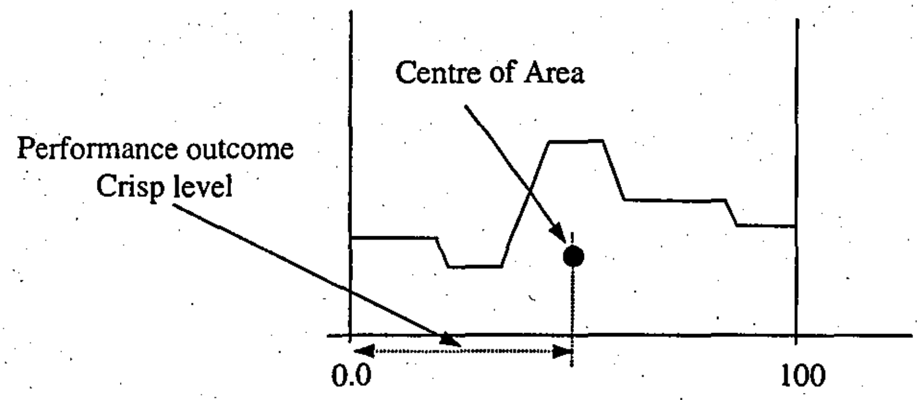


Figure 6.7: The overall membership function for the performance evaluation

Like other quantitative approaches to risk evaluation, sensitivity analysis can be performed to see the effect of changes in inputs and assumptions on the final evaluation result.

6.7 Summary and Conclusions

This chapter has presented a simulation tool for the evaluation of innovation performance. The tool's results help managers to decide whether to accept or iterate an innovative process towards achieving satisfactory performance. The main advantage of the fuzzy logic approach, which was used to simulate project performance, is its ability to express linguistic judgements. It fits well in simulating the innovation performance where a linguistic judgement, such as bad or adequate, is more appropriate for assessing this performance. The fuzzy logic approach also converts qualitative criteria into numerical measures that can simulate an innovation process where mathematical precision is impossible or impractical. In conjunction with this chapter, microcomputer-based software was developed to help decision-makers incorporate uncertainties associated with the influence factors on the innovation process (see Appendix D for the program code of the simulation tool). The software also has the ability to simulate subjectivity associated with ambiguous performance. Sensitivity analysis can be performed to see the effect of changes in inputs and assumptions on the final evaluation result.

Applying the fuzzy logic approach to assess the innovation performance could result in an iterative implementation to obtain satisfactory performance. Chapter 7, therefore, deals with the problem of iteration inherent in implementing innovations. Chapter 8 demonstrates the simulation tool application for a case study including sensitivity analysis.

CHAPTER 7

SIMULATING THE ITERATIVE NATURE OF THE IMPLEMENTATION Of INNOVATION

CHAPTER 7

SIMULATING THE ITERATIVE NATURE OF THE IMPLEMENTATION OF INNOVATION

7.1 Introduction

The fundamental challenge in innovation management is the planning and control of work. Innovation management is influenced by things such as innovation barriers, expected changes during its development and high level of uncertainties. Innovation implementation is also evaluated by performance indicators in managerial and technological aspects. Traditional planning techniques (such as network analysis and bar charts) of production process (such as construction) were developed on the basis that these processes have definable logic in a sequential progress.

Planning the implementation of innovation, however, requires estimating information that affects implementation and the performance related to it. The process has to be repeated until satisfactory outcomes are obtained. This type of planning has a special feature that is the interdependency between a process and its results. While the results are dependent on the process, the process could not be approved until these results are obtained. This makes the traditional network analysis tools inappropriate for planning innovation basically because it takes no account of this interdependency. The iterative nature of the innovation process requires a new planning methodology to overcome the shortcomings of the traditional planning ones. The proposed simulation tool was devised to overcome these limitations. This tool adopts the Dependency Structure Matrix (DSM) technique to simulate the interdependency of the innovation process.

This Chapter was preceded by introducing two techniques. The technique of Monte Carlo simulation was used to model the impact of influence information on the innovation process described in Chapter 5. A fuzzy logic approach was used to evaluate the innovation performance (Chapter 6). The proposed simulation tool is linked to the dependency structure matrix (DSM) tool to define the expected loop tasks.

After identification of the implementation tasks planned to achieve an innovative project, DSM is used to identify tasks of the expected loops within the innovation implementation. DSM is used, again after running Monte Carlo and fuzzy techniques, to evaluate the performance of each implementation and to manage and schedule the implementation tasks. The simulation tool produces an innovation programme that requires some iteration between the DSM and programming phases.

Techniques that have been used to develop such iterations in construction are the Cyclone and Design Structure Matrix (DSM) techniques. Both of them can simulate repetitive/iterative works. Cyclone has been used to simulate repetitive operations in construction but it is not suitable for cases that have interdependent relationships such as those found in innovation projects between the project phase deliverables and the performance assessment.

According to the assessment resulting from the fuzzy logic approach, managers can define the relationship between each process phase, its performance and its succeeding phases. Also, managers can decide if the process phase is acceptable or the work should be repeated to achieve satisfactory performance. The latter decision describes the iteration associated with implementing innovations. The relationships (dependencies) mentioned here are the main inputs to the DSM.

This Chapter presents the principles of DSM to simulate iterations resulting from any experimentation or refinement that are always expected in implementing construction innovations. The Chapter also discusses the potential application of the DSM during planning and control of innovation implementation. The Chapter presents a new classification system for the interdependency among the iterated tasks within the DSM which was developed using fuzzy logic. Using the simulation tool resulted in the implementation of innovation being programmed more effectively. In addition, an associated computer tool was developed to facilitate effective planning for the innovation process.

7.2 DSM methodology

Although network analysis and bar chart techniques for planning construction work schedule the sequential processes on the basis of the completion of elements of work, they do not have the capability to deal with the iteration in an innovation process.

DSM developed by Steward (1981) is a powerful tool that may be used to demonstrate the optimum order of the interdependent tasks, identify iterative tasks and plan the engineering works based on a required number of iterations. The interdependency within the innovation process always exists between the implementation tasks and their performance assessment tasks. The interdependency is represented by the DSM in a square matrix form.

Eppinger (1991) developed Steward's technique of the DSM with the objective of using it as a modelling tool for managing concurrent engineering for design and manufacture. Three possible models of activity relationships between any tasks are classified, namely; Dependent Tasks (Series), Independent Tasks (Parallel) and Interdependent Tasks (Coupled). Managing the first two types is relatively straightforward, however, the third type (the Interdependent) is more complex and requires more achievement time and many iterations of information transfer. The Interdependent model is more realistic for simultaneous engineering where iteration is typical.

Considering the proposed simulation tool of implementing innovation in construction and Steward's DSM, innovation implementation tasks can include the three above-mentioned types. Many innovative tasks can be treated as coupled tasks that require interdependency among a series of implementation tasks. These type of tasks must be solved simultaneously and require iteration.

7.3 Using DSM in construction

This technique has been applied in the manufacturing industry mainly by Steward (1981) and has been extended by Eppinger (1991), Gebala and Eppinger (1991), Krishnan et al. (1993), Pimmler and Eppinger (1994) and Smith and Eppinger (1995).

In construction, McCord and Eppinger (1993) used DSM to design project teams and identify when co-ordination of these teams is essential to carry out the coupled tasks of a component of the product under consideration. Baldwin et al (1995) applied DSM for simulating problems in the scheme stage of a building's design. Discrete event simulation was applied to predict the effects of changes in the design with regard to the overall duration and resource allocation of the process (Baldwin et al 1998). The technique was also used to schedule work across all stages of a construction project (Vahala, 1997). This work has been focused on problems at an overview level. Huovilla et al (1995) applied this technique on a case study of a building design project. The majority of the problems encountered during the design process were connected with the tasks within the iterative blocks. It was envisaged that the DSM might be used in construction for planning and management of design, fast tracking analysis and visualising the effects of change initiated by clients.

Austin et al (1999) described the use of DSM in a simple building design problem comprising 50 activities across the architectural, civil engineering and structural engineering disciplines. This work led to the conclusion that DSM is a tool that could be used to demonstrate areas in a design that need to be undertaken in an iterative manner.

Recent work has applied the technique to problems outside of design and hence it is now known as the Dependency Structure Matrix (DSM) technique (Browning, 1997). A new approach is proposed in this research to use DSM for simulating innovation implementation in construction and this is discussed in this Chapter.

7.4 DSM structure

The main structural element of the DSM is a square matrix containing the project tasks. For example, Figure 7.1a interprets the matrix notations. The problem activities are listed arbitrarily down the left-hand side of the matrix and across the top of the matrix. Each mark in the matrix cells indicates that the task on the left hand side is dependent upon the task at the top of the matrix. If the tasks are listed by the sequence they were undertaken then a mark below the diagonal shows that a task is dependent on information produced by a previous task, whereas a mark above the diagonal indicates that a task is dependent on information that has yet to be produced. If this unavailable information is estimated, the dependent task can be performed as can the independent task, following which the estimate can be verified. It may be that the task dependent on the estimated information has to be redone if the original estimate was not accurate, resulting in an iterative loop of innovation tasks. The shaded block in Figure 7.1a indicates the loop tasks, such as 'task 3' that requires an estimate of information from 'task 5' while 'task 3' is on the dependent path of 'task 5'. Working on the matrix requires re-arranging tasks to minimise the importance of the elements above the diagonal.

The aim of planning these tasks is to reduce the need for estimates and therefore iteration within the process. This can be achieved by reordering the matrix's tasks so that as many marks fall below the diagonal or as close to it as possible. The re-ordering process is called partitioning. Figure 7.1b shows the matrix of Figure 7.1a after partitioning. Note the smaller loop that it has in comparison to Figure 7.1a. For projects that have large number of tasks, partitioning significantly minimises the size of iterative loops within the process.

7.5 Operating DSM

Operating DSM mainly includes two procedures; partitioning and tearing. Partitioning may be done manually in the case of small processes, but for large processes a computer program has been developed. Many techniques can achieve the "Partitioning" such as path searching (Steward, 1981), the mathematical system of Boolean algebra (Ledet and Himmelblau, 1970), a knowledge-based expert system (Roger, 1989) or a genetic algorithm (McCulley and Bloebaum, 1994 and Rogers, 1996).

	1	2	3	4	5	6	7	8	9
Task 1									
Task 2	X						X		
Task 3		X			X				
Task 4			X						
Task 5				X					
Task 6			X						
Task 7					X				
Task 8						X	X		
Task 9								X	

(a)

	1	2	3	4	5	7	6	8	9
Task 1									
Task 2	X					X			
Task 3		X			X				
Task 4			X						
Task 5				X					
Task 7					X				
Task 6			X						
Task 8						X	X		
Task 9								X	

(b)

Figure 7.1: Example of a Dependency Structure Matrix (DSM)

7.5.1 Partitioning and tearing

Partitioning a matrix is a process by which tasks that do not belong to iterative loops are re-ordered and tasks that are within iterative loops are indicated. The interrelationship between any loop's tasks enable any of them to be estimated to complete the loop. Optimising these estimations to the minimum number, which is called 'tearing loops', enhances the implementation outputs.

The marks above the diagonal, in Figure 7.1a or b, show where estimates are required to start an iteration. Therefore, tearing aims to use the partitioning order to choose marks above the diagonal to represent reasonable estimates. These estimates can be made with some confidence and thus do not need to be re-estimated for the iterative process.

The tearing process includes reordering the loop's tasks to minimise estimations, identifying the point at which the loop undertakes, scheduling the rest of the loop's tasks and removing dependencies to reduce the loop's size. The tearing process needs assigning levels to the task dependencies. High level dependencies are given to good estimates or non-sensitive poor estimates at which loops are torn first, then the matrix is re-ordered by partitioning. If further estimates are required to break all loops, then the next highest level numbers have to be torn.

Many methods have been developed to classify levels for the loop activity dependencies. Smith and Eppinger (1993) introduced a percentage weighting scale for dependency importance and also developed a three-point scale of dependencies in iterative loops to indicate the probability of a dependency contributing to the iteration. Rogers and Bloebaum (1994) developed a seven-point scale of design information dependence strengths that can either be determined subjectively or calculated by an algorithm. Mathematical models were developed by Nukala et al (1995) to identify the key tasks that influence the iteration of highly repetitive manufactured products. Smith and Eppinger (1995) proposed another numerical measures approach for each dependency to indicate the probability of an additional iteration being necessary if the interdependent tasks are performed in the specified order. The numerical value was considered a measure of the portion of information produced during the first iteration that will need to be changed during the second iteration. Austin et al (1999) described a further three-point scale of classification based on the strength of dependence of information, sensitivity of activities to changes in information and the ease with which information can be estimated. As most of the loop tasks are taken place between tasks of implementation and their performance assessment, this research introduced a new scaling system resulting from a fuzzy logic approach for assessment of innovation performance that will be presented later in this Chapter.

As the tearing process will not eliminate all the cycles, the loop's tasks may then be unwrapped to provide a precedence diagram without loop. Figure 7.1b shows a matrix of ordered tasks with loops included which is re-drawn as a precedence diagram in Figure 7.2. Managers can assume, for instance, two iterations of work within the cycle, i.e. preliminary and final work for both the inner and outer cycle. Tasks being repeated several times can have less duration on successive cycles due to the experience gained from previous cycles.

Steward (1981) provided a method of assessing the task duration of each iteration that assumed a set up time for the first iteration and then a percentage reduction in task time for each subsequent iteration.

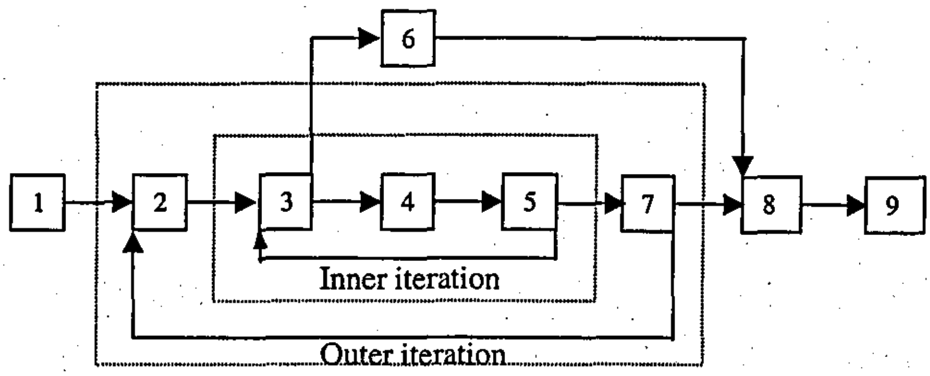


Figure 7.2: A precedence graph developed from the matrix of Figure 7.1b

Rogers (1989) presented a heuristic approach algorithm to achieve the tearing which removes dependencies that are most responsible for causing the loop on the basis of an algorithm calculation. Steward (1993) presented the shunt diagram method to obtain a series of suggested tears and a weighting of their effectiveness in reducing the loop's size that allow users to assess the feasibility of each tear based on practical experience.

The shunt diagram method collects the loop's tasks in a rolled-up task and removes the interrelationships from the loop allowing the loop's tasks to be undertaken concurrently. The method keeps the dependencies between the rolled up task and the previous and subsequent tasks unchanged. This method only requires an estimate for the rolled up task duration. The individual loop's tasks durations and the number of iterations to achieve the all loop are not required.

Austin et al. (1999) illustrated alternative methods for representing tasks in an iterative loop with different implications for the way of programming, see Figure 7.3. For example, options A and B assume that all tasks begin simultaneously which means co-ordination between tasks in the loop can be sought from the very beginning. Alternatively, finishing the loop's tasks concurrently (options A and C) indicates achievement of the final co-ordination for the proposed tasks. No single option is appropriate as the sole means of programming iterative work, Austin et al. (1999). Assessment of the above alternative ways of loop programming should consider the achievement of the overall project duration, the available allocated resources for each option (which may need to be heavy for undertaking tasks in parallel) and both initial and final co-ordination for each loop.

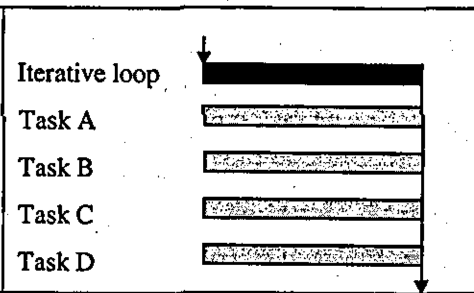
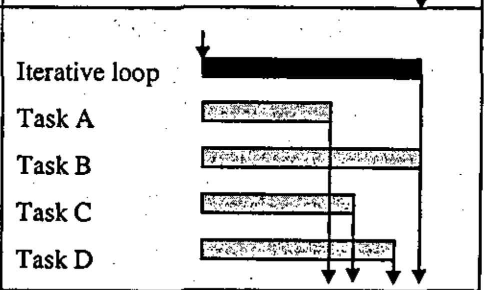
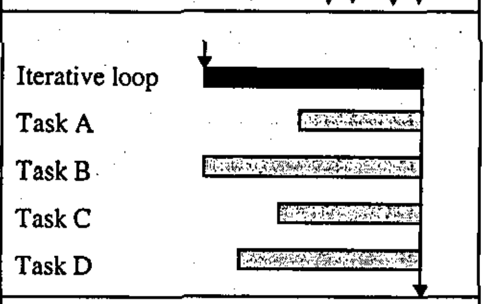
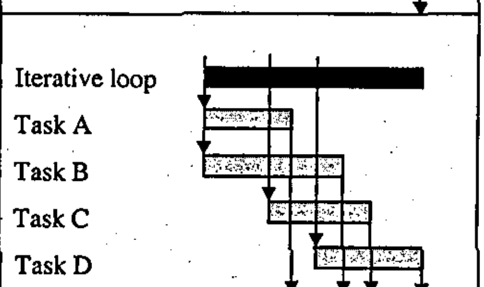
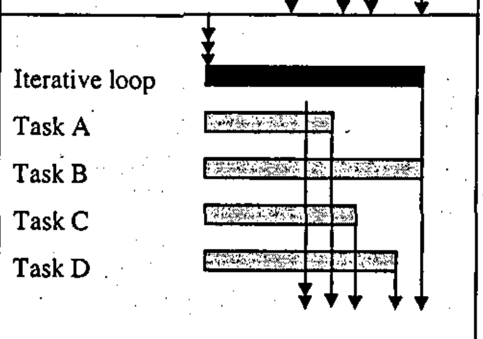
A	All tasks within the loop are allocated the same duration. Resource allocation to the tasks is not levelled. This means no task begins until all can begin, and no information is released from the loop tasks until they are 100% complete (the undertaking of the loop is delayed) and fully co-ordinated. The project duration may be extended and resources may require heavy allocation, but co-ordination is endured.	
B	Activity durations are allocated independently and tasks are programmed within the loop to begin simultaneously. Again, resource allocation may need to be heavy. Initial co-ordination should be achieved but final co-ordination is only achieved after the rest of the design is under way, meaning some overdesign may be necessary to avoid the need to readdress tasks in the loop.	
C	Activity durations are allocated independently and tasks are programmed within the loop to finish simultaneously. Again, resource allocation may need to be generous. Final co-ordination should be achieved but initially, activities are undertaken and not co-ordinated.	
D	Activity durations are allocated independently and tasks are programmed within the loop to begin and finish at times dictated by the resource levelling. This is the approach automatically assumed by the resource levelling in a project planning tool. Resource levels can easily be achieved but the project duration is extended. Some assumptions must be made because some design tasks are completed before others begin.	
E	Activity durations are allocated independently and tasks are programmed within the loop to begin simultaneously. Full co-ordination is to be achieved at a specified point in the loop, and further work is based on that co-ordination. Resource allocation may need to be heavy up to the point where co-ordination is achieved.	

Figure 7.3: Options for programming iterative loops activities (Austin et al 1999)

After partitioning and tearing, the final matrix can be used as a basis for planning the engineering work, e.g. a critical path schedule can be developed. Hence, DSM does not replace critical path but provides a preliminary analysis before developing a critical path. Reviews should be undertaken at the end of each block to see whether the real implementation confirms these estimations or not.

7.5.2 Fuzzy classification for DSM dependencies

The innovation implementation confirms the fact that unacceptable performance causes iterations. A fuzzy scaling system has been developed in this research on the basis of the linguistic terms of the performance assessment (see Chapter 6 for details). The research tool gives five levels for performance assessment in terms of time and cost which are; Bad, Inferior, Adequate, Superior and Excellent. This classification starts from strong relationship (Bad) to weak relationship (Excellent). For example, if the fuzzy classification is 'Bad', then it expresses a strong relationship between the dependent tasks which means iteration is highly expected for this group of tasks while the fuzzy result 'Excellent' means no iteration is expected. Managers can, therefore, eliminate the least important dependencies among the implementation tasks.

7.5.3 DSM in the innovation implementation

The methodology to represent and analyse the innovation process by DSM includes:

1. identification of the implementation phases and tasks;
2. identification of the influence information and the performance indicators that are used to assess the implementation in fuzzy rule notations;
3. using the DSM tool to identify the expected loop tasks;
4. running the developed simulation tool to get the fuzzy level classifications of the dependencies among the loop tasks;
5. analysis of the fuzzy results to decide on which loop can be torn; and
6. in the case of iterated loops, re-visiting the DSM to check tasks' relationship classifications for the next iteration. This check will affect the tool running for the new iteration and consequently, the fuzzy results.

For the purpose of specifying the dependency classification using the DSM, the AMMP program developed by Austin et al. (1999) has been linked to the proposed simulation tool (INOVICET) where the former includes the DSM application. As the AMMP uses a three-point dependence classification system, the developed tool's outputs have been modified to adapt this classification system.

AMMP uses three factors to classify the dependency according to the information required to complete the dependent tasks. These factors are the strength of information dependence; sensitivity to change of information and the ease of estimating information. Figure 7.4 describes this system of information classification from 'A' that expresses a strong relationship to 'C' that expresses a weak relationship. Weak dependencies (C) can be omitted from the matrix partitioning, where an accurate estimate can be made, and therefore the loop's size can be reduced. The tearing approach deals with A and B classifications. The required estimations for both A and B need particular care and must incorporate an appropriate margin of allowance error for later stages of implementation. The simulation tool developed in this research can help managers specify these classifications by using the fuzzy logic results as 'A' classification is corresponding to 'Bad' or 'Inferior', 'B' classification is corresponding to 'Adequate' and 'C' classification is corresponding to 'Superior' or 'Excellent'.

Information flow	Task is	Task is	Information is
Class A Class B Class C	Increasingly dependent	Increasingly sensitive	Increasingly estimable

Figure 7.4: Characteristics of each information classification (Austin et al 1999)

7.5.4 Linking a planning tool to DSM

A planning tool can interpret the DSM output where the sequence of activities and their information dependencies (the partitioned matrix) can be represented on a program that requires durations and resources of the assigned activities and the activities undertaken in parallel.

Tasks undertaken within the innovation process may change due to decisions relating to the type of construction product/process or the innovation objectives. Consequently, different information may be required with varying performance. Barriers to innovation, expected changes and uncertainties about the innovative construction work might demand adding/releasing certain packages of information and modifying performance standards before the innovative product/process is accepted. The simulation tool allows a review of the innovation tasks that involves such changes and the time required to complete the work. When an agreed programme for the innovation work is established, managers may effectively monitor the production of the innovation deliverables based on critical path planning techniques.

7.6 Summary and Conclusion

A planning methodology is required to overcome the shortcomings of current planning practices which takes little account of the interdependency, iterative nature of the innovation process and its performance outcomes. This leads to a compromised innovation process containing inevitable cycles of rework together with associated time and cost overruns in both design and construction.

This chapter introduced the DSM tool and discussed its structure and operation. The main function of this technique is simulating iterative loops of the innovation work. DSM linked to the proposed simulation tool results in producing a project management programme that maintains the implementation of innovation.

The AMMP program, which is a computer application of the DSM, was linked with the proposed tool to improve the planning process and simulate the iterations of implementing innovations. It allows the effects of change during the implementation to be rapidly assessed through analysis of the DSM.

Planning the implementation of construction innovations using the proposed simulation tool has been verified by producing an effective programme for the innovative project "Automatic vehicle location system using satellite facilities" as a case study. The procedures cover all three stages of the proposed tool, namely; the influence information, the innovation implementation phases and the performance indicators. The following chapter describes this project.

CHAPTER 8

TESTING AND VALIDATION OF THE SIMULATION TOOL

CHAPTER 8
TESTING AND VALIDATION OF THE SIMULATION TOOL

8.1 Introduction

This chapter introduces a case study that has been used to test and validate the proposed simulation tool of innovation implementation in construction. The study was launched in one of the biggest construction companies in UK. The project is 'Highway Maintenance Satellite Support System' (HMSSS) that aims to install a location control system using satellite facilities for the company vehicle fleets.

The collected data were verified through interviews held with the project designers and managers involved. This resulted in some refinements and suggestions that have been incorporated into the simulation tool. The developed tool was also validated against the actual innovation implementation of this case study. The simulation tool was used to investigate different scenarios of typical events that occur during the implementation and the impact of changes on other activities and on the project duration and costs.

The process protocol phases were adopted to manage the case study which were not incorporated during the initial stages of the actual project, and consequently, some refinements were required to these phases and the required deliverables to suit the structure of the simulation tool. This was achieved mainly by merging some of these requirements. Difficulties that faced collecting data included the lack of availability all people who were involved in the project implementation, some information was not recorded and many effective decisions were undertaken through informal processes.

This Chapter details the case study data that were required to run the simulation tool 'INOVICET'. More details of the case study project are presented in Appendix C.

The Chapter also discusses the application and results of INOVICET for this case study.

8.2 Requirements and function of the simulation tool

The proposed simulation tool (INOVICET) is used at the initial stage of a project after deciding to implement an innovation for that project. It is mainly used to simulate and plan the proposed implementation of innovation. The proposed tool requires users to input three sets of data: the planning data of the implementation tasks that include tasks' durations, resources, costs and the required dependencies among them; the stochastic data of the influence information; and the fuzzy sets of the performance indicators. The output of the tool includes the deterministic and stochastic results of each loop tasks. The output also includes the fuzzy evaluation of the performance achieved.

The main functions of using this tool for innovative project include:

1) it may be used by managers throughout the different implementation stages as a checklist to aid managers in identifying the innovation implementation tasks and their relevant information requirements;
2) the DSM can assist managers to identify loops of iterative innovation tasks. Knowing these tasks will enable managers to specify certain estimations of the information that causes iterations;
3) the Monte Carlo simulation results will provide managers with planning schedules and costs for different implementation scenarios;
4) the tool helps managers to decide whether to accept or iterate an innovative process to achieving satisfactory performance. The fuzzy logic approach, which was used to simulate project performance, reflects the nature of simulating innovation performance in linguistic judgements, such as bad or adequate. The fuzzy logic approach also converts qualitative criteria into numerical measures that can simulate an innovation process where mathematical precision is impossible or impractical; and
5) the tool will allow managers to investigate:

- the sensitivity of the subjective estimates of the influence information on the implementation tasks;
- the changes in the performance standard required to accept the innovation;
- the number of iterations to achieve satisfactory performance in terms of time or cost;
- the loop sizes to get the minimum number of dependency estimations;
- the different duration/cost of loop tasks for each iteration;
- the most critical information that influences project implementation; and
- the fuzzy evaluation of project performance to decide on iterated work.

8.3 Aims and objectives of the case study

The main aim of this case study was to test and validate the use of the proposed simulation tool as a technique for simulating the innovation implementation. The objectives of the case study included:

- validating the use of the process protocol phases and deliverables in the proposed tool as a base for construction projects stages;
- investigating the DSM technique as a method for simulating the iterative nature of the innovation implementation;
- assessment the use of the Monte Carlo technique in simulating the influence information on an innovative project; and
- examining the use of a fuzzy logic approach in simulating the performance evaluation of an innovative project.

8.4 Background to the project

The project was developed by Balfour Beatty' Specialist Holdings Division. The installation of a location control system was seen to be beneficial from two major perspectives: the improvement of company efficiency; and the extra service supplied to the client. Other benefits, such as a marketing tool, were not considered at the stage of implementation. Clients were likely to be concerned with the Vehicle Location System (VLS) for the following reasons:

- it enhances the supervision of the operatives and gives the client a better service;

- the client's GIS systems and inventories can be augmented; and
- it provides proof of work.

The proposed VLS architecture is shown in Figure 8.1. The application of the new location control system has been concerned specifically with the company's contracts that would benefit most financially from the tool. A trial period has been undertaken first to test the new system's validity for cash flow and planning reasons.

