Application of the Systems Approach to Defining Major Projects for Successful Implementation

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CONTENTS

LIST OF EXHIBITS

LIST OF APPENDICES

GLOSSARY

ABB	Asea Brown Boveri
ACC	Area Control Centre
APT	Advanced Passenger Train
APT-E	Advanced Passenger Train – Experimental Vehicle
APT-P	Advanced Passenger Train – Prototype Vehicle
APT-U	Advanced Passenger Train – Production
AWT	Advanced Water Treatment
BOO	Build-Own-Operate
BOOT	Build-Own-Operate-Transfer
BOT	Build-Operate-Transfer
BR	British Rail
BREL	British Rail Engineering Limited
BSEL	Bristol Siddeley Engines Ltd
C-C	Complex Coercive
C-P	Complex Pluralist
C-U	Complex Unitary
CAPEX	Capital Expenditure
CCC	Coordination Control Centre
CCTA	Central Computer and Telecommunications Agency
CEO	Chief Executive Officer
CF	Containing Framework
CFC	Chlorofluorocarbon
CMEE	Chief Mechanical and Electrical Engineer
CSF	Critical Success Factor
DBO	Design Build and Operate
DBFO	Design Build Finance and Operate
DCF	Discounted Cash Flow
DFA	Design For Assembly
DFM	Design For Manufacture
DoD	Department of Defense (USA)
DoE	Department of the Environment
DTp	Department of Transport

EAC	Equipment Approvals Committee
EC	European Community
ECML	East Coast Main Line
ESA	European Space Agency
FMCG	Fast Moving Consumer Good
FMECA	Failure Mode Effect Cause Analysis
GAO	General Accounting Office (USA)
GE	General Electric
GPS	Global Positioning System
HBPR	High By-Pass Ratio
HP	High Pressure (Compressor)
HST	High Speed Train
ICE	Institute of Civil Engineers
IDEF	Integrated Definition Framework
IEE	Institute of Electrical Engineers
IP	Intermediate Pressure (Compressor)
IRC	Industrial Reorganisation Corporation
IRR	Internal Rate of Return
ISDP	Integrated System Design for the Product
ISDPM	Integrated System Design for Project Management
ISM	Interpretive Structural Modelling
KPI	Key Performance Indicator
LCIP	Local Control and Interlock Panel
LWRM	London Water Ring Main
MCA	Management Consultancies Association
MLD	Mega-litres per Day
MM Model	Morris M'Pherson Model
MoD	Ministry of Defence
NAO	National Audit Office
NPV	Net Present Value
PAC	Public Accounts Committee
PanAm	Pan American Airlines
PCB	Polychlorinated Biphenyl
PD	Project Definition

PFI	Public Finance Initiative
POP	Power-O-Power
PROFISY	Project Financial Information System
PSBR	Public Sector Borrowing Requirement
R and D	Research and Development
RAM	Reliability, Availability and Maintainability
ROA	Return On Assets
ROE	Return On Equity
ROI	Return On Investment
RR	Rolls Royce
RSRE	Royal Signals Radar Establishment
S-C	Simple Coercive
S-P	Simple Pluralist
S-U	Simple Unitary
SBU	Strategic Business Unit
SCADA	Supervisory Control And Data Acquisition
SID	Strategic Investment Decision
SNCF	Societé Nationale de Chemin de Fer
SOI	System Of Interest
SSM	Soft System Methodology
TAPS	Trans Alaskan Pipeline System
TGV	Train Grande Vitesse
TWA	Trans World Airlines
TWUL	Thames Water Utilities Limited
UK	United Kingdom
US	United States
WBS	Work Breakdown Structure
WCML	West Coast Main Line
WSOI	Wider System Of Interest

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ABSTRACT

Despite advances in project management techniques and greatly improved levels of experience in managing major projects, a significant number of these projects still experience serious problems during implementation resulting in unacceptable loss of functionality with related cost and schedule growth, and sometimes outright cancellation. Research has shown that major contributors to these problems are systematic and can be associated with project size, complexity, technical uncertainty, schedule duration and urgency, physical and social environment, and government and politics. Several authors advocate that the application of systems problem solving methods and techniques during project definition could resolve these systematic problems and should be used to augment traditional project management approaches.

This research is concerned with bringing together two important models, one concerned with traditional project definition (the Morris Model) and the other concerned with systems engineering (the M'Pherson Model), and harmonising the result with other systems methods and techniques to form a comprehensive model (to be called the MM Model) for defining major projects for successful implementation.

The Morris Model is introduced in Chapter 2 as part of a study into the nature of major projects and what makes them successful or problematic. As part of the study, a compendium of project success criteria is compiled for later testing of the MM Model. Chapter 3 concentrates on discovering how systems methods and techniques, including those that can be categorised under the soft systems banner, could be used in project problem solving. The M'Pherson Model is introduced during the path through the Chapter. An important step in the early life of a project is the approval stage. If decisions regarding a project's viability are to be meaningful, appropriate information for good decision making must be generated during the project definition. Project approval is the subject of Chapter 4.

The MM Model for project definition is formulated in Chapter 5 and tested firstly against the compiled compendium of project success criteria and, secondly, against three careful selected case studies; British Rail's Advanced Passenger Train, Thames Water's London Water Ring Main, and the Rolls Royce RB 211 Aero-engine. The first case study represents a cancelled project, the second a highly successful project, and the third a project that experienced extreme problems but resulted in a highly successful product.

Finally, in Chapter 9 the author provides a reader's guide to the formulation of the MM Model, discusses the extent to which the objectives have been achieved, the contribution to knowledge and possible areas for further work.

CHAPTER: 1 INTRODUCTION

1.1 BACKGROUND

Projects are business or government undertakings that are planned to achieve specified objectives. These objectives define projects' technical performance, budget and schedule, and the benefits to be delivered to sponsoring organisations. Capital or major projects are those projects that are particularly demanding because their size, complexity, schedule urgency, and their calls on resources and know-how.

Surprisingly, capital projects are not confined to engineering but may be found in social and welfare programmes, and in third-world development and aid programmes. However, the more common and obvious capital projects are within engineering and may be associated with aerospace and defence, computers and telecommunications, petroleum and oil and gas, utilities such as water and electricity supply, civil engineering and building, and research and development. This research will focus on these engineering discipline projects, although most of the principles identified apply to social and aid type projects.

All too often capital projects fail to meet their objectives, frequently with catastrophic effects on business, government, national economies, and on communities as a whole. Large overruns to budget and schedule are common, particularly on the more complex undertakings. It has been noted that more than 70% of all capital projects experience substantial difficulties at an estimated cost of £750bn world wide each year (World Bank, 1995). Poor application of project management techniques can sometimes be blamed for project failures; however, research into project failures has shown that systematic problems associated with project size, complexity, technical uncertainty, schedule duration and urgency, physical and social environment, and government and politics are major contributors to problems experienced.

The full scope of a project should be first realised during the project definition stage in the project's lifecycle; ie, the systematic impacts of size, complexity, technical uncertainty, schedule duration and urgency, physical and social environment, and government and politics are qualified and quantified. If this scoping is not undertaken to the right level of detail or important elements are missed, a project may be approved and established on a false premise, with the likelihood of failure greatly increased.

Despite better project understanding and substantially advanced project management techniques and processes, major projects are still suffering from problems that can be traced to poorly conducted project definitions. There is evidence to suggest that no comprehensive model for formulating and planning a project definition exists, and that the availability of such a model could improve significantly the success of major projects.

However, the development of such a model, if it is to be effective, must be based on research into project success criteria and on ways by which the scoping and subsequent approval of project may be improved.

1.2 THE BASIS FOR THIS RESEARCH

Morris and Hough undertook a detailed study into why major projects had experienced significant problems. As a result of their work they developed a model (to be called the Morris Model in this research) that identified in broad terms those activities that had to be undertaken during early project work in order to scope the project correctly; ie, those activities required during project definition. The Model as published identifies the activities in the form of checklists, and as such does not specify the processes required for work planning and the logical order for the processes to be undertaken.

On the other hand, a framework developed by M'Pherson (to be called the M'Pherson Model in this research) for systems design, used concepts from systems engineering and was presented in the form of a structured process schematic. The model is ideal for addressing the systematic problems associated with project size, complexity, technical uncertainty, schedule duration and urgency, physical and social environment, and government and politics but lacks the attention of the Morris Model to the project related aspects including those that belong to the project management discipline.

From initial studies it would seem feasible to integrate the two models to form a complete model for project definition as this would provide both the project management view and the systems view required for defining major projects for success. However, neither model addresses sufficiently well the full information requirements of the project approval process, which directly follows a project definition, and neither specifies methods, tools and techniques that can employed within the various processes involved; particularly those tools that can deal with ill structured and ambiguous problems. Therefore, in order to define a comprehensive model for project definition (to be called the MM Model after Morris and M'Pherson) it will be important to research related topics in order to augment the MM Model accordingly.

Equally important will be the integrity of the MM Model. To achieve an acceptable level of integrity, the emerging model will firstly need to be tested with a comprehensive compendium of project success criteria in order to validate it against important published research on project success and failure. These criteria will be specially prepared for this research by combining other authors' findings and enhancing them from work undertaken in this research. Secondly, the model will need to be tested against three case studies; British Rail's Advanced Passenger Train, the Thames Water's London Water Ring Main, and the Rolls Royce RB211 Aero-engine in order to get a real project perspective. The case studies have been selected because in their combination they fully exercise all important aspects of the model, and because each case study is richly documented thereby making essential information readily available.

1.3 OBJECTIVES OF THE RESEARCH

The research has five main objectives:

- **Objective 1** – to understand the foundation and nature of major projects, to develop from various published works a compendium of project success criteria, and to introduce Morris and Hough's Research Model for Preconditions for Project Success
- **Objective 2** – to understand how the application of hard and soft system methods and techniques can combine with those of project management to define a major project for success. As a part of this understanding, M'Pherson's System Design Model will be introduced and described
- **Objective 3** – to understand the decision-making activities in the project approval process in order to identify the information that must be provided from a project definition for good decision making
- **Objective 4** – to combine the Morris Model, the M'Pherson Model and other methods and techniques identified in this research to formulate the MM Model, together with an associated tool kit, for major project definition.
- **Objective 5** – to test the MM Model against a specially developed comprehensive compendium of project success criteria, and against three case studies selected for their combined ability to exercise all elements of the model.

1.4 STRUCTURE OF THE THESIS

1.4.1 Overview to Chapter 2 – Preconditions for Success in Major Projects

The aim of this Chapter is to address Objective 1, ie to develop a compendium of project success criteria, and to introduce the Morris and Hough's Research Model for Preconditions for Project Success. However, in order to develop such a compendium and to fully understand the basis of Morris' Model, which is essential for the formulation of the MM Model, it is important to understand the foundation of major projects (Section 2.2), and the nature of major project issues and how they can impact a project's success (Section 2.3). A compendium of preconditions for major project success that draws together the findings of the major researchers of the subject is compiled in preparation for the formulation and testing the MM Model (Section 2.4), and the Chapter concludes with the introduction and description of the Morris Model (Section 2.5).

1.4.2 Overview to Chapter 3 – Systems Approach to Managing Projects

The aim of this Chapter is to address Objective 2, ie to understand how the application of system methods and techniques can combine with those of project management to define a major project for success, and to introduce M'Pherson's System Design Model. To comprehend this model fully and to understand its strengths and weaknesses, the emergence of the systems approach, both hard and soft, is reviewed (Section 3.2), together with a more considered study of systems engineering (Section 3.3). The M'Pherson Model is described in detail (Section 3.4) followed by a review of how soft system thinking could be incorporated into project management (Section 3.5). Finally, consideration is given on how a project may be managed as an open system.

1.4.3 Overview to Chapter 4 – Project Approval

The aim of this Chapter is to address Objective 3, ie to understand the decision-making activities in the project approval process in order to identify the information that must be provided from a project definition. Section 4.2 looks at capital investment in projects through Pike's Project Approval Framework; this framework provides the thread to the business and financial part of this Research. The next five sections (Investment Decisions, Public Projects, Financing of Major Projects, Quantitative Methods and Project Risk) add new dimensions and enhancements to Pike's thinking by introducing findings of other authors and researchers on related topics. It is not the intention in the Chapter to study each of the subjects in depth but to have enough scope to identify tasks and considerations which should be included in the project definition.

1.4.4 Overview to Chapter 5 – Formulation of the MM Model

The aim of this Chapter is to address Objectives 4 and 5, ie to combine the Morris Model, the M'Pherson Model and other methods and techniques identified in this research to develop the MM Model for major project definition. The first step (Section 5.2) will be to combine the M'Pherson Model with the Morris Model and other related work to form the base MM Model. The MM Model is positioned into Pike's Framework as this framework links the project definition with the business and decision makers. Section 5.3 sees the base model tested against the Compendium of Project Success Criteria and the 3 case studies (see below). Once the MM Research Model satisfies the success criteria tests a suitable tool kit is specified (Section 5.4) for use with the model.

1.4.5 Overview to Chapter 6 – Case Study 1; The Advanced Passenger Train

British Rail's (BR) Advanced Passenger Train (APT) can only be described as a project failure. The project began life in 1962 in response to the airlines threat against BR's West Coast London/Glasgow service. The journey time of 6.5 hours was considered to be unacceptable; BR needed a journey time of just over 4 hours in order to remain competitive. Throughout its 20 year life, the project was dogged by technical difficulties, lack of senior management support, wildly varying political enthusiasm, union disagreements on future working practices, media ridicule, and a continuous decline in public confidence. The project was cancelled in 1982 with a sunk cost to the taxpayer of £240m. The case study is an excellent example of a project failure; could the failure have been predicted during project definition, and could the project have been set up for success?

1.4.6 Overview to Chapter 7 – Case Study 2; The London Water Ring Main

The London Water Ring Main Project is the largest capital project to date undertaken by any of the recently privatised water companies in the UK. The aim of the project was to improve the flexibility and efficiency of water distribution and reduce operating costs for the capital's water supplies. The project commenced in 1989, with a planned completion date in 1996; benefits from the project are being realised progressively as the schedule advanced and so parts of the main become operational prior to completion of the whole main. The planned project budget was £250 million and was entirely privately funded. The progress of the project was excellent. All tunnelling was completed in February 1993, approximately 21 months ahead of schedule. The whole project was completed in 1995, one and a half years ahead of schedule. The project can be described as a good example of success.