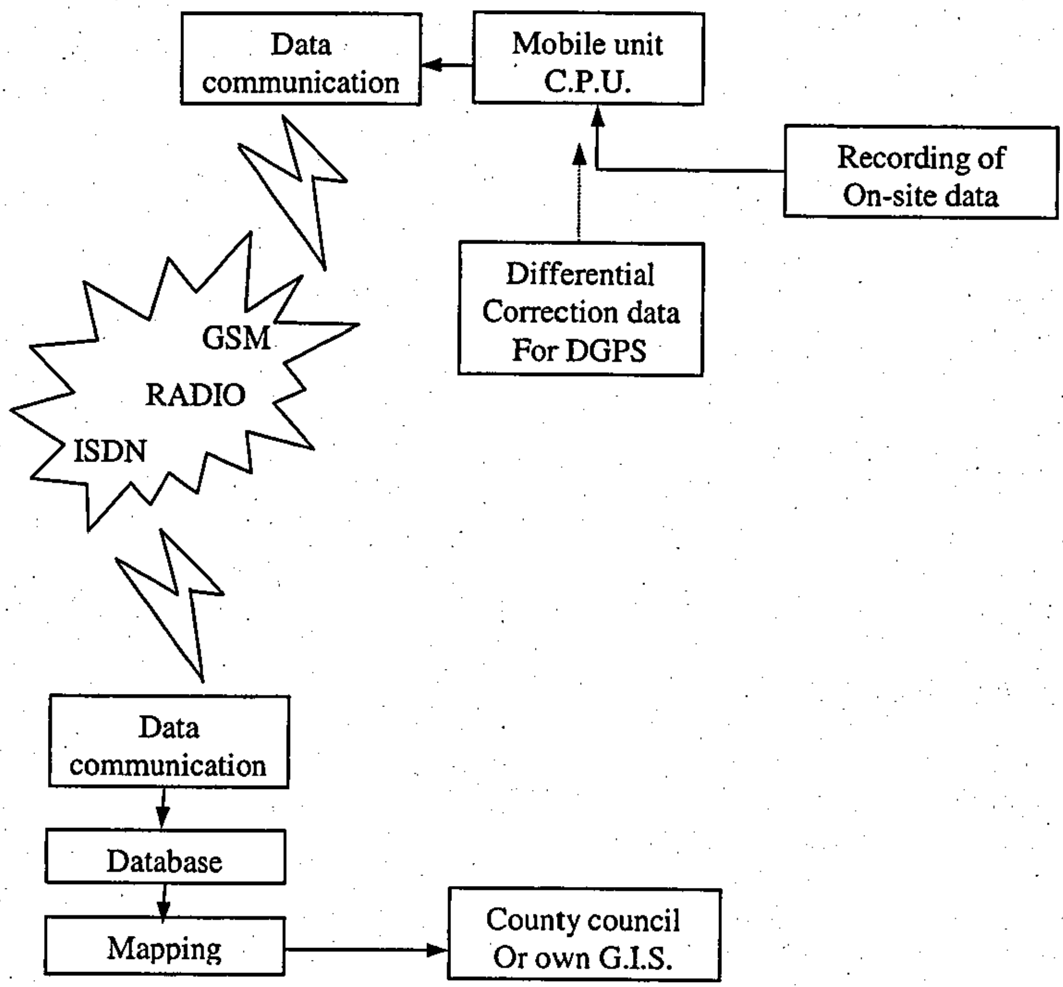


Figure 8.1: VLS Architecture

The decision-making process for choosing suppliers of the proposed VLS considered that most of the vehicle fleet used by the company was on contract hire and as such the installation of the system might pose problems for the following reasons.

- Approval to modify the vehicles has to be gained from the hiring company. Some of them have already approved the modifications. However, vehicles owned by the company may be a more realistic target for the trial. This situation could mean an agreement for lower hire-rates if the system's installation suggests that the hire will be longer term.
- Hired vehicles may need to be changed. While attempts will be made to ensure the hardware is easily interchangeable between vehicles, this may cause the hire companies some concern.
- Many vehicles in the fleet are very old. The use of the vehicle may be improved but its remaining lifetime may not be long.

The initial installation would be performed by the supplier's operatives, but the possibility of training company workshops to install equipment to large numbers of vehicles might save time and money.

The issue of operator acceptance was very important. Systems run by the company have seen vehicle mistreatment as drivers do not wish to be tracked. The operators must be involved from the start and made aware of the implications of the new system. If the equipment is not used properly the gains will not be fully realised.

It is important to consider that, for full use of the system, there must be a base station at each set of sites. This is not a problem as such but will have to be examined for cost implications.

8.5 The current work process and the suggested innovation

Currently the 'scout' vehicle travels along set patrol routes and records 'outages' on a dictaphone. These are written down by office staff from the dictaphone tape on the next day, then passed to work gangs who determine their route to complete the work for the day. If the scout can record the position of the item and its current status on the proposed control system, the database will hold this information so that it can be passed directly to the work gangs via their vehicle console, cutting out the middle person, which was the main aim of this innovative application.

Because the current work process breaks down the work into labour carried out and material used, it is suggested to record the labour activity and materials used on each job in a series of choices' forms using a 'pick-list' database of hardware. As a short description, it will enable the operator to identify a job which must be performed with the pressing of some buttons, and then record the actual work carried out by pressing others.

The philosophy of this method is to enable any operator to choose a job and then record his/her work without the necessity of paperwork, while ensuring that a minimal amount of complications are faced by this user. By cutting down the number of operations, the system may be easier to develop.

This pick-list must encompass the tasks of scouting (Identification of problems in general), Routine Maintenance, Special Maintenance, Emergency response and any other work, as shown in Figure 8.2.

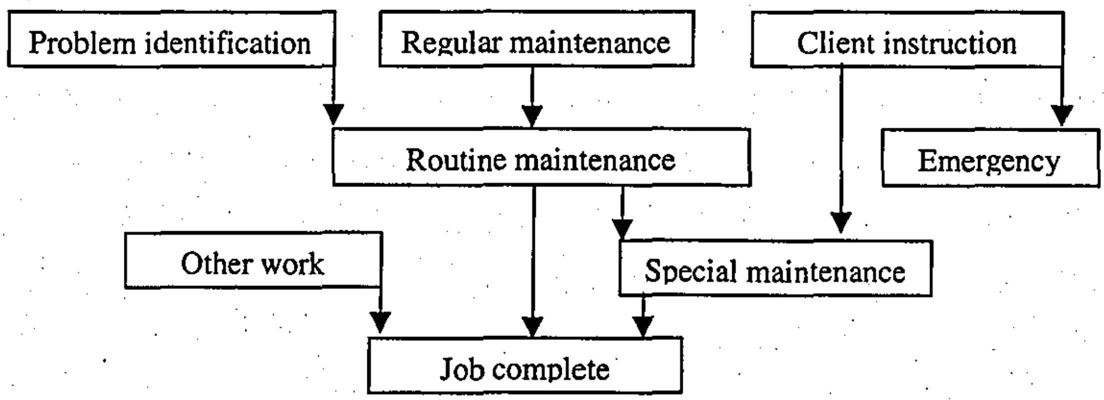


Figure 8.2: Job flow

The data flow diagram, as shown in Figure 8.3, explains the data sent when problems are spotted by the scout, or during the course of a work crew's day. Data will also be fed to the database after an emergency call. This information is available to the vehicle on site to facilitate rectification of identified problems. Once the work has been completed, the system allows the work to be recorded in terms of the labour activity and the materials used, by feeding data back to the database. The pick-list is described as follows.

Problem identification.

This branch is used by any operator who sees a problem with a unit including the Scout.

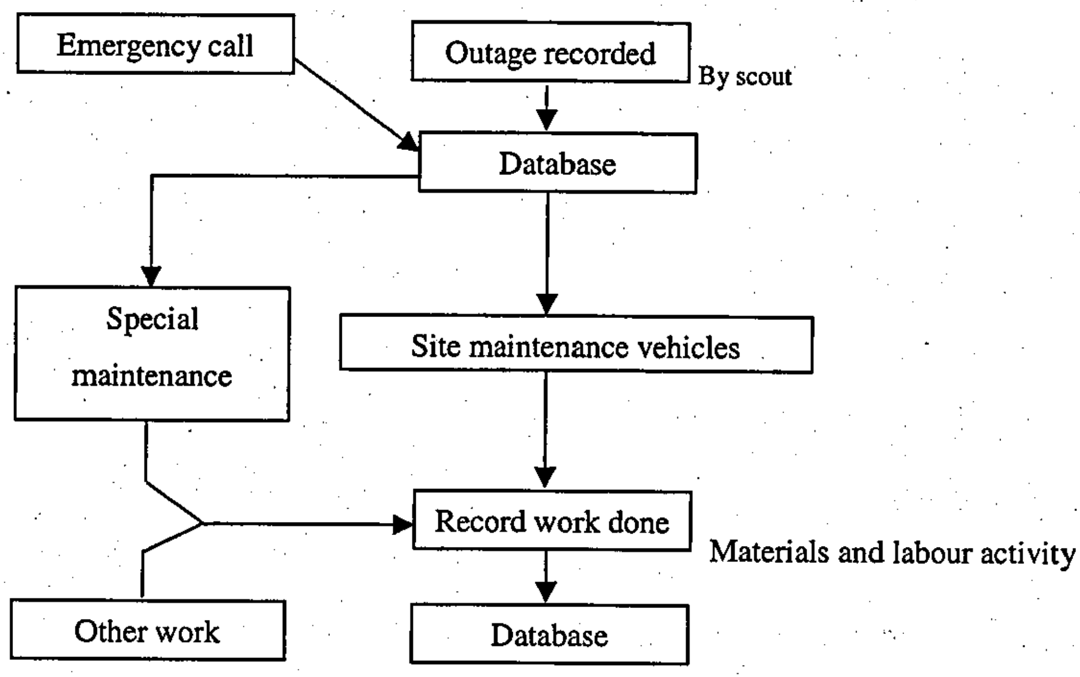


Figure 8.3: Data flow

Routine maintenance.

On choosing this branch the operator will face a list of identified problems. It is important that for the system to work, when an operator identifies a fault then decides to fix it, he/she must input it as a fault, then pick the job from the work list. The next stage involves the following three choices.

- 'To attend' prohibits any other vehicle from picking this item. However, only vehicles assigned to this particular area may want to select this job. This problem of how to assign any vehicle to a particular job must be investigated.
- 'Cannot complete' may be due to insufficient materials or the need for traffic management, for instance. If the job is deemed a special maintenance task, it will be transferred to the Special maintenance pick-list.
- 'Work completed' enables the recording of the work to be carried out.

Special maintenance.

This selection will provide a pick-list of jobs of this type for the operator to choose from.

Emergency response.

Emergencies are problems identified by the client or by members of the public. If specified by the client the response time must be within two hours. The response time is a key figure by which the contract is assessed.

Other work.

These are any other activities that require responses from the site maintenance vehicles.

Regular maintenance.

These are the certain tasks that will have to be carried out by a certain time, therefore, a pick-list of programmed work should be made available to the operators giving what work is to be carried out and a date by which it must be completed.

The data capture process should be more 'automatic' and less reliant on the operators making decisions. The ideal solution for recording the material used within the process is by bar-coding. This record could be attached to the data regarding the unit position and the labour activity carried out. It may also be possible to create a similar tool to record the labour activities. A sheet of paper with all relevant bar-codes for each activity may be produced. A hybrid of the picklist and bar-code ideas could perhaps work well.

Table 8.1 shows the final allocation of vehicles installed first in three different sites. Alongside this are the initials of the members of the working parties responsible for the analysis of the activities.

Table 8.1: Vehicles installed first

<table>
<tr><th>Operation</th><th>Site 1</th><th>Site 2</th><th>Site 3</th><th>Working party</th></tr>
<tr><td>Gully cleansing</td><td>5</td><td>4</td><td></td><td>SF/BS/RS</td></tr>
<tr><td>Safety patrols/Emergency response</td><td></td><td></td><td>3</td><td>PK/RS</td></tr>
<tr><td>Street lighting</td><td></td><td>5</td><td></td><td>PH/RS</td></tr>
<tr><td>Signing</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Construction gangs</td><td colspan="2">4</td><td></td><td>SF/RS</td></tr>
<tr><td>Routine maintenance</td><td>1</td><td>2</td><td></td><td>RC/RS</td></tr>
<tr><td>Winter maintenance</td><td></td><td></td><td>1</td><td>PK/RS</td></tr>
</table>

The initial programme for the installation procedure indicated two milestones for assessing the required preparation. The first milestone is 21 days after the initial plan while the second milestone is 40 days after it. This initial programme would not be reached during the actual implementation.

The first milestone assessment

At this stage the current system will continue to run, with the new service running alongside it. This enables verification of the records made by the HMSSS. Details of the emergencies will have to be placed into the database after extraction from the daily log. The current work procedure includes ten steps, and implementing the new procedure will change five of them.

Outstanding Actions

- Install the system to 2 vehicles.
- Training of 20 operators and 5 supervisors.
- Monitor improvements for the following:
  - improvements in average response times to emergencies;
  - working hours claimed by operatives on standby;
  - client satisfaction regarding quality of information;
  - on-going fuel costs per vehicle; and
  - time saved through improved information recording.

The second milestone assessment

The full capacity of the system is available at this stage. Interaction between the base station and the vehicles is two way; the completion of many of the daily log sheets will be internal to the system and completed electronically partially by the office and partially on site. At this stage of the implementation, time and actions according to each type of work can be recorded, without the need for individual log sheets.

Outstanding Actions

- Install the system to 18 vehicles.
- Training of 37 operators and 15 supervisors.
- Monitor improvements for the following:
  - improvements in average response times to emergencies;
  - working hours claimed by operatives on standby;
  - client satisfaction regarding quality of information;
  - on-going fuel costs per vehicle; and
  - time saved through improved information recording.

The installation of HMSSS required a coding system and programming models to be set up. These models have been refined and tested several times before being accepted for the proposed installation. The planning programme of the HMSSS installation and the initial cost estimate are shown in Appendix C. The main conclusion of the above details is that the planning of installation was set through several occasional meetings (i.e. unstructured planning).

8.6 Information sources and difficulties encountered during data collection

During validation, the collected information included some historical documents and progress reports that were prepared by the project designers or managers. Many sources had informal information that were summarised and documented by the writer. Appendix C contains the available documented material for this case study. The main difficulty of the data collection during validation was to collect data about durations and costs of some implemented activities that are necessary to run the simulation tool. The inability to allocate these data is caused by the following.

- Many deliverables had been prepared simultaneously by the project team. This can be seen from the revision or refinement required for deliverables through many process phases.
- Thinking about the project implementation consumed a substantial amount of time that occurred either inside or outside the company offices. Thinking time may vary according to the team's experience and background relating to the project's phases.
- Discontinuity has been undertaken to complete many tasks. A substantial amount of waiting time was consumed by the project stakeholders in making decisions or collecting certain information.
- A considerable amount of time was spent in meetings between the project stakeholders that cannot be directly attributed to a particular task.

These problems have been dealt with in the proposed simulation tool by considering the time sheets of the project team who were involved in the implementation phases and then by rationalising estimated times using the Monte Carlo technique.

8.7 Application of the proposed simulation tool to the project

Applying the proposed tool 'INOVICET' needs the project team to review the listed data of the project phases, influence information and the performance indicators. Adjustments can be made by adding any special data to reflect the particular project under consideration. The listed data within INOVICET will be used by the project team throughout the different implementation phases as a monitoring tool to ensure the completeness of the innovative project. The process protocol phases will organise the planning of the innovative project in terms of the required tasks for each implementation phase that can be used as a check-list for the implementation activities. The project team will allocate durations, resources and costs for the project tasks. The Monte Carlo technique will assist in simulating the high level of uncertainty inherent in the implementation of this innovative project by simulating the influence of information on the tasks of each phase. The fuzzy logic approach will simulate the performance assessment of the innovative tasks which results in identification of unacceptable performance. The matrix modelling for these fuzzy logic results using DSM will assist the project team in making decisions regarding the iterations of the innovative tasks. Tasks in loops will be planned simultaneously and require careful co-ordination. Running INOVICET will produce a stochastic estimation for the project time and cost. If these estimations do not fit the completion time and cost objectives of the project, the project team would attempt different scenarios on different durations and resources or would manipulate the influence information' impact values by advanced actions towards achieving the project objectives. In another scenario, the project team would adjust the standard of performance indicators required for the innovation acceptance that is expressed in fuzzy set values. This adjustment may eliminate the iterative loops from the implementation phases.

INOVICET has been validated using the case study data and through interviews with the project team. These interviews showed that INOVICET tool could represent the actual process with minor adjustments. Tabular forms were prepared to be completed by the project team to extract data about the influence information and the performance indicators assigned to each project phase. Minor modifications to these table layouts were suggested to suit data collection. These adjustments were mainly related to adding/removing some of the influence information on the project implementation or the importance of this information. Also, some modifications have been made for the assigned performance indicators that assess the project phases. The feedback indicated that some tasks' requirements should be merged due to similarity on this project. Additionally, it was suggested that it would be appropriate to leave the project team to list the tasks they undertake and rationalise these with the phases listed in INOVICET. This comment produced many difficulties when matching some activities with INOVICET because some of the project team listed some tasks in a very broad and general manner. The application highlighted that INOVICET represented the innovative project activities clearly and could be used as a check-list for a project phases and monitoring the planning activities.

The steps that a user should follow to apply INOVICET are as follows (See Figure 4.6 in Chapter 4 for the tool procedure and techniques).

1. Input data of the implementation tasks that include tasks' durations, resources, costs and the required dependencies among them, the stochastic data of the influence information and the fuzzy sets of the performance indicators.
2. Run the DSM package to identify the inherent loops within the overall project plan. At this stage all dependencies have strong relationships. The identification of these loops enables users to estimate where iterations are required which will be verified by the results of the fuzzy approach of performance assessment, later in these steps.
3. Run the planning tool, developed for this research, to get the basic deterministic duration and cost for the loop's tasks which will be used in the analysis of the stochastic results and the fuzzy logic approach.
4. Run the stochastic analysis tool, developed for this research, to get the effect of the influence information on the implementation progress. This will result the probability distribution functions for both the duration and cost of the loop's tasks.
5. Run the fuzzy logic tool, developed for this research, to assess the loop tasks' performance. The results of this tool will be used to identify the relationship levels of the iterative tasks, assigned in Step 2 above. According to this level, users can decide on the iterations required to achieve satisfactory performance.

After this, steps 3, 4 and 5 could be re-run to show the effect on the implementation plan.

8.7.1 Step (1) Input Data

Table (8.2) identifies the phase tasks. The available data for this case study were detailed for the process protocol phases of 4,5,6,7 and 8 (mainly pre-construction and construction phases, Appendix A gives more details for the all process protocol phases). Not all tasks of the process protocol phases were included because of lack of data within the case study project. The project team also estimated the duration, cost and required resources of these tasks. Figure 8.4 shows how these data could be input on the INOVICET interface. Figure 8.5 shows the dependencies among the project tasks using the DSM, extracted from the system architecture in Figure 8.1. The stochastic range of the information influence on the project implementation, given in

Table 8.3, was estimated according to subjective judgement of the project managers. Figure 8.6 and 8.7 show how a user can input these stochastic data while the data of this case study are shown in Figure 8.8.

Table 8.2: The innovative tasks of the case study according to the process protocol phases

Task code	Task identification
P110	The scope of the project should be clearly defined
P111	Preliminary information on potential solutions to the problem(s)
P26	Project success criteria and performance measures
P413	Major assumptions defined for the outline conceptual design
P416	Cost plan based on system solutions and key supplier selection
P516	Updating the cost plan based on full concept design
P6161	Updating the cost plan based on detailed design elements
P6162	Value engineering report for design considerations
P441	Project execution plan based on the defined system solutions
P442	Project execution programme i.e. Gantt chart
P443	Project execution quality plan
P54	Updating Project execution plan based on full concept design
P64	Updating Project execution plan based on co-ordinated design
P74	The project execution should be firmly set to enable construction works and facilitate the measurement of the performance criteria
P481	Key suppliers for system solutions for Procurement plan
P482	Product supply chain for Procurement plan
P581	Review membership of the design team for the procurement plan
P583	Preliminary equipment requirements for construction for the procurement plan
P5141	For the full conceptual design, Major design elements and recommendations made identifying key assumptions
P5143	For the full conceptual design, Enable validation of functional attributes
P5171	Maintenance needs for the full concept design
P5172	Preliminary budgetary requirements for the maintenance plan
P5173	Special considerations such as equipment and facilities for the maintenance plan
P56	Updating performance management report (productivity, duration and budgetary measures for phase six and possibly through to the end of phase 8)
P66	Updating performance management report based on co-ordinated design
P76	The performance criteria for the project should be firmly finalised and not revisited unless circumstances are changed significantly i.e. main client requirement
P6151	Major design elements of the product model have been defined and agreed to allow co-ordinated design
P6152	Work packages defined for the product model

Table 8.2: The innovative tasks of the case study according to the process protocol phases (continued)

P715	Co-ordinated, structural, mechanical and electrical elements should be prepared to a high level of technical detail with corresponding specifications
P8151	Site related requirements and fully responsive to any prescribed statutory requirements
P8153	All actual procurement, health and safety, cost and performance criteria should be presented and compared with pre-construction estimation to enable the feedback loop for future projects
P7161	Cash flow resources and requirements
P7181	Include phasing of construction works
P7182	Detail description of work packages and interfaces between them to enable 'trouble free' construction work
P8191	As built drawings
P8192	Service and operations information
P8194	Defects rectification period

Table 8.3: The influence information on the innovative tasks of the case study (+ Time effect * Cost effect)

Code	Information title	Impact Range	Tasks affected						
1	Codes	-10 : +10	P26 +*	P413 +	P5141 +	P6151 +	P715 +	P76 +	
2	Reaction of other construction partners	-15 : +25	P416 *	P441 +	P482 +	P74 + *	P7182 +		
3	Labour relations issues	-30 : +15	P111 +	P482 +	P56 +	P8151 *			
4	Safety considerations	-5 : +10	P416 *	P5171 +*	P8151 *				
5	Economic and political conditions	0 : +25	P416 *	P6162 +*	P7161 *				
6	Capital intensiveness	0 : +20	P416 *	P6162 *	P583 *	P7161 *			
7	Resistance to change	0 : +20	P441 +	P56 +					
8	Workforce skills	0 : +15	P26 +	P441 +	P56 +	P7181 +			
9	Company size (capability of implementation)	-15 : +10	P110 +	P482 +	P583 *	P7161 *	P74 +		
10	The priority attached to the project	0 : +10	P110 +						
11	Functional requirements due to the type of facility	-5 : +5	P26 +*	P413 +	P5141 +	P5143 +	P76 +*		
12	Funding and resources made available	0 : +20	P111 +	P416 *	P6162 *	P74 +*	P583 *	P5172 +*	P7161 *
13	Owner's view	-5 : +5	P110 +	P416 *					
14	Operational requirements	0 : +15	P413 +	P416 *	P583 +	P715 +	P7182 +*		
15	Market circumstances	0 : +5	P6162 *						
16	Level of complexity of the project	-10 : +10	P111 +	P413 +	P715 +	P76 +			
17	Damage to existing utility construction lines	0 : +10	P111 +	P 416 *	P7181+*				
18	Productivity decline (learning curve)	0 : +15	P26 +*	P441 +	P56 +	P74 +			
19	Technological function risk	0 : +25	P26 +*	P413 +	P5143 +	P5171 +*	P715 +	P76 +*	P7182 +*
20	Contractual and tendering methods	-5 : +5	P482 *						
21	Rules and regulatory bodies	-10 : +10	P413 +						

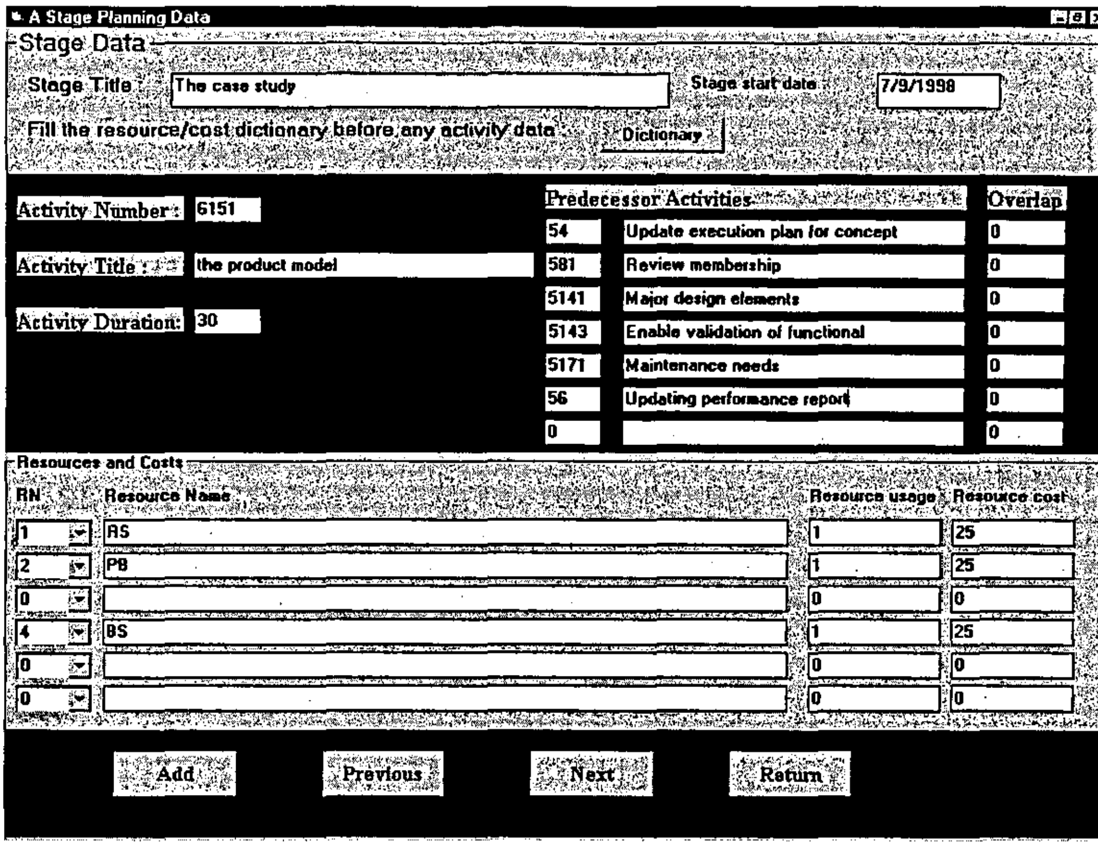


Figure 8.4: The input of the phase tasks

Table (8.4) provides details of the performance indicators that were used by the project managers to assess the innovative tasks within the case study project. These indicators were assigned first to the overall project performance and were also re-visited after the DSM identified the expected loops within the project progress. The re-visit is mainly to identify the fuzzy set of the required performance resulting from the loop tasks that in turn identify the level of relationships among the loop tasks. These relationships will be used to deal with scheduling these loops, as previously detailed in Chapter 7.

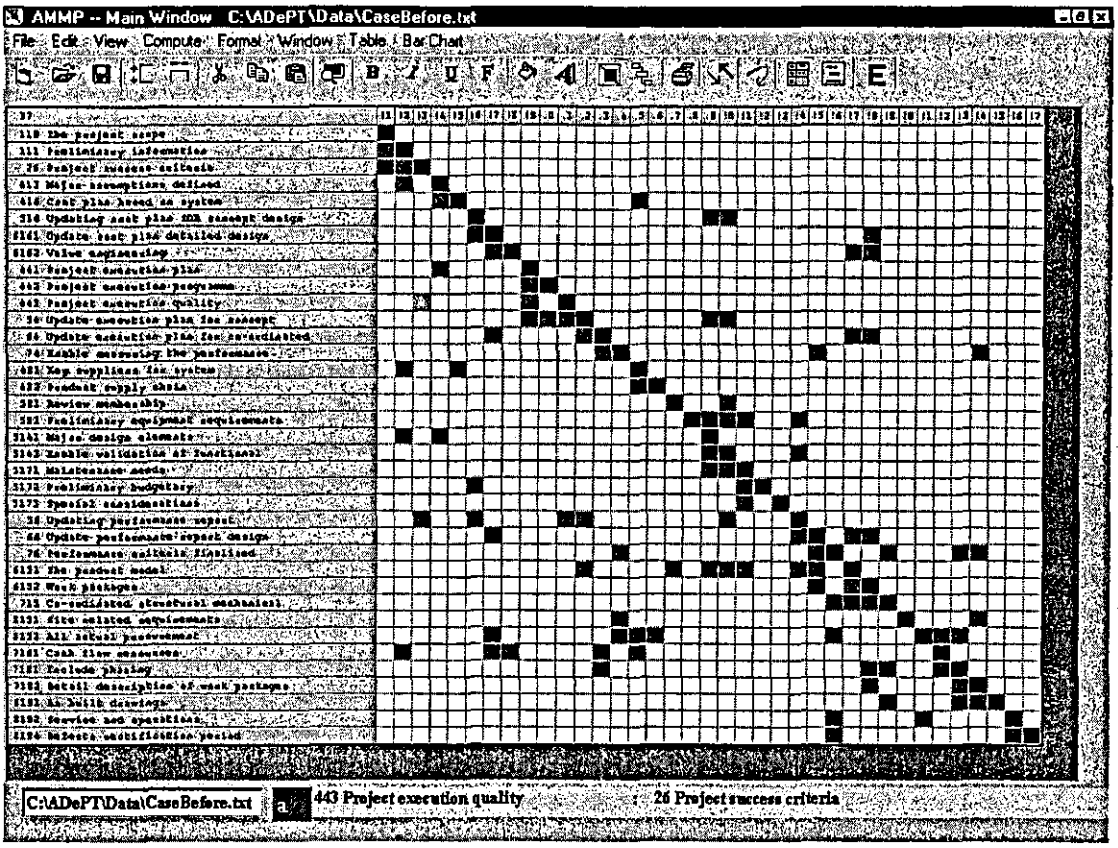


Figure 8.5: Dependency matrix for the innovative tasks of the case study (before partitioning)

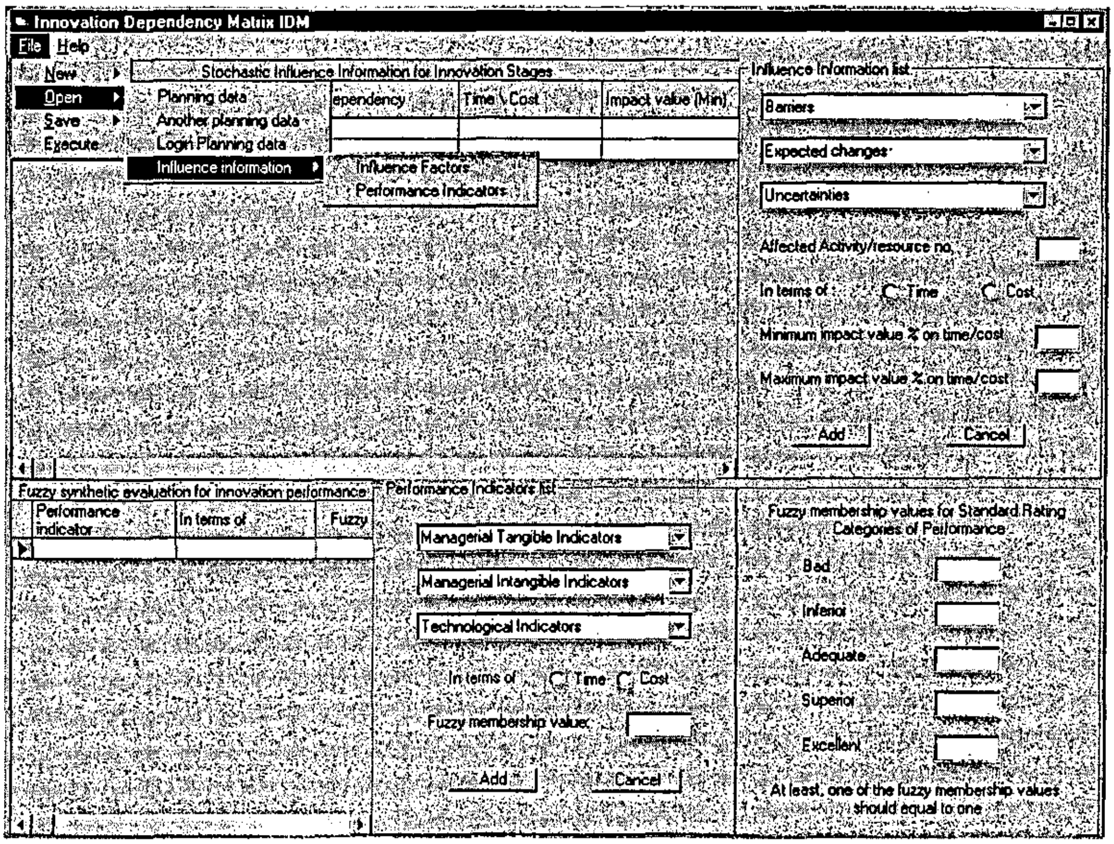


Figure 8.6: The stochastic data input

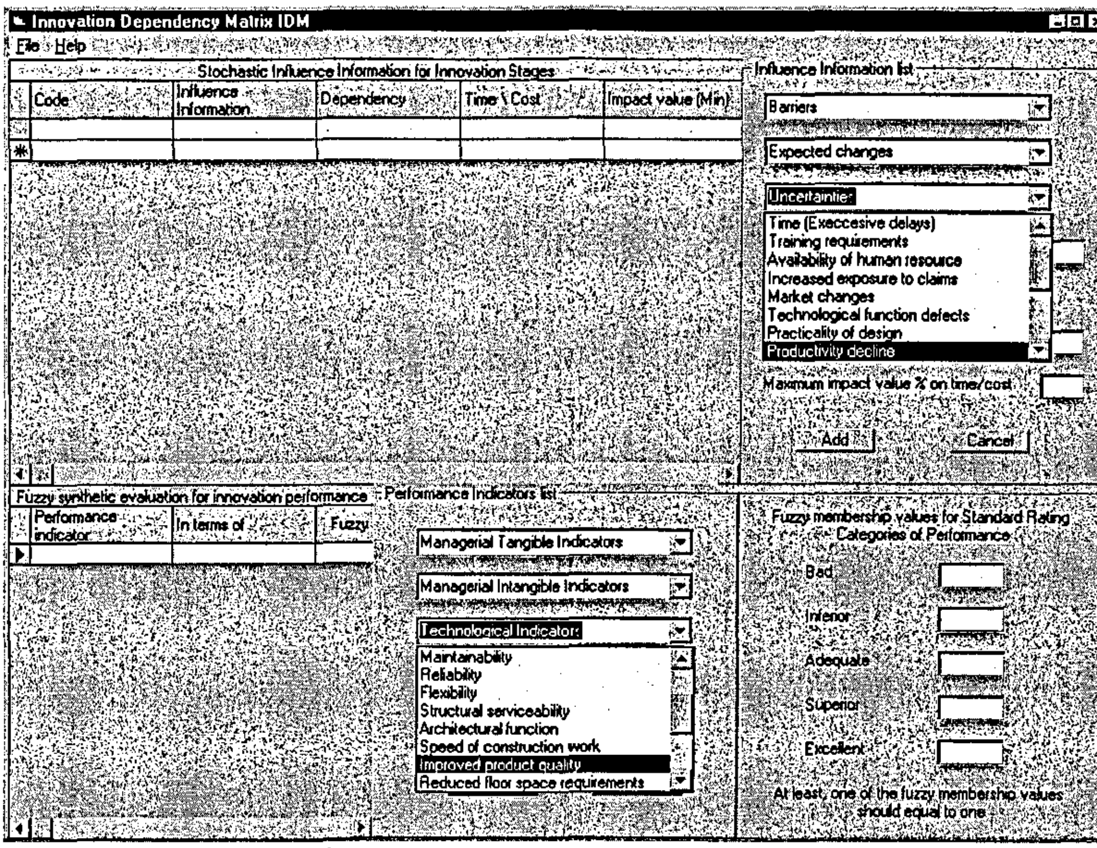


Figure 8.7: INOVICET checklist for the stochastic information and the performance indicators

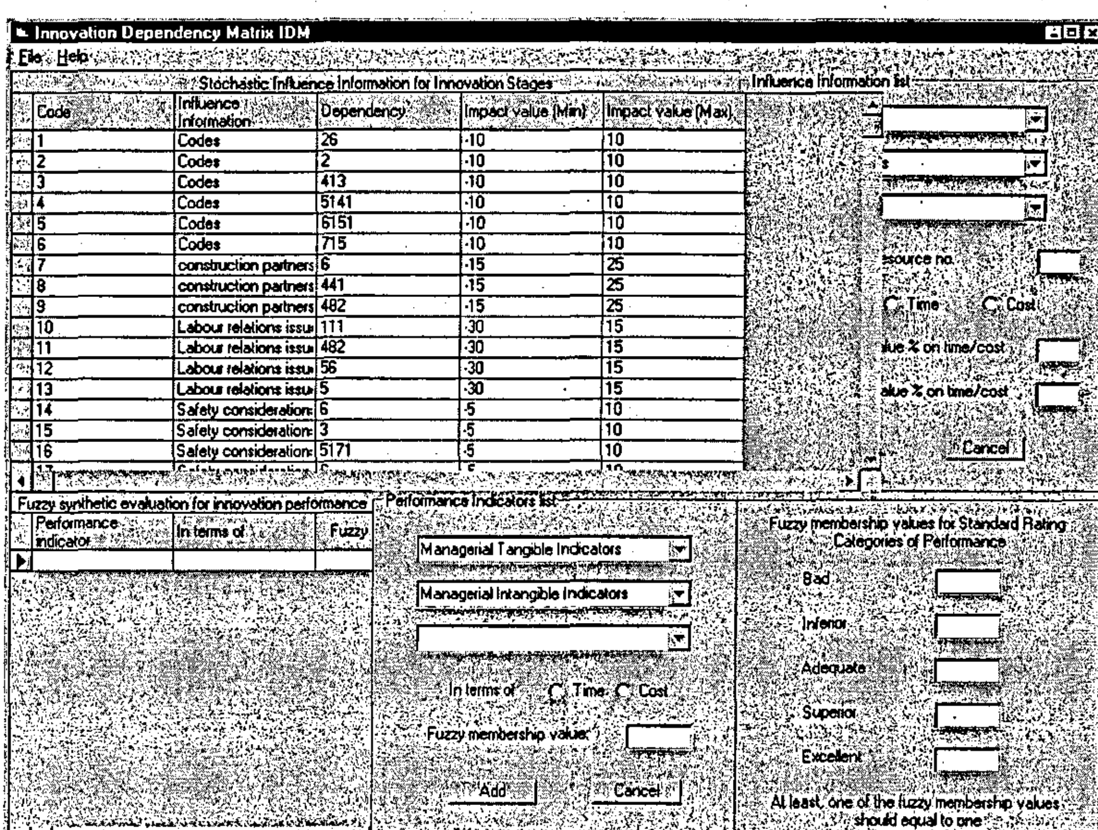


Figure 8.8: The stochastic data of the case study project

Table 8.4: The general performance indicators of the case study project

Performance indicator	The fuzzy set rating
High efficiency improvement (up to 20%)	High priority
Quality assurance	
Over all cost reduction	
Client inventory improvements	
Emergency response time improvements	Medium priority
Paperwork reduction	
Logistical improvement	
Financial benefit	
Service improvements	Low priority

8.7.2 Step (2) Running the DSM package

DSM helps plan the implementation tasks and the performance assessment tasks. Iterations are always expected among these tasks where performance needs to be evaluated before innovation is accepted. As Figure 8.5 shows the dependency matrix of the case study tasks, INOVICET uses the DSM to identify loops inherent in the project tasks. The results of this run are shown in Figure 8.9 where the highlighted blocks show the tasks included in each loop.

8.7.3 Discussion of the DSM results

Figures 8.10a, b, c, and d show the four loop blocks of the case study project extracted from Figure 8.9. In Figure 8.10a, only two tasks are dependent on each other. This interdependency means that data assumptions for one of them should be made to implement the other. In Figure 8.10d, the iterative loop has more than two tasks detailed in Figure 8.11.

The loop tasks of Figure 8.11 are within the design stage of the innovative project, which are as follows.

Task 28: The project execution should be firmly set to enable construction works and facilitate the measurement of the performance criteria.

Task 29: The performance criteria for the project stage.

Task 30: Co-ordinated, structural, mechanical and electrical elements should be prepared to a high level of technical detail with corresponding specifications.

Task 31: Include phasing of construction works.

Task 32: Detail description of work packages and interfaces between them to enable 'trouble free' construction work.

From this loop, the project manager should assume some information at the initial stage to tear the link between the iterated tasks. After implementation, these assumptions should be evaluated with the actual implementation results. For example, task 29 (the performance assessment of this stage) will confirm the correctness of the technical details (task 30) and if these criteria are inadequate then (task 30) needs to be redone. Table 8.5 was assigned by the project team to identify the performance indicators of the loop's tasks shown in Figure 8.11 (See Chapter 6 for assigning fuzzy sets to the linguistic judgements in more details).

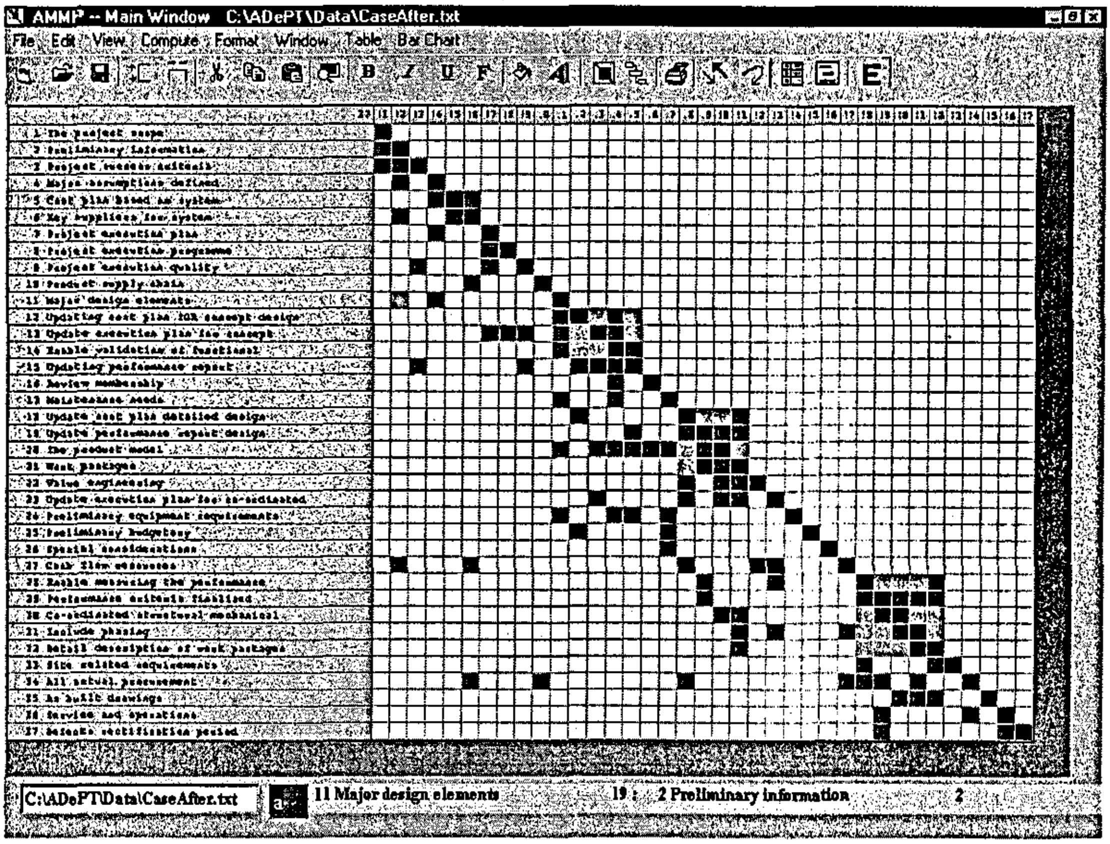


Figure 8.9: Dependency matrix for the innovative tasks of the case study (After partitioning)

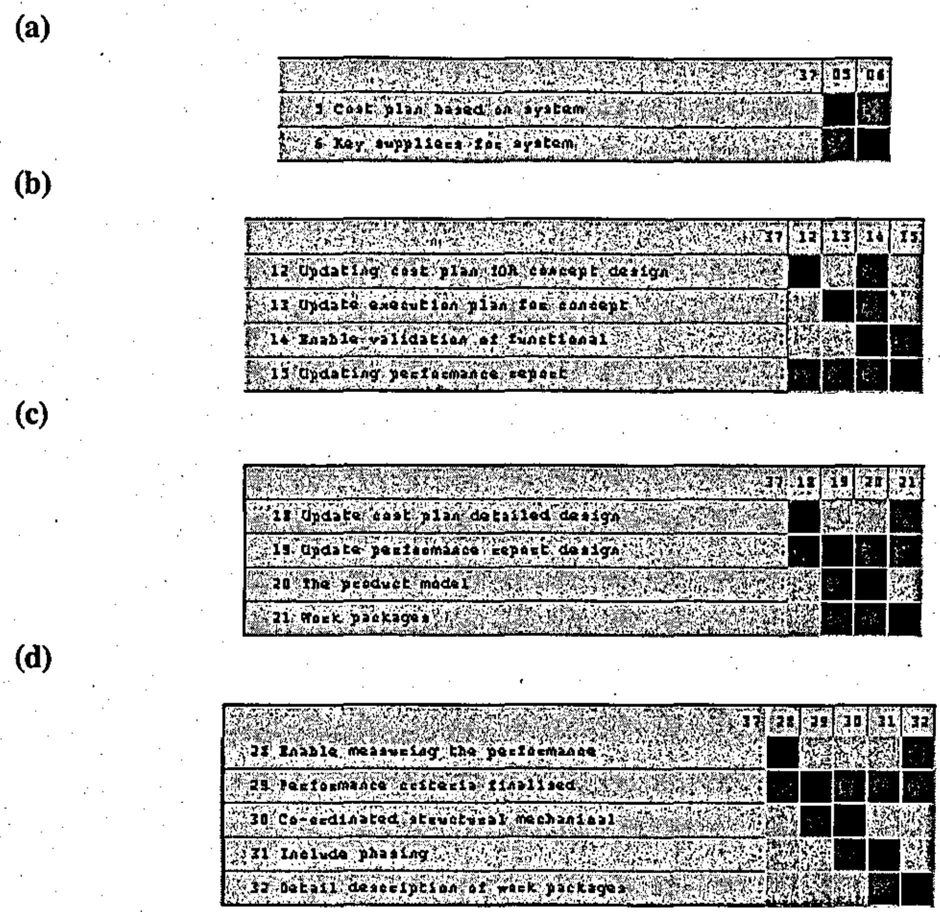


Figure 8.10: The loop blocks of the case study project (extracted from Figure 8.9)

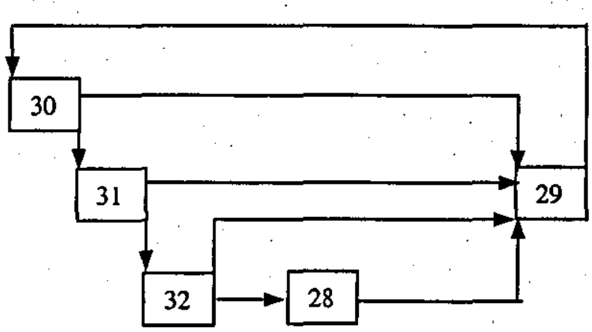


Figure 8.11: The loop tasks included in Figure 8.10 d

Table 8.5: The performance indicators for the loop's tasks of Figure 8.11

Code	Performance indicator	In term of	The fuzzy standard
I1	High efficiency improvement (up to 20%)	Time	.7
I2	Quality assurance	Cost	.6
I3	Over all cost reduction	Cost	1
I4	Client inventory improvements	Cost	.5
I5	Emergency response time improvements	Time	.5
I6	Paperwork reduction	Cost	.6
I7	Logistical improvement	Cost	.4
I8	Financial benefit	Cost	.6
I9	Service improvements	Time	.3

The project team should assign fuzzy rating categories that the performance indicators are measured against where at least one takes the value of 1.0. INOVICET proposes these categories as; "Bad" (B), "Inferior" (I), "Adequate" (A), "Superior"(S) or "Excellent" (E). For the loop's tasks shown in Figure 8.11, the project team estimated the fuzzy set {.2, .5, 1., .7, .4} for these categories respectively. According to this estimation, the bad performance (the first category) has a membership of 0.2 to the overall membership function of the performance and so on for the other values of the fuzzy set. These values act as fuzzy rates identifying five levels of dependencies among the loop tasks. For example, if the dependency of task 29 on task 30 has taken the level 'Excellent' then the information required from task 29 to implement task 30 can be easily estimated. While for the level 'Bad', iteration will be required between these tasks until a satisfactory performance is obtained.

In addition to the above fuzzy rating categories, fuzzy set values, expressed in Zadeh's notation for discrete fuzzy variables, should be estimated by the project team for the performance indicators as shown in the fuzzy standard column of Table 8.5. Each value expresses the membership of an indicator to the overall membership function of the overall performance. All standards should be expressed in terms of cost or time units to suit the structure of the simulation tool INOVICET.

The main objective of the INOVICET tool at this point is to use the above data to evaluate the performance output of each loop tasks to decide whether to implement iterations to achieve satisfactory performance. This evaluation is described in the remaining steps.

8.7.4 Step (3) Running the planning tool

The planning tool, developed for INOVICET, should be run first to get the deterministic duration and cost of the loop tasks, eliminating the dependency relationships that cause looping and the information that causes uncertainty. This will mean that satisfactory performance is gained by implementing this group of tasks under ideal conditions, i.e. no uncertainties and no loops. For example, if the iterative links for the above block (in Figure 8.10d and detailed in Figure 8.11) are eliminated then the non-loop block, shown in Figure 8.12, consists of a sequence of tasks that can be planned by a planning tool. The results given by INOVICET to implement these tasks under such an ideal case were 59 units of time for the schedule and 5450 units of cost. These results will be used to link the stochastic analysis with the fuzzy logic approach.

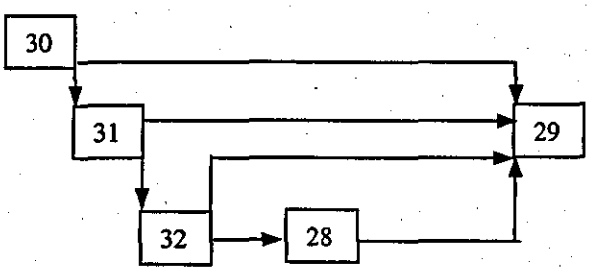


Figure 8.12: The non-loop block of Figure 8.11

8.7.5 Step (4) Running Monte Carlo Simulation

Information that influences the implementation phases changes the duration/costs of certain tasks. INOVICET deals with these changes using the Monte Carlo technique (See Chapter 5 for the technique details). Each information item will be simulated by a range of values of their effect on the deterministic estimate of the time/cost of the implementation tasks, as shown earlier in Table 8.3. INOVICET determines the stochastic analysis of each loop tasks for both the duration and cost, as shown in Figure 8.13.

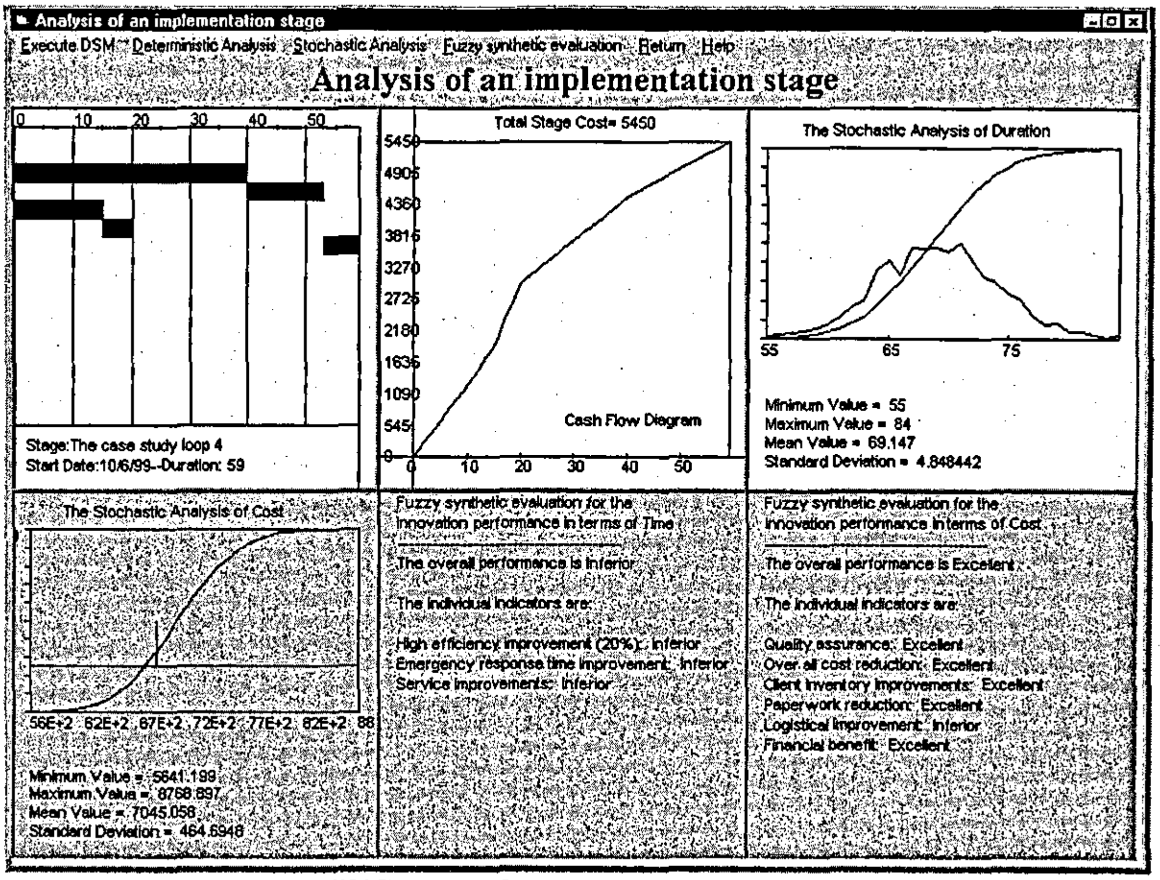


Figure 8.13: INOVICET results according to the initial information

8.7.6 Step (5) Running the fuzzy logic tool

At this step, the fuzzy logic tool will deal with the user estimates of the membership values of the performance indicators shown in Table 8.5. The fuzzy tool accomplishes INOVICET's evaluation of the overall performance and also of each performance indicator in terms of time and cost.

By running the fuzzy logic tool for the loop tasks, INOVICET determines the actual membership values of each performance indicator and the overall performance in terms of time and cost which are in turn interpreted by its linguistic terms. This will be according to the planning data (deterministic and stochastic) that have been used to plan the loop tasks. The project team uses these results to assign the dependency levels among the loop tasks, especially those that cause tasks to iterate. For example, if the evaluated performance is 'Bad' for the link that cause iteration, the dependency link approves iteration to be expected for the dependent tasks.

8.7.7 Discussion of the fuzzy evaluation results

As shown in Figure 8.13, the fuzzy evaluation for the innovation performance in terms of time (i.e. the achieved performance in terms of time) is Inferior. This figure also shows each indicator assessment. The same results are given for the performance in terms of cost.

As previously discussed in Chapter 7, the program AMMP developed by Austin et al (1999) which is used to execute the DSM, uses three levels of dependency importance (A = strong, B = moderate, and C = weak). So, if the dependency of task 29 on task 30, in Figure 8.11, has 'weak' importance then the information required from task 29 to implement task 30 can be easily estimated (i.e. no iteration is required). The fuzzy tool identifies such estimation in five fuzzy evaluations, namely, Bad, Inferior, Adequate, Superior, and Excellent. To accommodate these five evaluations with the dependency levels of AMMP, INOVICET identifies the fuzzy evaluation of Bad and Inferior as 'A' level, Adequate as 'B' and Superior and Excellent as 'C'. Therefore, Bad or Inferior result of the fuzzy synthetic evaluation, the dependency of 'A' indicates that iteration will be required between these tasks until giving a satisfactory performance of Adequate, Superior or Excellent.

For the given loop tasks of Figure 8.11, the fuzzy synthetic evaluation for the initial run gives 'Inferior' performance in terms of time and 'Excellent' performance in terms of cost which is considered unsatisfactory performance which means another iteration is required to achieve satisfactory performance. This means that the project team has to review the input data to improve the performance by taking action regarding the influence information to ensure satisfactory performance from the early beginning or they have to estimate a number of iterations to obtain satisfactory performance. For both cases, reductions to the duration or cost of some tasks for later iterations are expected due to the experience gained from the earlier iterations. The stochastic range of the influence information can be minimised to reduce the effect of uncertainties. The chance of obtaining satisfactory performance simulated by the fuzzy evaluation tool can be increased. The project team adjusted the previous information of the loop tasks, as shown in the column "after the first iteration" of Tables 8.6, 8.7 and 8.8.

The results obtained by running the INOVICET tool after adjustment of information are shown in Figure 8.14. The main change occurred in the information that influences the duration of the tasks. The results gave 'Superior' performance in terms of time, while the fuzzy evaluation of cost was not affected. These actions resulted in reducing the overall duration of the loop tasks by 13.5 per cent and the cost by 11.4 per cent due to the work has been repeated. Also these adjustments gave performance in terms of time and cost as 'Superior' and 'Excellent' respectively which is satisfactory. The overall duration and cost of this loop' tasks can be determined as the summation of the two iterations' results. This demonstration shows how INOVICET can simulate the iterative progress of an innovative project incorporating the effect of the high level of uncertainty and the performance assessment.

Table 8.6: The loop's tasks durations

Task code	Tasks	Durations at the initial running	Durations after the first iteration
30	Co-ordinated, structural, mechanical	40	35
31	Include phasing of construction works	13	11
32	Detail description of work packages	15	13
28	The project execution should be set	5	5
29	The performance criteria	6	5

Table 8.7: The influence information on the loop tasks

Code	Information title	Impact Range at the initial running	Impact Range after the first iteration
1	Codes	-10 : +10	-5 : +5
2	Reaction of other construction partners	-15 : +25	-10 : +10
3	Labour relations issues	-30 : +15	-10 : +10
4	Safety considerations	-5 : +10	-5 : +10
5	Economic and political conditions	0 : +25	0 : +15
6	Capital intensiveness	0 : +20	0 : +10
7	Resistance to change	0 : +20	0 : +10
8	Workforce skills	0 : +15	0 : +10
9	Company size (capability of implementation)	-15 : +10	-10 : +10
10	The priority attached to the project	0 : +10	0 : +10
11	Functional requirements due to the type of facility	-5 : +5	-5 : +5
12	Funding and resources made available	0 : +20	0 : +10
13	Owner's view	-5 : +5	-5 : +5
14	Operational requirements	0 : +15	0 : +15
15	Market circumstances	0 : +5	0 : +5
16	Level of complexity of the project	-10 : +10	-10 : +10
17	Damage to existing utility construction lines	0 : +10	0 : +10
18	Productivity decline (learning curve)	0 : +15	0 : +10
19	Technological function risk	0 : +25	0 : +5
20	Contractual and tendering methods	-5 : +5	-5 : +5
21	Rules and regulatory bodies	-10 : +10	-5 : +5

Table 8.8: The performance indicators for the loop's tasks

Code	Performance indicator	In term of	The fuzzy standard	
			At the initial running	After the first iteration
I1	High efficiency improvement (up to 20%)	Time	.7	.8
I2	Quality assurance	Cost	.6	.6
I3	Over all cost reduction	Cost	1	1
I4	Client inventory improvements	Cost	.5	.5
I5	Emergency response time improvements	Time	.5	.7
I6	Paperwork reduction	Cost	.6	.6
I7	Logistical improvement	Cost	.4	.4
I8	Financial benefit	Cost	.6	.6
I9	Service improvements	Time	.3	.6

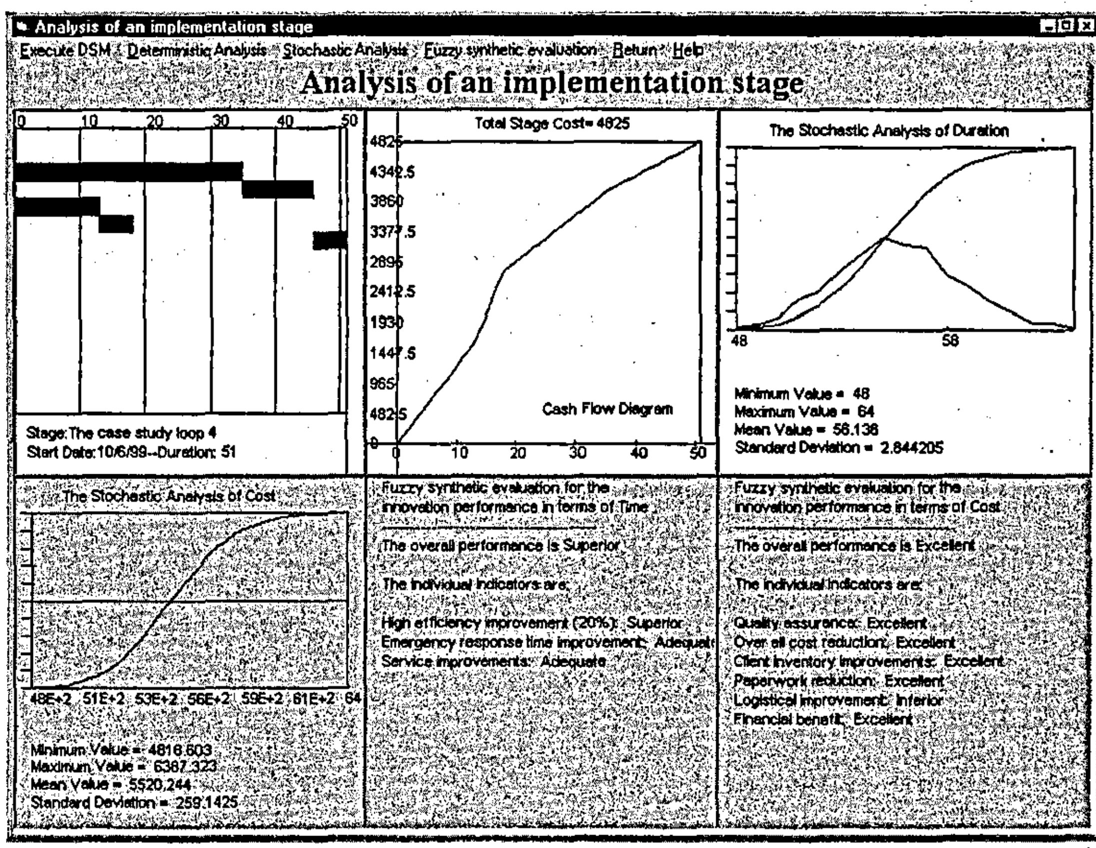


Figure 8.14: INOVICET results after changing information

8.8 Summary and conclusion

This chapter used a case study project to validate the proposed simulation tool 'INOVICET' of simulating innovation implementation in construction. The case study project purposed installation of a location control system using satellite facilities for a construction company vehicle fleets. The developed tool was validated against the actual innovation implementation of this case study. The simulation tool was used to investigate different scenarios of typical events that occur during the implementation and the impact of changes on other activities and on the project duration and costs.