1.4.7 Overview to Chapter 8 – Case Study 3; The Rolls Royce RB211 Aero-engine

In a little under three years, Rolls Royce Ltd sank from the zenith of what was hailed as the greatest technical and commercial success by a British company in this century, to the ignominy of bankruptcy and total collapse. The principle cause of this collapse was the contract in 1968 to design, develop and build the RB211 aero-engine for the Lockheed Tristar medium-haul airbus. The size, cost and technical complexity of the engine, coupled with the terms of the contract with Lockheed, exposed structural and management weaknesses inherent in the company. Furthermore, it exposed shortcomings in the company's approach to defining projects. Ironically, the RB211 engine went on to become a highly successful product. The project problems affected two countries and their governments (the UK and the USA), six of the world's major airlines, two of the world's most prestigious companies, and in excess of 100 suppliers.

Following a government rescue the aeroengine went on to become one of the worlds most successful aviation products used by over 50 of the world's airlines. With hindsight the project could be described as a success, but it arose from a serious failure.

1.4.8 Overview to Chapter 9 – Conclusions

Chapter 9 provides the detailed conclusion to the research. The first section (9.1) presents a brief overview of the research by reiterating the fundamental issues that cause major project problems, and how the systems approach was used to address these issues. Furthermore the section provides a reader's guide to the emergence of the MM Model by highlighting the key foundation information and constructs developed as part of the evolving research. The guide will enable a reader to achieve a basic understanding of the topology of the MM Model in preparation for the more detailed consideration. Section 9.2 describes the extent to which objectives 1 to 5 have been achieved, and Section 9.3 explains the author's contribution to knowledge. The final section (9.4) describes possible areas for further research identified in the course of developing the thesis.

CHAPTER 2: PRECONDITIONS FOR SUCCESS IN MAJOR PROJECTS

2.1 INTRODUCTION

Morris (1986) described a project as an undertaking to achieve a specified objective, which was usually defined in terms of time, cost and technical performance. Fraser (1984) described major or capital projects as those which are particularly demanding because of their size, complexity, schedule urgency, and their calls on existing resources and know-how. Major projects in particular are found in aerospace and defence, electronics-based industries, petroleum and process industries, utilities, national infrastructure and civil construction, and social service programmes.

Smith and Tucker (1984) observed that all projects experienced problems that occur at various times throughout their lifecycle. These problems can range from minor issues that do not affect the project such as constraints of time, cost or technical performance, to major set-backs that cause the project to be significantly affected. These set-backs can often cause serious budget and schedule overruns, missed milestones, and deliberate relaxing of technical performance in order to save the project. Set-backs on major projects can have disastrous financial impacts on both their owners and implementors, and often socio-economic impacts on national economies (Morris, 1986).

Taking a business perspective, Wightman (1988) observed that too many projects focused attention solely upon specifying, developing and delivering the product. They ignored the fact that without clear business needs there was no basis for specifying the right product no matter how innovative, if that product was not used to deliver real and lasting benefit. Without adequate attention to business needs and delivery of the benefits, the project was likely to face serious downstream problems. The business needs drive the specification of project objectives therefore it is paramount to identify these needs precisely.

Difficulty exists in determining the causes of serious project problems, or indeed what must be done to make projects successful. If determining project success criteria can be achieved, then it should be possible to reduce the impact of project problems. However, Greenson (1982) observed the influential impact of early project activities on the outcome of the whole project. These early activities together with the associated decisions that define the boundaries for a project could be considered to set the framework from within which success or failure can be judged. Problems can often be traced to wrong or questionable decisions in these early activities and decisions. Thornton (1985) claimed that the early project definition phase accounted for less than 10% of the overall project cost, but influenced up to 70% of the overall project cost as shown at Exhibit 2.1.1.

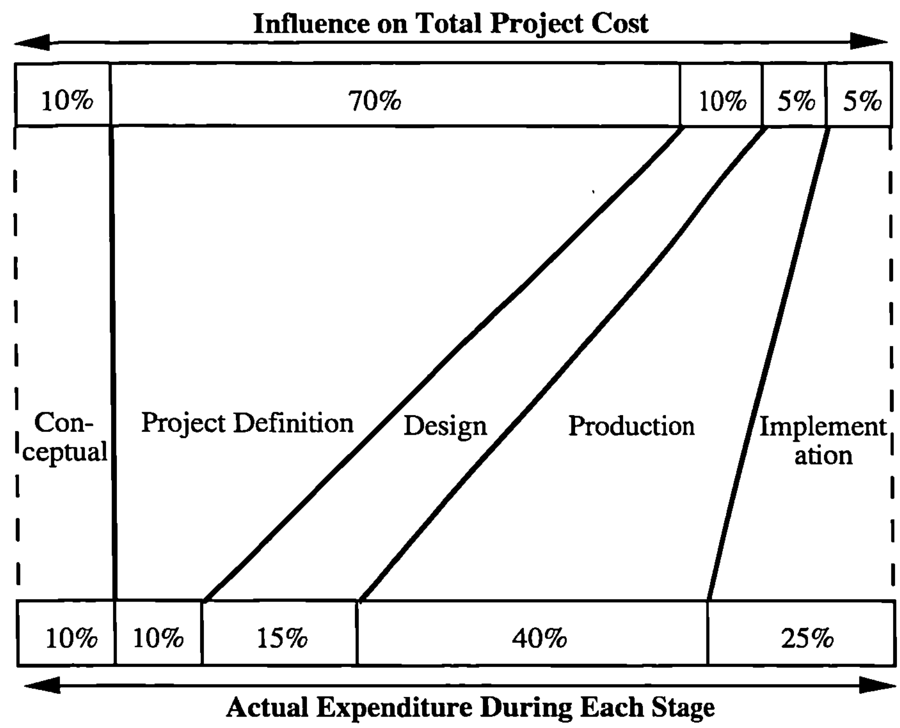


Exhibit 2.1.1 – Influence of Early Stages

There are few detailed studies of what influences success or failure in projects; those which relate to major projects are even fewer. The most significant work to be published recently was undertaken by Morris and Hough (1986) from which they developed a Preconditions Model for Project Success (1987); ie, the Morris Model. Later work by Merrow (1988) added further to the knowledge base when he and his fellow researchers studied problems encountered by 50 mega-projects (ie those projects that cost more than $1bn).

The primary aim of this Chapter is to address Objective 1; ie to develop a compendium of project success criteria, and to introduce the Morris and Hough's Model for Project Success (called the Morris Model in this research). However, in order to develop such a compendium and to fully understand the basis of for Morris' Model, which will be essential for the formulation of the MM Model, it is first necessary to understand the foundations of major projects (Section 2.2), and the nature of project issues and success criteria (Section 2.3). A compendium of preconditions for major project success that draws together the findings of the major researchers of the subject will be presented at section 2.4 in preparation for formulating and testing the MM Model, and the Morris Model is described at Section 2.5. A summary of the Chapter is provided at Section 2.7.

2.2 FOUNDATION OF MAJOR PROJECTS

To be able to study projects in depth it is first necessary to have a grasp of the basic foundation and processes. This section addresses the foundation by giving a definition of a project, by describing the project lifecycle processes and by providing background to the management of projects. The section concludes with a discussion on the management demands and challenges of major projects.

2.2.1 Definition of a Project

Many individuals have experience of projects; however, developing a definition of a project is difficult (Harris, 1990). Any definition of a project must be general enough to include examples of the wide variety of organisational activities that managers consider to be project functions, and narrow enough to include only those specific activities that researchers and practitioners can meaningfully describe as project orientated (Pinto, 1987).

Cleland and Kerzner (1985) described a project as a combination of human and non-human resources pulled together in a temporary organisation to achieve a specified purpose. Steiner (1969) stated that a project was an organisation of people dedicated to a specific purpose or objective. Projects generally involve large, expensive, unique, and high risk undertakings, that have to be completed within a given timescale, to an agreed budget, delivering a required level of performance. Therefore, as a minimum, all projects need to have well defined objectives and sufficient resources to undertake all the tasks.

For this research, a project will be defined as having the following characteristics (House, 1988); a defined beginning and end (ie a set time for completion), prescribed goals and objectives, a specified budget, and a series of interrelated activities (these activities will be described in the next sub-section).

2.2.2 Project Lifecycle

Project management teaches that to achieve the desired project objectives, certain formal processes must be followed and these processes are ordered to form the project lifecycle (Morris, 1989); however there is no formal agreement as to what processes these should be. Assad and Pelser (1983) described a project lifecycle comprising twelve distinct phases as shown in the diagram at Exhibit 2.2.1.

The aero engine manufacturer Pratt and Whitney (1985) published the lifecycle shown at Exhibit 2.2.2 in its management guide. Kelley's lifecycle model (1982), shown at Exhibit 2.2.3, adds project control and product control in order to differentiate between those activities which are project related and those which are business related.

The Ministry of Defence in the UK adopted the Downey recommendation (1966) for project lifecycle model that is similar to Kelley's model – which it still uses to this day. The lifecycle has 5 stages; concept formulation, feasibility study, project definition, full development, and production. This model was re-confirmed by Rayner (1971) as an acceptable staging process, and again by Jorden, Lee and Cawsey (1988).

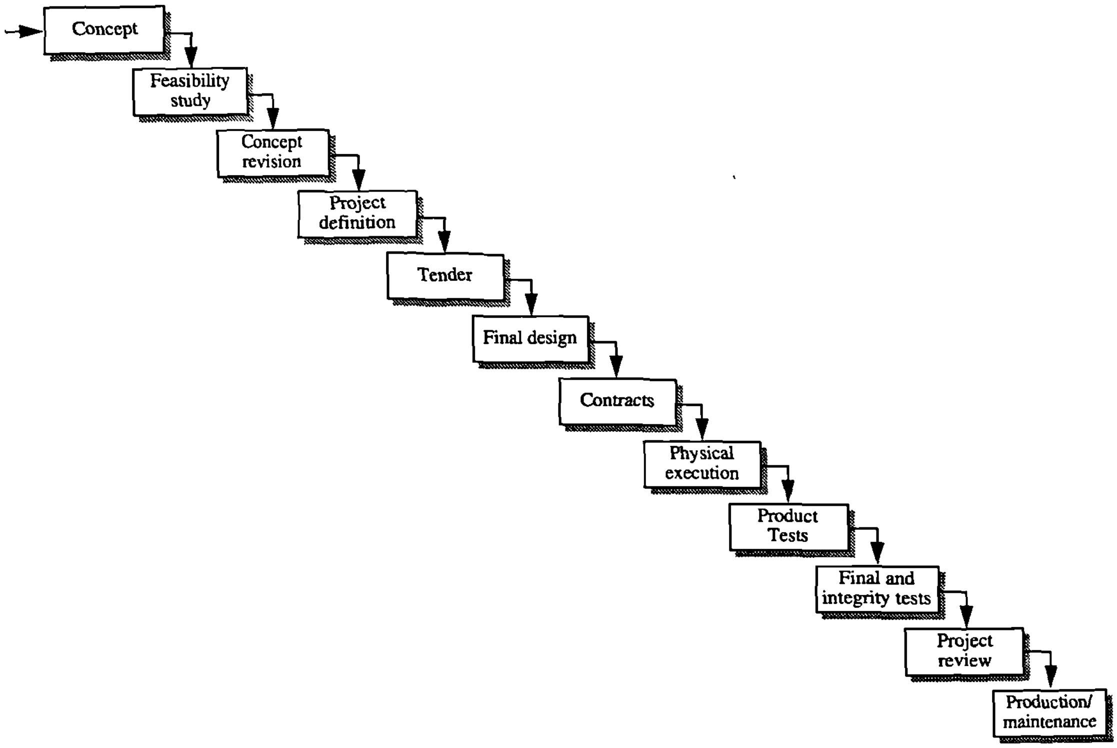


Exhibit 2.2.1 – Assad and Pelser's Lifecycle Model

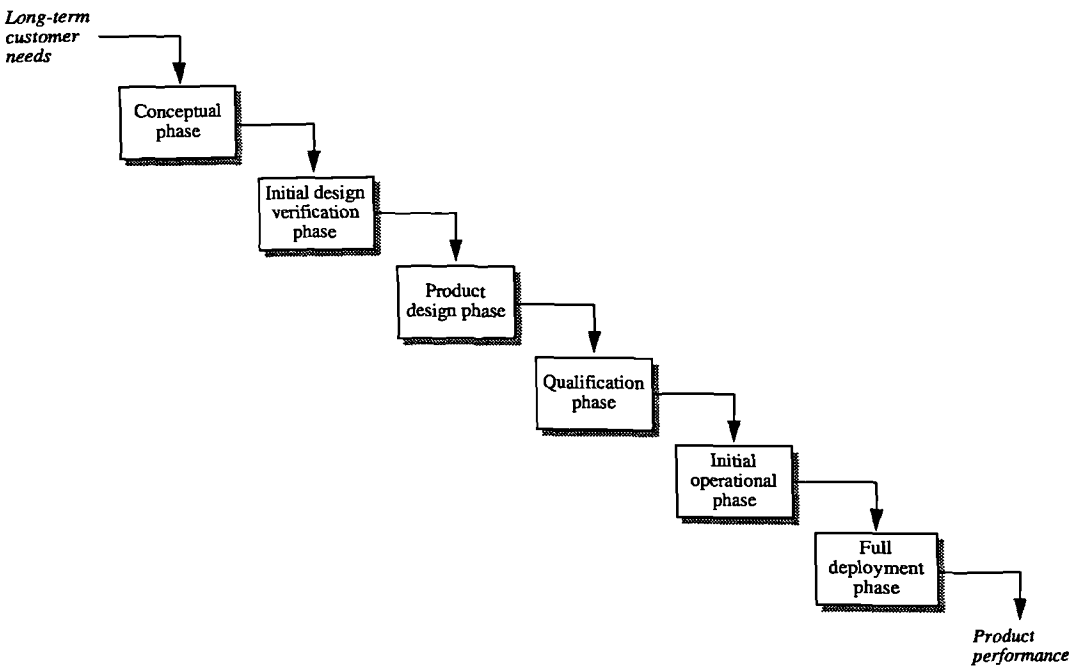


Exhibit 2.2.2 – Pratt and Whitney's Lifecycle Model

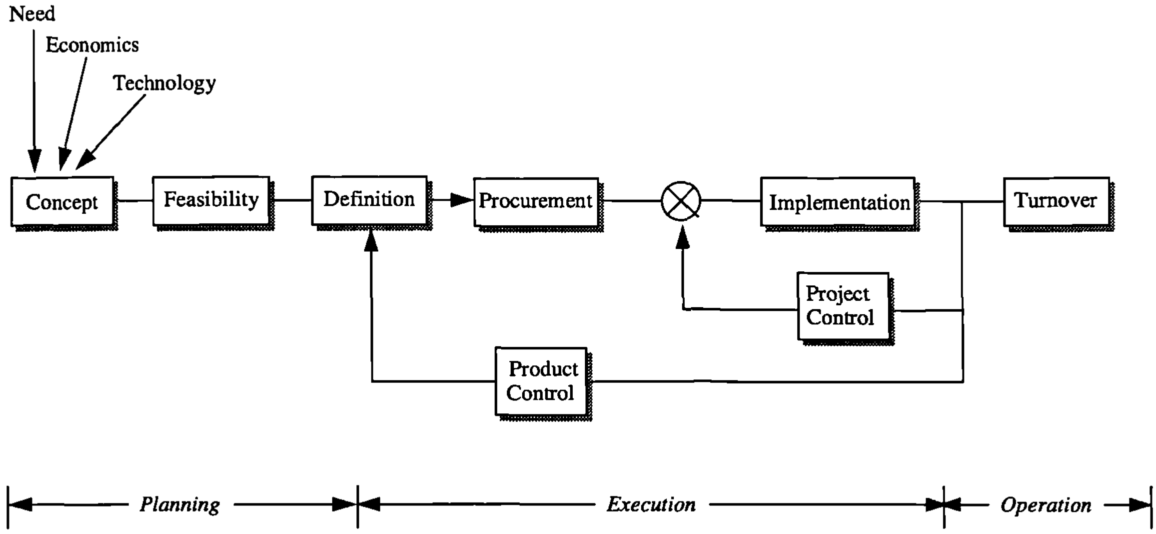


Exhibit 2.2.3 – Kelley's Lifecycle Model

The phases or stages of a project are somewhat dependent on the type of project, but essentially they involve a gradual build-up of design as definitions and specifications are established and working characteristics understood, a full-bodied implementation and a phasing out as the work is completed and the project winds down. For the purposes of this research, a general 4 phase lifecycle model described by Kerzner (1982) is used – see Exhibit 2.2.4. The activities to be undertaken within each stage are summarised at Exhibit 2.2.5 (King and Cleland, 1978). The model also shows the investment profile for a project which is addressed properly in Chapter Four.