The implementation of the case study project according to INOVICET structure had many difficulties due to various reasons such as locating all people who were involved in the project implementation, some information not being recorded and many effective decisions being undertaken through informal processes.

This validation mainly included four approaches that were:

- validating the use of the process protocol phases and deliverables in the proposed simulation tool as a base for construction projects stages;
- investigating the DSM technique as a method for simulating the iterative nature of the innovation implementation;
- assessing the use of the Monte Carlo technique in simulating the influence information on an innovative project; and
- examining the use of a fuzzy logic approach in simulating the performance evaluation of an innovative project.

Running the INOVICET simulation tool allows the project team to investigate the following:

- the number of iterations to achieve satisfactory performance in terms of time or cost;
- the loop sizes to get the minimum number of dependency estimations;
- the different duration/cost of the loops' tasks for each iteration;
- the most critical information that influences the project implementation; and
- the fuzzy evaluation of the project performance to decide on iterated work.

Running the INOVICET tool identified the iterated tasks of the case study project and implemented these tasks' plan. The tool also provided the fuzzy evaluation of the performance of the iterated tasks in terms of time and cost. According to these results the project team decided to check the influence information and adjust the corresponding performance after getting experiences from the first estimation.

The programme produced by the simulation tool showed a systematic methodology applicable to implementing an innovative project, as concluded by the case study's project team. The application illustrated that the INOVICET tool represented the innovative project activities clearly and could be used as a check-list for the project phases to monitor the planned activities.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

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9.1 Introduction

This research has focused on the implementation phase of innovation in construction. The aim of this research, as presented in Chapter 1, has been to study and simulate the implementation phase of innovation to facilitate analysis of its characteristics. These characteristics exhibit high levels of uncertainty and the iterative in nature of its activities. To meet this aim, the following research objectives were formulated:

- to study the innovation process in construction and identify its planning and monitoring stages;
- to examine the existing decision support systems used to assess innovations; and
- to simulate the implementation stage of innovation considering the influence information and the method of assessment.

To achieve these objectives the following steps were performed:

1. a systematic approach for the innovation implementation phase was proposed;
2. a technique for simulating the influence information of this phase was developed;
3. a technique to simulate the implementation phase assessment was developed;
4. a technique to identify loops of iterative tasks of innovation was developed;
5. the above techniques were integrated within a user-friendly computer package for planning purposes; and
6. the targeted techniques and package were validated.

The hypothesis of the research was proven by performing the adopted methodology and through the proposed simulation tool application. The aim and objectives of the research were achieved through: a literature review in Chapter 2 and 3; semi-structured interviews with teams of two innovative construction projects (Chapter 4); designing the simulation tool (Chapter 5, 6 and 7); and validation exercise with another innovative case in Chapter 8. The main conclusion is that existing planning techniques are unsuitable for the management of innovation implementation. Techniques based on a combination of DSM, Monte Carlo Simulation, a planning tool and fuzzy logic will improve the management of implementing innovations in construction. Other conclusions derived from this research are described in the following sections.

9.2 Main Conclusions

The conclusions drawn from this research can be summarised under the following headings:

- the nature of implementing innovations in construction;
- the current practice for planning and managing the innovation implementation;
- planning innovation implementation stages;
- using DSM to simulate the iterative activities of the implementation;
- using Monte Carlo technique to simulate uncertainties inherent in the implementation;
- assessment of the performance of the innovation implementation; and
- application of the Fuzzy Logic Approach to simulate performance evaluation.

9.2.1 The nature of implementing innovations in construction

The literature review has shown that innovation is, by its nature, an iterative process. This iterative nature makes it complex and difficult to manage. Implementing innovations in construction has been considered as a sequential process incorporating iterations in addition to the high level of inherent uncertainty.

9.2.2 The current practice for planning and managing the innovation implementation

Early models of the innovation process demonstrated the different stages of innovation and emphasised its iterative nature. Any stage model is an analytical device to segment a flow of activity through time. Transition between stages ought to be meaningfully specifiable. The models reviewed attempted to describe the content of each stage, but did not specify the outcomes of the activities within each stage or how managers could simulate these activities in tools and techniques.

Although current planning techniques such as network analysis and bar-charts are suitable for planning deterministic activities which are either sequential or parallel, they are not suitable for planning activities with an iterative nature, such as innovation activities, because they do not allow for any iterative procedures.

The characteristics of construction innovation reviewed in this research emphasise that traditional planning techniques need to be developed to support more effectively the implementation progress of innovative projects. Such modelling techniques should simulate the nature of experimentation, iteration and refinement activities considering the 'influence information' affecting these projects and the 'performance indicators' to assess the implementation process of innovation and foreseeing the effects of changing different parameters that affect the implementation. The techniques should deal with the various uncertain outcomes inherent in innovative projects, define all situations of a particular innovation, plan the innovation activities and improve the ability to causally extrapolate theory into uncertain events.

9.2.3 Planning the innovation implementation stages

Many models have been devised for the innovation process and techniques and tools have been developed to assess new technologies (Chapter 2 and Chapter 3). Few of them have looked deeply in the way of implementation and the deliverables required for each implementation stage. This does not help achieve effective innovation management which aims to ensure the smooth running of an innovative project under controlled budgets and time.

The implementation plan required to achieve the proposed innovation should be developed totally at the initial stage of the project and should include the basic procedures required to complete the project. These procedures require certain deliverables to ensure the completion of each process phase. Accordingly, procedures provided by the "Process Protocol" were adopted during this research to simulate the implementation phase of innovation. The Process Protocol provides a general procedure for carrying out any construction project. It covers the whole life of the project from recognition of a need to the operation and maintenance of the finished facility considering both the business and technical point of view. As the planning of an innovation implementation requires, in addition to these basic procedures, to simulate the interdependency of the procedures and their resulted performance, this research provides a further simulation development to the 'Process Protocol' IT map in order to incorporate this interdependency.

While performance is dependent on the procedures, the procedures could not be approved until this performance is obtained. Thus, it may require several iterations to complete the implementation phases. This development resulted in a systematic methodology applicable to implement an innovative project, as concluded by the case study's project team.

9.2.4 Using DSM to simulate the iterative activities of the implementation

Planning of the innovation implementation, as described in Chapter 4, required estimating information that affects the implementation and the performance related to it. This planning has a special feature that is the interdependency between a process and its results. This required a new planning methodology to take any interdependency into account. Therefore, the research focused on the application of the Dependency Structure Matrix (DSM) tool to simulate the interdependency of the innovation process. The implementation tasks represented were analysed using partitioning techniques of the DSM to identify the inter-dependent tasks and loops of iterative implementation tasks. Using the simulation tool resulted in the implementation of innovation being programmed more realistically.

9.2.5 Using Monte Carlo technique to simulate uncertainties inherent in the implementation

Implementing innovation in construction requires many scenarios to be analysed where decision-makers may use subjective judgements for the likelihood of particular scenarios. This analysis is complicated by uncertainties because, invariably, the decision-maker may lack control over the consequences of one or more of the scenarios under consideration. A structured methodology, that puts uncertainties into perspective and then takes them into account, is an effective way to deal with these problems.

The simulation tool developed during this research has transformed the simulation of implementation from a static state to a dynamic state through allocating durations, resources and costs to the implementation tasks. In addition, the tool can simulate uncertainties inherent in the implementation phase by applying Monte Carlo simulation. The tool has the capability of identifying influence variables on either the time or the cost of a specific task.

9.2.6 Assessment of the performance of the innovation implementation

The literature review of performance assessment in construction described in Chapter 6 addressed the lack of the assessment methods for innovative projects. The decision to accept a particular innovation in construction needs a systematic project evaluation process and a comprehensive set of evaluation criteria with the corresponding indicators for such criteria. As the inherent uncertainty in construction innovation often requires several iterations to obtain a degree of performance, translation of an innovative process into performance requirements often results in a vague and imprecise definition of the relevant performance indicators. Simulating innovation performance precludes the probabilistic analysis approach because innovation outputs are considered non-probabilistic results and may be measured in linguistic terms, therefore, fuzzy models are more suitable for simulating innovation performance.

9.2.7 Application of Fuzzy logic approach to simulate performance evaluation

Conventional rules (non-fuzzy rules) require precise numerical values in a causal relationship. This approach has difficulties in justifying the accuracy of numerical values given by experts, particularly, when dealing with vague situations. Fuzzy rules can overcome these shortcomings by using linguistic terms to represent the fuzziness contained in causal relationships between the implementation duration/cost and the expected performance. This approach provides a more practical solution for capturing uncertainties contained in the causal relationship.

It was concluded that performance evaluation can be enhanced by using non-probabilistic tools and techniques. The results of the proposed simulation tool help managers decide whether or not to accept or iterate an innovative process towards achieving satisfactory performance.

9.3 Recommendations for the industry

This research has developed a simulation tool that project teams can use for planning the implementation of construction innovations. The tool has been provided in a computer package. Sample windows of the input data and the output were presented in Chapter 8 and the program code is presented in Appendix D. It was validated and found to be functional, has a user-friendly interface and to be useful by the case study project team. Through the validation phase of this research, some recommendations have been addressed to improve the management of the innovation implementation. These recommendations are for the industry and also for further work to this research, as presented in the following sections.

9.3.1 Benefits that the developed tools offer to improve the management of the innovation implementation.

In order to evaluate the benefits and the validity of the proposed tool (INOVICET) for simulating the implementation of technological innovations in construction, a case study was conducted on the project of installation of a location control system using satellite facilities for a company vehicle fleet (see Chapter 9 and Appendix C for details). The main conclusion of the validation exercise was that the INOVICET tool could be applied to any project with minor adjustments to fit the specific nature of each project. The value of the simulation tool for the project stages is primarily that of a checklist to aid managers in identifying the innovation implementation tasks and their relevant information requirements. Other conclusions include:

1) INOVICET may be used by managers throughout the different implementation stages as a monitoring tool to ensure the completeness of the information requirements for the different implementation tasks;

2) the matrix modelling using the DSM can assist managers to identify loops of iterative innovation tasks. Knowing these tasks will enable managers to specify certain estimations of the information that causes iterations;
3) the Monte Carlo simulation results will provide managers with planning schedules and costs for different implementation scenarios;
4) the tool helps managers to decide whether to accept or iterate an innovative process to achieving satisfactory performance. The fuzzy logic approach, which was used to simulate project performance, reflects the nature of modelling innovation performance in linguistic judgements, such as bad or adequate. The fuzzy logic approach also converts qualitative criteria into numerical measures that can simulate an innovation process where mathematical precision is impossible or impractical; and
5) the INOVICET simulation tool will allow managers to investigate:

- the sensitivity of the subjective estimates of the influence information on the implementation tasks;
- the changes in the performance standard required to accept the innovation;
- the number of iterations to achieve satisfactory performance in terms of time or cost;
- the loop sizes to get the minimum number of dependency estimations;
- the different duration/cost of loop tasks for each iteration;
- the most critical information that influences project implementation; and
- the fuzzy evaluation of project performance to decide on iterated work.

9.3.2 Feedback from the industry

Feedback from the interviewees during data collection and validation demonstrated the following:

1) the problems in innovation management which were identified by this research were valid and often require significant solutions; and
2) the suitability of the developed tools for providing solutions to the identified problems. This confirms the benefits offered to improve the management of the innovation implementation.

The case study project was simulated using the INOVICET tool and the outputs were compared with the planning that was undertaken in practice. This showed that the latter did not take full account of the iteration within the implementation process that was planned almost entirely by INOVICET.

Within overall innovation implementation programmes, specific activities are recommended to improve the implementation of construction innovation, as presented below.

- To increase efficiency and effectiveness of innovation implementation, there is a need to invest in and increase the use of simulation tools of the implementation and especially the decision support tools and techniques (e.g. techniques used for this research).

- To ensure continuous improvement by developing innovative products or processes, knowledge management becomes essential to guarantee effective learning from innovation experiences and keeping an organisation in a motivated culture. Successful organisations are those that consistently create new knowledge, disseminate it widely throughout the organisation and quickly embody it in new technologies. These activities define the "Knowledge-creating" organisation, whose sole business is continuous innovation (Harvard Business Review on knowledge management, 1998). The traditional view in an organisation is that the only useful knowledge is formal, systematic, hard data and codified procedures. This view considers that measuring the value of new knowledge is also hard and quantifiable (e.g. increased efficiency, lower costs and improved return on investment). This view is countered by the approach of knowledge management involving the creation of new knowledge. This approach recognises that creating new knowledge is not simply a matter of "processing" objective information. Rather, it depends on tapping the tacit and often highly subjective insights, intuitions and hunches of individual employees and making these insights available for testing and use by the organisation as a whole. Making personal knowledge available to others is the central activity of the knowledge-creating organisation. It takes place continuously and at all levels of the organisation.

- To minimise the time/cost inefficiencies that are often the result of implementing innovations, building comprehensive data bases that summaries how information influences innovative projects and performance indicators to be assessed for these projects is highly recommended. These data should be collected from innovative projects during their implementation and comprehensively documented.

9.4 Recommendations for future work

The following recommendations for further research are derived from this study:

1) the research has proven that techniques based on DSM, Monte Carlo simulation, planning tool and fuzzy logic can improve the management and implementation of innovation. Further research is still needed to fully implement these techniques in construction organisations and to assess the viability of such implementation;
2) further research should be undertaken to link the simulation tool with current project management software;
3) further research should be undertaken to develop standard forms to record the progress of implementation on innovative projects. These forms should have a flexible structure to enable the project team to document various information on the project under investigation;
4) this research has demonstrated that the application of concurrent engineering concepts, such as DSM, offer potential benefits to the construction industry. Further research should be undertaken to apply other concurrent engineering techniques such as the Quality Function Deployment technique (a method of designing and optimising the process of developing new product based on customer needs). This technique may be applied to simulate the impact of the influence information on the innovation implementation stages and the resulting performance according to this information;
5) identify and codify the criteria of effectiveness and efficiency relating to each performance indicator to obtain a more accurate estimation of the fuzzy sets for performance and possibly provide more objective measures for it; and
6) develop a knowledge-base of criteria, indicators and associated target values and ranges with rules for weighting the values and ranges according to a project profile.

REFERENCES & APPENDICES

REFERENCES

- AbouRizk, S. M., Mandalapu, S. R., and Skibniewski, M., 1994. Analysis and Evaluation of Alternative Technologies. *J. Mgmt. in Engrg.* ASCE, **10** (3), pp. 65-71.
- Adeli, H., 1988. Expert systems in construction and structural engineering. *Chapman and Hall Ltd.*, New York.
- Alarcon, L.F and Ashley, D. B., 1996. Modelling project performance for decision-making. *J. Constr. Engrg. and Mgmt.* ASCE, **122** (3), pp 265-273.
- Alarcon, L.F, 1997. Lean construction. *A. A. Balkema Publishers*, USA.
- Aouad, G., Hinks, J., Cooper, R., Sheath, D., Kagioglou, M. and Sexton, M., 1998. An IT map for a generic design and construction process protocol. *Journal of construction procurement*, Nov. 1998, **4** (1), pp. 132-151.
- Arditi, D., Kale, S. and Tangkar, M., 1997. Innovation in construction equipment and its flow into the construction industry. *J. Constr. Engrg. and Mgmt.* ASCE, **123** (4), pp. 371-378.
- Austin, S, Baldwin, A., Li, B., and Waskett, P, 1999. Analytical design planning technique for programming building design. *Proc. Instn Civ. Endrs Structs & Bldgs.* **134**, pp 111-118.
- Austin, S, Baldwin, A., Li, B., and Waskett, P, 1999. Analytical design planning technique: a model of the detailed building design process. *Design Studies*, **20**(3), pp 279-296.
- Baldwin, A., Austin, S., Thorpe, A. & Hassan, T., 1995. Simulating Quality within the Design process. *ASCE second congress on computing in civil Engineering*, Atlanta, Georgia, June, pp 1475-1482.
- Baldwin, A., Austin, S., Hassan, T. & Thorpe, A., 1998. Planning building design by simulating information flow. *Journal of Automation in Construction*, **8**, pp 149-163.
- Betts, M. and Ofori, G., 1992. Strategic planning for competitive advantage in construction. *J. Construction Management and Economics*, **10**, pp 511-532.
- Betts, M. and Ofori, G., 1994. Strategic planning for competitive advantage in construction: The institutions. *J. Construction Management and Economics*, **12**,

pp 203-217.

- Bititchi, U. M., Carrie, A. S., and McDevitt, L. 1997. Integrated performance measurement systems: as audit and development guide. *The TQM magazine*, **9**(1), pp 46-53.
- Boland, R. Greenberg, R., Park, S. and Han, I., 1990. Mapping the process of problem reformulation, implications for understanding strategic thought. *In A.S. Huff, Mapping Strategic Thought,* Wiley, Chichester.
- Boles, W., Maxwell, D. A., and Scott, W. D., 1995. Construction Automation and Robotics-pathway to Implementation. *J. Constr. Engrg. and Mgmt.* ASCE, **121**(1), pp 143-152.
- Browning, T. R., 1997. Dependency structure matrix-based system engineering, organisation planning, and schedule management. *MIT Lean Aircraft initiative Working Paper*, MIT, Cambridge, MA.
- Byron, S. G., 1984. Elements of stochastic process simulation. *Prentice Hall.*
- Chang, L., Hancher, D.E., Napier, T.R. and Kapolnek, R.G., 1988. Methods to identify and assess new building technology. *J. Constr. Engrg. and Mgmt.* ASCE, **114** (3), pp. 408-425.
- Chao, L. and Skibniewski, M. J., 1995. Neural Network method of estimating construction technology acceptability. *J. Constr. Engrg. and Mgmt.* ASCE, **121**(1), pp. 130-142.
- Chao, L. and Skibniewski, M.J., 1998. Fuzzy logic for evaluating alternative construction technology. *J. Constr. Engrg. and Mgmt.* ASCE, **124**(4), pp. 297-304.
- Chua, D.K.H., Kog, Y.C., Loh, P.K. and Jaselskis, E.J., 1997. Model for construction budget performance – Neural network approach. *J. Constr. Engrg. and Mgmt.* ASCE, **123**(3), pp. 214-222.
- Cooper, R., Kagioglou, M., Aouad, G., Hinks, J., Sexton, M. and Sheath, D., 1998. The development of a Generic Design and Construction process. *Proceedings of the European conference on Product Data Technology, Building Research Establishment,* March 1998, Garston, Watford, UK, pp. 205-214.
- Crandall, K.C., 1977. Analysis of schedule simulation. *Journal of Construction division,* ASCE, Sep. 77, pp 387-394.

- Cushman N. S., Nam C. H. and Tatum C. B., 1992. Technology Transfer in Building Construction-Case of Seismic Design. *J. Constr. Engrg. and Mgmt.* ASCE, **118** (1), pp. 129-141.
- De La Garza, J. M. and Mitropoulos, P., 1991. Technology Transfer (T2) Model for Expert Systems. *J. Constr. Engrg. and Mgmt.* ASCE, **117**(4), pp. 736-755.
- De La Garza, J. M. and Mitropoulos, P., 1992. Flavors and Mixins of Expert Systems technology transfer model for AEC industry. *J. Constr. Engrg. and Mgmt.* ASCE, **118**(3), pp. 435-453.
- Egan, J, 1998. Rethinking construction, *DETR*, UK.
- Ellis Jr, R. D., 1997. Lean construction. *A. A. Balkema Publishers*, USA.
- Eppinger, S., 1991. Model based approaches to managing concurrent engineering. *Journal of Engineering design*, 2(4), pp 283-290.
- Evangelidis, K., 1992. Performance measured is performance gained. *The Treasurer*, February, 45-7.
- Farid, F., El-Sharkawy, A.R., and Austin, L.K., 1993. Managing for Creativity and Innovation in A/E/C organisations. *J. Mgmt. in Engrg.* ASCE, **9** (4), pp. 399-409.
- Fellows, R. and Liu, A., 1997. Research methods for construction. *Blackwell Science.*
- Ferrell, W. R., 1994. Discrete subjective probabilities and decision analysis: elicitation, calibration and combination. *John Wiley & Sons Ltd.*
- Fishman, G. S., 1996. Monte Carlo – concepts, algorithms and applications. *Springer series in operations research, Springer – Verlag*, New York.
- Fleming, A., Lee, A., Cooper, R. and Aouad, G., 2000. The development of a process mapping methodology for the Process Protocol Level 2. *Third European conference on Product and Process Modelling in the Building and Related industries*, Portugal, 2000.
- Freeman, C., 1989. The economics of Industrial innovation. *MIT Press*, Cambridge, MA.
- French, S., 1988. Decision Theory: an introduction to the mathematics of rationality. *Ellis Horwood Series in mathematics and its applications.*

- Gann, D. M., 2000. Building innovation – complex constructs in a changing world. *Thomas Telford Publishing*, London, UK.
- Gardiner, P. and Rothwell, R. 1985. Tough customers: Good designs. *Design studies*, Vol. **6**.
- Gebala, D. and Eppinger, S. 1991. Methods for analysing design procedures. *ASME conference on design theory and methodology*, Miami, Sept., pp 227-233.
- Hage, J., 1980. Theories of organisations. *John Wiley*, New York.
- Harvard Business Review on knowledge management, 1998. *Harvard Business School Publishing*, Boston, US.
- Heijden, K., 1994. Probabilistic planning and scenario planning. *John Wiley & Sons Ltd.*
- Hinks, J., Aouad, G., Cooper, R., Sheath, D., Kagioglou, M. and Sexton, M., 1997. IT and the design and construction process: a conceptual model of co-maturation. *The international journal of construction IT*, July 1997.
- Huovilla, P., Koskela, L., Lautanala, M., Pietilainen, K. & tanhuanpaa, V., 1995. Use of the Design Structure Matrix in construction. *3rd international workshop on lean construction*, Albuquerque.
- Ioannou, P. G. and Carr, R. I., 1988. Advanced Building Technology Matrix System. *J. Constr. Engrg. and Mgmt.* ASCE, **114** (4), pp 517-531.
- Ioannou, P. G. and Liu, L. Y., 1993. Advanced Construction Technology System – ACTS. *J. Constr. Engrg. and Mgmt.* ASCE, **119** (2), pp. 288-306.
- Kagioglou, M., Cooper, R., Aouad, G., Hinks, J., Sexton, M., and Sheath, D. M. (1998). "A generic guide to the design and construction Process Protocol." *ISBN No: 0-902896-17-2*, The University of Salford, UK.
- Kagioglou, M., Cooper, R., and Aouad, G., 2001. Performance management in construction – a conceptual framework. *Construction Management and Economics,* **19** (1), pp 85 – 95.
- Keeney, R. L., 1982. Decision analysis: An overview. *Operations Research,* **30**, pp. 803-38.
- Koskela, L., 1992. Application of the new production philosophy to construction. *Technological Report No. 72, CIFE, Stanford University, US.*
- Kraft, W. H., 1997. Building a Consensus: How Tos & How not Tos. *J. Mgmt. in*

Engrg., pp. 20-22.

- Krishnan, N., Eppinger, S. and Whiteny, D., 1993. Overlapping product development activities by analysis of information transfer practice. *Ninth international conference on engineering design, ICED 93*, The Hague, Sept., pp 685-688.
- Kumaraswamy, K. and Thorpe, A., 1996. Systematising construction project evaluations. *J. Mgmt. in Engrg. ASCE,* **12**, pp. 34-39.
- Laborde, L. and Sanvido, V., 1994. Introducing New Process Technologies into Construction Companies. *J. Constr. Engrg. and Mgmt.* ASCE, **120** (3), pp. 488-508.
- Lansley, P., 1996. Innovation: The role of research, education and practice. *The Chartered Institute of Building.* Construction paper No. **59**.
- Ledet, W.P. and Himmelblau, D.M., 1970. Decomposition procedures for the solving of large scale systems. *Advances in Chemical Engineering*, **8**, pp 185-254.
- Lewis, P.A.W. and Orav, E.V., 1989. Simulation methodology for statisticians. *Operations analysts and engineers*, **1**, Wadsworth Inc., Belmont, California.
- Lindley, D., 1994. Subjective Probability - Foundation. *John Wiley & Sons Ltd.*
- Liu, A.M.M. and Walker, A., 1998. Evaluation of project outcomes. *Construction Management and Economics,* **16**, pp. 209-219.
- Lorterapong, P. and Moselhi, O., 1996. Project network analysis using fuzzy sets theory. *J. Constr. Engrg. and Mgmt. ASCE,* **122**(4), pp. 308-318.
- Lutz, J.D., Chang, L., and Napier, T.R., 1990. Evaluation of new building technology. *J. Constr. Engrg. and Mgmt.* ASCE, **116** (2), pp. 281-299.
- MacLeod, I.A., Kumar, B. and McCullough, J., 1998. Innovative design in the construction industry. *ICE*, **126**, pp. 31-38.
- McCabe, B., AbouRizk, S.M. and Goebel, R., 1998. Belief networks for construction performance diagnostics. *J. Computing in Civil Engrg. ASCE,* **12**, pp. 93-100.
- McCord, K. & Eppinger, S., 1993. Managing the integration problem in concurrent engineering. *Working paper WP 3594-93-MSA*, Sloan school of management, Massachusetts Institute of Technology, USA.

- McCulley, C. and Bloebaum, C.L., 1994. Optimal Sequencing for complex Engineering systems using genetic algorithms. *AIAA paper No. 94 – 4327.*
- Mitropoulos, P. and Tatum, C. B., 2000. Forces driving adoption of new information technologies. *J. Constr. Engrg. and Mgmt.* ASCE, **126** (5), pp. 340-348.
- Morris, D., 1982. Modelling project milestones: dependent activities. *J. Constr. Division.* ASCE, Vol. **108**, pp 247-258.
- Murtaza, M. B., Fisher, D. J., and Skibniewski, M., 1993. Knowledge-Based Approach to Modular Construction Decision Support. *J. Constr. Engrg. and Mgmt.* ASCE, **119** (1), pp. 115-130.
- Nam, C. H. and Tatum, C. B., 1988. Major characteristics of constructed products and resulting limitations of construction technology. *J. Constr. Mgmt. and Econ.*, **6**, pp. 133-148.
- Nam, C. H. and Tatum, C. B., 1989. Toward understanding of product innovation process in construction. *J. Constr. Engrg. and Mgmt.* ASCE, **115** (4), pp. 517-534.
- Nam, C. H. and Tatum, C. B., 1992a. Non-contractual methods of integration on construction projects. *J. Constr. Engrg. and Mgmt.* ASCE, **118** (2), pp. 385-398.
- Nam, C. H. and Tatum, C. B., 1992b. Strategies for Technology Push: Lessons from Construction Innovations. *J. Constr. Engrg. and Mgmt.* ASCE, **118** (3), pp. 507-524.
- Neely, A., Richards, H., Mills, J., Platts and Bourne, M., 1997. Designing performance measures: a structured approach. *International Journal of Operations & Production Management*, **17** (11), 1131-52.
- Newendorp, P.D., 1975. Decision analysis for petroleum exploration. *Ch.6 and Ch. 8, Petroleum Publishing Company*, Tulsa.
- Noori, H., 1990. Managing the dynamics of new technology: issues in manufacturing management. *Englewood Cliffs, N.J.; London: Prentice Hall.*
- Nukala, M., Eppinger, S., Whiteny, D., 1995. Generalised models of design iteration using signal flow graphs. *DE-Vol. 83, Design Engineering Technical Conferences*, Vol. 2, ASME, pp 413-422.

- O'Connor, J.T. and Davis, V.S., 1988. Constructability Improvement during field operations. *J. Constr. Engrg. and Mgmt.,* ASCE, **114** (4), pp 548-564.
- Ofori, G., 1994. Construction industry development: role of technology transfer. *J. Construction Management and Economics*, **12**, pp 379-392.
- Oglesby, C.H., Parker, H.W., and Howell, C. A., 1989. Productivity improvement in construction, *Mac Graw Hill Book Company, US.*
- Paek, J. H., Lee, Y.W. and Napier, T.R., 1992. Selection of Design/Duild Proposal using Fuzzy-Logic System. *J. Constr. Engrg. and Mgmt.,* ASCE, **118** (2), pp. 303-317.
- Paek, J. H., Lee, Y.W. and Ock, J.H., 1993. Pricing Construction Risk: Fuzzy set Application. *J. Constr. Engrg. and Mgmt.,* ASCE, **119** (4) , pp. 743-756.
- Partridge, J., 1987. Computer Aided Design Integration and the Integration of Design and Manufacture. *Doctoral Thesis, University of Southampton*, UK.
- Pidd, M., 1992. Computer simulation in management science. *Third Edition, John Wiley & Sons*, Chichester, UK.
- Pimmler and Eppinger, S.D., 1994. Integration analysis of product decompositions. *Proceedings of the 6th International Conference on Design Theory and Methodology*, Sept., Minnwapolis, MN.
- Pocock, J.B., Hyun, C.T., Liu, L.Y. and Kim, M.K., 1996. Relationship between project interaction and performance indicators. *J. Constr. Engrg. and Mgmt. ASCE,* **122**(2), pp. 165-176.
- Pries, F. and Janszen, F., 1995. Innovation in the construction industry: the dominant role of the environment. *J. Constr. Mgmt. and Econ.*, **13**, pp. 43-51.
- Rogers, E. M., 1983. Diffusion of innovations, *Free Press*, New York.
- Rogers, J., 1989. A knowledge-based tool for multilevel decomposition of a complex design problem. *Technical paper, NASA*, May 1989, US.
- Rogers, J.L. and Bloebaum, C.E., 1994. Ordering design tasks based on coupling strengths. *AIAA paper No. 94-4326.*
- Rogers, J.L., 1996. DeMAID/GA User's guide – Design manager's aid for intelligent decomposition with a genetic algorithm. *Technical memorandum 110241*, NASA.

- Rosenfeld, Y., 1994. Innovative construction methods. *J. Constr. Mgmt. and Econ.*, **12**, pp. 521-541.
- Ross, T. J., 1995. Fuzzy logic with engineering applications. *McGraw-Hill, Inc.*, US.
- Russell, J.S., Jaselskis, E.J. and Lawrence, S.P., 1997. Continuous assessment of project performance. *J. Constr. Engrg. and Mgmt.* ASCE, **123**, pp. 64-71.
- Saaty, T. L., 1980. The analytical hierarchy process: Planning, priority setting, resource allocation. *McGraw-Hill International Book Co.*, London, UK.
- Sanger, M., 1998. Supporting the balanced scorecard. *Work study*, **47** (6), 197-200.
- Schumacher, T., Kaye, R., Egbu, C. and Young, B., 1998. Training champions with multimedia simulation. *International society for professional innovation management (ISPIM).* Workshop conference, Vienna, Sep. 14 -16.
- Sheath, D. M., Woolley, H., Cooper, R., Hinks, J. and Aouad, G. A., 1996. Process for change – the development of a generic design and construction protocol for the UK construction industry. *International construction information technology (INCIT 96) conference*, Sydney, Australia, 91-98.
- Shin, H.J., 1994. A fuzzy approach to construction activity estimation. *Ph. D. Thesis, Loughborough university, Loughborough*, UK.
- Sink, D. S., 1985. Productivity management: planning, measurement and evaluation, control and improvement. *John Wiley & Sons*, US.
- Skibniewski, M. J., 1991. Information management system for new construction technologies. *J. Construction Management and Economics*, **9**, pp. 39-49.
- Skibniewski, M. J. and Chao, L., 1992. Evaluation of advanced construction technology with AHP method. *J. Constr. Engrg. and Mgmt.* ASCE, **118** (3), pp. 577-593.
- Slaughter, S., 1993. Innovation and learning during implementation: a comparison of user and manufacturer innovations. *Research Policy*, **22** (1), pp. 81-95.
- Slaughter, S., 1998. Models of construction innovations. *J. Constr. Engrg. and Mgmt.* ASCE, **124** (2), pp. 226-31.
- Slaughter, S., 1999. Assessment of construction processes and innovations

through simulation. *J. Construction Management and Economics,* **17**, pp. 341-350.

- Slaughter, S. and Shimizu, H., 2000. 'Clusters' of innovations in recent long span and multi-segmental bridges. *J. Construction Management and Economics,* **18**, pp. 269-280.
- Smith, R. P. and Eppinger, S.D., 1993. Characteristics and models of iteration in engineering design. *International conference on Engineering design (ICED 93),* The Hague, Aug, pp 564-571.
- Smith, R. P. and Eppinger, S.D., 1995. Identifying controlling features of engineering design iteration. *Working paper WP 3348-91-MS,* Sloan school of management, Massachusetts Institute of Technology, USA.
- Steward, D., 1981. Systems Analysis and Management: Structure, Strategy and Design. *Petrocelli Books*, New York.
- Steward, D., 1981. The Design Structure System: A method for managing the Design of complex systems. *IEEE Transactions on Engineering Management,* Vol. EM-28, No.3, August 1981, pp 71-74.
- Steward, D., 1993. Re-engineering the design process. *Proceedings of the second workshop on enabling technologies: Infrastructure for collaborative enterprises,* April, Morgantown, WV.
- Tatum, C. B., 1986. Potential Mechanisms for Construction Innovation. *J. Constr. Engrg. and Mgmt.* ASCE, **112** (2), pp 178-191.
- Tatum, C. B., 1987. Process of Innovation in construction Firm. *J. Constr. Engrg. and Mgmt.* ASCE, **113** (4), pp. 648-663.
- Tatum, C. B., 1988. Classification System for Construction Technology. *J. Constr. Engrg. and Mgmt.* ASCE, **114** (3), pp. 344-363.
- Tatum, C. B., Bauer, M.F. and Meade, A.W., 1989. Process of innovation for Up/Down construction at Rowes Wharf. *J. Constr. Engrg. and Mgmt.* ASCE, **115** (2), pp. 179-195.
- Tatum, C. B., 1989. Organising to increase innovation in construction firms. *J. Constr. Engrg. and Mgmt.* ASCE, **115** (4), pp. 602-617.
- Technology Foresight Panel on Construction, 1995. *Progress Through Partnership, 2, Office of Science and Technology,* London: HMSO.

- The KPI Working Group, 2000. KPI Report for The Minister for Construction, *Department of the Environment, Transport and the Regions, UK*, January.
- Tornatzky, L. G., 1983. The process of technological innovation: Reviewing the literature. *Productivity Improvement Res. Sect., national Science Foundation*, Washington, D.C.
- Touran, A., 1990. Integration of Simulation with Expert Systems. *J. Constr. Engrg. and Mgmt.* ASCE, **116** (3), pp. 480-493.
- Trinh, T.T.P. and Sharif, N., 1996. Assessing construction technology by integrating constructed product and construction process complexities: a case study of embankment dams in Thailand. *J. Constr. Mgmt. and Econ.*, **14**, pp. 467-484.
- Vahala, P., 1997. Prototype tool for construction process modelling and management. *http://www.vtt.fi/cic/projects/star/star1/103.html*
- Van Gelder, A., 1967. Some new results in Pseudo Random Number generations. *Journal of the association for computing Machinery*, Vol. 14.
- Van Slyke, R.M., 1963. Monte Carlo methods and PERT problem. *Operation Research*, Vol.**11**, pp 839-860.
- Van Tetterode, L.M., 1971. Risk analysis or Russian roulette. *Trans. Of the American Association of Cost Engineers*, pp 124-129.
- Voss, C. A., 1988. Implementation: A Key Issue in Manufacturing technology: The need for a field of study. *Research Policy*, Vol. **17**.
- Wakeman, T. H., 1997. Engineering leadership in public policy resolution. *J. Mgmt. in Engrg.* ASCE, **13** (4), pp. 57-60.
- Wang, C., Wang, M. and Huang, Y., 1998. Hierarchical indices for measuring the effectiveness of construction automation implementation. *J. Construction Management and Economics,* **16**, pp. 257-267.
- Willis, E.M., 1986. Scheduling construction projects. John Wily.
- Winch, G. M., 1994. Managing Production – Engineering change and stability. *Clarendon Press, Oxford*, New York.
- Winch, G. M., 2000. Innovativeness in British and French construction: the evidence from Transmanche-Link. *J. Construction Management and Economics,*

18, pp. 807-817.

- Winistorfer, S. G., 1996. Product Champion in Government Agencies. *J. Mgmt. in Engrg.* ASCE, **12** (6), pp. 54-58.
- Wright, G. and Ayton, P., 1994. Subjective Probability. *John Wiley & Sons Ltd.*
- Wu, S., Aouad, G. and Cooper, R., 2000. IT support for process protocol. *Bizarre Fruit Postgraduate Research conference on the Built and Human Environment*, Salford, UK, 2000.
- Yates, J. K., 1994. Construction Competition and Competitive Strategies. *J. Mgmt. in Engrg.* ASCE, **10** (1), pp. 58-69.
- Yin, R. K., 1994. Case Study Research: Design and Methods. *Sage Publications*, London.
- Zadeh, L.A., 1965. Fuzzy sets, *Information and control,* **8**(3), pp. 338-353.
- Zaltman, G., Duncan, R. and Holbek, J. (1973), Innovations and Organisations, *John Wiley*, New York.

BIBLIOGRAPHY

- Abd El-Razek, M., E., 1999. New method for construction of diaphragm walls. *J. Constr. Engrg. and Mgmt.* ASCE, **125** (4), pp 233-241.
- Alkass, S., Aronian, A. and Moselhi, O., 1993. Computer-Aided Equipment Selection for transporting and placing concrete. *J. Constr. Engrg. and Mgmt.* ASCE, **119** (3), pp 445-465.
- Amirkhanian, S.N. and Baker, N. J., 1992. Expert System for Equipment Selection for Earth-Moving Operations. *J. Constr. Engrg. and Mgmt.* ASCE, **118** (2), pp 318-331.
- Ball, M. 1988. Rebuilding Construction. *Routledge*, London.
- Barlow, J. and Gann, D. M., 1995. Flexible planning and flexible buildings? Re-using redundant office space. *International Journal of Urban Affairs*, **17** (3), pp 263 – 276.
- Basha, I. M., Gab-Allah, A. A. and Amer, M. I., 1995. Construction of Ameria Caisson in Egypt. *J. Constr. Engrg. and Mgmt.* ASCE, **121** (1), pp 13-19.
- Bates, G. D., 1996. I don't believe in change just for the sake of change. *J. Mgmt. in Engrg.* ASCE, May/June, pp 20-24.
- Beliveau, Y.J., 1997. Building a consortium for advanced positioning systems. *J. Mgmt. in Engrg.* ASCE, July/Aug., pp. 26-29.
- Bender, M. and Simonovic, S.P., 1994. Decision-Support System for Long-Range Stream Flow Forecasting. *J. of Computing in Civil Engineering*, **8** (1), pp 20-34.
- Bernstein, H. M. and Lemer, A.C. 1996. Solving the innovation puzzle: challenges facing the U.S. design and construction industry. *ASCE Press*, New York.
- Bottom, D., Gann, D., Groak, S. and Meikle, J. 1996. Innovation in Japanese prefabricated house-building industries. *CIRIA, Special publication*, **139**, London.
- DEGW/Technibank, 1992. The intelligent building in Europe. *European Intelligent Building Group*, London.
- Demski, S., 1993. Resistance to change: Why your TQM efforts may fail? *J. Mgmt. in Engrg.* ASCE, 9(4), pp 426-432.
- Eden, C., 1989. Using cognitive mapping for strategic option development and analysis. *Rational analysis for a problematic world, Wiley,* Chichester.

- Edwards, K., 1998. Technological change in the elevator industry. *MSc Thesis, SPRU, University of Sussex*, Brighton, UK.
- EPSRC, 1994. Innovative manufacturing – a new way of working. *Engineering and Physical Sciences Research Council*, Swindon.
- Egbu, C. O., Henry, J., Kaye, G. R., Quintas, P. Schumacher T.R. and Young B. A., 1998. Innovation in construction: building capability through collaboration in project based teams. *MKIRU workshop, The Open University*, UK.
- Egbu, C. O., Henry, J., Kaye, G. R., Quintas, P. Schumacher T.R. and Young B. A., 1998. Cultural and managerial aspects of construction innovation. *Construction 21, congress proceedings*, The Mandarin Singapore, pp 93-97.
- Elazouni, A.M., 1997. Constructability improvement of steel silos during field operations. *J. Constr. Engrg. and Mgmt.* ASCE, **123** (1), pp. 21-25.
- Everett, J. G. and Slocum, A. H., 1994. Automation and Robotics Opportunities: Construction versus Manufacturing. *J. Constr. Engrg. and Mgmt.* ASCE, **120** (2), pp 443-452.
- Farr, J. V. and Sullivan Jr., J. F., 1996. Rethinking Training in the 1990s. *J. Mgmt. in Engrg.* ASCE, **12**(3), pp 29-33.
- Freeman, C., 1991. Innovation, changes of techno-economic paradigm and biological analogies in economics. *Revue Economique*, **42** (2), pp 211-231.
- Gann, D. M., 1996. Construction as a manufacturing process? Similarities and differences between industrialised housing and car production in Japan. *Construction management and economics*, **14**, pp 437-450.
- Gann, D. M. and Salter, A., 1998. Learning and innovation management in project-based, service-enhanced firms. *International Journal of Innovation Management*, **2** (4), pp 431-454.
- Gann, D. M., Wang, Y. and Hawkins, R., 1998. Do regulations encourage innovation? – The case of energy efficiency in housing. *Building Research and information*, **26** (5), pp 280-296.
- Gerwick Jr., B. C., 1990. Implementing Construction Research. *J. Constr. Engrg. and Mgmt.* ASCE, **116** (4), pp 556-563.
- Groak, S., 1996. The idea of Building: thought and action in the design and protection of buildings. *J. Mgmt. in Engrg.* ASCE, July/Aug., pp 15-17.

- Halpin, D. W., 1993. Process-Based research to meet the International Challenge. *J. Constr. Engrg. and Mgmt.* ASCE, **119** (3).
- Hampson, K. and Tatum, C. B., 1997. Technology strategy and competitive performance in bridge construction. *J. Constr. Engrg. and Mgmt.* ASCE, **123** (2), pp. 153-161.
- Hansen, K. L. and Tatum, C. B., 1996. How Strategies Happen: A Decision-Making Framework. *J. Mgmt. in Engrg.* ASCE, **12**(1), pp 40-48.
- Herbsman, Z. and Ellis, R., 1992. Multiparameter Bidding System - Innovation in Contract Administration. *J. Constr. Engrg. and Mgmt.* ASCE, **118** (1), pp 142-150.
- Hodgson, A.M., 1992. Hexagons for systems thinking. *European Journal of Operational Research*, **59**, pp. 200-230.
- Hodkinson, R, 2000. New technology and innovation at Greenwich millennium village. *Proceeding of ICE,* **138,** pp 79-84.
- Ioannou, P. G., 1989. Dynamic Probabilistic Decision Processes. *J. Constr. Engrg. and Mgmt.* ASCE, **115** (2), pp 237-257.
- Ioannou, P. G. and Martinez, J.C., 1996. Comparison of construction alternatives using matched simulation experiments. *J. Constr. Engrg. and Mgmt.* ASCE, **122** (3), pp. 231-241.
- Jaafari, A. and Mateffy, V.K., 1990. Realistic Model for Equipment Replacement. *J. Constr. Engrg. and Mgmt.* ASCE, **116** (3), pp 514-532.
- Johnson, K. D. and Tatum, C.B., 1993. Technology in Marine Construction Firms. *J. Constr. Engrg. and Mgmt.* ASCE, 119(1), pp 148-162.
- Jungermann, H. and Thuring, M. 1987. The use of mental models for generating scenarios. *Judgemental Forecasting, Wiley,* Chichester.
- Kakoto, T. and Skibniewski, M., 1991. Engineering Decision Support of Automated Shield Tunnelling. *J. Constr. Engrg. and Mgmt.* ASCE, **117**(4), pp 674-690.
- Kamarthi, S. V., Sanvido, V. E. and Kumara, S. R. T., 1992. Neuroform - Neural Network System for Vertical Formwork Selection. *J. of Computing in Civil Engineering,* ASCE, **6**(2), pp 178-199.

- Kangari, R. and Miyatake, Y., 1997. Developing and managing innovative construction technologies in Japan. *J. Constr. Engrg. and Mgmt.* ASCE, **123** (1), pp. 72-77.
- Latham, Sir M., 1994, Constructing the Team, *HMSO.*
- Lewis, B. J., 1994. Leading Creative People as Consulting Engineering Becomes Globalized. *J. Mgmt. in Engrg.*, ASCE, **10**(2), pp 39-43.
- Mak, S. W., 1995. Risk analysis in construction: a paradigm shift from a hard to soft approach. *J. Construction Management and Economics,* **13**, pp. 385-392.
- McCraw, L., 1996. Accelerating Innovation. *J. Mgmt. in Engrg.*, ASCE.
- Mitropoulos, P. and Tatum, C. B., 1998. Technology adoption decisions in construction organisations. *J. Constr. Engrg. and Mgmt.* ASCE, **125** (5), pp. 330-338.
- Miyatake, Y., 1996. Technology Development and Sustainable Construction. *J. Mgmt. in Engrg.*, ASCE, July/Aug., pp 23-26.
- Mohan, S., 1990. Expert systems applications in construction management and engineering. *J. Constr. Engrg. and Mgmt.* ASCE, **116** (1), pp. 87-99.
- Moselhi, O., Hegazy, T. and Fazio, P., 1991. Neural Network as Tools in construction. *J. Constr. Engrg. and Mgmt.* ASCE, **117**(4), pp 606-625.
- Murtaza, M. B. and Fisher, D. J., 1994. Neuromodex - Neural Network system for Modular construction decision-making. *J. of Computing in Civil Engineering,* **8**(2), pp 221-233.
- Nam, C. H., Gasiorowski, J. G. and Tatum, C. B., 1991. Microlevel study of integration in high-strength concrete innovation. *J. Constr. Engrg. and Mgmt.* ASCE, **117**(2), pp 294-309.
- Nam, C. H. and Tatum, C. B., 1992. Government-Industry cooperation : Fast-Track concrete innovation. *J. Constr. Engrg. and Mgmt.* ASCE, **118**(3), pp 454-471.
- Nam, C. H. and Tatum, C. B., 1997. Leaders and champions for construction innovation. *J. Construction Management and Economics*, **15**, pp 259-270.
- Paek, J. H. and Ock, J. H., 1996. Innovative Building Construction Technique: Modified Up/Down Method. *J. Constr. Engrg. and Mgmt.*, ASCE, **122**(2), pp 141-146.

- Reich, Y., Medina Jr., M.A., Shieh, T. and Jacobs, T.L., 1996. Modeling and Debugging Engineering Decision Procedures with machine Learning. *J. of Computing in Civil Engineering*, ASCE, **10** (2), pp 157-166.
- Reyna, S. M., Vanegas, J. A.and Khan, A. H., 1994. Construction Technologies for Sewer Rehabilitation. *J. Constr. Engrg. and Mgmt.*, ASCE, **120** (3), pp 467-487.
- Sanders, S. R. and Eskridge, F., 1993. Managing Implementation of Change. *J. of Management in Engineering*, **9** (4), pp 365-381.
- Shah, J. B., 1996. Innovative Design/Bulid Approach: Ambassador Bridge Project. *J. of Management in Engineering*, **12** (4), July/Aug., pp 58-61.
- Slaughter, S., 1993. Builders as sources of construction innovation. *J. Constr. Engrg. and Mgmt.* ASCE, **119**(3), pp 532-549.
- Songer, A. d. and Molenaar, K. R., 1996. Selecting design/Build: Public and Private sector owner attitudes. *J. Mgmt. in Engrg.* ASCE, **12** (6), pp. 47-53.
- Stewart, W.S. and Tatum, C. B., 1988. Segmental Placement of Renton outfall: construction innovation. *J. Constr. Engrg. and Mgmt.* ASCE, **114**(3), pp 390-407.
- Tatum, C. B., 1984. What prompts construction innovation? *J. Constr. Engrg. and Mgmt.* ASCE, **110** (3), pp. 311-323.
- Tatum, C. B. and Funke, A.T., 1988. Partially automated Grading: Construction Process Innovation. *J. Constr. Engrg. and Mgmt.* ASCE, **114** (1), pp 19-35.
- Tidd, J., Bessant, J. and Pavitt, K., 1997. Managing innovation, *Wiley*, Chichester.
- Toole, T.M., 1998. Uncertainty and home builders' adoption of technological innovations. *J. Constr. Engrg. and Mgmt.* ASCE, **124** (4), pp. 323-332.
- Venegas, P. C. and Alarcon, L. F., 1997. Selecting long-term strategies for construction firms. *J. Constr. Engrg. and Mgmt.* ASCE, **123** (4), pp. 388-398.
- Winch, G. E., 1999. Innovation in the British Construction industry: The role of public policy instruments. *The UK TG35 Team, Working paper*, London.

APPENDIX A

PROCESS PROTOCOL MAP

This appendix presents the main components of the process protocol phases of a construction project, the deliverables required for each phase and the activity zones that describe who undertakes a project's activities. The following sections present a brief description for the protocol components. More details were presented by Kagioglou et al (1998).

A.1 PHASES

Phase 0: Demonstrating the need (What is the problem?)

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 business customer communicates the problem to the client. A master plan of the client's strategic issues should be available.

Phase 1: Conception of need (What are the options and how will they be addressed?)

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

Phase 2: Outline feasibility (Which option(s) should be considered further?)

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.

Phase 3: Substantive feasibility study - outline financial authority (Should the proposed solution(s) be financed for development?)

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.

Phase 4: Outline conceptual design (How does the solution translate to an outline design?)

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.

Phase 5: Full conceptual design (Can we apply for planning permission?)

The conceptual design should present the chosen solution in a 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.

Phase 6: Co-ordination design, procurement and full financial authority (Are the major design elements fixed?)

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

Phase 7: Production information (Is the detail 'right' for construction?)

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.

Phase 8: Construction (Are we ready to hand-over the facility?)

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-occur in future projects.

Phase 9: Operation and Maintenance (What can we learn?)

The facility is handed over to the client as planned. The post project review should identify any areas that need to be 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.

The lifecycle of the product is likely to be more than a decade. Therefore the facility Lifecycle should be considered and the facility examined in planned intervals either as part of the contractual arrangements or as part of continuous customer service. All lessons learned should be entered in the Legacy Archive and used for future projects.

Table A.1 gives the states that each deliverable has for each phase. Table A.2 summarises the construction project phases linking the required deliverable for each phase and the contents of these deliverables.

Table A.1 Deliverable states

State	Description
Initial (I)	Preliminary information is presented
Updated (U)	Current information is updated
Revised (R)	Major changes/decisions will significantly alter the content and context of the document
Finalised (F)	The information presented is agreed and it is unlikely to change throughout the duration of the project

Table A.2 Deliverables required for each project phase

	Phase 0	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6	Phase 7	Phase 8	Phase 9
Stakeholder list • Prioritised naming of the Stakeholders • A brief summary of their views, interests and/or requirements	I	F								
Statement of Need • Key objectives in strategic terms • Outline problem, need or opportunity • Preliminary assessment of risk	I	F								
Business Case • Financial capabilities • Financial alternatives • Financial Trade-off's • Product requirements • Product specifications • Product usability • Customer needs, requirements and/or opportunities • Customer satisfaction	I	U	U	U	R	U	U	F		
Project Execution Plan • Resources and duration needs for the potential and actual construction project • Methods for developing and producing the proposed project solution(s) • Identification of significant work items • Contingency plans for specific elements of the project • Programme optimisation elements	I	U	U	R	R	U	U	F		

Process Execution Plan • Breakdown of the project into distinct phases • Identification of the deliverables required at the end of each phase • Duration estimations for each phase • Information regarding the enactment of phase reviews i.e. content of phase review report, agenda etc.	I	U	U	R	R	U	U	F		
Performance management report The Performance Indicators introduced by this model can be used to complete this report. (Productivity, Duration, Budget, etc.)			I	U	U	U	U	F		
Communications strategy • Indicate the means by which data should be exchanged • Ensure the compatibility of all systems and software in use • Plan external and internal public relations and communications				I	R	U	U			
Procurement plan • Resource plan for the next phase(s) • Supplier and expert advice needed to undertake the activities at a particular phase • Equipment (in-house or sub-contracted) needed to mainly, undertake construction works				I	U	U	U	U		
CDM assessment • Pre-tender health and safety plan • Health and safety files for proposed and chosen solution(s)				I	R	U	U	F		
Project brief • Definition of the scope of the project • Completion dates and budgetary requirements • Proposed project solution(s) • Specifications for the proposed solution(s) • Specific site related issues		I	R	U	R	U	U	F		

Design brief • Possible solutions to the need(s) • Costs and benefits of proposed solutions • Initial specification for the solution(s) • Site and 'product' issues		F								
Concept design plan • Which options should be considered in phase 4 • Likely time scales • Resources needed to carry out the activities needed to produce the conceptual design(s)				F						
Outline concept design At the end of the feasibility studies and after the site of the development has been decided an outline concept design for the proposed solution(s) should be prepared. This will expand upon the detail of the substantive feasibility work carried out. The outline concept design should aim to inform the business case with regards to the form, function, specialist requirements and programme likely to be associated with the proposed solution(s). The outline concept design should be informed by the project brief and at this phase special attention should be paid to any alterations made to the brief.					F					
Full concept design The full concept design should identify the major design elements of the proposed solution. It should be sufficiently architecturally detailed so that a submission for detailed planning approval can be made. The design sholud also be developed as to enable the validation of the functional attributes i.e. end user working environment. The full concept design should be informed by production management to ensure that it considers the methods of construction to be used and problems/needs/issues with regards to those methods are taken into consideration with the concept design.						F				

Product model Coordinated; comprise all of the major design elements such as structural, mechanical and electrical and it should be prepared to a high level of technical detail with corresponding specifications. The 'buildability' aspects of the design should be considered and reviewed. Operational; the coordinated product model is presented in terms of 'work packages' to enable the construction work to be carried out. When the compatibility between 'work packages' has been established, there should be complete production information to enable construction works.							I	U	F	
Cost plan • Cost/benefit analyses for proposed solutions based on feasibility studies • Cash flow requirements • Resourcing of cash flow • Value engineering report for design considerations					I	U	U	F		
Maintenance plan • Planned maintenance schedule • Budgetary requirements • Human resources requirements • Special considerations such as equipment and facilities • Bill of quantities						I	U			
Production process map It may be necessary depending on the project in hand to phase the production of the project solution. In such cases the production process map should indicate the phasing strategy based on the latest project execution plan. A number of factors may influence the decision for phasing of the production works such as: Timing of the delivery of the project solution, complex construction works, very large projects, facility requirements, and accomodate alternative project solutions.								F		

Handover plan • As built drawings • Service and operations information • Commissioning information • Defects rectification period									F	

A.2 DELIVERABLES

Stakeholder list

Stakeholders are those persons or organisations 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. Stakeholders may be prioritised to illustrate their importance and involvement from a client's perspective, in the proposed project.

Statement of Need

It is very important that the clients' needs are clearly identified and understood before a building project is initiated. The statement of need should aim to provide the project team with a succinct indication of the clients' reason(s) for the potential project.

Business Case

Being able to make informed decisions throughout the duration of a project is critical to its successful implementation. The business case should consider the risks, costs and benefits associated with any proposed solution from a number of perspectives.

Project Execution Plan

A clear understanding of the requirements for project execution will potentially increase the chances for the successful implementation of the project. The project execution plan will change as the project progress in particular with regards to design changes.

Process Execution Plan

A clear and early understanding and identification of the process requirements for the project will potentially increase visibility and enable the production of the respective phase deliverables. The process execution plan will change according to the proposed project solutions offered.

Performance management report

In order for the development management, which is the project management to gauge the progress of the project, a performance management plan should be produced. In addition to the strategic critical success factors (from the client's viewpoint) a number of operational measures should be established. Process and project management should ensure that those measures are included for each phase of the process for consideration at the phase review meeting by development management. The Performance Indicators introduced by INOVICET model can be used to complete this report.

Communications strategy

Effective communications can potentially reduce lead times, improve quality and ensure accurate and prompt information to everybody involved in the project. A communication strategy report could potentially improve the 'change' and design management activities.

Procurement plan

The success or failure of a project could depend on providing the 'right' resources at the 'right' time and at the 'right' location. Procurement of resources can include the following categories: Services, Products, Finance, and Programme.

CDM assessment

In accordance with current CDM regulations, all health and safety issues related to any proposed project solution(s) must be addressed. Care should be taken to include the latest version of the CDM regulations to ensure conformity. It is the client's responsibility to comply with the CDM regulations and therefore provisions for reporting on those issues should be made.

Project brief

The aim is to mainly identify and define the scope of the project and more specifically that of the proposed solutions. The brief is, for the most part of the process, a 'live' document that changes as new information is presented.

Design brief

Prior to the enactment of the feasibility studies a number of possible solutions to the need(s) might be presented. These should be documented and form the design brief. The information presented in the design brief should be used to form part of the initial project brief and the updated business case. Design brief differs from the 'concept design plan' in that the solutions offered might not be 'construction' related e.g. operations management might satisfy the need and therefore solve the problem.

Concept design plan

At the end of the substantive feasibility phase, the result of the studies should enable the project to proceed to the outline conceptual design phase after approval by development management.

Outline concept design

At the end of the feasibility studies and after the site of the development has been decided an outline concept design for the proposed solution(s) should be prepared. This will expand upon the detail of the substantive feasibility work carried out. The outline concept design should aim to inform the business case with regards to the form, function, specialist requirements and programme likely to be associated with the proposed solution(s). The outline concept design should be informed by the project brief and at this phase special attention should be paid to any alterations made to the brief.

Full concept design

The full concept design should identify the major design elements of the proposed solution.. It should be sufficiently architecturally detailed so that a submission for detailed planning approval can be made. The design should also be developed as to enable the validation of the functional attributes i.e. end user working environment. The full concept design should be informed by production management to ensure that it considers the methods of construction to be used and problems/needs/issues with regards to those methods are taken into consideration by the concept design.

Product model

After the major design elements of the single solution have been decided upon, the detailed design work can be carried out. This will aim to present the design in the form of the product model. It should take into account any site related information available and be fully responsive to any prescribed statutory requirements. The model will become more defined as more detail is added to it.

Cost plan

The cost plan aims to identify the costs of the potential and actual construction project. The plan is for most part of the process a 'live' document which is updated, revised and finalised depending on the phase of the project as described by the process.

Maintenance plan

As the design becomes increasingly defined and major design elements fixed, the maintenance needs of the finished facility/project may be considered. This will help the preparation of the project for hand-over and it may also inform the design through value engineering exercises.