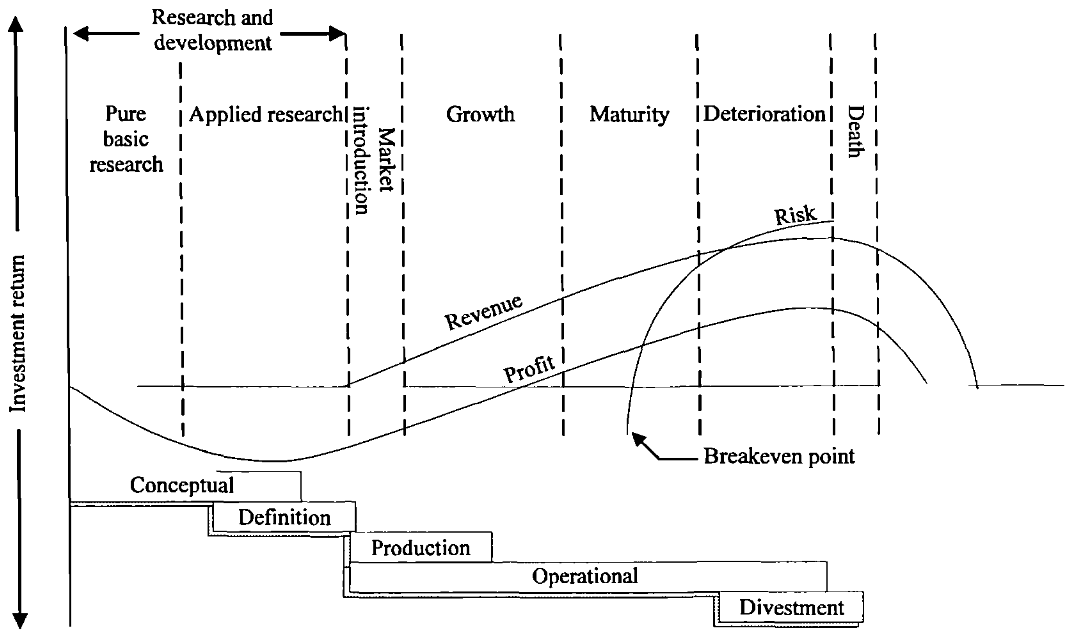


Exhibit 2.2.4 – Kerzner's Lifecycle Model

This general model is acceptable for this research as the overall list of activities is no less comprehensive than for the most detailed models. The detailed models either group the same or similar activities under different headings or introduce qualification or rework phases. The Divestment phase is not considered to be part of the project lifecycle but rather part of the system lifecycle or product lifecycle. A product lifecycle will include activities for marketing, production planning and management, public relations and product launch. Furthermore, this type of lifecycle will also identify periods for product revitalisation. A project lifecycle becomes part of the product lifecycle for activities where development is required.

The US DoD Military Acquisition Programme employs a similar approach to that of the UK MoD and thus can be suitably addressed through considerations of Kerzner's model. However, it must be acknowledged that the US DoD incorporates the systems engineering lifecycle into its acquisition processes and therefore the project lifecycle would appear to have more detail. The mapping of the systems engineering lifecycle to the project lifecycle is covered in the next chapter.

Conceptual Phase. The conceptual phase provides the opportunity to determine if the project is worth doing. It evolves functional detail and design requirements with the goal of achieving the proper balance between operational, economic, and logistic factors. Conceptual design provides the basis for the project definition, and the initial foundations for the success of the project. In literature the conceptual phase is often described as a the feasibility study. In other literature elements of conceptual design are undertaken as part of strategic analysis (Johnson and Scholes, 1988). The process should however identify elements of the project that are not technically, environmentally or economically feasible or impracticable or just very difficult.

A capital or major project usually involves an organisation or firm in a major investment decision and, therefore, the board of directors (or government equivalent) will study the results of this phase as part of an investment decision. Cleland (1988) described how the board of directors not only has the responsibility for authorising a capital project to proceed to project definition, but also has the responsibility for maintaining strategic surveillance over projects for the duration of their lifecycles.

Definition Phase. The purpose of the definition phase is to determine the project's time, cost, technical performance, objectives, resource requirements, and whether all work packages fit together economically and logically. The definition phase provides an organisation with a full understanding of a project before it makes the decision to commit significant resources. Moreover, the phase provides the opportunity for the organisation to review the original initiative in terms of quantified risk and benefits. Fieldman and Milch (1982), Hayfield (1985), and Myers and Devey (1984) amongst others emphasised the importance of the definition phase to project success. Furthermore, Herbert (1983) stated that the definition of how the project was to be conducted affects fundamentally how it was to be managed for success. Moreover, authoritative studies (National Audit Office, 1986, General Accounting Office, 1985, etc) have shown that projects fail because the technical content of a project was not correctly scoped during the definition phase.

Accuracy in the project definition is also key to a project's success. A Rand Corporation report (Merrow et al, 1981) found that errors in cost estimates for pioneer process plants were much greater when the estimates were based upon vague rather than detailed specifications. The conceptual and definition phases therefore appear to provide the key ingredients to establishing a successful project. It will be shown later that these two phases are the foundation elements of this research.

Conceptual Phase of Project 1. Determine existing needs or potential deficiencies of existing organisational capabilities 2. Establish strategic concepts which provide initial guidance to overcome existing or potential deficiencies 3. Determine initial technical, political, legal, social, competitive and economic feasibility and practicability of the project 4. Examine alternative ways of accomplishing the project objectives to include alternative projects 5. Provide initial answers to the questions: • what will the project cost? • when will the project be available? • what will the project do? • how will the project be integrated into existing systems? 6. Identify the human and nonhuman resources required to support the project 7. Select initial project designs which will satisfy the project objectives 8. Determine initial project interfaces 9. Establish a project team organisation 10. Determine the "strategic fit" of the project, ie. how will the operational use of the project be determined; how well does the project play its role as a means for executing the strategy of the project owner?
Definition Phase of Project 1. Firm identification of the human and nonhuman resource required 2. Preparation of final project performance requirements and the project design 3. Preparation of detailed project plans required to support the project 4. Determination of realistic cost, schedule, and performance requirements 5. Identification of those areas of the project where high risk and uncertainty exist, and delineation of plans for further exploration of these areas 6. Definition of intersystem and intrasystem interfaces 7. Determination of necessary support subsystems 8. Identification and initial preparation of the documentation required to support the project, such as the project manager charter, policies, procedures, job descriptions, budget and funding papers, letters, memoranda, etc 9. Final design and development of the Project Management system to support the project to include (1) matrix organisation; (2) the cultural ambience; (3) the human subsystem; (4) the planning subsystem; (5) the project management information subsystem; (6) the project control; and (7) the selection of contemporary state of the art project management concepts, processes, techniques and methodologies.
Production / Construction Phase of Project 1. Updating of detailed plans conceived and defined during the preceding phases 2. Identification and management of the resources required to facilitate the production or construction processes, such as inventory, supplies, labour, funds, etc 3. Verification of production specifications 4. Beginning of production, construction, and installation 5. Preparation and dissemination of suitable policy and procedural documents 6. Performance of final testing to determine adequacy of the project or service to do the things it is inteded to do 7. Development of technical manuals and afiliated documentation describing how the project product or service is intended to operate 8. Development of plans to support the product or service during its operational phase.
Operational Phase of Projects 1. Use of the project results by the intended user or customer 2. Actual integration of the project's product or service into the customer's organisational systems 3. Evaluation of the technical, social, and economic sufficiency of the project to meet actual operation conditions 4. Provision of feedback to organisational planners concerned with developing new projects 5. Evaluation of the adequacy of supporting systems such as maintenance, service and other logistic support 6. Training of user personnel.

Exhibit 2.2.5 – King and Cleland's Lifecycle Activities

Production Phase. This phase differs dramatically from the previous two. Firstly, whereas the Conceptual and Definition phases are organic and evolutionary in character, the Production phase is highly mechanistic (Burns, 1961). The aim is not to develop new technical options but to build as efficiently as possible the thing that has been specified in the Definition phase. The Production phase can comprise activities such as the development of detailed specifications, manufacture, testing, installation, training and documentation. However, it is difficult to recognise here a specific build profile for every project type since they are so diverse, eg software projects and civil engineering projects, but the general principles apply. Secondly, there is usually a large expansion in the organisation; there may have been only tens or hundreds of persons involved in the first two phases, there may be thousands or tens of thousands involved in this phase. Adams (1983) indicated that in moving between the Definition and the Production phases, the project essentially transfers from an organistic exercise to that of management of resource. Thirdly, the characteristic mode of control changes from one of estimating costs and durations to one of tight monitoring of quality, schedule, and cost to keep actual performance within the target estimates (Dickson, 1985). Quality assurance practices are also important in this phase. Manufacturing efficiency and the productive use of resources can make the difference between profit and loss on the project's product.

Operational Phase. The Operational phase, sometimes known as Turnover or Start Up, generally overlaps the Production phase and involves all the activities necessary for the acceptance of the project into operational use. During this phase, the project loses its project identity and is assimilated into the ongoing business of the user. If the project leads to the product to be marketed, the Operational phase begins the sales lifecycle portion of the overall product lifecycle as described by Kerzner (1982) – see Exhibit 2.2.4. For software projects the beginning of this phase is often where many operational difficulties occur since the acceptance testing can never fully discover all the errors in the delivered product. The system will therefore be required to enter operations with users knowing that months of frustrating failures lie ahead. For new complex systems it may be necessary to change the whole culture of an organisation if full benefit is to be obtained from the new system. If this is the case, then a parallel project for "Managing Change" will have to be initiated. The two projects will then require harmonising if the new system is to be introduced effectively.

2.2.3 Management of Projects

Project management pulls together the functional disciplines needed to achieve the project's budgetary, schedule and technical objectives. Olsen (1971) offered the following definition; "project management is the application of a collection of tools and techniques to direct the use of diverse resources towards the accomplishment of a unique, complex, and one-time undertaking within time, cost and quality constraints. Each task requires a particular mix of these tools and techniques structured to fit the task environment and lifecycle". Morris and Hough (1987) provided a resume' of project management techniques which is shown at Exhibit 2.2.6.

Morris (1989) also identified that managing project interfaces was an important ingredient to project success. He noted two types of project interface; static, which represented a project's relationships with support functions such as engineering, procurement, etc; and dynamic, which reflected the way the project was developing through the lifecycle, ie its pattern of activity. Morris emphasised that the dynamic interfaces between lifecycle phases or stages were important for two reasons; the project's running clock, and the early phases had a dominant role over later stages (like project definition over production).

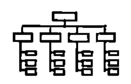
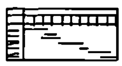
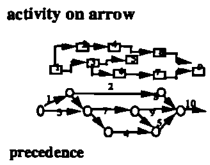
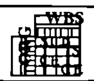
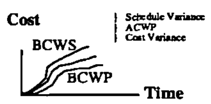
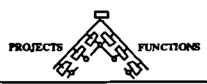
Specifications		A traditional engineering tool specifications play a fundamental part in establishing the project baseline. Specifications can be very detailed or merely performance.
Work Breakdown Structure		Developed in the US defence industry, a WBS is offically defined as "a product-oriented family tree division of hardware, software services and other work tasks which organises, defines and graphically displays the product to be produced, as well as the work to be accomplished to achieve the specified product". The top 2-4 hierarchic levels define the functional basis of the project the bottom 1-2 define the project's activities.
Configuration Management		The technique of defining and monitoring the projects engineering configuration and when used with change control of ensuring all parties are using the same appropriate up-to-date configuration information.
Bar charts		Developed by Gantt in the early 1900 bar charts show activities as horizontal bars displayed against a horizontal time scale. Bar charts do not show activity interrelationships.
Network Scheduling		Network schedules are of two types; activity-on-node (precedence) and activity-on-arrow (i-j). Developed in the late 1950's networks show activity interrelationships. Essentially, no activity can leave a node until all those entering it are completed. (activities usually proceed from left to right). Precedence is considered by novices to be more difficult to use but probably is not, does have greater communicative power and avoids dummies (dotted arrows) which are often necessary for purely logic reasons on i-j. The critical path is the longest path through the netwrok (zero slack).
Task-Responsibility Matrices		T-R matrices range organisational unit against WBS elements so that responsibilities are clear (eg. S=Supervision, C=Control, E=Execution). This is particularly valable on large, complext projects.
Performance Measurement		Project control requires knowing accurately the actual progress achieved. This necessitates that progress be measured physically. Measurement based on inovices is too imprecise. Combining physical and financial reporting is difficult. Measured Bills of Quantities is one method. Earned Value (illustrated opposite) is another.
Matrix Organisation		There are essentially three kinds of organisation found on project: functional, project and matrix. In functional managers (eg. engineering procurement) in projects with the project manager. In a matrix they are shared. A team member thus has two bosses. The three forms are not mutally exclusive.
Cost Control		All with performance measurement, cost control necessitates knowing actual costs. There are four basic classes of cost data budgeted (approved and appropriated), committed incurred (earned and invoiced) are forecast.
Contract Administration		At the contract management level, project management often becomes the skill of negotiating and administrating the contract its risks contingencies and clauses - particularly when variations are introduced.
Quality Assurance		Quanlity control is the checking that quality is satisfactory. Quality assurance is all activities and functions concerned with the attainment of quality, it is a whole philosophy of management geared to this end in the USA, a key aspect of QA is documented.
Team Building		Selecting the group of people who will work on the project, and welding them into a team by providfing leadership and motivation and by properly handling conflict, is a prerequisite of effective project management. Specific tools exist to facilitate this task.

Exhibit 2.2.6 – Project Management Techniques

Millar and Rice (1967) argued that in any system, boundaries should be positioned where there were major discontinuities in technology, territory, time or organisation. This argument was also supported by Adams and Barndt (1983) when they stated that the major actions and activities change from stage to stage which results in differing pressures and problems affecting the project's organisation. Major breakpoints in the project lifecycle (ie, between the stages) provide important dynamic interfaces as they serve as "natural" check points for management control and performance monitoring.

Morris claimed that static interfaces should be fully identified and clearly defined before each phase in the lifecycle, and a management plan for handling them formulated and operated. Dynamic interfaces, on the other hand, should be managed through careful project planning. However, the differing nature and requirements of the various project lifecycle stages require that different issues be addressed as the project unfolds. Project planning cannot be done comprehensively, once and for all, at the beginning of the project. The uncertainties, according to Morris (1989), are too great. Instead, planning must be incremental. Initial planning however, especially during the project definition, should concentrate on building a viable planning base for the whole project that identifies and positions dynamic interfaces. It is upon this base that detailed schedules for the various lifecycle phases are developed prior to the start of each stage. Seamans and Ordway (1977) emphasised the importance of this concept in their study of the Apollo Programme.

Morris' work on project interfacing is fundamental to managing projects for success and as such will be influential in formulating the MM Model. The MM Model will incorporate processes for developing a planning base for the whole project during project definition that especially considers dynamic interfaces. Furthermore, processes will be identified for determining the nature of static interfaces between a project and its containing environment.

2.2.4 The Management Demands of Major Projects

Business and government progress through the vehicle of major projects, but as advancement becomes more demanding the projects become ever more difficult to implement. Morris (1986) identified several facets of management difficulty where problems of a systematic nature can arise; size, complexity, technical uncertainty, schedule duration and urgency, physical and social environment, and government and politics. The management of today's projects is required to deal with these facets in order to facilitate advancement but, as will be shown later, the combination of these facets provides the conditions for project failure.

Size. The size of a project can present a significant challenge to management. Size can represent one or a combination of a large physical areas that can create logistic and communications problems, difficult financing arrangements, joint ventures – often with international participants, diverse disciplines needing to be brought together to produce the end product, and large structures or complicated plant (Kershaw, 1978). Important for this research is the fact that for a large project a considerable amount of money is required to be spent in order to define and evaluate it prior to its launch (Sykes, 1982). Sykes also observed that it was often difficult to persuade a commercial sponsor or a government to invest the necessary capital to fund the level of definition work needed to contain or reduce risks as there always seemed to be an urgency to complete it.

Complexity. Complexity can be more significant than size as it requires more intellectual management rigour to deal with it. Klir (1985) defined complexity as having many varied interrelated parts, patterns, or elements and resulting in difficulty in achieving a full understanding. This definition is certainly true for the macro projects. Complexity on macro or very large projects usually emerges from strategic management requirements rather than design requirements, ie the interactions between the project and the customer and sponsors, and the various stakeholders (Cleland, 1990). Smith and Tucker (1984) pointed out that strategic management issues were usually outside the control of the project management team, but on large complex projects they formed part of the day to day activities. As an example, for macro projects in Australia, Jaafari (1986) identified complex management relationships existing between each participating owner and the joint venture company; the owner and the government(s); the owner and the lenders; the owner and the purchaser of the end product(s); the owner and the insurer/underwriters; the owner and the project manager; and finally the owner and the implementors. Clelend (1990) stated that project issues arising from these complex management relationships are often nebulous, defying management in the literal sense of the word. The MM Model must be able to identify complex management issues in order that processes are put in place to handle them during project implementation.

Technical Uncertainty. The US General Accounting Office (GAO) in its report on recurring problems on major acquisitions (1988) cited technical uncertainty as one of the major problem areas. The GAO found that the primary cause of acquisition problems was the attempt to produce complex systems on the basis of unproven designs. The GAO recommended that technical risks should be addressed in the early phases of a project. Furthermore, the UK National Audit Office (NAO) in its 1991 statement on major defence projects (1992) stated that two factors emerged as the main reason for cost overrun; changes to technical specifications and technical uncertainty. However, technical innovation cannot be avoided as it plays a key part in advancement. Technical uncertainty arises if a project implementation commences without a satisfactory demonstration that the new technology can be made to work (GAO, 1970). Merrow (1988) in his study of mega-projects (civilian projects) observed that the introduction of unproven technology usually resulted in a cost overrun, and Pugh (1985) commented that it could ultimately lead to a failure to achieve the desired technical performance. Jordan et al (1989) found that projects typically reveal their technical difficulty only when the hardware is built and tested. This research will consider two case studies in which technical uncertainty emerges as one of the primary causes for the problems that beset the projects; the Advanced Passenger Train (APT) and the Rolls Royce RB211 Aeroengine.

Schedule Duration. Morris and Hough (1986) stated that long duration projects were more likely to be affected by changes caused by economic or political events, or changes in business strategy as it was annually upgraded to reflect changes in the business environment. Worse still, some projects that require a long schedule time may not be even started owing to government "short-termism". Snow (1992) described short termism as a particular British disease which manifested itself as lack of investment or the will to start any project that spanned over the life of a parliament. In a presented paper on Telecommunications Operations Policy (Wylleman, 1992) the point was made that long-term investment was also proving difficult in eastern-European telecommunication infrastructure projects because of the length of such projects coupled with the possible political instabilities (see also Suratgar, 1990). Furthermore, due to their short-time horizons for return on investment, many US firms refused to invest in long-term projects (MIT, 1989). Moreover, the GAO and NAO in many of their reports cited inflation as one of the prime causes for cost overrun in long running projects. For these reasons it is difficult to estimate the cost of long running projects, and Paul (1982) suggested that wherever possible projects should be accomplished in economic phases (not to be confused with the project lifecycle phases).

Schedule Urgency. Schedule urgency can also cause management difficulty. This urgency can manifest itself through a need to make quick decisions with minimal information, compressing timescales in order to get a facility available quickly or product to the market early to maintain competitive edge, or through introducing complexity by overlapping design and production (ie concurrency). In order to achieve a faster schedule many organisations reduce the time spent on the early project lifecycle stages with disastrous consequences (Merrow et al, 1981). Merrow and his colleagues noted that cost overruns were dramatic when cost estimates were based on vague or quickly prepared design specifications. Compressing the schedule, according to Morris and Hough (1985), would also require additional skilled resource which may not be available at the designated times; a point also borne out by Harvey (1980). Harvey (1980) also noted that there was a tendency for an increased cost overrun when there was a significant overlap between development and production. Paxton (1994) observed that urgency had often caused the build or production stage to start before detailed design work had been completed with the result that a considerable amount of rework had to be undertaken in order to correct design errors that went forward into production. Earlier, Jordan et al (1989) advocated avoidance of compressing the schedule; they recommended that commitment to full development should only be made after a successful demonstration of the technology – a clear linkage to avoiding technical uncertainty.

Physical and Social Environment. Not surprisingly a great many major projects interact with the physical and social environment. A high percentage of all major projects are associated with national infrastructures (eg roads, bridges, tunnels, etc) or large production plant (eg power generation, oil and gas processing, chemical processing, mining, etc). Roome (1990) identified three such interactions as being resource misuse, system instabilities and global impacts. According to Roome examples of system instability resulting from this type of interaction are accumulation of persistent toxic substances via global cycles such as the presence of dioxins like polychlorinated biphenyls (PCBs) and chlorofluorocarbons (CFCs), and urban growth dependent on excessive resource extraction via non-sustainable trade and aid. Roome also defined global impact as climatic change, ozone depletion, and species loss. Numerous authors have commented on the social consequences of major projects; Morris and Lapp (1983), for instance, observed that projects that affect people, such as major highways or noisy aircraft, could generate considerable conflict that could threaten their success. Furthermore, Morris and Hough (1986) identified that multiple conflicting goals impinging on a project in an uncertain way, such as housing, health and organisation change, also increased the likelihood of failure. The major project industry (Snow, 1992) has a particular responsibility to understand the environmental impact of proposed projects in order to limit disruption and damage. Issues that must be addressed include:

- establishment of the project need
- examination of the cultural diversity of the area in which the project is to be sited
- consideration of the economic pattern of incentives and taxation
- judgement on whether it is appropriate to undertake the project at that time in that place
- assessment of the environmental impact of both the project and the resulting product
- construction of environmental and community packages that leave an area no worse off than before the project began.

Snow continued, projects should not be limited to their engineering aspects but broadened to include the physical social and environment. Roome (1990) went further; he suggested a manual of "good practice" to be applied to projects[1].

Government and Politics. The majority of major projects (especially infrastructure projects) require government involvement; eg, the sponsor, the owner, the provider of finance (directly or indirectly) or the authoriser (Morton, 1984). Morris and Hough (1986) stated that for these reasons, political considerations, together with the skills to manage them, are of great importance to major projects. They went on to observe that a government's influence on regulation, price setting and procurement brings considerable uncertainty to the undertaking of major projects. Cooper (1990) provided a brief history of major political events that occurred during the 1980s, all of them caused major change and all of them were unpredictable – "if you cannot forecast events twenty four hours ahead what are your chances for 20 years". The consequences for the planning of major projects are quite dramatic in terms of increased risk and greater difficulty in securing private sector financing. The process for gaining consent for major infrastructure projects is addressed in Chapter 4; Stringer (1991) explains the issues involved and describes how the risks associated with political uncertainty can be contained.

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[1] Since completing this part of the research, the US Project Manager's Association has published such a practice (1994). There is no contradiction between the suggested codes of practice and the findings of this research.

Size, complexity, schedule duration and urgency, and environmental issues coupled with political uncertainties make the management of major projects a challenge, and it becomes understandable why they suffer from schedule and cost overruns and often fail to deliver the planned benefit. However, the need to undertake major projects will always be there and participants must be wary of the difficulties if the project is to be successful (Morris and Hough, 1986). The management team of major projects must put in place measures to address these management demands from the outset, otherwise it is quite likely that the project will drift from crisis to crisis as it proceeds through its lifecycle. Elder (1989) stated that it was good management practice to expect difficulties and therefore plans and contingencies can be laid early in a project's life, ie during the project definition; a sentiment echoed by Thornton (1985) – see again Exhibit 2.1.1.

2.3 NATURE OF PROJECT ISSUES AND SUCCESS CRITERIA

Project management has had some fifty years of formal development with the major advances being made in the 1950s and 1960s. Its acceptance as a management discipline began with the Atlas and Polaris missile programmes (Beard, 1976). These two programmes can be credited with giving birth to the management techniques for planning and control which are in general use today. So with such a mature discipline why is it that the majority of major projects fail to be delivered on time, to budget, meeting the expected specification?

Taylor (1994) thought that lessons were not being learned, he noted that a number of recent developments had significantly exceeded their budgets; the Thames Barrier cost £46m against a budget of £23m, and the Selkan rail tunnel in Japan was 14 years late and £3bn over budget. Against this he reviewed a number of distant past projects and found Thomas Telford in 1826 had expected the Menai Bridge to be completed in 3 years at a cost of £70k, in the event it took 8 years and cost £170k. The Suez Canal was forecast to cost £8m but eventually cost £18m and was 1 year late. In 1880 the Panama Canal was forecast to cost $240m and scheduled to take 12 years. In the event it cost $640m and was completed 22 years late in 1914.

A dilemma arises when deciding whether to study successful projects or unsuccessful projects in order to develop better methods for managing projects. Paul (1982) argued that the factors that achieved success may not be readily identified by studying failures. However, the definition of whether a project is a success or failure is not an easy one either; Baker et al (1988). Morris (1986) agreed, and added that any selection of projects for studying success or failure should not follow the Paul stricture but should be on the basis of being major projects posing substantial management challenges; apropos size, complexity, technical uncertainty, schedule duration, schedule urgency, physical and social environment, and government and politics. This research follows the Morris and Hough approach, but takes due note of Paul's observations by placing emphasis on "success criteria".

The purpose of the section is to determine the nature of project issues and success criteria. In order to achieve this, a review of the most relevant major studies on the subject is undertaken. These studies are diverse in nature but between them they provide the best insights into ways of setting up and controlling large and complex projects. However, to prepare the way for this review a general survey of project trends over the past 20 years is provided.

2.3.1 General Survey of Project Trends

Morris (1986), commented on the poor track record of major projects and observed that many of the projects were completed late or over budget or both. A large number of authors have reviewed many of the publicly available reports that document the performance of several thousand major projects drawn from all over the world from different industries. They found that overruns to both budget and schedule were normal, being typically between 20 and 400%. The larger overruns often related to defence industry projects and those concerned with the US nuclear industry. A representative sample of these reports is provided at Appendix 1.

It can be seen from Appendix 1 that there emerges a common theme to the encountered problems that should give cause for concern. It would appear that organisations are failing to learn from experience as observed by the UK's National Audit Office in its 1991 Statement On Major Defence Projects, and by the USA's General Audit Office in its 1988 report on Major Acquisitions: Summary of Recurring Problems and Systemic Issues; 1960 – 1987. The 10 most recurring themes from the general surveys are listed at Exhibit 2.3.1. It was not possible to ascertain from these general surveys the relative positioning of the themes, and therefore the list is not in priority order.

- Poor Project Definition
- Slow Decision Times
- Underestimation of Cost
- Underestimation of Schedule
- Design Difficulties (unproven or complex)
- Unproven Technology
- Procurement or Contract Difficulties
- Concurrency in the Work Programme
- Inflation
- Engineering Changes

Exhibit 2.3.1 – Recurring Project Problems

The UK's National Audit Office 1994 (published in 1995) report on 25 major defence projects (worth £30bn) identified that over one third of all schedule and cost overrun was caused by technical difficulties that should have been foreseen during project definition. This would indicate that poor project definition would probably rank as number one. A further National Audit Office report (1995) on the European Fighter Aircraft noted that the detailed design phase had experienced a cost growth of £2.5bn and cited poor scoping, poor project management and a poorly set-up joint venture agreement as the root cause.