Production process map

It may be necessary, depending on the project in hand, to phase the production of the project solution. In such cases the production process map should indicate the phasing strategy based on the latest project execution plan. A number of factors may influence the decision for phasing of the production works such as: Timing of the delivery of the project solution, complexity of construction works, very large projects, facility requirements, and accommodation of alternative project solutions.

Hand-over plan

When the construction works have been finished, the facility is handed over to the operation and maintenance team

A.3 ACTIVITY ZONES

An activity zone is a structured set of sub-processes involving tasks which guide and support work towards a common objective. A single person or firm can carry out an activity zone in small-scale projects. In contrast, in a large-scale project, an activity zone may consist of a complex network of people within, and between, relevant functions and/or organisations. Activity zones generally overlap and are interactive. Activity zones include the following zones.

Development management

Responsible for creating and maintaining business focus throughout the project, which satisfies both relevant organisational and stakeholder objectives and constraints. It is likely to include senior client representation, suppliers of finance to the client and professional advisors.

Resources management

Responsible for the planning, co-ordination, procurement and monitoring of all financial, human and material resources. It is likely to include quantity surveying, buying, project management and human resources.

Design management

Responsible for the design process and integrates all design input from other activity zones. It is likely to include design professionals, suppliers of materials/components, main contractor, subcontractors and representatives from production management, facilities management, development management, project management and health & safety management activity zones.

Facilities management

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. It is likely to include facilities management professionals, building maintenance professionals, building services professionals and representatives from the design management activity zone.

Health & safety, statutory and legal management

Responsible for the identification, consideration and management of all regulatory, statutory and environmental aspects of the project. It is likely to include development management, design management, production management, facilities management, project management, change management, main contractor and subcontractors, suppliers and resources management activity zones.

Project management

Responsible for effectively and efficiently implementing the project to agreed performance measures and preparing the project execution plan. It is likely to include project management professionals.

Process management

Develops and operates the Process Protocol and plans and monitors each phase. It should consist of construction professionals who are independent of the project.

Production management

Responsible for ensuring the optimal solution for the buildability of the design, the construction logistics and organisation for delivery of the product. It is likely to include suppliers, main contractors and subcontractors and representatives from design management, project management, health & safety management and development management activity zones.

Change management

Responsible for effectively communicating project changes to all relevant activity zones. The roles of project, process and change management may be combined and this will be dependent on the size and complexity of the project.

APPENDIX B
INTERVIEW STRUCTURE

B.1 Introduction

The literature review undertaken for this research highlighted the limitation of planning tools for innovative projects. After setting the research aim and objectives, specific semi-structured interviews were held with industry professionals involved in innovative construction projects. Semi-structured interviews vary from a questionnaire type (structured interviews) that include asking questions and recording the responses with very little detail, to an unstructured interviews in which the interviewer introduces the topic briefly and then records the replies of the respondent (Fellows and Liu, 1997).

The innovative projects were: the development of a satellite positioning system for piling rig positioning and the development of a new continuous flight auger instrumentation system which were Stent Somercotes projects. Another project, the development of a GPS tracking, work instruction and recording system for road maintenance, has been used for the model validation, which was a Raynesway project. The purpose of these interviews was to present the research objectives, the proposed methodology, the model's hypothesis and the contribution that this research would make to improving the management of the innovation process. The interviewees confirmed that they expected benefits to be drawn from the research that would reflect the need of industry practitioners for tools to improve the management of the innovation process. Collecting data from on going or completed projects was challenging for several reasons. No formal data were recorded for many of the on going innovative projects and there were many difficulties encountered in meeting all project partners of the completed projects due to them moving to other regions. It was observed, and confirmed by the interviewees, that the process of introducing new technologies to the construction industry is slow compared to other industries. Capital intensiveness, complex legal responsibilities, resistance to change, the fragmented nature of the industry, labour-relations issues, safety considerations, regulations and standard building codes were commonly cited as major barriers to innovation in construction.

Purpose of interview is to:

- identify the characteristics of an environment that nurtures innovation;
- identify the implementation stages required for successful innovation;
- identify the information that influences the innovation implementation stages;
- identify the barriers and difficulties to implementation and recommend actions to deal with this;
- identify the key success factors of implementation;
- incorporate information from readings and experience;
- identify methods of measuring innovation performance; and
- assess the effectiveness of the current simulation tools and techniques related to innovation implementation in construction.

The following is a condensed overview of the key points discussed during the interviews, which in turn, were followed up by reviewing any relevant literature available or pursuing pointers to other sources as shown earlier in Chapter 4.

Personal Details

Name

Organisation

Position

Brief job description

The innovation case identification

1. Describe the innovation and its characteristics.
2. Was this innovation: adopted; modified and adapted; incrementally improved; or developed?
3. List the components of the design or construction process affected by this innovation (replacement, used concurrently).
4. What was the amount of testing that this innovation has and by whom. (i.e. How reliable is the innovation ?)

5. What codes does this innovation comply with?
6. List the major benefits and shortcomings of the innovation.
7. Compare the existing system with the new one (productivity, quality, safety, cost, etc.)
8. Identify the prospects that can be opened by the innovation and its development in future.
9. Is the innovation based on sound design principles?
10. Have test models of the innovation been constructed?
11. Has a full scale version of the innovation been constructed?
12. Has there been a commercial installation of the innovation?
13. Has the innovation been used in environmental conditions similar to those for the proposed design site?
14. Are there multiple suppliers of the innovation?
15. Has the innovation been used successfully in any construction projects?
16. Any comments.....

The following details may provide a clearer description of the project.

Innovation Objectives

What are the main objectives of the proposed innovation (forces that drive innovation)?

Examples

- Market and competitive demands
- Strategic focus to set priorities
- Solving problems on a project basis
- Owner demands
- Regulatory demands
- New knowledge/technology
- Industry change
- Demographic/ perception change
- Business practice
- R&D results
- Entrepreneurial opportunity

- Highest quality for a given cost
- Lowest cost for a given quality
- Lowest initial cost
- Lowest whole life cost
- High quality
- Consistent quality
- Certainty of time or cost
- Early project completion
- Satisfied users
- Other

The Influence information

- What information influenced this innovation? *(details are required)*

Examples

Market structure

Firm size

Project organisation

Stage of development

Role of suppliers

Capability and experience of personnel

Organisational climate

Procurement

Building codes

Financial aspects

Construction market

Uncertainty

- What are the innovation culture attributes?

Examples

Well-defined dynamic and flexible objectives

Management's commitment to innovation

Vision, commitment for improvement and desire for progress

Time for dialogue, education and introspection

Leaders who recognise and stimulate creativity

Tolerance for dissent, nonconformity and mistakes

Recognition and reward system

Commit resources

Fostering autonomy

- What are the demotivators of creativity and innovation?

  Ambiguity in the project goals, scope, and resources

  Ambiguity in roles of the team members

  Arbitrary task assignment without consultation with the team members

  Inequitable distribution of workload

  Lack of opportunity to exercise one's expertise and experience

  Managers' failure to listen to creative ideas

- What are the key success factors of implementation?

  Tailor to specific company needs

  Top level commitment

  Empowered employees

  Bench marking current state

  Formal change-management system

  Importance of planning (strategic, tactical, operational)

  Training

  Formal communication and feedback system

  Rewards and recognition

  Formal measurement and evaluation procedure

  Champions

  Documentation

  Living with continuance change

  Alignment of interests between decision makers, workers and the established mission statement and objectives

Evaluation of the culture of innovation:

1. Was technology sought as a result of a specific project or for the sake of innovation?
2. Who in the organisation saw the need for new technology?
3. Who evaluated the new technology and who decided to implement it?
4. Is top management supportive of innovation and what is the organisational climate?
5. Were field people sceptical of new technology?
6. Was there ever a thought of discontinuing the use of the new technology?
7. Is construction research and development feasible?
8. From where did the money for the new technology come?
9. How/who provided feedback to evaluate success/failure of the new technology?
10. Miscellaneous comments

- Assess the impact of the mentioned information on the innovation progress to guide the decision-maker.
- Identify the communication problems during the innovation stages.
- Investigate different means for the expected changes.
- Identify the problems arising from innovation on the organisation and its projects.

The implementation plan

1. Identify the most appropriate innovation stages and tasks to be simulated.
2. Have the above innovation objectives changed during the implementation stage.
3. If yes, how did these changes affect the implementation process? i.e. what have been initiated, iterated or released.
4. Identify the difficulties encountered by managers during the implementation stage.

Manipulating the planning data

1. What type of planning techniques were used (traditional, probabilistic, scenario)?
2. Who prepares the plan (foreman, managers, outsiders) (individuals or groups)?
3. When is this done and reviewed (regular periods, according to needs or changes)?
4. What is the perspective of the plan (local innovation problem, site, project)?
5. What is the level of autonomy (limited to prepare crew level plans, suitable to define and solve problems)?

6. What does this plan produce (Basic i.e. logistics; place; timing; resource (who and when), or Techniques as well (how))?
7. What are the sources of data (drawing, specification, site situation or collecting data from on and off site)?
8. How explicit is data processing (implicit only, partially explicit with simple technique, fully explicit with complex techniques)?
9. What does this plan contribute to the project (mesh of job knowledge, techniques for problem identification, analysis, solution and innovation)?
10. How does it comply with the actual implementation (comply, restrict)?
11. What is the aspiration (satisfice, optimise for local immediate action, optimise for global and other projects)?
12. How does the process start (as a work assignment, group identifies opportunity)?
13. How are problems diagnosed during implementation (personal review of assignment, cause and effect techniques, sophisticated analysis)?
14. How is a solution developed (Adaptation of previous plans, individual creativity, engineering synthesis of data)?
15. How are alternatives evaluated (trial and error, using multiple criteria)?
16. When is a solution implemented (immediately, planning of change process and gradual implementation)?
17. What are the difficulties associated with the plan (lack of skill to apply master plan to field, supply capability changes, conflict between line and staff)?
18. How is the outcome evaluated (personal observation, cost control, tangible and intangible measures)

- Identify typical events that occur during the implementation?

<u>Examples</u>

The variation of the quality of expected exchanges between innovation tasks

Performing an innovation task based on assumed data inputs

Changes in innovative project information

The problem of missing information

Gate keeping of information among team members

Resources allocation and assessment of their utilisation throughout the work

- Specify what causes iterations during the implementation?

Examples

Experiment

Testing

Refinement

Performance assessment

Measurement of performance

- Investigate measures for the implementation quality
- How are the assessment made under the following categories:

before implementation (choose between alternatives);

during implementation to refine;

in case of failure (partially or completely);

after implementation to fix it for the future; and

on the long-term benefits.

Tools and techniques

- Identify and assess the existing innovation models and simulation tools of planning, controlling and documentation of implementing innovations.

APPENDIX C
THE CASE STUDY PROJECT

C.1 Introduction

A case study project was used to test and validate the proposed model of simulating innovation implementation in construction. The project was to install a location control system using satellite facilities for a company vehicle fleets. This appendix in conjunction with Chapter 8 presents the information available for this project.

The application of the new location control system was concerned specifically with the company's contracts that would benefit most financially from the tool. As a complete scenario the company's vehicles (337 vehicles) were targeted for the installation. Table C.1 presents the vehicle fleet numbers for each area of the company business. A trial period was undertaken first to test the new system validity for cash flow and planning reasons.

Table C.1: The vehicle fleet numbers for each area of the business

	Hampshire	Area 3	MCP	Surfacing	Surry	Bucks*	Surry CC. Wint. maint.	S. Street light
Gully emptiers	4	3			4			
Road sweepers		1			12			
Tippers	47	42	8	1	28	30	19	2
Artic lorries			1					
Habs lorries	1	2		1				1
Barrier rigs		3						
Medium van	14	4				10		1
Heavy van	2	5		3	10			3
Astra van	5	3			4			3
Scout van								1
Flat bed	2	3						
Towers								14
Chipping spreader				2	1			
Paver				2				
Roller				3				
Winter maintenance tippers	20					20		
JCB	7		3	1				
Totals	102	66	12	13	59	60	19	25

Installation was broken into phases, Table C.2. These phases covered the contracts proposed for this installation and were merely a suggestion based on the most useful applications being undertaken first, derived from the criteria shown in Table C.3.

Table C.2 Installation phases

		Number of vehicles
Phase 1	Hampshire gully emptiers	4
	Surrey street lighting	4
	Routine (Term) maintenance	2
Phase 2	Surrey gully emptiers	4
	Area 3 Emergency Response	6
Phase 3	Surrey street lighting remaining vehicles	17
	Hampshire Routine (Term) Maintenance (those vehicle used for winter maintenance)	8
	Surrey Routine (Term) maintenance	5

C.2 The project specification

Preparing the project specification and specifying the requirements were achieved first in order that its development could be clarified. This allowed the pricing of the system to be accurate. These needs were centred on the data movements, within the new system of the vehicle operations, as opposed to how the data were physically collected so that the software developments and hardware requirements could be identified.

The generic requirements

- The data collection is to be broken into two parts for every vehicle:
  1. Automatic (essential) readings. These will vary per vehicle function; and
  2. Desirable (driver initiated) readings. These will vary per vehicle function.
- Ability to store positional and status data continually in vehicle hardware memory.
- Assurance that the critical data will continue to be collected if GPS is not operational.
- Data downloaded to base station database on request or at specified intervals.
- Data collected in vehicle hardware through the following options;
  1. Position and status recorded by driver; and

2. Position and status recorded automatically according to base station configuration (per unit distance, per unit time and if the vehicle travels above a certain speed)

- All data capable of being downloaded from database to the company or County Council G.I.S. systems.
- Facility to send data and maps to the in-cab consoles from the G.I.S. systems eventually.
- Ability to copy data to spreadsheets from the database for manipulation.
- System should be capable of carrying digital pictures in the future.

Table C.3 Performance criteria for the project objectives' assessment

Objective	**Performance criteria**	**Objective's fuzzy rating**
Gully Emptying	High efficiency improvement (up to 20%)	High priority
	Quality assurance	
	Over all cost reduction	
	Client inventory improvements	
	Paperwork reduction	
Street Lighting	Efficiency improvements (5%)	High priority
	Over all cost reduction	
	Client inventory improvements	
	Quality assurance	
	Emergency response time improvements	
	Paperwork reduction	
Emergency Response	Emergency response time improvements	Medium priority
	Paperwork reduction	
Winter Maintenance	Quality assurance	Medium priority
	Efficiency improvement	
	Logistical improvement	
	Financial benefit	
	Paperwork reduction	
Road sweeping	Quality assurance	Medium priority
	Efficiency improvement	
	Logistical improvement	
	Financial benefit	
	Paperwork reduction	
Coating Plant	Logistical improvements	Low priority
	Service improvements	
	Paperwork reduction	
General Maintenance	Logistical improvements	Low priority
	Service improvements	
	Paperwork reduction	

Data required to aid resource handling:

- Vehicle use and operative actions; times and dates when operational to confirm cost allocations;
- The amount of work carried out per unit time i.e. the number of gullies cleaned, street lights attended, street gritted;
- Vehicle location at these times;
- Time spent at each location; and
- Supplementary readings could be taken for the fuel entry (time, location, amount) and overspeed detection

System set-up:

Differential GPS capability (GSM, Vodafone, or similar communication links)

Base station capabilities:

DGPS reference station (could be available and accessible to use at the County Council)

Mapping:

- Small scale 1:50000 for three areas of the project system's application.
- Large scale 1: 10000 raster map datasets for the same areas (it costs for the conversion).

Costs will be required for converting county council supplied maps assuming the maps are given in a certain type.

C.3 Description of the activities of the Street lighting contract

Business improvements within street lighting are to achieve the following:

- Vehicle tracking to verify operational use;
- Measurement and recording of work achieved on site; both in labour terms and in material quantities; and
- Supply the operatives with their work more efficiently and accurately.

Methods to achieve automatic data collection

Each of the labour units has to be measured per unit time, but the operatives must not be relied on to register manually at what time they arrive and when they leave the site. This must be done by the system automatically in some way. There is a particular need to measure vehicle downtime, and this must be done automatically. The desirable data collection can be carried out using the in-cab console with little difficulty. The automatic reading will require methods which cannot provide false data i.e. it must be operative-proof.

Scouting

Currently the night-time 'scout' travels along set patrol routes and records 'outages' on a dictaphone. These are written down by office staff from the dictaphone tape the next day, then passed on to maintenance gangs who determine their route for the day to complete the work. If the scout can record the position of the item and its current status on the proposed control system, the database will hold this information so that it can be passed directly to the maintenance gangs via their vehicle console, cutting out the middle person. There may be a need for an operator at the base station to organise the data initially, but eventually the system would run itself. The physical data collection could be difficult to achieve. The 'scout' will be best placed to collect the required accurate positional data but will need to make a conscious effort to do so, but the ideal is automation. The position of the aerial for the scout will have to be carefully considered in order that the driver can take a repeatable reading each time without moving from his/her seat. A necessary addition would be to make the aerial removable from the vehicle to record the position of units away from vehicular access. Such a tool could supplement any other operation for positional recording.

Routine maintenance

The routine maintenance vehicle set-up will require a lot of forethought to record a street-light unit position as accurately as possible. For cherry pickers the aerial could be mounted on the bucket as most work is carried out at the top of the column. Somewhere in the work process it is necessary for an automatic positional reading to be taken of the unit. This could be triggered as the cherry picker lowers its stabalising feet, for instance, with the status of this unit being attached to the position before the vehicle moves to another unit.

Vehicle equipment

GSM interface

DGPS capability with decoding device (Classic F.M. tool +/- 1.0 m accuracy)

Suppliers' tools to facilitate system

Further advancements

The following section is a suggestion for the recording of the labour activity and materials used on each job in direct relation to the Bill of Quantities. It would be desirable for this to be incorporated into the company, but if it is seen to be more economical it may be supplied by a specialist data capture device in conjunction with the system. The most useful method was seen to be in the form of a series of choices using the in-cab hardware made by any operative on any operation, or a 'picklist'. As a short description, it will enable the operative to identify a job which must be carried out with the pressing of about two buttons, then record the actual work carried out by pressing a further four. This job identification will be with respect to the contract Bill of Quantities so that invoicing will be very simple.

Street lighting pick-list description

Philosophy of this method

To enable any street lighting operative to chose a job then record his/her work without the necessity of paperwork, while ensuring that a minimal amount of complications are faced by this user. By cutting down the number of operations, the system may be easier to develop.

Background to the method adopted

This picklist must encompass the tasks of Scouting (Identification of problems in general), Routine Maintenance, Special Maintenance, Emergency response and any other activities.

The database is sent data when problems are spotted by the scout, or during the course of a maintenance crew's day. Data will also be fed to the database after an emergency call. This information is available to the vehicle on site to carry out the rectification of the problems identified. Once the work has been completed the system allows the work to be recorded in terms of the labour activity and the materials used, by feeding data back to the database.

C.4 An assessment phase during the project (1)

This assessment report was prepared by the team member R.S. during the project progress dated 7/9/98.

Table C.4 shows the final allocation of vehicles to which the company will be installed first. Alongside this are the members of the working parties responsible for the analysis of the activities shown to identify the relevant data which needs to be collected.

Table C.4 The final allocation of vehicles

Operation	Site A	Site B	Site 3	Working party
Gully cleansing	5	4		SF/BS/RS
Safety patrols/Emergency response			3	PK/RS
Street lighting		5		PH/RS
Signing				
Construction gangs	4			SF/RS
Routine maintenance	1	2		RC/RS
Winter maintenance			1	PK/RS

Training and integration of the system to the working routines

The first task is to produce a booklet identifying the following points:

- What it will record?
- When will the system record data?
- What will be done with the data? and
- Instruction on use of the vehicle installation.

This booklet will facilitate 'induction' to the system where operatives are introduced to the system and their opinions for the smooth running of it sought. If possible, as many operatives as are available should be present whether they are receiving the system initially or not. This will educate as to the principle of the system in one process rather than several. Technical instruction may have to be carried out in smaller groups.

C.5 An assessment phase during the project (2)

This assessment report was prepared by the team members B.C. and R.S. during the project progress of the standby operations, dated 28/9/98.

This is the first procedure for the implementation and installation for the proposed system HMSSS into the two standby vehicles in Site 2 so any errors would be pointed out before passes to other procedures.

Installation recipients:
Vehicles: Two dedicated vehicles cover all three areas on site 2; and
Personal: 20 No. operatives and 5 No. supervisors

Procedure improvements needed in spite of HMSSS

- Details and comments from the operatives regarding work carried out and problems encountered to be more comprehensive.
- Verification of time leaving site to confirm manual time sheets completed weekly.
- Proof of work on site; did they go to site and do nothing?
- Did the operative pick his mate up directly then travel directly to site, and the same on the return journey?

Implementation procedure (stage 1)

At this stage the current system will continue to run, with the new service running alongside it. The watchman at the headquarter will continue to complete the daily log of details from the emergencies, but the times will also be recorded by the HMSSS concurrently. This enables verification of the records made by the HMSSS.

Details of the emergencies will have to be placed into the database after extraction from the daily log. The description below in Table C.5 confirms this dual recording procedure on this stage. The left-hand column confirms the current procedure, with the right hand column describing the necessary additions to the process for the HMSSS to run.

Table C.5: The implementation additions to the current procedure

	Current standby procedure	Implementation additions
1	Outside of normal working hours the client telephones the 24-hour watchman at the headquarter to pass details of the emergency	Unchanged
2	The watchman refers to the list of standby operatives and telephones the person on duty	Unchanged
3	The time at which the watchman was called by the client is noted. The company is contractually obliged to attend the emergency within one hour of that call	Unchanged
4	The operative will travel to his mate's home then to site	Record of position and time when ignition turned on in vehicle
5	When arriving on site he operative uses his mobile telephone to call the headquarter to confirm the time of arrival. This is recorded	Button pressed in cab to confirm arrival
6	The operative carry out the work then call the headquarter once more to confirm completion of work. This time is recorded. (In the interim it may be necessary for the operatives to travel to the depot to pick up more materials and equipment)	Button pressed in cab to confirm departure
7	The operatives return home	Record of position and time when ignition turned off.
8	The watchman at the headquarter fills in the daily log of standby call-outs by hand during this process	Unchanged
9	This daily log is then typed-up the following morning by the secretary at the headquarter. (see sheet attached)	Unchanged
10	The log is faxed to the client office by 9.00 AM	This sheet faxed to system manager so that details of emergency are placed into database.

Implementation procedure (stage 2)

The watchman will input data directly into the HMSSS database as calls arrive from the client and will be in direct view of the vehicles actions at all times (if necessary). All information entered into the current daily log of emergency call-outs will be completed partially (automatically) by the system, and partially by the watchman as details arrive. Details of call-outs are printed out directly from the system at the end of the watchman's shift for transfer to the client. This does mean that the watchman needs to be computer literate. This arrangement does mean that a call-centre could be set-up and managed from one position within the company for all clients to call. This centre would also be in contact with all company's personnel on standby duty.

Outstanding actions:

- install system to 2 vehicles;
- training of 20 operatives and 5 supervisors; and
- monitors of improvements for the following:
  - improvements in average response times to emergencies;
  - monitoring of working hours claimed by operatives on standby;
  - monitoring of client satisfaction regarding quality of information;
  - on-going monitoring of fuel costs per vehicle; and
  - monitoring of time saved through improved information recording.

C.6 An assessment phase during the project (3)

This assessment report was prepared by the team members P.H. and R.S. during the project progress for the street lighting operations, dated 16/10/98.

Installation recipients:

Vehicles for site 2 and site 3: 5 No. Towers, 1 Scout vehicle , Escort Van; and

Personnel : 5 No. operatives, 4 No. supervisors

The following two Tables C.6 and C.7 present the implementation additions for the current 'Make Safe' procedure and the 'Fault and Repair' procedure.

Table C.6: The 'Make Safe' procedure

	Current 'Make Safe' procedure	Implementation additions (Phase 1)	Implementation additions (Phase 2)
1	Outside of normal working hours the client telephones the night watchman at the headquarter to pass	Unchanged	Unchanged

	details of the emergency		
2	The watchman refers to the list of standby operatives and telephones the person on duty	Continues, but the watchman records the time of the client call.	The watchman will now input the time of client call to the database
3	During normal working hours the supervisor will call the operatives direct after a briefing from the client	Continues, but the supervisor records the time of the client call	The person receiving the call will now input the time of client call to the database
4	The company is contractually obliged to attend the emergency within two hours of that call	Button pressed in cab to confirm arrival on site. Button pressed in cab to confirm departure. This functions record the time of work duration	The in-cab 'block box' allows the operative to change his working status from 'working' to 'emergency', which also records the time of call, after the details of the emergency are sent directly to the vehicle. When arriving on site he can confirm time of arrival. The actual type of work may be recorded eventually.
5	This is a single-man operation and he will travel from home to site, or from one site to another	Record of 'ignition on'	Record of 'ignition on'
6	Emergency call-outs are paid at a fixed rate and therefore the timing of the site visit is not recorded for the client	Verification from records made of the timings of the site visit can verify the time sheets of the operatives during call-outs.	Verification from records made of the timings of the site visit can verify the time sheets of the operatives during call-outs.
7	The operative returns home/ to site	Record of 'ignition off'	Record of 'ignition off'
8	The daily log of call-outs is passed to the Street Lighting office. An example of this log is attached	The daily log can be automatically input with the site visits.	There is investigation into the log sheet being initiated at the Street Lighting office, then passed in a convenient format directly to the vehicle. From here, the log is completed by way of the picklists' are returned to the database for the office to print-off.

Table C.7: The 'Fault and repair' procedure

	Current 'Fault and Repair' procedure	Implementation additions (Phase 1)	Implementation additions (Phase 2)	Future additions
1	Problems will be spotted by the night-time scout or other gangs driving past will make a note of them.	Unchanged. The Scout will have GPS to provide proof of work to the client	Unchanged. The Scout will have GPS to provide proof of work to the client	Investigation into the Scout identifying problems on with a GPS facility and input of problems electronically
2	These problems are passed to the Street Lighting office for placement onto the existing computer register of work.	Continues, but the watchman records the time of the client call.	The watchman will now input the time of client call to the database	The problems from above will be sent directly to the vehicle
3	A list of assignments for the gangs is printed out, indicating the location of the job and a simplistic description of the likely problem involved on site.	Unchanged	The current status of the operative is input from the vehicle i.e. travel to site, working, on lunch, broken down. These will be changed as the status is changed	Aims to have the outstanding work broadcast to all vehicles with each vehicle selecting the work from the list. This will need some thought.
4	The operative leaves the depot to travel to site	Record of 'ignition on'	Record of 'ignition on' and time of leaving depot a possibility from geofencing	
5	The assignments are actioned by the operative in any convenient order appropriate to him.	Record of 'ignition on'	Record of 'ignition on'	
6	The list of assignments is updated by the operative, by hand, with a record of the action involved, the materials used,	Verification from records made of the timings of the site visit can verify the time sheets of the operatives during call-outs.	Verification from records made of the timings of the site visit can verify the time sheets of the operatives during call-outs.	

	and the date of completion.			
7	The operative returns to the depot at the end of the shift	Record of 'ignition off'	Record of 'ignition off'	
8	This fully completed list is inputted into the existing computer system, from which the client is informed of the work carried out from which the costing of the jobs can be achieved.	Unchanged. The sheets are also passed to the system manager so that the next phase can be planned	The log is completed by way of the picklists' are broadcast to the database for the office to print-off.	

Outstanding actions

Monitors of improvements for the following:

- improvements in average response times to emergencies;
- monitoring of working hours claimed by operatives on standby;
- monitoring of client satisfaction regarding quality of information;
- on-going monitoring of fuel costs per vehicle; and
- monitoring of time saved through improved information recording.

C.7 An assessment phase during the project (4)

This assessment report was prepared by the team members P.K. and R.S. during the project progress for the Salting implementation, dated 16/10/98. Table C.8 presents the current and the implementation procedures for this area of work.

Installation recipients:

Vehicles : Parkgate Depot, L625 HHX, Foden

Personnel: 6 operatives, 3 supervisors

Table C.8: Salting implementation

	Current working procedure	Implementation additions
1	The client makes the decision to salt the highways	Unchanged
2	All machines are assigned their particular routes	Unchanged
3	The machines are started up first of all to warm up before moving off	Ignition 'on' recorded in terms of time, position and date
4	The machines are given the routine maintenance and safety check	Unchanged
5	The machine is loaded with salt	Unchanged
6	The machine moves to the weighbridge	Unchanged
7	Once the weight of salt has been measured, the machine travels to the start of its route	A geofence will be placed around the depot. The time of leaving the depot will automatically be logged
8	The 'treatment time' is now being measured (i.e. the time between leaving the depot and finishing salting)	Unchanged
9	When the start of the route is reached, the driver turns on the salt	The time and position of the 'salt on' is recorded
10	When the end of the route is reached, the salt is turned off	The time and position of the 'salt off' is recorded
11	The machine travels from site to the depot	A geofence will be placed around the depot. The time of reaching the depot will automatically be logged
12	The machine is switched off at the end of the day	Ignition 'off' recorded in terms of time, position and date
13	A log sheet is completed by the supervisor in charge of the shift (attached). This is passed to the client.	

Future phases

1. It could be possible to use geofences as start and stop points on the salt route to facilitate automatic salting as the driver drives along.
2. Linking of the HMSSS with the weighbridge sofware. The aim of this is to produce an automatic log for each route containing the following information.
   - The assigned driver and vehicle for the route.
   - Wright of salt used on the route.
   - Treatment time.
   - The time at which the vehicle reached key stages of the route.
   - Time of arrival back at the depot.
   - Average speed in route.

3. Links with Thermal Maps will also enable an even greater improvement. A live link to a temperature contoured map will indicate (via software) when to salt, since the positions measured by the GPS will configure to the map. The assessment for this will have to compare the cost of the extra airtime over GSM with the potential cost savings of salt.

Outstanding actions

Install system to 1 vehicle

Training of 6 operatives and 3 supervisors

Monitors of improvements for the following:

- Improvements in average response times to emergencies;
- Monitoring of client satisfaction regarding quality of information;
- On-going monitoring of fuel costs per vehicle; and
- Monitoring of time saved through improved information recording.

C.8 An assessment phase during the project (5)

This assessment report was prepared by the team members B.S., S.F. and R.S. during the project progress of the two sites of the Gully emptying, dated 16/10/98. Table C.9 presents the current and the implementation procedures for this area of work.