Project management, as has already been noted, is a mature discipline with very many companies throughout the world capable of implementing it to best practice. The general survey at Appendix 1 demonstrates that even the most experienced world renowned companies have been involved with projects that have experienced major problems. It would seem, therefore, that project management incompetence cannot be solely blamed for the observed problems. Morris (1987) noted that incompetence could sometimes be to blame for this poor track record, however, it was almost certainly less significant than might at first be imagined.

2.3.2 Specific Case Studies

Smith and Tucker – Early Project Problems: Assessment of Impact and Cause

Smith and Tucker (1984) undertook an in-depth study of a very large industrial project ($1bn) in order to identify the significant problems it faced and the factors that caused or influenced the problems. The project was concerned with upgrading the capability of an oil refinery. Through a series of interviews with key managers from the project management team and from the client organisation, Smith and Tucker were able to identify 13 significant problems together with their corresponding rates of occurrence and impact. Their findings are shown at Exhibit 2.3.2. Although this study was limited to one major project, the similarity of problems to the recurring themes of the general survey should be noted. Smith and Tucker went on to list 22 factors that managers agreed influenced the problems; see Exhibit 2.3.3.

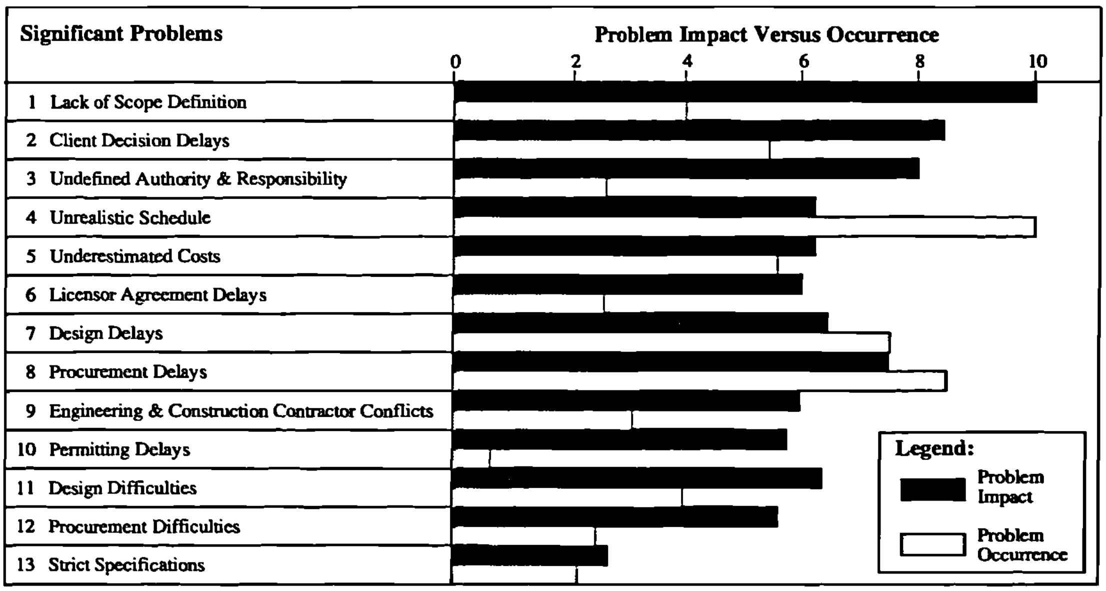

Exhibit 2.3.2 – Significant Problem Impact Against Occurrence

Against each influence factor there is a project controllability rating; ie, some could be controlled by project management others could not. Some of these factors are specific to Smith and Tucker's study project, but most are valid for all projects. Another important point is that the uncontrollable factors should be handled under the heading described by Morris (1989) as project interfaces. Controllable or not these factors should have been assessed before the start of each stage in the project lifecycle, and particularly during the project definition. Furthermore, elements of the demanding management aspects outlined above appear in the uncontrollable or highly uncontrollable columns of the matrix; this would suggest that if they are not addressed and resolved in the early stages of the project, the project team would not be able to deal with them during a running project.

Influence Factors \ Controllability Category	Highly Controllable	Controllable	Uncontrollable	Highly Uncontrollable
Corporate Planning	0	6	36	58
Intracorporate Communications	0	21	52	27
Technology Expertise	15	41	41	3
Company specifications	18	70	9	3
Manpower Availability	6	50	38	6
Time Availability	3	32	56	9
Historical Information	15	41	29	15
Contract Type	9	33	33	25
Escalation Rate	0	3	30	67
Past Project Procedures	13	37	16	34
Equipment Availability	3	29	50	18
Equipment Vendor Quantity	9	29	38	24
Operating Plan Preference	6	42	37	15
Plant Layout	12	36	37	15
Site Conditions	0	3	45	52
Environmental Conditions	0	3	45	52
Utilities Availability	0	18	58	24
Output Guarantees	9	49	36	6
Geographical Location	0	15	39	46
Pollution Control Limits	0	6	30	64
Technology Development	0	30	52	18
Market Conditions	0	3	24	75

Exhibit 2.3.3 – Influence Factor Controllability

Baker Study – Factors Affecting Project Success and Failure

Some projects were perceived as failures when they had been completed on time, within the agreed budget, and meeting the full specification. Conversely, some projects were perceived as successful when they were not competed on time and they exceeded the set budget. Baker et al (1988) offered the following definition of success, "if a project meets the technical performance specifications and/or mission to be performed, and if there is a high level of satisfaction concerning the project's outcome among key people in the parent organisation, key people in the client organisation, key people in the project team, and key users or clientele of the project effort, the project is considered an overall success". Hopkins (1980) took a more simplistic view, he defined project success as simply "meeting management's objectives".

It should be noted that cost and schedule performance does not form part of either Baker or Hopkins' definitions. Baker et al justified this exclusion through researching the outcome of 650 mixed projects. It was found that cost and schedule overruns were not included in a list of 29 project management characteristics significantly related to perceived project failure. Conversely, acceptable cost and schedule performance were not included in a list of 23 project management characteristics related to perceived project success. It should also be noted that the survey only considered completed projects when time and budget may seem less important. The lists of characteristics for success and failure are detailed at Appendix 2. The Baker characteristics are the softer management aspects that form a conducive management environment for the formal control mechanisms to be established. They also provide the conduits for the communications necessary for monitoring the effectiveness of the static interfaces (see Morris, 1988).

Thornton et al (1985) observed that a project's budget, its schedule and its scope formed the points of a finely balanced triangle; if one point of the triangle changed in value then one or both of the other points must change in sympathy in order to restore the balance. Therefore, the Baker et al definition of not considering cost and schedule should be treated with care. It should be realised that if a project manager relaxed both cost and budget controls to the extent where the project was no longer viable then this would contradict Baker's definition of a successful or unsuccessful project; ie Thornton's triangle would become unbalanced. This research will observe the soft management aspects together with those more typically associated with project management controls.

Murphy Study – Determinants of Project Success

Murphy et al (1974) conducted a comprehensive investigation on the subject of project management effectiveness. This study, although undertaken in 1974, is still considered a classic and is quoted by many authors today as authoritative. The survey represented 646 responses to a 17 page questionnaire from a variety of industries; 34% manufacturing, 22% construction, 17% government and 27% services, transportation and others. One third of the projects were public. The major activity or end product was apportioned at 43% construction, 22% hardware or equipment, 14% new processes or software, and 11% other. The study revealed fifteen principle determinants of cost and schedule overruns which are as shown at Exhibit 2.3.4. In addition, cost overruns were found to have a high correlation with the size of the project and the demanding nature of technical specification.

A "buy-in" is an intentional underestimation of costs in order to obtain a contract or to obtain approval to proceed in the hope that follow-on contracts, or changes or additional funding will compensate for the original low estimate. This is often referred to as "going in lean and mean to get well later". This is an important finding – very few other studies identified it as a problem but it is a common problem with public sector projects as 'lowest price' principle is usually adopted. Rayner (1971) established procedures to overcome this problem for UK MoD projects; the correct use of these procedures was re-emphasised by Jordan et al (1989). These procedures directed the use of the project definition to establish cost and schedule estimates based on an in-depth understanding of the technical difficulties. It is not uncommon for the UK MoD to arrange for two parallel project definition studies by two distinct companies in order to improve the chances of covering all risk areas (Jordan et al, 1989).

- Cost underestimates
- Use of 'Buy-in' strategies
- Lack of alternative backup strategies
- Lack of project team goal commitment
- Functional, rather than project organisation
- Lack of project team participation is setting schedules
- Lack of team spirit, sense of mission
- Inadequate control procedures
- Insufficient use of networking techniques
- Over-optimistic status reports
- Decision delays
- Inadequate change procedures
- Insufficient use of networking techniques
- Over-optimistic status reports
- Decision delays
- Inadequate change procedures
- Insufficient project manager authority and influence
- Lack of commitment to budget and schedule
- Overall lack of similar experience

Exhibit 2.3.4 – Determinants of Cost and Schedule Overruns

Murphy together with his colleagues derived several strategies for improving the potential for project success. Using path analysis they developed a model for deriving contingent strategies for successful projects. The model is shown at Exhibit 2.3.5. The model identifies some seven large project characteristics listed in the left column. From one or more of these characteristics it is possible to associate actions that will build towards higher levels of success.

A further important finding of the Murphy study was the need to seek to establish definitive goals for the project, and the need to develop a clear understanding and consensus among the principal project participants regarding the relative priorities of these goals. This finding has been identified by Morris and Hough (1986), Hitchins (1992), and M'Pherson (1980) as probably the most important success criterion of all. Finally, in order to address cost and schedule overruns it was necessary to tackle political, managerial, and technical uncertainties early in a project's life.

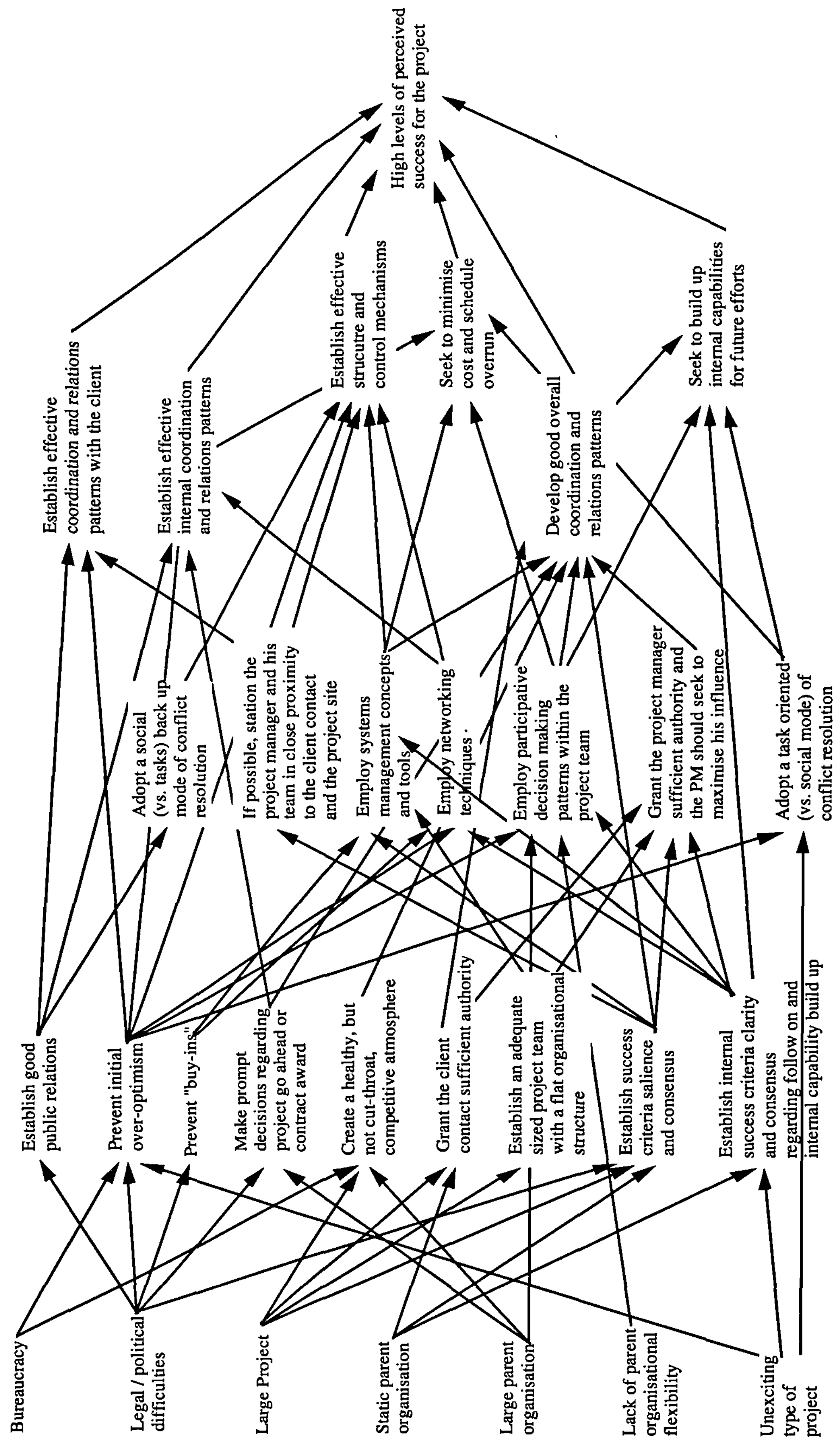

Exhibit 2.3.5 – Contingent Strategies for Successful Projects

Merrow Study - Review of Megaprojects

Merrow (1988) noted that very large projects (or as he describes them Megaprojects; ie those that exceed $1bn) have become common over the past 20 years. The rise in the number of this type of project has been driven by the need to extract minerals, to exploit economies of scale, and to build new infrastructures. Merrow and his colleagues studied 52 very large projects which are identified at Appendix 3. A summary of the findings is as follows:

- **cost overruns**; of the 52 projects examined, 47 had an average cost overrun of $2bn, this figure did not include the overruns that occurred after construction (this could add a further 5% to the average cost growth)
- **schedule overrun**; schedule overruns averaged only 17% with half of the projects experiencing some late delivery. Merrow observed that many project owners preferred cost overrun to schedule overrun, in fact extraordinary efforts were made in a number of projects to maintain the schedule. Furthermore, Merrow could find no evidence that schedules were relaxed to reduce the cost growth.

Merrow assessed that the overruns were driven primarily by conflicts between the projects and institutional problems relating to environmental regulations and opposition, health and safety rules and regulations, local labour restrictions and procurement controls; ie the very uncontrollable influencing factors (from the project management viewpoint) as described by Smith and Tucker (1984). Merrow noted that the importance of such institutional factors clearly distinguished mega-projects from their smaller cousins. He also found that the introduction of new technology, even a small amount, increased risk which usually resulted in cost overruns. The 1960-1975 Channel Tunnel Project failure exemplified these failings (Hall, 1980).

Merrow went further by singling out poorly conducted project definition phases as the key contributor to both cost and schedule overruns. He noted that, in the majority of cases, the definition processes had failed to address cultural, linguistic, legal and, above all, political factors. He reiterated that a great many of the project definitions undertaken did not adequately address risks associated with either new technology or innovative design. Costin (1980) also highlighted the problems that can be generated by an inadequate scope of study during the project definition. Furthermore, Stannard (1990) observed that for mega infrastructure projects not enough attention was being paid during early project planning phases to project financing and government involvement. The result being that there is an increasing level of instability during the production/construction phase. Stannard also noted that as more infrastructure projects were being undertaken by the private sector under "build-own-operate-transfer" (BOOT) arrangements (or under similar business arrangements) there was a increasing need to get the early phase right. BOOT projects will be addressed in more detail in Chapter 4.

Management Consultancies Association's Study – Review of Projects

The Management Consultancies Association (MCA) (1993) surveyed some 205 UK-based senior managers from large public companies, state-owned companies, central and local government, and the health sector. The survey was concerned with assessing project success and failure rates for both hard and soft projects. Soft projects are defined as those projects dealing with subjects such as reorganisation and information technology system implementation. Unfortunately, the survey did not consider values and therefore it is not possible to deduce the magnitude of problems. It did, however, confirm the findings of most authors mentioned so far in this section; nearly all projects were late, they cost more than the original budget and they rarely met all goals and objectives set.

The survey found that up to 50% of the tested projects experienced schedule and cost overruns and they failed to achieve the defined objectives. Furthermore, the survey attributed failure to 4 main categories of problem area: poor, muddled or conflicting objectives; poor team leadership; poor planning; and poor management. Exhibit 2.3.6 provides a more detailed list in rank order.

Cause	Ranking
Objectives not defined or agreed	1
Poor planning and monitoring	2
Ineffective team leader	3
Lack of management commitment	4
External factors not controlled	5
Uncontrolled ownership involvement	5
Uncontrolled project interfaces	7
Project team morale	7
Resistance to change	9

Exhibit 2.3.6 -The MCA Study into Reasons for Project Failure

The survey also made an important observation regarding soft projects. It claimed that many undertakings were being adversely affected by project managers not having adequate appreciation of business issues resulting in difficulty in defining and monitoring less easily measured variables. In general, soft projects were found to have a higher failure rate than the more traditional hard projects.

In a separate but similar study in the US where some 60 failed IT projects were assessed, Johnson (1995) identified the top ten reasons for failure (in descending order): incomplete requirements (13.1%); lack of user involvement (12.4%); lack of resources (10.6%); lack of executive support (9.3%); changing requirements (8.7%); lack of planning (8.1%); didn't need it any long (7.5%); lack of IT management (6.2%); technical illiteracy (4.3%).

The remarkable similarity of the MCA and Johnson studies shows that very little year on year improvement in project performance can be noted.

Morris and Hough – Pre-Conditions of Success and Failure in Major Projects

In 1986, Morris and Hough published the results of their study into preconditions for project success. They decided at an early stage that they would not take as the baseline published theories on what might influence the success or failure of a project. They decided instead to use a case study approach that would allow them to investigate the organisational, managerial, political and dynamic factors influencing projects. They recognised that the difficulty of managing large, complex projects was not that the principles were not properly understood, but there was a need to deal with the variety of difficult management situations in a compressed timeframe. They noted that previous studies into the management of projects had generally been within a relatively narrow industry base. Furthermore, there had been remarkably few studies into project success or failure. Morris identified only 34 such studies of any significance had been undertaken.

Morris and Hough noted that there were many common features to all projects, but these could normally be characterised under five headings: (1) the industry/technology; (2) project purpose; (3) sources and pattern of sponsorship (public/private, nature of finance markets, loan/equity stake); (4) the degree of technological uncertainty, particularly the extent to which technology is "advanced"; and (5) location. Morris developed 22 hypotheses under six headings: project definition; technical; finance and commercial; environmental, social and political pressures; schedule; and managerial and organisational factors. The 22 Morris and Hough hypotheses are presented at Appendix 4.

Morris and Hough tested these hypotheses against eight major projects that satisfied the five distinguishing features listed above, and found them to be valid. The projects used for the test are identified at Exhibit 2.3.7. The hypotheses were tested in detail against each of the projects in turn; a summary of the findings is given at Appendix 5. The hypotheses can now be considered as key success criteria. It should be noted that these success factors are aimed at getting the project set up right during the early stages. The scope of a full project definition (as defined by King and Cleland, 1978) should cover these success criteria.

Morris and Hough concluded that the pattern that emerged from the case studies strongly supported the premise that the management challenges of project size, complexity, technical uncertainty, schedule duration, schedule urgency, physical and social environment, and government and politics must be addressed as the project is initialised, and must be observed throughout the life of the project. In particular, they focused on the need for clear goals and objectives, for top management commitment, for a clearly defined organisation and consistent strong leadership, for a workable risk management strategy, and for good project management. They also singled out financial commitment and, where appropriate, firm political support as prerequisites for success.

Project	Industry/ Technology	Purpose	Sponsor	Degree of technology advance	Domestic/ International
Channel Tunnel (1960-1975)	Construction (tunnelling)	Public transport	90% government, 10% private	Low	50:50
Concorde	Aircraft	Political/ commercial	100% UK and French governments	High	50:50
Advanced Passenger Train	Rail (mechanical engineering)	Improve rail service competitiveness	50% government, 50% BR (a nationalised industry)	Medium	Domestic
Thames Barrier	Construction (marine)	Public safety	100% government	Low	Domestic
Nuclear Power	Power	Utility	100% government entity	Medium/high	Domestic
Fulmar: North Sea oil	Oil & Gas	Commercial	100% private	Medium	Domestic/ International
PAYE Computerisation	Computerisation	Improve efficiency	100% government	Low/Medium	Domestic
European spacecraft Giotto	Space	Scientific measurement of physical properties of Halley's Comet	ESA – multi-government funded	High	International

Exhibit 2.3.7 – Morris and Hough's Case Studies

Other similar studies of significance are those by Bignall and Fortune (1984), Kharbanda and Stallworthy (1983), and Feldman and Milch (1982). The first was concerned with systems failures with an emphasis on a number of major projects including the Rolls Royce RB211 aeroengine and the Humber Bridge. The second reviewed major project disasters and successes, and the last reviewed major airport projects.

2.3.3 External Factors

The very frequency of the problems across so many industries in which there is extensive project management experience suggests that there must be other factors involved – many of these could be considered as external to the project (Morris 1989). Analysis of the reasons quoted in the reports suggests that the causes of this poor performance are generally in areas that have traditionally not been the concern of project management. It would seem that if projects are to be managed more effectively then organisations must learn to manage these other factors more effectively. Such factors include political influences, inflation, government or client induced changes (ie, scope creep), increased order quantities, increased safety or environmental requirements, increased interest charges, land acquisition charges, impact of uncontrolled risk, changes in the business environment, and so on.

A report in the Sunday Times (1993) highlighted the need for an approach to defining project influences better. The development of the Rolls Royce Trent 800 Aeroengine is reported to have overrun its budget by around £100m (ie, by 33%). The reasons given include introduction of new technology, the schedule urgency of getting the RR product to the market quicker than its two main rivals (GE and Pratt and Whitney), and the political problems of getting government support for further expensive developments necessary to stay in business.

Jacob (1994) cited complexity and political influence as the major cause for concern on large infrastructure projects in the emerging Pacific Rim economies. He noted that many governments in the area could not understand why they should compensate companies for accepting risk for prime contract undertakings. The governments liked the idea of privately funded projects because they did not have to pay for them, but then objected to the level of charge for use of facilities provided as it impacted the socio-economic conditions.

2.3.4 Concluding Comment

An assessment of a significant number of research studies and reports into major project issues confirms Morris' 1986 observations that problems experienced are institutional or systematic in nature rather than directly attributable to inadequate project management. Furthermore, the studies show that root of most of the systematic problems can be traced to poorly conducted project definitions, and that these problems can be grouped under the headings of project size, complexity, technical uncertainty, schedule duration, schedule urgency, physical and social environment, government and politics and management.

2.4 COMPENDIUM OF PROJECT SUCCESS CRITERIA

To maintain consistency in this thesis, project success criteria have been specifically developed for this research and are grouped under Morris' (1986) facets of management difficulty: project size, complexity, technical uncertainty, schedule duration, schedule urgency, physical and social environment, government and politics and management. Success criteria associated with project management or the project's environment are grouped under a "management" banner which has been added for this research.

Each of the success criteria has been identified by one or more of the many researchers who have investigated project issues and problems or in one of PA Consulting Groups (1995) independent project audit reports, and consolidated as an element of this research.

Project Size

- the size of the project must be understood from the outset and boundaries defined and maintained (see also complexity)
- good communication must be established both within the project, and between the project and all interacting organisations
- logistics requirements must be fully defined and suitable suppliers identified
- financing, contracting and possible international participation should avoid adding management and control complexity
- government support and agreements should be in place before the project commences
- long and difficult projects should be implemented in phases in order to avoid political instabilities
- minimise the number of public/government agencies involved and where possible establish single point contact and responsibility
- establish an appropriate project management structure for the size of the project.

Complexity

- define the whole picture or system, ie the project and all of the organisations with which the project must interface, and specify the information flows and the control and monitoring needs
- understand fully both the dynamic and static interfaces
- structure the project into parts whose elements have strong relationships
- identify the controllable and uncontrollable influence factors
- evolve the project through a gradual build up of specifications
- simplify wherever possible the management, organisational, technical, contractual, legal and political aspects of a project
- reflect project complexity in the risk assessment and establish suitable contingency to both the cost and schedule.

Technical Uncertainty

- define technical uncertainties during the project's early phases
- establish the real need for new technology
- reduce these uncertainties wherever possible by adopting proven technologies
- reflect technical uncertainties in the risk assessment and establish suitable contingency to both the cost and schedule
- ensure that new technologies are demonstrated before the project moves onto production or implementation
- ensure that the project team has access to suitably qualified staff or that these staff are part of the project team.

Schedule Duration (for long running projects)

- install formal and comprehensive planning for the whole of the project
- identify clear and substantial milestones in order to judge real progress and provide confidence in a successful outcome
- ensure that the human aspects of the project team are being catered for
- recognise the major impact that price, inflation, regulation, technical developments, government or corporate changes have on the definition of success
- phase the project wherever possible in order to avoid unnecessary over commitment (phase in this case means a progressive build-up in the implemented project).

Schedule Urgency

- take due note that schedule urgency and technical uncertainty together can be the cause of major problems (refer to the Rolls Royce RB211 case study)
- full cognisance should be given to the possible detrimental effects of unnecessary or unplanned urgency
- be aware of the project times that emerge from a realistic schedule and systematically consider whether any reductions in time can be accommodated
- where schedule urgency has to be accepted, then the risk assessment should reflect the possible outcomes and contingency should be identified
- consider economic phasing in order to get parts of the project in production faster
- simplify or cut functionality
- ensure that formal and comprehensive planning techniques are used, possibly incorporating the techniques developed for simultaneous engineering if ordered concurrency is needed.

Physical and Social Environment

- establish the real need for the project
- examine the cultural diversity of the area in which the project is to be sited
- consider the economic pattern of incentives and taxation
- judge whether it is appropriate to undertake the project at that time in that place
- assess the environmental impact of both the project and the resulting product
- construct environmental and community packages that leave an area no worse off than before the project began.

Government and Politics

- for public sector projects and those being built under "BOOT" (see Chapter 4) arrangements, ensure that there is effective sponsorship
- recognise the short termism of governments and reflect this in the schedules and financing arrangements

- recognise that both central and local governments pay attention to the fiscal, safety, and employment aspects of projects; particularly the use of labour domiciled in the country or area of origin
- constrain nationalistic aspirations on international projects
- acknowledge that community factors must be considered.

Management

- ensure that the project's goals and objectives have been defined and agreed with the sponsor and all managers responsible for the approval decision
- define an achievable scope of the project in terms of technical options and choice (to include suitable back-up strategies), schedule and cost, taking into account the project's size, complexity, technical uncertainty, schedule duration and urgency, physical and social environment, and government and politics (covering the points outlined above)
- assess the risks that the project may face and identify suitable contingencies
- assess the project's financial requirements, paying attention to budget validity, political support, owner's or sponsor's commitment, inflation, currency fluctuations, etc
- define carefully the benefits that the project is expected to deliver and agree these with all beneficiaries
- assess the financing options for the project and select one that fits best for the business environment of the project
- define how the project is to be managed, considering: organisation; authority levels and decision structures; issue management and escalation procedures; communications; control and reporting; change control; project interfaces; interaction with owners, sponsors, governments, pressure groups, local authorities, contractors and subcontractors
- identify possible procurement and contracting options, selecting an approach that best fits the project organisation, financing arrangement, and risk assessment
- establish how any licensing agreements will be reached
- define the project's influencing factors and establish who is responsible for controlling each one
- ensure that the project team is signed up to the achievability of the project and that the sponsor and owner(s) are fully committed to the project's success
- avoid any buy-in strategies; ie going in lean and mean to get well later on change
- make a coherent and financially viable business case for the project.

Processes to handle each of these success criteria will be included in the MM Model. The underlying detail of the criteria will be culled from the original source material.

2.5 THE MORRIS MODEL

The Morris Model, as presented in Morris and Hough (1987) is shown at Exhibit 2.5.1. This model was developed from the factors for project success which they derived from their case studies (see Appendix 4). The model shows nine grouped areas of interest under the headings of Attitudes, Project Definition, External Factors, Finance, Organisation and Contract Strategy, Resources Management, Human Qualities, Scheme, and Communication and controls. The items listed under each of the headings describe the actions that should be undertaken in order to set up the project for a successful implementation. The items listed were generated directly from Morris and Hough's (1986) case studies.

There are three important points to note about the model. The first is that it does not cover the conceptual phase and therefore it must be assumed that the need for the project has been determined, ie there is an agreement that a proper balance between operational, economic and logistical factors has been achieved. Furthermore, the project is feasible without having to accept high levels of risk that jeopardise its success. The second is that the model specifically covers the early project activities, ie the activities before implementation. The third point is that the model only provides a checklist or more simply an aide memoir of things that must be done. It is not a process model; ie a model that prescribes the processes, the relationship between processes and a logical order for the processes to be undertaken.