Installation recipients:

Vehicles for site 2: R160 PNN, R159 PNN, N353 TPK, D640 XPF

Personnel for site 2: 10 operatives, 3 supervisors

Vehicles for site 1: N852 TUJ, R640 ENT, R641 ENT, R475 BUJ, R476 BUJ

Personnel for site 1: 10 operatives, 2 supervisors

Procedure improvements needed in spite of HMSSS

- Details and comments from the operatives regarding work carried out and problems encountered to be more comprehensive.
- Verification of time taken for a day works.
- Proof of work on site; where have they gone and how long were they there?:
  - time to/from tip;
  - time taken between last gully cleanse and arrival at depot; and

- excessive durations between cleanses of individual gullies.

- Accurate recording of gullies which cannot be cleaned, in terms of position and status.

Table C.9: Gully emptying implementation

	Current working procedure	Implementation additions
1	All machines work to programmes for particular areas	Unchanged
2	The machines are started up first of all to warm up before moving off	Ignition 'on' recorded in terms of time, position and date
3	The machines are given the daily maintenance and safety check	Unchanged
4	The machine travels to site	Unchanged
5	One of three operations is then carried out: ▪ Filling up with water ▪ Cleansing ▪ Tipping	Unchanged
6	The machine will change between these activities in the working day	Unchanged
7	Lunch breaks will be taken	Recording of any gullies worked-on under dayworks is possible
8	The machine will be required to attend work as a diversion from the programmed work as daywork	Unchanged
9	The machine travels from site to the depot	Unchange, but gullies positions will be recorded additionally
10	During the course of the day the operatives complete their paperwork for: ▪ Gully recording ▪ Plant resource sheets ▪ Time sheets	Recording of 'ignition off'
11	The machine is switched off at the end of the day	

Implementation procedure (stage 1)

At this stage the current system will continue to run, with the new service running alongside it. The positions of gullies will be recorded by the system at this phase by two options:

- automatic recording as the machine's boom is pulled lower than a certain angle; and

- manual recording as a button is pressed by the driver or the operative

The current gully record sheets will have to be completed at this stage in order that the condition of any faulty gullies can still be recorded and followed up by the client. The above table gives comparisons between existing procedures and the Phase 1 implementation.

Implementation procedure (stage 2)

The in-cab facilities enable the full capability of the system. The positions of the gullies can be upgraded with its condition in terms of:

- 'Broken Lid';
- 'Spalled Brickwork'; and
- 'Vehicle Over'; this message will follow an approximate GPS position recorded by the operative with the system override

The recording of the following information will be available from this phase:

- driver I.D. is input when system boots up in the vehicle to enable each operator to be identified against each vehicle, even if the drivers change vehicles;
- the plant resource sheet for the vehicle will be completed automatically; and
- the current gully cleansing record log will be computerised. There will have to be an agreement between the counties to produce a generic log sheet

Outstanding actions

Install system to 9 vehicle

Training of 20 operatives and 5 supervisors

Monitors of improvements for the following:

- improvements in average response times to emergencies;
- monitoring of client satisfaction regarding quality of information;
- on-going monitoring of fuel costs per vehicle; and
- monitoring of time saved through improved information recording.

C.9 An assessment phase during the project (6)

This assessment report was prepared by the team members P.K. and R.S. during the project progress for emergency response, dated 16/10/98. Table C.10 presents the current and the implementation procedures for this area of work.

Installation recipients:

Vehicles : Parkgate Depot, M365 CUF, Iveco Hightop

Personnel: 6 operatives, 3 supervisors

Table C.10: The emergency response implementation

	Outside of normal working hours i.e. standby	**Implementation additions**
1	Outside of normal working hours the client telephones the 24 hour watchman at the headquarter to pass details of the emergency	Unchanged
2	The watchman refers to the list of standby operatives and telephones the person on duty. This time is noted by the operative on the 'Emergency response form' (copy attached)	Unchanged
3	The time at which the watchman was called by the client is not noted in this contract	Unchanged
4	The operative will travel to his mate's home then to site, or will travel to the Depot to collect the vehicle	Ignition 'on' recorded in terms of time, position and date. A geofence will be placed around the depot. The time of leaving the depot will automatically be logged
5	When arriving on site the operative records the time of arrival	A button is pressed to record time and position of arrival
6	The operatives carry out the work then call record the time of completion of work. (In the interim it may be necessary for the operatives to travel to the depot to pick up more materials and equipment)	A button is pressed to record time and position of departure
7	The operative return home or to the Depot to leave the vehicle	A geofence will be placed around the depot. The time of reaching the depot will automatically be logged. 'Ignition off' is recorded
8	The operative fill in the daily log of standby call-outs by hand during this process	Unchanged
9	The log is sent to the client office. No	The log is faxed to the system manager

	time of arrival of the report is specified	for the details to be verified against the system's records.

Procedure improvements needed in spite of HMSSS

- An improvement in the quality of the information recorded by the operatives.
- Proof of attendance on site. This can enable:
  - reduction in the need for supervision. One supervisor looking after client and contractor interests;
  - a reliable measurement of the time taken to attend;
  - a more efficient methods of data transfer to the client; and
  - a reduction in the time taken to allocate a vehicle during the normal working day to an emergency.

Implementation procedure (stage 1)

At this stage the current system will continue to run, with the new service running alongside it. All route logs will be completed by hand as before. Table C.10 gives comparisons between existing procedures and the phase 1 implementation.

The log sheet currently compiled by the supervisor will have some of its information completed only (a copy is attached). These will be for the one installed vehicle only:

- time left depot;
- time of arrival/departure on/from site; and
- time completed.

For daytime operation the supervisor will have a real-time position of this vehicle available. Identical time/position records will be made of any emergencies attended in the daytime also.

Implementation procedure (stage 2)

The in-cab facilities enable the full capability of the system. The watchman at the headquarter will be required to call the driver in at night, sending details of the emergency as a text message to the vehicle. Otherwise the supervisor can send an emergency call, which will include a text message, during the day, using HMSSS. The driver I.D. can be input when system boots up in the vehicle to enable each operator to be identified against each vehicle, even if the drivers change vehicles. The emergency response form will be entirely completed with a combination of automatic readings from the HMSSS and the operative inputting data from the picklist menu in-cab.

Future Phases

The addition of the Rapid Response Vehicle to the site 3 service will see vehicles permanently patrolling the network. Upon full installation of the system, these vehicles will be precisely pinpointed as the ideal vehicle to attend an emergency, real-time.

This arrangement does mean that a call-centre could be set-up and managed from one position within the company for all clients to call. This centre would also be in contact with all company's personnel on standby duty.

Outstanding actions

Install system to 1 vehicle.

Training of 6 operatives and 3 supervisors.

Monitors of improvements for the following:

- improvements in average response times to emergencies;
- monitoring of client satisfaction regarding quality of information;
- on-going monitoring of fuel costs per vehicle; and
- monitoring of time saved through improved information recording.

APPENDIX D

CODE OF THE SIMULATION TOOL

The Fuzzy logic code

```
Public Sub fuzzification(MaxMLT As Single, MaxMPT As Single, MLT As Single, MPT As Single,
PY As Single, YB As Single, YI As Single, YA As Single, YS As Single, YE As Single)
Dim Bad(1 To 4) As Single, Inf(1 To 6) As Single, Ade(1 To 7) As Single, Sup(1 To 6) As Single,
Exc(1 To 4) As Single
' Equations for the membership functions are:
'
'Prob Low
If PY <= 0.5 Then Y1 = 0.5 * (1 - PY)
If PY > 0.5 Then Y1 = 0
'Prob Medium
If PY <= 0.5 Then Y1 = 2 * PY
If PY > 0.5 Then Y1 = 2 * (1 - PY)
'Prob High
If PY <= 0.5 Then Y1 = 0
If PY > 0.5 Then Y1 = PY
'
'+ve performance Low Time
If MPT <= MaxMPT / 2 Then Y2 = 1 - ((2 * MPT) / MaxMPT)
If MPT > MaxMPT / 2 Then Y2 = 0
'+ve performance Medium Time
If MPT <= MaxMPT / 2 Then Y2 = 2 * MPT / MaxMPT
If MPT > MaxMPT / 2 Then Y2 = 2 * (1 - (MPT / MaxMPT))
'+ve performance High Time
If MPT <= MaxMPT / 2 Then Y2 = 0
If MPT > MaxMPT / 2 Then Y2 = (2 * MPT / MaxMPT) - 1
'
'-ve performance Low Time
If MLT <= MaxMLT / 2 Then Y3 = 1 - ((2 * MLT) / MaxMLT)
If MLT > MaxMLT / 2 Then Y3 = 0
'-ve performance Medium Time
If MLT <= MaxMLT / 2 Then Y3 = 2 * MLT / MaxMLT
If MLT > MaxMLT / 2 Then Y3 = 2 * (1 - (MLT / MaxMLT))
'-ve performance High Time
If MLT <= MaxMLT / 2 Then Y3 = 0
If MLT > MaxMLT / 2 Then Y3 = (2 * MLT / MaxMLT) - 1

'M+L+H=Bad
If PY <= 0.5 Then Y1 = 2 * PY
If PY > 0.5 Then Y1 = 2 * (1 - PY)
If MPT <= MaxMPT / 2 Then Y2 = 1 - ((2 * MPT) / MaxMPT)
If MPT > MaxMPT / 2 Then Y2 = 0
If MLT <= MaxMLT / 2 Then Y3 = 0
If MLT > MaxMLT / 2 Then Y3 = (2 * MLT / MaxMLT) - 1
Bad(1) = Y1
If Y2 < Bad(1) Then Bad(1) = Y2
If Y3 < Bad(1) Then Bad(1) = Y3
'L+M+H=Bad
If PY <= 0.5 Then Y1 = 0.5 * (1 - PY)
If PY > 0.5 Then Y1 = 0
If MPT <= MaxMPT / 2 Then Y2 = 2 * MPT / MaxMPT
If MPT > MaxMPT / 2 Then Y2 = 2 * (1 - (MPT / MaxMPT))
```

```
If MLT <= MaxMLT / 2 Then Y3 = 0
If MLT > MaxMLT / 2 Then Y3 = (2 * MLT / MaxMLT) - 1
Bad(2) = Y1
If Y2 < Bad(2) Then Bad(2) = Y2
If Y3 < Bad(2) Then Bad(2) = Y3
'L+L+H=Bad
If PY <= 0.5 Then Y1 = 0.5 * (1 - PY)
If PY > 0.5 Then Y1 = 0
If MPT <= MaxMPT / 2 Then Y2 = 1 - ((2 * MPT) / MaxMPT)
If MPT > MaxMPT / 2 Then Y2 = 0
If MLT <= MaxMLT / 2 Then Y3 = 0
If MLT > MaxMLT / 2 Then Y3 = (2 * MLT / MaxMLT) - 1
Bad(3) = Y1
If Y2 < Bad(3) Then Bad(3) = Y2
If Y3 < Bad(3) Then Bad(3) = Y3
'L+L+M=Bad
If PY <= 0.5 Then Y1 = 0.5 * (1 - PY)
If PY > 0.5 Then Y1 = 0
If MPT <= MaxMPT / 2 Then Y2 = 1 - ((2 * MPT) / MaxMPT)
If MPT > MaxMPT / 2 Then Y2 = 0
If MLT <= MaxMLT / 2 Then Y3 = 2 * MLT / MaxMLT
If MLT > MaxMLT / 2 Then Y3 = 2 * (1 - (MLT / MaxMLT))
Bad(4) = Y1
If Y2 < Bad(4) Then Bad(4) = Y2
If Y3 < Bad(4) Then Bad(4) = Y3
'H+L+H=Inferior
If PY <= 0.5 Then Y1 = 0
If PY > 0.5 Then Y1 = PY
If MPT <= MaxMPT / 2 Then Y2 = 1 - ((2 * MPT) / MaxMPT)
If MPT > MaxMPT / 2 Then Y2 = 0
If MLT <= MaxMLT / 2 Then Y3 = 0
If MLT > MaxMLT / 2 Then Y3 = (2 * MLT / MaxMLT) - 1
Inf(1) = Y1
If Y2 < Inf(1) Then Inf(1) = Y2
If Y3 < Inf(1) Then Inf(1) = Y3
'M+M+H=Inferior
If PY <= 0.5 Then Y1 = 2 * PY
If PY > 0.5 Then Y1 = 2 * (1 - PY)
If MPT <= MaxMPT / 2 Then Y2 = 2 * MPT / MaxMPT
If MPT > MaxMPT / 2 Then Y2 = 2 * (1 - (MPT / MaxMPT))
If MLT <= MaxMLT / 2 Then Y3 = 0
If MLT > MaxMLT / 2 Then Y3 = (2 * MLT / MaxMLT) - 1
Inf(2) = Y1
If Y2 < Inf(2) Then Inf(2) = Y2
If Y3 < Inf(2) Then Inf(2) = Y3
'M+L+M=Inferior
If PY <= 0.5 Then Y1 = 2 * PY
If PY > 0.5 Then Y1 = 2 * (1 - PY)
If MPT <= MaxMPT / 2 Then Y2 = 1 - ((2 * MPT) / MaxMPT)
If MPT > MaxMPT / 2 Then Y2 = 0
If MLT <= MaxMLT / 2 Then Y3 = 2 * MLT / MaxMLT
If MLT > MaxMLT / 2 Then Y3 = 2 * (1 - (MLT / MaxMLT))
Inf(3) = Y1
If Y2 < Inf(3) Then Inf(3) = Y2
If Y3 < Inf(3) Then Inf(3) = Y3
'L+H+H=Inferior
If PY <= 0.5 Then Y1 = 0.5 * (1 - PY)
If PY > 0.5 Then Y1 = 0
If MPT <= MaxMPT / 2 Then Y2 = 0
If MPT > MaxMPT / 2 Then Y2 = (2 * MPT / MaxMPT) - 1
```

```
If MLT <= MaxMLT / 2 Then Y3 = 0
If MLT > MaxMLT / 2 Then Y3 = (2 * MLT / MaxMLT) - 1
Inf(4) = Y1
If Y2 < Inf(4) Then Inf(4) = Y2
If Y3 < Inf(4) Then Inf(4) = Y3
'L+M+M=Inferior
If PY <= 0.5 Then Y1 = 0.5 * (1 - PY)
If PY > 0.5 Then Y1 = 0
If MPT <= MaxMPT / 2 Then Y2 = 2 * MPT / MaxMPT
If MPT > MaxMPT / 2 Then Y2 = 2 * (1 - (MPT / MaxMPT))
If MLT <= MaxMLT / 2 Then Y3 = 2 * MLT / MaxMLT
If MLT > MaxMLT / 2 Then Y3 = 2 * (1 - (MLT / MaxMLT))
Inf(5) = Y1
If Y2 < Inf(5) Then Inf(5) = Y2
If Y3 < Inf(5) Then Inf(5) = Y3
'L+L+L=Inferior
If PY <= 0.5 Then Y1 = 0.5 * (1 - PY)
If PY > 0.5 Then Y1 = 0
If MPT <= MaxMPT / 2 Then Y2 = 1 - ((2 * MPT) / MaxMPT)
If MPT > MaxMPT / 2 Then Y2 = 0
If MLT <= MaxMLT / 2 Then Y3 = 1 - ((2 * MLT) / MaxMLT)
If MLT > MaxMLT / 2 Then Y3 = 0
Inf(6) = Y1
If Y2 < Inf(6) Then Inf(6) = Y2
If Y3 < Inf(6) Then Inf(6) = Y3
'H+M+H=Adequate
If PY <= 0.5 Then Y1 = 0
If PY > 0.5 Then Y1 = PY
If MPT <= MaxMPT / 2 Then Y2 = 2 * MPT / MaxMPT
If MPT > MaxMPT / 2 Then Y2 = 2 * (1 - (MPT / MaxMPT))
If MLT <= MaxMLT / 2 Then Y3 = 0
If MLT > MaxMLT / 2 Then Y3 = (2 * MLT / MaxMLT) - 1
Ade(1) = Y1
If Y2 < Ade(1) Then Ade(1) = Y2
If Y3 < Ade(1) Then Ade(1) = Y3
'H+L+M=Adequate
If PY <= 0.5 Then Y1 = 0
If PY > 0.5 Then Y1 = PY
If MPT <= MaxMPT / 2 Then Y2 = 1 - ((2 * MPT) / MaxMPT)
If MPT > MaxMPT / 2 Then Y2 = 0
If MLT <= MaxMLT / 2 Then Y3 = 2 * MLT / MaxMLT
If MLT > MaxMLT / 2 Then Y3 = 2 * (1 - (MLT / MaxMLT))
Ade(2) = Y1
If Y2 < Ade(2) Then Ade(2) = Y2
If Y3 < Ade(2) Then Ade(2) = Y3
'M+H+H=Adequate
If PY <= 0.5 Then Y1 = 2 * PY
If PY > 0.5 Then Y1 = 2 * (1 - PY)
If MPT <= MaxMPT / 2 Then Y2 = 0
If MPT > MaxMPT / 2 Then Y2 = (2 * MPT / MaxMPT) - 1
If MLT <= MaxMLT / 2 Then Y3 = 0
If MLT > MaxMLT / 2 Then Y3 = (2 * MLT / MaxMLT) - 1
Ade(3) = Y1
If Y2 < Ade(3) Then Ade(3) = Y2
If Y3 < Ade(3) Then Ade(3) = Y3
'M+M+M=Adequate
If PY <= 0.5 Then Y1 = 2 * PY
If PY > 0.5 Then Y1 = 2 * (1 - PY)
If MPT <= MaxMPT / 2 Then Y2 = 2 * MPT / MaxMPT
If MPT > MaxMPT / 2 Then Y2 = 2 * (1 - (MPT / MaxMPT))
```

```
If MLT <= MaxMLT / 2 Then Y3 = 2 * MLT / MaxMLT
If MLT > MaxMLT / 2 Then Y3 = 2 * (1 - (MLT / MaxMLT))
Ade(4) = Y1
If Y2 < Ade(4) Then Ade(4) = Y2
If Y3 < Ade(4) Then Ade(4) = Y3
'M+L+L=Adequate
If PY <= 0.5 Then Y1 = 2 * PY
If PY > 0.5 Then Y1 = 2 * (1 - PY)
If MPT <= MaxMPT / 2 Then Y2 = 1 - ((2 * MPT) / MaxMPT)
If MPT > MaxMPT / 2 Then Y2 = 0
If MLT <= MaxMLT / 2 Then Y3 = 1 - ((2 * MLT) / MaxMLT)
If MLT > MaxMLT / 2 Then Y3 = 0
Ade(5) = Y1
If Y2 < Ade(5) Then Ade(5) = Y2
If Y3 < Ade(5) Then Ade(5) = Y3
'L+H+M=Adequate
If PY <= 0.5 Then Y1 = 0.5 * (1 - PY)
If PY > 0.5 Then Y1 = 0
If MPT <= MaxMPT / 2 Then Y2 = 0
If MPT > MaxMPT / 2 Then Y2 = (2 * MPT / MaxMPT) - 1
If MLT <= MaxMLT / 2 Then Y3 = 2 * MLT / MaxMLT
If MLT > MaxMLT / 2 Then Y3 = 2 * (1 - (MLT / MaxMLT))
Ade(6) = Y1
If Y2 < Ade(6) Then Ade(6) = Y2
If Y3 < Ade(6) Then Ade(6) = Y3
'L+M+L=Adequate
If PY <= 0.5 Then Y1 = 0.5 * (1 - PY)
If PY > 0.5 Then Y1 = 0
If MPT <= MaxMPT / 2 Then Y2 = 2 * MPT / MaxMPT
If MPT > MaxMPT / 2 Then Y2 = 2 * (1 - (MPT / MaxMPT))
If MLT <= MaxMLT / 2 Then Y3 = 1 - ((2 * MLT) / MaxMLT)
If MLT > MaxMLT / 2 Then Y3 = 0
Ade(7) = Y1
If Y2 < Ade(7) Then Ade(7) = Y2
If Y3 < Ade(7) Then Ade(7) = Y3
'H+H+H=Superior
If PY <= 0.5 Then Y1 = 0
If PY > 0.5 Then Y1 = PY
If MPT <= MaxMPT / 2 Then Y2 = 0
If MPT > MaxMPT / 2 Then Y2 = (2 * MPT / MaxMPT) - 1
If MLT <= MaxMLT / 2 Then Y3 = 0
If MLT > MaxMLT / 2 Then Y3 = (2 * MLT / MaxMLT) - 1
Sup(1) = Y1
If Y2 < Sup(1) Then Sup(1) = Y2
If Y3 < Sup(1) Then Sup(1) = Y3
'H+M+M=Superior
If PY <= 0.5 Then Y1 = 0
If PY > 0.5 Then Y1 = PY
If MPT <= MaxMPT / 2 Then Y2 = 2 * MPT / MaxMPT
If MPT > MaxMPT / 2 Then Y2 = 2 * (1 - (MPT / MaxMPT))
If MLT <= MaxMLT / 2 Then Y3 = 2 * MLT / MaxMLT
If MLT > MaxMLT / 2 Then Y3 = 2 * (1 - (MLT / MaxMLT))
Sup(2) = Y1
If Y2 < Sup(2) Then Sup(2) = Y2
If Y3 < Sup(2) Then Sup(2) = Y3
'H+L+L=Superior
If PY <= 0.5 Then Y1 = 0
If PY > 0.5 Then Y1 = PY
If MPT <= MaxMPT / 2 Then Y2 = 1 - ((2 * MPT) / MaxMPT)
If MPT > MaxMPT / 2 Then Y2 = 0
```

```
If MLT <= MaxMLT / 2 Then Y3 = 1 - ((2 * MLT) / MaxMLT)
If MLT > MaxMLT / 2 Then Y3 = 0
Sup(3) = Y1
If Y2 < Sup(3) Then Sup(3) = Y2
If Y3 < Sup(3) Then Sup(3) = Y3
'M+H+M=Superior
If PY <= 0.5 Then Y1 = 2 * PY
If PY > 0.5 Then Y1 = 2 * (1 - PY)
If MPT <= MaxMPT / 2 Then Y2 = 0
If MPT > MaxMPT / 2 Then Y2 = (2 * MPT / MaxMPT) - 1
If MLT <= MaxMLT / 2 Then Y3 = 2 * MLT / MaxMLT
If MLT > MaxMLT / 2 Then Y3 = 2 * (1 - (MLT / MaxMLT))
Sup(4) = Y1
If Y2 < Sup(4) Then Sup(4) = Y2
If Y3 < Sup(4) Then Sup(4) = Y3
'M+M+L=Superior
If PY <= 0.5 Then Y1 = 2 * PY
If PY > 0.5 Then Y1 = 2 * (1 - PY)
If MPT <= MaxMPT / 2 Then Y2 = 2 * MPT / MaxMPT
If MPT > MaxMPT / 2 Then Y2 = 2 * (1 - (MPT / MaxMPT))
If MLT <= MaxMLT / 2 Then Y3 = 1 - ((2 * MLT) / MaxMLT)
If MLT > MaxMLT / 2 Then Y3 = 0
Sup(5) = Y1
If Y2 < Sup(5) Then Sup(5) = Y2
If Y3 < Sup(5) Then Sup(5) = Y3
'L+H+L=Superior
If PY <= 0.5 Then Y1 = 0.5 * (1 - PY)
If PY > 0.5 Then Y1 = 0
If MPT <= MaxMPT / 2 Then Y2 = 0
If MPT > MaxMPT / 2 Then Y2 = (2 * MPT / MaxMPT) - 1
If MLT <= MaxMLT / 2 Then Y3 = 1 - ((2 * MLT) / MaxMLT)
If MLT > MaxMLT / 2 Then Y3 = 0
Sup(6) = Y1
If Y2 < Sup(6) Then Sup(6) = Y2
If Y3 < Sup(6) Then Sup(6) = Y3
'H+H+M=Excellent
If PY <= 0.5 Then Y1 = 0
If PY > 0.5 Then Y1 = PY
If MPT <= MaxMPT / 2 Then Y2 = 0
If MPT > MaxMPT / 2 Then Y2 = (2 * MPT / MaxMPT) - 1
If MLT <= MaxMLT / 2 Then Y3 = 2 * MLT / MaxMLT
If MLT > MaxMLT / 2 Then Y3 = 2 * (1 - (MLT / MaxMLT))
Exc(1) = Y1
If Y2 < Exc(1) Then Exc(1) = Y2
If Y3 < Exc(1) Then Exc(1) = Y3
'H+H+L=Excellent
If PY <= 0.5 Then Y1 = 0
If PY > 0.5 Then Y1 = PY
If MPT <= MaxMPT / 2 Then Y2 = 0
If MPT > MaxMPT / 2 Then Y2 = (2 * MPT / MaxMPT) - 1
If MLT <= MaxMLT / 2 Then Y3 = 1 - ((2 * MLT) / MaxMLT)
If MLT > MaxMLT / 2 Then Y3 = 0
Exc(2) = Y1
If Y2 < Exc(2) Then Exc(2) = Y2
If Y3 < Exc(2) Then Exc(2) = Y3
'H+M+L=Excellent
If PY <= 0.5 Then Y1 = 0
If PY > 0.5 Then Y1 = PY
If MPT <= MaxMPT / 2 Then Y2 = 2 * MPT / MaxMPT
If MPT > MaxMPT / 2 Then Y2 = 2 * (1 - (MPT / MaxMPT))
```

```
If MLT <= MaxMLT / 2 Then Y3 = 1 - ((2 * MLT) / MaxMLT)
If MLT > MaxMLT / 2 Then Y3 = 0
Exc(3) = Y1
If Y2 < Exc(3) Then Exc(3) = Y2
If Y3 < Exc(3) Then Exc(3) = Y3
'M+H+L=Excellent
If PY <= 0.5 Then Y1 = 2 * PY
If PY > 0.5 Then Y1 = 2 * (1 - PY)
If MPT <= MaxMPT / 2 Then Y2 = 0
If MPT > MaxMPT / 2 Then Y2 = (2 * MPT / MaxMPT) - 1
If MLT <= MaxMLT / 2 Then Y3 = 1 - ((2 * MLT) / MaxMLT)
If MLT > MaxMLT / 2 Then Y3 = 0
Exc(4) = Y1
If Y2 < Exc(4) Then Exc(4) = Y2
If Y3 < Exc(4) Then Exc(4) = Y3

YB = Bad(1)
For I = 2 To 4
If Bad(I) > YB Then YB = Bad(I)
Next I
YI = Inf(1)
For I = 2 To 6
If Inf(I) > YI Then YI = Inf(I)
Next I
YA = Ade(1)
For I = 2 To 7
If Ade(I) > YA Then YA = Ade(I)
Next I
YS = Sup(1)
For I = 2 To 6
If Sup(I) > YS Then YS = Sup(I)
Next I
YE = Exc(1)
For I = 2 To 4
If Exc(I) > YE Then YE = Exc(I)
Next I
End Sub


Public Sub union(poly() As Single, a() As Single, YB As Single, YI As Single, YA As Single, YS As
Single, YE As Single, sum1 As Single, sum2 As Single, centerX As Single)
For I = 0 To 16
poly(I, 0) = 0
poly(I, 1) = 0
Next I
' first for YB
I = 0
If (YB >= 0.5 And YI <= 0.5) Or (YB <= 0.5 And YI < YB) Then
 poly(I, 0) = 0
 poly(I, 1) = 0
 poly(I + 1, 0) = 0
 poly(I + 1, 1) = YB
 poly(I + 2, 0) = 30 - 20 * YB
 poly(I + 2, 1) = YB
 poly(I + 3, 0) = 30 - 20 * YI
 poly(I + 3, 1) = YI
ElseIf (YB >= 0.5 And YI > 0.5) Then
 For J = 0 To 16
 If poly(J, 0) = 0 Then
 I = J
```

```
Exit For
End If
Next J
poly(I, 0) = 0
poly(I, 1) = 0
poly(I + 1, 0) = 0
poly(I + 1, 1) = YB
poly(I + 2, 0) = 30 - 20 * YB
poly(I + 2, 1) = YB
poly(I + 3, 0) = 20
poly(I + 3, 1) = 0.5
poly(I + 4, 0) = 20 * YI + 10
poly(I + 4, 1) = YI
ElseIf (YB <= 0.5 And YI >= YB) Then
For J = 0 To 16
If poly(J, 0) = 0 Then
I = J
Exit For
End If
Next J
poly(I, 0) = 0
poly(I, 1) = 0
poly(I + 1, 0) = 0
poly(I + 1, 1) = YB
poly(I + 2, 0) = 20 * YB + 10
poly(I + 2, 1) = YB
poly(I + 3, 0) = 20 * YI + 10
poly(I + 3, 1) = YI
End If
' second for YI
If (YI >= 0.5 And YA <= 0.5) Or (YI <= 0.5 And YA < YI) Then
For J = 1 To 16
If (poly(J, 0) = 0 And poly(J, 1) = 0) Then
I = J
Exit For
End If
Next J
poly(I, 0) = 50 - 20 * YI
poly(I, 1) = YI
poly(I + 1, 0) = 50 - 20 * YA
poly(I + 1, 1) = YA
ElseIf (YI >= 0.5 And YA > 0.5) Then
For J = 1 To 16
If (poly(J, 0) = 0 And poly(J, 1) = 0) Then
I = J
Exit For
End If
Next J
poly(I, 0) = 50 - 20 * YI
poly(I, 1) = YI
poly(I + 1, 0) = 40
poly(I + 1, 1) = 0.5
poly(I + 2, 0) = 20 * YA + 30
poly(I + 2, 1) = YA
ElseIf (YI <= 0.5 And YA >= YI) Then
For J = 1 To 16
If (poly(J, 0) = 0 And poly(J, 1) = 0) Then
I = J
Exit For
End If
```

```
 Next J
 poly(I, 0) = 20 * YI + 30
 poly(I, 1) = YI
 poly(I + 1, 0) = 20 * YA + 30
 poly(I + 1, 1) = YA
End If
'third for YA
If (YA >= 0.5 And YS <= 0.5) Or (YA <= 0.5 And YS < YA) Then
 For J = 1 To 16
 If (poly(J, 0) = 0 And poly(J, 1) = 0) Then
 I = J
 Exit For
 End If
 Next J
 poly(I, 0) = 70 - 20 * YA
 poly(I, 1) = YA
 poly(I + 1, 0) = 70 - 20 * YS
 poly(I + 1, 1) = YS
ElseIf (YA >= 0.5 And YS > 0.5) Then
 For J = 1 To 16
 If (poly(J, 0) = 0 And poly(J, 1) = 0) Then
 I = J
 Exit For
 End If
 Next J
 poly(I, 0) = 70 - 20 * YA
 poly(I, 1) = YA
 poly(I + 1, 0) = 60
 poly(I + 1, 1) = 0.5
 poly(I + 2, 0) = 20 * YS + 50
 poly(I + 2, 1) = YS
ElseIf (YA <= 0.5 And YS >= YA) Then
 For J = 1 To 16
 If (poly(J, 0) = 0 And poly(J, 1) = 0) Then
 I = J
 Exit For
 End If
 Next J
 poly(I, 0) = 20 * YA + 50
 poly(I, 1) = YA
 poly(I + 1, 0) = 20 * YS + 50
 poly(I + 1, 1) = YS
End If
' last for YS
If (YS >= 0.5 And YE <= 0.5) Or (YS <= 0.5 And YE < YS) Then
 For J = 1 To 16
 If (poly(J, 0) = 0 And poly(J, 1) = 0) Then
 I = J
 Exit For
 End If
 Next J
 poly(I, 0) = 90 - 20 * YS
 poly(I, 1) = YS
 poly(I + 1, 0) = 90 - 20 * YE
 poly(I + 1, 1) = YE
 poly(I + 2, 0) = 100
 poly(I + 2, 1) = YE
 poly(I + 3, 0) = 100
 poly(I + 3, 1) = 0
 poly(I + 4, 0) = 0
```

```
poly(I + 4, 1) = 0
ElseIf (YS >= 0.5 And YE > 0.5) Then
For J = 1 To 16
If (poly(J, 0) = 0 And poly(J, 1) = 0) Then
I = J
Exit For
End If
Next J
poly(I, 0) = 90 - 20 * YS
poly(I, 1) = YS
poly(I + 1, 0) = 80
poly(I + 1, 1) = 0.5
poly(I + 2, 0) = 20 * YE + 70
poly(I + 2, 1) = YE
poly(I + 3, 0) = 100
poly(I + 3, 1) = YE
poly(I + 4, 0) = 100
poly(I + 4, 1) = 0
poly(I + 5, 0) = 0
poly(I + 5, 1) = 0
ElseIf (YS <= 0.5 And YE >= YS) Then
For J = 1 To 16
If (poly(J, 0) = 0 And poly(J, 1) = 0) Then
I = J
Exit For
End If
Next J
poly(I, 0) = 20 * YS + 70
poly(I, 1) = YS
poly(I + 1, 0) = 20 * YE + 70
poly(I + 1, 1) = YE
poly(I + 2, 0) = 100
poly(I + 2, 1) = YE
poly(I + 3, 0) = 100
poly(I + 3, 1) = 0
poly(I + 4, 0) = 0
poly(I + 4, 1) = 0
End If
For J = 1 To 16
If (poly(J, 0) = 0 And poly(J, 1) = 0) Then
n = J
Exit For
End If
Next J
sum1 = 0
sum2 = 0
For I = 0 To n - 1
a(I) = poly(I, 0) * poly(I + 1, 1) - poly(I + 1, 0) * poly(I, 1)
sum1 = sum1 + a(I) * (poly(I + 1, 0) + poly(I, 0))
sum2 = sum2 + a(I)
Next
centerX = sum1 / (3 * sum2)
End Sub
```