In a discussion with Dr Peter Morris (1992) it was agreed that the research model was a first attempt at grouping the success factors identified in the Morris and Hough (1987) research, under appropriate headings, in a manner where they could be used as stimulus for defining successful projects. It was further agreed with Dr Morris that the model would need substantial development if it were to be used for directing the work to establish the foundation for a successful project.

Although the activities are grouped under nine discrete headings, some literature would claim that most belong to a super grouping called "project definition"; see King and Cleland (1978). This research will accept these groupings as the MM Model will be aimed at setting up a project for success. The MM Model will be a process model that will cover a logical sequence of activities to the point of implementation. The enhancements to the Morris Model will be taken systems engineering which observes projects from processes that must be undertaken.

The next chapter will concentrate on those aspects of systems engineering that are concerned with the processes belonging to the project lifecycle, and how these processes can be managed. It will become evident how the Morris Model can be developed, but more importantly just how much of a contribution the Morris and Hough research has made to project management as a whole.

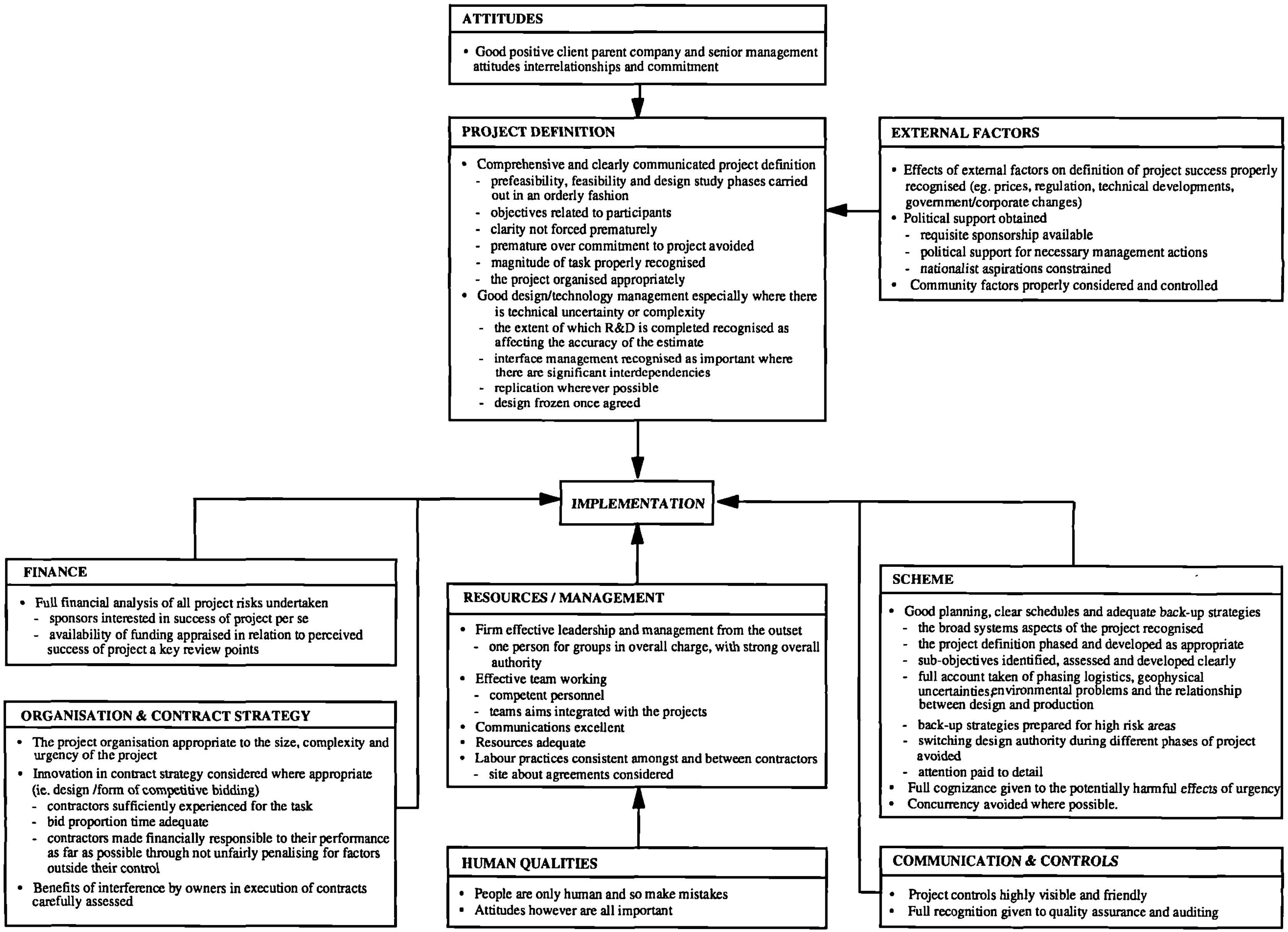

Exhibit 2.5.1 – Morris & Hough's Research Model (the Morris Model)

2.6 SUMMARY OF THE IMPORTANT POINTS EMERGING FROM CHAPTER 2

In satisfaction of Objective 1, a compendium of project success criteria has been developed and Morris and Hough's Model for Project Success introduced. The route through the Chapter saw the foundation for major projects established, with the introduction to Kerzner's Project Lifecycle Model given, and a detailed analysis of all relevant published material on the nature of project issues and project success; the latter providing all the base data for the compendium.

From the topics covered to meet the objective four important points emerged that must be considered during the development of the MM Model:

- problems affecting the management of major projects are systematic in nature and can be addressed under the headings of size, complexity, technical uncertainty, schedule duration and urgency, physical and social environment, and government and politics; these facets must be fully addresses during project definition
- identification of the dynamic interfaces (between the stages in the lifecycle) and static interfaces (between the project and its environment) during project definition are key to the success of a project
- the existence of static interfaces defines a project as an open system which will influence management organisation options
- the need to seek and establish definitive goals and objectives for a project, and the need to develop a clear understanding and consensus among principal project participants regarding the relative priorities of these goals and objectives was paramount to success.

There is a need for further work, beyond the scope of this research, to understand the special needs of the so called "soft" projects. These projects for instance can be associated with major business change programmes where business' are changed in character and in organisation to meet a newly defined role or set of business objectives, or associated with social aid programmes such as the eradication of an epidemic, or the relief of famine or war stricken areas in third world countries. The scoping of such projects has proved difficult owing to little or no historic data for reference purposes; ie each project is a unique undertaking. Furthermore. the setting of agreed objectives by all parties involved has proved difficult or in some cases impossible.

CHAPTER 3: SYSTEMS APPROACH TO MANAGING PROJECTS

3.1 INTRODUCTION

As noted by Morris (1986 and 1987) and confirmed by this thesis, poor application of project management techniques can sometimes be blamed for a project failure; however, research into project failures has shown that systematic problems associated with project size, complexity, technical uncertainty, schedule duration and urgency, physical and social environment, and government and politics are the major contributors to the problems experienced. Cleland and King (1983) identified the need to combine the techniques of systems analysis and project management in order to address systematic problems, and suggested a framework for achieving the combination. Yeo (1993) noted that new systems techniques were not being employed by project managers and suggested a new impetus for combining the techniques of project management and "systems thinking" in order to address the continuing failure of major project delivery.

Systems thinking over the past thirty to forty years has emerged as one of the most important intellectual disciplines for problem solving and decision taking. In fact, according to Morris (1989), the systems emphasis had contributed substantially to the early development of modern project management. Firstly, systems thinking describes a project as an open system with the management of the project being the integrating factor. Secondly, systems thinking has shown how projects should work as regulated organisations; for example, the need for clearly defined objectives, the recognition that projects are organisations in constant change, and the need to define and manage major subsystems and their interfaces. Thirdly, systems thinking has observed how the dynamic control needs of projects can be better applied.

Yeo (1993) claimed that the development of project management could be traced to the so called "hard" system techniques of systems engineering, systems analysis and operational research, but noted that none of the recent soft system techniques were widely used in project work. In an earlier paper, Checkland (1981) said that these traditional hard systems were lacking when dealing with ill structured and ambiguous problems, such as those encountered at the conceptual stage of project definition, in strategic planning, in physical and social environment consideration, and in government and politics. These problems were described as "messy" real-world problems (Checkland, 1972) that often defied precise formulation in the hard sense; eg, project management situations that involved major infrastructure projects, the formulation of long-term marketing strategy, or business re-engineering. In response to this challenge Checkland (1972), pioneered Soft System Methodology (SSM) to deal with these ill structured problems.

To address the need for getting products to the market faster in order to gain competitive advantage, or to deny a competitor any time advantage, simultaneous (or concurrent) engineering has been developed. This form of engineering compresses a new product's time to the market by significantly overlapping lifecycle phases or handling them in a simultaneous manner. So rather than all phases being sequential with a clean interface between each, there will exist a planned level of concurrent work. Adopting this approach could introduce significant problems associated with complexity and schedule urgency. Morris (1986) identified uncontrolled concurrency within projects was a major cause of project failure, but acknowledged that concurrent engineering was feasible under controlled conditions. The MM Model must be flexible enough to deal with controlled concurrency of work.

The aim of this Chapter is to address Objective 2 by introducing the M'Pherson Model and other related topics. However, to comprehend the model fully and to provide essential input to its formulation, it is necessary to have background on the emergence of the systems approach (Section 3.2), and an understanding of systems engineering (Section 3.3). The M'Pherson Model is described in detail in Section 3.4. Section 3.5 describes how soft system thinking can be incorporated into project management, and Section 3.6 describes how a project can be managed as an Open System.

3.2 EMERGENCE OF THE SYSTEMS APPROACH

The emergence of the systems approach has revolutionised the application of scientific method to design and decision making over the last 50 years. The first 25 years being dominated by the so-called hard systems, and the second 25 years seeing the so-called soft systems grow in importance. Today hard and soft systems share equally in importance and together dominate the management approach to complex situations. However system dynamics, which crosses the hard/soft divide (and hence termed a matrix method) is gaining position particularly in the modelling of complex military projects in the USA. This Section provides and overview to the emergence of the approach.

3.2.1 Hard Systems

It is accepted generally that three methodologies form the backbone of the hard systems group; operations research, systems analysis, and systems engineering (Sage, 1992). The three methodologies are reviewed below.

Operations Research

Operations research was brought into being during the second World War with the aim of improving the operational effectiveness of military forces. From that time, the methodology has been successfully transformed for use in all parts of commerce and society, and it has evolved considerably; a comparison of the handbooks by Churchman et al (1957) and Moder et al (1978) demonstrates the advancements made; the former focused on military applications and the latter focused almost entirely on business applications (Sage, 1992). Operations research is described as providing an overall understanding of optimal solutions to executive-type problems in organisations (Churchman et al, 1957). However, a basic premise prevails; formulate the problem as an objective to be achieved, build a model of the situation, derive from experiments on the model the solution that best achieves the objective, and implement the solution. Daellenbach et al (1983) described a five phase model:

- **formulation of the problem** is concerned with identifying the organisation and levels and authorities of the decision makers within the organisation, the nature of the problem, the objectives of the solution and the alternative courses of action
- **construction of a mathematical model** to represent the problem making good use of modelling techniques such as simplification, aggregation and approximation, etc
- **derivation of a solution to the problem using the model** through exercising the variable parameters within viable bounds to generate a set of solutions and then selecting the most promising solution
- **testing of the model and evaluating the solution** through sensitivity analysis and empirical evaluation. The former will test the stability of the model and identify optimal points, and the latter will test for viability and will forecast future behaviour
- **implementation and maintenance of the solution** involves the conversion of the mathematical model into operational systems; which may involve a project following through a typical implementation lifecycle.

This method can be used extensively during the conceptual and project definition phases of a lifecycle to support design work. Furthermore, implementation may also involve engineering which in turn involves capital investment, and therefore modelling support may involve solution economics which operational research provides. However, it does not provide an overall time-related design methodology and as such focuses on specific problems as they arise.

Systems Analysis

The RAND Corporation in the early 1950s introduced another methodology known as systems analysis. According to Hitch (1955), the elements of this methodology included: the definition of objectives; the identification of system options for meeting the objectives, the costs and resources required by each option; the models showing the interdependencies of objectives, systems, resources and environment; and the criterion for choosing the preferred option.. In fact it was McKean (1958), in his book on systems analysis, that put forward the case for the introduction of quantitative cost-benefit analysis in all aspects of government.

A later description of the RAND approach is provided by Quade and Boucher (1968) in which they emphasised the method's ability to view the whole problem, ie the system, the system's environment, and the interfaces to the environment. Future developments appeared in the 1970s which concentrated on the methods use in business and industrial management (see Optner, 1975).

Atthill (1975) suggested a four step approach to "whole" system analysis, as opposed to the specific problem solving approach of operations research, that concentrated on business applications of systems analysis: problem analysis; generation of alternative solutions; evaluation of the alternatives; and selection of the optimal solution. In more detail:

- **problem analysis** is concerned with defining the limitations or problems associated with the current system, together with the costs of operating the current system. During this step the technical and economic measures by which the alternatives can be measured are formulated and developed
- **generation of alternative solutions** involves identifying the requirements for a systems change, the alternative solutions available together with the major features of each, and the economics involved in adopting each of the alternatives. Alternatives may include modifications to or upgrading of the current system
- **evaluation of alternatives** involves assessing the technical, environmental, and economic case for each of the alternatives
- **selection of the optimal alternative** involves choosing the best all round option that meets the requirement, and specifying the option in readiness for implementation.

The important part of the exercise is to consider the "whole system", ie how the internal system, the external system and the interfaces fit together. It is necessary to be judicious in assessing how the system will interact with its environment, ie an "open system". Systems analysis plays an important part in establishing the project through its definition, but as with operational research, systems analysis does not provide a progressive time-related framework for design and build work.

Systems Engineering

Systems engineering began life with the Bell Telephone Laboratories in the late 1930s/early 1940s with the aim of providing a framework for conceiving, designing, evaluating, and implementing a system to meet defined goals. Goole and Machol (1957) described the increasing complexity of human requirements as the prime reason for the development of systems engineering. Later, Gosling (1962) stated that systems engineering should be capable of predicting the emergent properties of the system, ie those properties that are possessed by the system but not its parts.

This is a clear pointer perhaps to the emergent systematic project problems identified in Chapter 2 associated with size, complexity, technical uncertainty, schedule duration and urgency, physical and social environment, and politics; an indicator to why systems engineering must be considered for improving the chances of project success.

Checkland (1981) showed that operations research, systems analysis, and systems engineering could all be reduced to the same intellectual proposition as all were predicated on the belief that an important class of real world problems could be solved systematically and scientifically. According to Checkland, operations research had a tactical focus and its concern was for existing, rather than future systems. On the other hand, systems engineering and systems analysis were concerned with strategic issues and planned systems.