The Project management code

Private Sub FPASS(NPA() As Integer, AN() As Integer, AD() As Integer, PA() As Integer, EF() As Integer, ES() As Integer, OV() As Integer, AST() As Integer, Big As Integer, NA As Integer, MMM As Integer)

```
    I = 1
    Do Until I = NA + 1
     IT(I) = 0
     I = I + 1
FP10: Loop
FP20: I = 1
FP30: If IT(I) = 1 Then GoTo FP70
    ES(I) = 1
    J = NPA(I)
    If J <> 0 Then GoTo FP40
    GoTo FP60
FP40: k = 1
    Do Until k = J + 1
    L = PA(I, k)
    II = 1
    Do Until II = NA + 1
      If L <> AN(II) Then GoTo FP45
      MM = II
      GoTo FP46
FP45:   II = II + 1
    Loop
FP46: If IT(MM) <> 1 Then GoTo FP70
    m = EF(MM) - OV(I, k) + 1
    If m > ES(I) Then ES(I) = m
    k = k + 1
FP50: Loop
FP60: If AST(I) > ES(I) Then ES(I) = AST(I)
    EF(I) = ES(I) + AD(I) - 1
    IT(I) = 1
FP70: I = I + 1
    If I <= NA Then GoTo FP30
    I = 1
    Do Until I = NA + 1
      If IT(I) = 1 Then GoTo FP80
      GoTo FP20
FP80:   I = I + 1
    Loop
    Big = 0
    I = 1
    Do Until I = NA + 1
     If EF(I) > Big Then GoTo FP84
     GoTo FP85
FP84: Big = EF(I)
    m = I
FP85: I = I + 1
    Loop
    MMM = m
End Sub
```

Private Sub BPASS(NA As Integer, Big As Integer, LF() As Integer, LS() As Integer, EF() As Integer, NSA() As Integer, SA() As Integer, AN() As Integer, OV() As Integer, AD() As Integer, AFT() As Integer, NPA() As Integer, PA() As Integer, MMM As Integer)

```
I = 1
Do Until I = NA
IT(I) = 0
I = I + 1
Loop
LF(MMM) = Big
LS(MMM) = LF(MMM) - AD(MMM) + 1
```

```
IT(MMM) = 1
B10: KJ = 1
Do Until KJ = NA + 1
I = NA - KJ + 1
LF(I) = Big
J = NSA(I)
If J = 0 Then GoTo B60
k = 1
Do Until k = J + 1
L = SA(I, k)
II = 1
Do Until II = NA + 1
If L <> AN(II) Then GoTo B20
MM = II
GoTo B30
B20: II = II + 1
Loop
B30: If IT(MM) <> 1 Then GoTo B60
J1 = NPA(MM)
K1 = 1
Do Until K1 = J1 + 1
If PA(MM, K1) <> AN(I) Then GoTo B35
M1 = K1
GoTo B36
B35: K1 = K1 + 1
Loop
B36: m = LS(MM) + OV(MM, M1) - 1
If m < LF(I) Then LF(I) = m
B40: k = k + 1
Loop
If LF(I) < EF(I) Then LF(I) = EF(I)
If AFT(I) = 0 Then GoTo B50
If AFT(I) > EF(I) And AFT(I) < LF(I) Then LF(I) = AFT(I)
If AFT(I) <= EF(I) Then LF(I) = EF(I)
B50: LS(I) = LF(I) - AD(I) + 1
IT(I) = 1
B60: KJ = KJ + 1
Loop
I = 1
Do Until I = NA + 1
If IT(I) = 1 Then GoTo B70
GoTo B10
B70: I = I + 1
Loop
End Sub
```

```
Private Sub Cost(TRC() As Single, RC() As Single, AD() As Integer, NA As Integer, Big As Integer,
TDC() As Single, TD() As Integer, RCC() As Single, RU() As Integer, PC() As Single, CPC() As
Single, PC2 As Single)
For I = 1 To NA
For J = 1 To 6
TRC(I, J) = RC(I, J) * AD(I) * RU(I, J)
Next J
Next I
PC2 = 0
For I = 1 To 6
For J = 1 To Big
TDC(I, J) = TD(I, J) * RCC(I)
PC2 = PC2 + TDC(I, J)
Next J
```

```
Next I
For I = 1 To Big
PC(I) = 0
For J = 1 To 6
PC(I) = PC(I) + TDC(J, I)
Next J
Next I
CPC(1) = PC(1)
For I = 2 To Big
CPC(I) = CPC(I - 1) + PC(I)
Next I
picResult2.Cls
picResult2.Scale (-0.1 * Big, 1.1 * PC2)-(1.05 * Big, -0.1 * PC2)
picResult2.Line (-0.1 * Big, 0)-(1.1 * Big, 0)
picResult2.Line (0, -0.1 * PC2)-(0, 1.1 * PC2)
picResult2.Line (Big, 0)-(Big, PC2)
picResult2.Line (0, PC2)-(Big, PC2)
picResult2.CurrentX = 0.45 * Big - picResult2.TextWidth("Total Stage Cost=") / 2
picResult2.CurrentY = 1.09 * PC2
picResult2.Print "Total Stage Cost="; PC2
picResult2.CurrentX = 0.7 * Big - picResult2.TextWidth("Cash Flow Diagram") / 2
picResult2.CurrentY = 0.15 * PC2
picResult2.Print "Cash Flow Diagram"
picResult2.Line (0, 0)-(1, CPC(1))
For I = 2 To Big
picResult2.Line (I - 1, CPC(I - 1))-(I, CPC(I))
Next I
For X = 0 To PC2 Step 0.1 * PC2
picResult2.Line (-0.5, X)-(0.2, X)
picResult2.CurrentX = -0.1 * Big
picResult2.CurrentY = X - picResult2.TextHeight("x") / 2
picResult2.Print X
Next X
For X = 0 To PC2 Step 0.01 * PC2
picResult2.Line (-0.1, X)-(0.2, X)
Next X
For X = 0 To Big Step 10
picResult2.Line (X, -0.01 * PC2)-(X, 0.01 * PC2)
picResult2.CurrentX = X - picResult2.TextWidth("x")
picResult2.CurrentY = 0.00001 * PC2
picResult2.Print X
Next X
For X = 0 To Big
picResult2.Line (X, -0.001 * PC2)-(X, 0.001 * PC2)
Next X
End Sub

Private Sub LOGIC(NA As Integer, AN() As Integer, NPA() As Integer, PA() As Integer, SA() As Integer, NSA() As Integer, OV() As Integer, AD() As Integer)
   I1 = 1
   Do Until I1 = NA + 1
   L1 = AN(I1)
   JJ = 0
   I2 = 1
   Do Until I2 = NA + 1
      If I2 = I1 Then GoTo LO20
      L2 = AN(I2)
      J = NPA(I2)
      If J = 0 Then GoTo LO20
      I3 = 1
```

```
        Do Until I3 = J + 1
            L3 = PA(I2, I3)
            If L1 <> L3 Then GoTo LO10
            JJ = JJ + 1
            SA(I1, JJ) = L2
LO10:   I3 = I3 + 1
        Loop
LO20: I2 = I2 + 1
    Loop
    NSA(I1) = JJ
LO30: I1 = I1 + 1
    Loop
    N1 = 0
    N2 = 0
    I = 1
    Do Until I = NA + 1
    J1 = NPA(I)
    J2 = NSA(I)
    If J1 = 0 Then N1 = N1 + 1
    If J2 = 0 Then N2 = N2 + 1
LO40: I = I + 1
    Loop
    If N1 = 0 Then
LO90: MsgBox "* NO START ACTIVITY *"
    Stop
    End If
    If N2 = 0 Then
LO92: MsgBox "* NO FINISH ACTIVITY *"
    Stop
    End If
    If N1 > 1 Then
LO94: MsgBox "* MORE THAN ONE ACTIVITY HAS NO PREDECESSORS *"
    Stop
    End If
    If N2 > 1 Then
LO96: MsgBox "* MORE THAN ONE ACTIVITY HAS NO SUCCESSORS *"
    Stop
    End If
    I = 1
    Do Until I = NA + 1
    J1 = NPA(I)
    If J1 = 0 Then GoTo LO80
    J = 1
    Do Until J = J1 + 1
    L = PA(I, J)
    k = 1
    Do Until k = NA + 1
    If L <> AN(k) Then GoTo LO50
    m = k
    GoTo LO60
LO50: k = k + 1
    Loop
LO88: MsgBox "* ACTIVITY", L, "DOES NOT EXIST *"
    Stop
LO60: n = AD(m)
    If OV(I, J) <= n Then GoTo LO70
LO98: MsgBox "* CHECK OVERLAPS WITH ACTIVITY", L, "*"
    Stop
LO70: J = J + 1
    Loop
```

```
LO80: I = I + 1
    Loop
End Sub

Private Sub FLOAT(NA As Integer, AN() As Integer, NSA() As Integer, SA() As Integer, ES() As
Integer, EF() As Integer, LF() As Integer, TF() As Integer, FF() As Integer, NPA() As Integer, PA() As
Integer, BF() As Integer, OV() As Integer, AST() As Integer)
I = 1
Do Until I = NA + 1
      TF(I) = LF(I) - EF(I)
      I = I + 1
FL10: Loop
I = 1
Do Until I = NA + 1
  If TF(I) = 0 Then GoTo FL50
  FF(I) = 1000
  J = NSA(I)
  If J = 0 Then GoTo FL50
    k = 1
    Do Until k = J + 1
      L = SA(I, k)
      II = 1
      Do Until II = NA + 1
       If L <> AN(II) Then GoTo FL20
       MM = II
       GoTo FL30
FL20:   II = II + 1
      Loop
FL30:   J1 = NPA(MM)
      K1 = 1
      Do Until K1 = J1 + 1
       If PA(MM, K1) <> AN(I) Then GoTo FL35
       M1 = K1
       GoTo FL36
FL35:   K1 = K1 + 1
      Loop
FL36:   m = ES(MM) - EF(I) - 1 + OV(MM, M1)
      If m < FF(I) Then FF(I) = m
FL40: k = k + 1
    Loop
    If FF(I) > TF(I) Then FF(I) = TF(I)
    GoTo FL60
FL50: FF(I) = TF(I)
FL60: I = I + 1
    Loop
I = 1
Do Until I = NA + 1
    BF(I) = 1000
    J = NPA(I)
    If J = 0 Then GoTo FL95
    k = 1
    Do Until k = J + 1
      L = PA(I, k)
      II = 1
      Do Until II = NA + 1
       If L <> AN(II) Then GoTo FL70
       MM = II
       GoTo FL80
FL70:   II = II + 1
      Loop
```

```
FL80: m = ES(I) - EF(MM) - 1 + OV(I, k)
    If m < BF(I) Then BF(I) = m
FL90: k = k + 1
    Loop
    If AST(I) = 0 Then GoTo FL100
    k = ES(I) - AST(I)
    If k > 0 Then GoTo FL100
    If k = 0 Then GoTo FL92
    If k < 0 Then GoTo FL94
FL92: BF(I) = 0
    GoTo FL100
FL94: If BF(I) > k Then BF(I) = k
    GoTo FL100
FL95:  BF(I) = ES(I) - 1
FL100: I = I + 1
    Loop
End Sub

Private Sub RESOURCE(STOC As Integer, Big As Integer, NA As Integer, AN() As Integer, ES() As Integer, EF() As Integer, TD() As Integer, TU() As Integer, RST() As Integer, RFT() As Integer, RMU() As Integer, RTT() As String, RU() As Integer)
For I = 1 To 6
TU(I) = 0
For J = 1 To Big
TD(I, J) = 0
Next J
Next I
For L1 = 1 To Big
For L2 = 1 To NA
If (ES(L2) <= L1 And EF(L2) >= L1) Then GoTo 10
GoTo 12
10: For m = 1 To 6
   TD(m, L1) = TD(m, L1) + RU(L2, m)
   TU(m) = TU(m) + RU(L2, m)
   Next m
12: Next L2
Next L1
For L1 = 1 To Big
For L2 = 1 To 6
If (IR(L2) = 1) Then GoTo 14
If (TD(L2, L1) = 0) Then GoTo 14
RST(L2) = L1
IR(L2) = 1
14: Next L2
Next L1
For I = 1 To 6
IR(I) = 0
Next I
For L1 = 1 To Big
m = Big + 1 - L1
For L2 = 1 To 6
If (IR(L2) = 1) Then GoTo 16
If (TD(L2, m) = 0) Then GoTo 16
RFT(L2) = m
IR(L2) = 1
16: Next L2
Next L1
If STOC <> 1 Then
picResult2.Cls
picResult2.Scale (0, 100)-(Big, 0)
```

```
picResult2.CurrentX = 0
picResult2.CurrentY = 100
For I = 1 To 6
If RST(I) = 0 And RFT(I) = 0 Then GoTo 100
picResult2.Print RTT(I), "start time="; RST(I); "-"; "finish time="; RFT(I)
100: Next I
End If
End Sub
```

The Monte Carlo Simulation code

Private Sub Monte(AD() As Integer, TAD() As Single, NA As Integer, NDIS As Integer, DIS() As Single, DISPB() As Single, KDIS() As Integer, NVAR As Integer, IA() As Integer, ITV() As Integer, SV() As Single, BV() As Single, X As Double, Y As Double, Z As Double, NPA() As Integer, PA() As Integer, AN() As Integer, OV() As Integer, OVT() As Single, CVARR() As Single, DAN() As Integer)

```
'SIMULATION SUBPROGRAM
For I = 1 To NA
TAD(I) = AD(I)
Next I
For J = 0 To NVAR - 1
If Array(J, 3) = "Cost" Then GoTo 30
 J1 = Array(J, 4) 'SV(J)
 J2 = Array(J, 5) 'BV(J)
Call Uni(RD, J1, J2, Var)
For k = 1 To NA
 kk = k
 If AN(k) = Array(J, 2) Then GoTo 26 'IA(J) Then GoTo 26
25: Next k
 message = "Error; activity numbers are not compatable with innovation data"
 MsgBox message,, "Information Incompatable"
 End
26: TAD(kk) = TAD(kk) + (AD(kk) * Var / 100)
30: Next J
90: For JJ = 1 To NA
   Y = TAD(JJ) - Int(TAD(JJ))
   If Y < 0.5 Then GoTo 100
    TAD(JJ) = TAD(JJ) + 0.5
100: TAD(JJ) = Int(TAD(JJ))
110: Next JJ
   For I = 1 To NA
   J = NPA(I)
   If J = 0 Then GoTo 14
   For k = 1 To J
   L = PA(I, k)
   For I1 = 1 To NA
   If L <> AN(I1) Then GoTo 11
   m = I1
   GoTo 12
11:  Next I1
12:  OVT(I, k) = OV(I, k) * TAD(m) / 100
13:  Next k
14:  Next I
End Sub
```

Public Sub MONTC(PC2 As Single, TRC() As Single, RC() As Single, Big As Integer, TDC() As Single, TD() As Integer, TRCC() As Single, RU() As Integer, PC() As Single, CPC() As Single)

```
'COST SIMULATION
'-----------------
For I = 1 To 6 'max. no. of resources=6'
```

```
TRCC(I) = RCC(I)
Next I
For J = 0 To NVAR - 1
If Array(J, 3) = "Time" Then GoTo 10
J1 = Array(J, 4) 'SV(J)
J2 = Array(J, 5) 'BV(J)
Call Uni(RD, J1, J2, Var)
kk = Array(J, 2)
If kk <= 6 Then GoTo 26 'max. no. of resources is 6
 message = "Error; Resource numbers are not compatable with innovation data"
 MsgBox message, , "Information Incompatable"
 End
26: TRCC(kk) = TRCC(kk) + (RCC(kk) * Var / 100)
10: Next J
PC2 = 0
For I = 1 To 6
For J = 1 To Big
TDC(I, J) = TD(I, J) * TRCC(I)
PC2 = PC2 + TDC(I, J)
Next J
Next I
End Sub
```

Private Sub LOGICProb(NA As Integer, AN() As Integer, NPA() As Integer, PA() As Integer, SA() As Integer, NSA() As Integer, OV() As Integer, AD() As Integer, OVT() As Single)

```
For I = 1 To NA
  J = NPA(I)
  If J = 0 Then GoTo 14
  For k = 1 To J
  L = PA(I, k)
  For I1 = 1 To NA
  If L <> AN(I1) Then GoTo 11
  m = I1
  GoTo 12
11: Next I1
12: OVT(I, k) = OV(I, k) * AD(m) / 100#
13: Next k
14: Next I
   I1 = 1
   Do Until I1 = NA + 1
   L1 = AN(I1)
   JJ = 0
   I2 = 1
   Do Until I2 = NA + 1
      If I2 = I1 Then GoTo LO20
      L2 = AN(I2)
      J = NPA(I2)
      If J = 0 Then GoTo LO20
      I3 = 1
      Do Until I3 = J + 1
         L3 = PA(I2, I3)
         If L1 <> L3 Then GoTo LO10
         JJ = JJ + 1
         SA(I1, JJ) = L2
LO10:    I3 = I3 + 1
      Loop
LO20: I2 = I2 + 1
   Loop
   NSA(I1) = JJ
LO30: I1 = I1 + 1
```

```
    Loop
    N1 = 0
    N2 = 0
    I = 1
    Do Until I = NA + 1
    J1 = NPA(I)
    J2 = NSA(I)
    If J1 = 0 Then N1 = N1 + 1
    If J2 = 0 Then N2 = N2 + 1
LO40: I = I + 1
    Loop
    If N1 = 0 Then
LO90: MsgBox "* NO START ACTIVITY *"
    Stop
    End If
    If N2 = 0 Then
LO92: MsgBox "* NO FINISH ACTIVITY *"
    Stop
    End If
    If N1 > 1 Then
LO94: MsgBox "* MORE THAN ONE ACTIVITY HAS NO PREDECESSORS *"
    Stop
    End If
    If N2 > 1 Then
LO96: MsgBox "* MORE THAN ONE ACTIVITY HAS NO SUCCESSORS *"
    Stop
    End If
    I = 1
    Do Until I = NA + 1
    J1 = NPA(I)
    If J1 = 0 Then GoTo LO80
    J = 1
    Do Until J = J1 + 1
    L = PA(I, J)
    k = 1
    Do Until k = NA + 1
    If L <> AN(k) Then GoTo LO50
    m = k
    GoTo LO60
LO50: k = k + 1
    Loop
LO88: MsgBox "* ACTIVITY", L, "DOES NOT EXIST *"
    Stop
LO60: n = AD(m)
    If OVT(I, J) <= n Then GoTo LO70
LO98: MsgBox "* CHECK OVERLAPS WITH ACTIVITY", L, "*"
    Stop
LO70: J = J + 1
    Loop
LO80: I = I + 1
    Loop
End Sub
```

Private Sub FPASSProb(NPA() As Integer, AN() As Integer, TAD() As Single, AD() As Integer, PA() As Integer, EF() As Integer, ES() As Integer, OVT() As Single, AST() As Integer, Big As Integer, NA As Integer, MMM As Integer)

```
    I = 1
    Do Until I = NA + 1
     IT(I) = 0
     I = I + 1
```

```
FP10: Loop
FP20: I = 1
FP30: If IT(I) = 1 Then GoTo FP70
    ES(I) = 1
    J = NPA(I)
    If J <> 0 Then GoTo FP40
    GoTo FP60
FP40: k = 1
    Do Until k = J + 1
    L = PA(I, k)
    II = 1
    Do Until II = NA + 1
      If L <> AN(II) Then GoTo FP45
      MM = II
      GoTo FP46
FP45:   II = II + 1
    Loop
FP46: If IT(MM) <> 1 Then GoTo FP70
    m = EF(MM) - OVT(I, k) + 1
    If m > ES(I) Then ES(I) = m
    k = k + 1
FP50: Loop
FP60: If AST(I) > ES(I) Then ES(I) = AST(I)
    EF(I) = ES(I) + TAD(I) - 1
    IT(I) = 1
FP70: I = I + 1
    If I <= NA Then GoTo FP30
    I = 1
    Do Until I = NA + 1
      If IT(I) = 1 Then GoTo FP80
      GoTo FP20
FP80:   I = I + 1
    Loop
    Big = 0
    I = 1
    Do Until I = NA + 1
     If EF(I) > Big Then GoTo FP84
     GoTo FP85
FP84: Big = EF(I)
    m = I
FP85: I = I + 1
    Loop
    MMM = m
End Sub

Private Sub BPASSProb(NA As Integer, Big As Integer, LF() As Integer, LS() As Integer, EF() As
Integer, NSA() As Integer, SA() As Integer, AN() As Integer, OVT() As Single, TAD() As Single,
AFT() As Integer, NPA() As Integer, PA() As Integer, MMM As Integer)
For I = 1 To NA
IT(I) = 0
Next I
LF(MMM) = Big
LS(MMM) = LF(MMM) - TAD(MMM) + 1
IT(MMM) = 1
B10: For KJ = 1 To NA
I = NA - KJ + 1
LF(I) = Big
J = NSA(I)
If J = 0 Then GoTo B60
For k = 1 To J
```

```
L = SA(I, k)
For II = 1 To NA
If L <> AN(II) Then GoTo B20
MM = II
GoTo B30
B20: Next II
B30: If IT(MM) <> 1 Then GoTo B60
J1 = NPA(MM)
For K1 = 1 To J1
If PA(MM, K1) <> AN(I) Then GoTo B35
M1 = K1
GoTo B36
B35: Next K1
B36: m = LS(MM) + OVT(MM, M1) - 1
If m < LF(I) Then LF(I) = m
B40: Next k
If LF(I) < EF(I) Then LF(I) = EF(I)
If AFT(I) = 0 Then GoTo B50
If AFT(I) > EF(I) And AFT(I) < LF(I) Then LF(I) = AFT(I)
If AFT(I) <= EF(I) Then LF(I) = EF(I)
B50: LS(I) = LF(I) - TAD(I) + 1
IT(I) = 1
B60: Next KJ
For I = 1 To NA
If IT(I) = 1 Then GoTo B70
GoTo B10
B70: Next I
End Sub

Public Sub STATCOST(NITR As Integer, RES2() As Single, FRE2() As Integer, CFRE2() As Single,
MEAN2 As Single, Min2 As Single, Max2 As Single, STAN22 As Single)
' STATISTICAL ANALYSIS
    For k = 1 To NITR
      FRE2(k) = 0
      CFRE2(k) = 0
10:  Next k
    STAN22 = 0
    SD22 = 0
    For I = 1 To NITR - 1
     If RES2(I) = 0 Then GoTo 30
      FRE2(I) = 1
     For J = I + 1 To NITR
       If RES2(I) = RES2(J) Then
        FRE2(I) = FRE2(I) + 1
        RES2(J) = 0
        FRE2(J) = 0
       End If
20: Next J
30: Next I
    If RES2(NITR) <> 0 Then FRE2(NITR) = 1
40: m = 0
  For I = 1 To NITR - 1
     If RES2(I) > RES2(I + 1) Then
       TEMP1 = RES2(I)
       RES2(I) = RES2(I + 1)
       RES2(I + 1) = TEMP1
       TEMP2 = FRE2(I)
       FRE2(I) = FRE2(I + 1)
       FRE2(I + 1) = TEMP2
       m = 1
```

```
    End If
50: Next I
    If m <> 0 Then GoTo 40
    Sum = 0
    For I = 1 To NITR
     If RES2(I) = 0 Then GoTo 60
     Sum = Sum + (RES2(I) * FRE2(I))
60: Next I
    AMEAN2 = (Sum / NITR)
    kk = NITR - 1
    If RES2(kk) = 0 Then AMEAN = RES2(NITR)
    For k = 1 To NITR
    If RES2(k) = 0 Then GoTo 65
    Min2 = RES2(k)
    Max2 = RES2(NITR)
    GoTo 66
65:  Next k
66:  For I = 1 To NITR
     SD22 = SD22 + FRE2(I) * ((RES2(I) - AMEAN2) ^ 2)
70:  Next I
    STAN22 = (SD22 / NITR) ^ 0.5
    CFRE2(1) = FRE2(1)
    For I = 1 To NITR - 1
    CFRE2(I + 1) = CFRE2(I) + FRE2(I + 1)
120:  Next I
    For I = 1 To NITR
    CFRE2(I) = (CFRE2(I) / NITR) * 100
130:  Next I
140:  Y = AMEAN2 - Int(AMEAN2)
    If Y < 0.5 Then GoTo 150
    AMEAN2 = AMEAN2 + 0.5
150:  MEAN2 = AMEAN2
End Sub

Private Sub STATIS(NITR As Integer, RES() As Single, FRE() As Integer, CFRE() As Single,
MEAN As Single, Min As Single, Max As Single, STAN2 As Single)
' STATISTICAL ANALYSIS
    For k = 1 To NITR
      FRE(k) = 0
      CFRE(k) = 0
10:  Next k
    STAN2 = 0
    SD2 = 0
    For I = 1 To NITR - 1
     If RES(I) = 0 Then GoTo 30
      FRE(I) = 1
     For J = I + 1 To NITR
      If RES(I) = RES(J) Then
       FRE(I) = FRE(I) + 1
       RES(J) = 0
       FRE(J) = 0
      End If
20: Next J
30: Next I
   If RES(NITR) <> 0 Then FRE(NITR) = 1
40: m = 0
  For I = 1 To NITR - 1
    If RES(I) > RES(I + 1) Then
     TEMP1 = RES(I)
     RES(I) = RES(I + 1)
```

```
        RES(I + 1) = TEMP1
        TEMP2 = FRE(I)
        FRE(I) = FRE(I + 1)
        FRE(I + 1) = TEMP2
        m = 1
      End If
50: Next I
    If m <> 0 Then GoTo 40
    Sum = 0
    For I = 1 To NITR
     If RES(I) = 0 Then GoTo 60
     Sum = Sum + (RES(I) * FRE(I))
60: Next I
    AMEAN = (Sum / NITR)
    kk = NITR - 1
    If RES(kk) = 0 Then AMEAN = RES(NITR)
    For k = 1 To NITR
    If RES(k) = 0 Then GoTo 65
    Min = RES(k)
    Max = RES(NITR)
    GoTo 66
65:  Next k
66:  For I = 1 To NITR
     SD2 = SD2 + FRE(I) * ((RES(I) - AMEAN) ^ 2)
70:  Next I
    STAN2 = (SD2 / NITR) ^ 0.5
    CFRE(1) = FRE(1)
    For I = 1 To NITR - 1
    CFRE(I + 1) = CFRE(I) + FRE(I + 1)
120:  Next I
    For I = 1 To NITR
    CFRE(I) = (CFRE(I) / NITR) * 100
130:  Next I
140:  Y = AMEAN - Int(AMEAN)
    If Y < 0.5 Then GoTo 150
    AMEAN = AMEAN + 0.5
150:  MEAN = AMEAN
End Sub

Private Sub Uni(RD As Double, J1 As Single, J2 As Single, Var As Single)
Var = J1 + (Rnd * (J2 - J1))
End Sub
```