It was obvious, according to Checkland (1981), that the two methods overlapped; but systems engineering was more all embracing as it was concerned with the totality of an engineering project in the broadest sense of the term, whereas systems analysis was concerned with the appraisal that preceded the setting up of an engineering project. In order then to consider the whole lifecycle within this research, systems engineering will provide the main input to the systems approach borrowing tools and techniques from the other two. M'Pherson (1981) acknowledged that systems analysis, and more importantly advanced systems analysis (a product of US aerospace industries during the 1970s and 1980s), could offer much to the definition of projects during their early stages and accordingly incorporated the techniques into his model (ie the framework for systems design).

It was during the 1960s that systems engineering became established as a generally accepted discipline for designing and implementing complex systems. Hall (1962) described systems engineering (now considered a classic work) as part of "organised creative technology" through which research knowledge was translated into practical reality. Furthermore, Hall described systems engineering as the discipline that formulated for a project the operational, performance and economic objectives, together with the broad technical plan to be followed.

Further developments in the 1960s focused on consideration of the whole system. Chestnut (1967) emphasised that systems engineering dealt with both the way that the operating system itself worked, and the systematic process of performing the engineering and associated work in producing the operating system. Jenkins (1969) prescribed a systems engineering methodology that addressed the whole problem as the science of designing complex systems in their totality. Hall in 1969 updated his original theories to include whole systems considerations.

The 1970s saw the application of systems engineering to softer projects; ie the systems that planners were expected to design. De Neufville and Stafford (1971) emphasised the need for criteria for evaluating public projects, or those private projects that had significant affect on the public, and the need for a theory on welfare economics. However, they accepted that any decision on how objectives should be prioritised in social projects was part of a political process. Wymore (1976) broadened the scope of systems engineering still further by defining how it could address not only communication, transportation and manufacturing systems, but also education, health and law enforcement systems, ie, the soft systems associated with society. Systems engineering methodology, according to Wymore had become powerful enough to deal with any system design or analysis problem. In fact Warfield (1976) went further by publishing a definitive work relating systems engineering to societal issues – addressing some of the management challenges of major projects. However, Checkland (1979, 1981) maintained that systems engineering could not deal with all of the issues associated with ill-structured problems related to social systems design; Warfield's (1976) theory requires more research in the light of the current knowledge of systems design.

Systems engineering developed further in the 1980s with variations on Hall's (1962) classic approach. M'Pherson (1980, 1981) provided a rigorous treatment in defining both a systems engineering approach to whole system design, and a workable framework for systems engineering design. A comprehensive model from this framework is used in this research to build the MM Model. However, Hitchins (1992) criticised "classic" systems engineering for not being able to address open systems; eg the interface of a project and the physical and social environment. He put forward a new look systems engineering that is based on "unified systems hypothesis". Hitchins claimed that this new approach was applicable to any system; ie, human, economic, technological, etc.

Systems engineering is still very much alive today with recent national standards being published in both the UK and the USA (see Institution of Electrical Engineers (1992), DoD (1990) and the IEEE (1994). The processes involved in applying the systems engineering approach were described in detail by the new US standard (IEEE, 1994), this Chapter only deals with the fundamentals of the approach – see Section 3.3. The processes are also described by Shaw and Laker (1993) in the context of product development and how they can help get products to the market more effectively. However, systems engineering is not without its critics, soft-systems advocates claim that it cannot deal with the ill-structured problems; eg the managerial, political and adversarial problems that a project manager has to contend with whilst steering and controlling the project through its lifecycle.

Checkland found that both systems engineering and systems analysis were unable to progress effectively beyond their early stages, as the definition of objectives and needs was not easily documented; ie, they were not able to deal with the messy situations such as organisation, policy, environmental issues, political inferences, etc. Hitchins (1992) alluded to this also, he claimed that systems engineering did not provide the means for formulating objectives. Moreover, systems engineering did not make provision for dealing with any of the on-going ill-structured problems that would occur during a projects life.

3.2.2 Soft Systems

An approach to ill-structured, or messy, problems was first proposed by Churchman in 1971, although the need for a more sympathetic and flexible approach to problem solving than those within the realm of hard systems was identified by Jenkins (1969). Ackcoff also addressed the need for a new systems approach in his article on the new systems revolution (1974). But it was Checkland (1972) who described the original version of the soft system methodology.

The soft systems methodology continued to evolve through the 1970s as Checkland further developed the method (1975, 1979, 1981). The soft systems methodology is outlined at Appendix 6. Later work by Atkinson (1986) described a range of other areas for application. Beer's Viable Systems Model (1985) provided a link between the insights and conclusions offered by organisational theorists and those put forward by systems practitioners. His aim was to bring together the laws that underpin the viability of systems in order to discover how they can be capable of independent existence. Beer stated that a system was viable if it was capable of responding to environmental change; a pointer as to why a project should respond to its environment in a controlled manner. The model however omits, according to Flood and Jackson (1991), the human factor and ignores the existence of social subsystems within the organisation – a key point in evaluating its use for the analysis of major projects.

Other soft system approaches have emerged during the 1980s including <u>viable system diagnosis</u>, general systems theory, socio-technical thinking, contingency theory, social systems design, <u>strategic assumption surfacing and testing</u>, <u>interactive planning</u> and <u>critical system heuristics</u> (in preparation for Section 3.4, the important soft-system approaches for this research are underlined above, and are outlined at Appendix 7).

The problem, according to Flood and Jackson (1990), is what method should be used for what type of problem. Earlier work by Jackson and Keys (1984) recognised this problem and introduced the concept of a system of system methodologies that examined the interrelationships between different methodologies together with the relative efficacy in solving problems in various "real-world" contexts. Following research, Jackson (1990), described a system of system methodologies which was further developed into a practical application (Flood and Jackson, 1991); which method to use for what problem is addressed in Section 3.5.

3.2.3 Systems Dynamics (A Matrix Methodology)

System dynamics is a methodology that crosses the soft-hard divide. It provides an organising framework for analysing how corporate and/or government policies and decisions interact in complex and often unexpected ways. The methodology was first suggested by Forrester (1961) after 6 years of research at the Massachusetts Institute of Technology (MIT). He described the basic philosophy of system dynamics as emphasising "transferability of structure"; he stated that if one understood the behaviour of a structure in one setting, then one should understand it in all settings. The problems that may be addressed using the method have two features in common; firstly they are dynamic and secondly, they involve quantities that change over time – ie both features can be expressed in terms of graphs and variables over time.

These two features indicate that the method is based on dynamic modelling employing "feedback" techniques. Examples of problems that have these features are: oscillating levels of employment in industry; rising pattern of health care costs; and cost and schedule overruns in major projects.

In a recent McKinsey report, Forrester, in an interview with Keough and Doman (1992), drew a clear distinction between general systems thinking and system dynamics. The former, according to Forrester, could demonstrate the existence of complexity but could not show why dynamic behaviours occurred as they did. He added that typically only 5% of systems understanding could be achieved using standard systems thinking methods. The other 95% of understanding could only come from the use of rigorous system dynamics-driven structuring of models and from the simulations based on the models. Forrester claimed that these simulations and nothing else could reveal the deep inconsistencies within mental models.

Since its first development, system dynamics has evolved considerably as a management discipline. Roberts (1978) described how the method could be used in a variety of complex management situations including those associated with major projects. In a later work, Lyneis (1980) applied the method to problems associated with corporate planning and policy design. In a recently published three-part paper, Cooper (1993a, 1993b, 1993c) used the properties of system dynamics to address the rework cycle within projects. Cooper identified that project cost and time overruns could often be attributed to the rework cycle being underestimated, or worse still, not understood during the project planning phases, ie in the definition phases. He showed how rework could account for the majority of the work content (and cost) on complex development projects. Any underestimation would, therefore, impact adversely the project's schedule.

Cooper's work will be incorporated into the MM Model. An overview to the method together with a description of the rework cycle is provided at Appendix 8.

3.3 SYSTEMS ENGINEERING FUNDAMENTALS

The term systems engineering has different meanings depending on the discipline it is being viewed from. Traditional technical disciplines claim it as belonging to them, and therefore it might be referred to, for example, as "computer" systems engineering, "telecommunications" systems engineering, or as "manufacturing" systems engineering. In this research the term systems engineering has a reserved meaning as defined by Sage (1993), it refers not only to physical systems and devices but to human and social systems as well; ie it considers the total impact of any technological system on society and the environment. This definition is in line with Morris' (1989) understanding of the systems influence on project management. This section is used to introduce systems engineering by providing a definition of systems engineering, an overview to the framework for systems engineering, and a catalogue of the tools to help set-up successful projects.

3.3.1 Definition of Systems Engineering

Systems engineering was described by M'Pherson (1990) as a management technology that dealt with the problems of complexity and interdisciplinary aspects of "large-scale systems" projects. He quoted from the American Institute of Industrial Engineers; "systems engineering is concerned with the design, improvement and installation of integrated systems of people materials, information, equipment and energy. It draws upon specialised knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of systems engineering analysis and design to specify, predict and evaluate the results to be obtained from such systems". Using the foundations on the subject laid down by Hall (1962) in his classic treatise, Sage (1993) needed to define systems engineering under three heading; structural definition, functional definition, and purposeful definition:

a. **Structural definition.** Systems engineering was a management technology to assist clients through the formulation, analysis, and interpretation of the impacts of proposed policies, controls, or complete systems upon the perceived needs, values, and institutional transactions of stakeholders.

b. **Functional Definition.** Systems engineering was an appropriate combination of theories and tools, carried out through the use of a suitable methodology and set of systems management procedures, in a useful setting appropriate for the resolution of real-world problems that are often of large scale and scope.

c. **Purposeful Definition.** Systems engineering would assist clients who desire to develop policies for management, direction, control and regulation activities relative to forecasting, planning, development, production and operation of total systems to maintain overall integrity and integration as related to performance and reliability.

This definition would indicate that systems engineering is well able to deal with the well-structured issues associated with project size, complexity, technical uncertainty, schedule duration and urgency, physical and social environment, and government and politics, but as will be shown later it cannot deal with the ill-structured aspects of these issues.

3.3.2 The Base Framework for Systems Engineering

According to Hall (1962), systems engineering had three orthogonal dimensions or axes; time, logic and knowledge (or, as defined by M'Pherson, management) as represented by Exhibit 3.3.1. The time dimension was concerned with stages or phases that a system would pass through (ie from the conception of an idea to retirement), the logic element was concerned with the process steps that had to be undertaken within each phase, and the knowledge element was concerned with the skills required to undertake the identified processes.

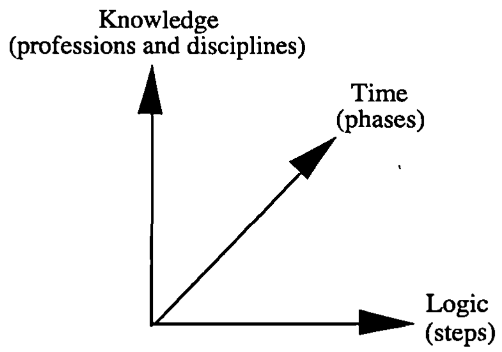

Exhibit 3.3.1 – Three Dimensions of Systems Engineering

Hall (1969) identified seven time phases; programme planning, project planning, systems development, production, installation, operation, and retirement. It has been estimated that 35% of the whole system cost of a nuclear power generation plant will be involved in retirement and decommissioning. With such a large tail-end loading careful consideration must be given to operating revenues; this future cost must be considered in any Return-On-Investment (ROI) calculations undertaken during programme planning. The phases are described at Exhibit 3.3.2.

Phase 1	**Programme planning**	Identifies requirements and translates these into solution options, and subsequently defines the selected option in terms of the system's worth.
Phase 2	**Project planning**	Configures a number of development projects that together comprise an implementation of the selected option.
Phase 3	**System development**	Translates the system definition into a product description through the preparation of specifications.
Phase 4	**Production**	Translates product specifications into a finished product.
Phase 5	**Installation**	Deploys the product through an ordered phase-in to operations – this could involve business functions such as sales and marketing, operations management, maintenance, and training.
Phase 6	**Operations**	Could involve production management, distribution, total quality management, management and cost accounting, and maintenance etc.
Phase 7	**Retirement**	Involves ordered run down and eventual phase out.

Exhibit 3.3.2 – Hall's Seven Phase Approach (Time)

The logic dimension addresses the steps to be undertaken within each of the time phases. Hall identified seven steps; problem definition, value system design, systems synthesis, systems analysis, optimisation of alternatives, decision making, and planning for action.

Step 1	**Problem Definition**	A definition of a need or the issues surrounding a problem.
Step 2	**Statement of Objectives**	A definition of a set of objectives or goals that provides a framework for evaluation, ie the value system.
Step 3	**Systems Synthesis**	Creation of possible solutions to meet the objectives.
Step 4	**Systems Analysis**	Analysis of the candidate solutions against the objectives.
Step 5	**Systems Selection**	Selection of the most promising solution or the one that has the best fit against the objectives.
Step 6	**Development**	Development of the best solution to a point where it may be implemented.
Step 7	**Planning for action**	Solution realisation; including monitoring, modifying and feeding back to design.

Exhibit 3.3.3 – Hall's Problem Solving Sequence (Logic)

The logic dimension provides the key foundation to the M'Pherson Model and hence its understanding is paramount to the development of the MM Model. The logic dimensions are described by Exhibit 3.3.3. Since the focus of the various phases are quite different, the specific tasks to be undertaken and the tools to be employed will be distinct from that phase.

The knowledge dimension refers to the skills required to undertake each element of work. Combining the time, logic and management axes forms Hall's Morphological Box. M'Pherson's interpretation of the box is shown at Exhibit 3.3.4 (M'Pherson, 1990).

Each face of the cube describes a function of systems engineering; design management, project management and design process. On first observation it would seem that the systems engineering approach is all embracing and provides the complete solution to setting up a successful complex project. Certainly it would appear to be able to address the systematic problems associated with project size, complexity, technical uncertainty, schedule duration and urgency, physical and social environment, and government and politics. However, according to Hitchins (1992), it failed to provide a complete solution from the outset as there was no generally accepted way to achieve the first three steps, ie problem definition, statement of objectives and systems synthesis.

Jenkins (1972) presented the systems engineering approach as logical and rational but not based on any science in the way that other engineering disciplines were. Hitchins (1992) added that despite these shortcomings, systems engineering survived simply because it was a theology, ie a way of approaching problems that was axiomatically sound. Furthermore, it was better to approach the whole system top down and view it as a whole, rather than viewing the parts in isolation. Over the past twenty years more

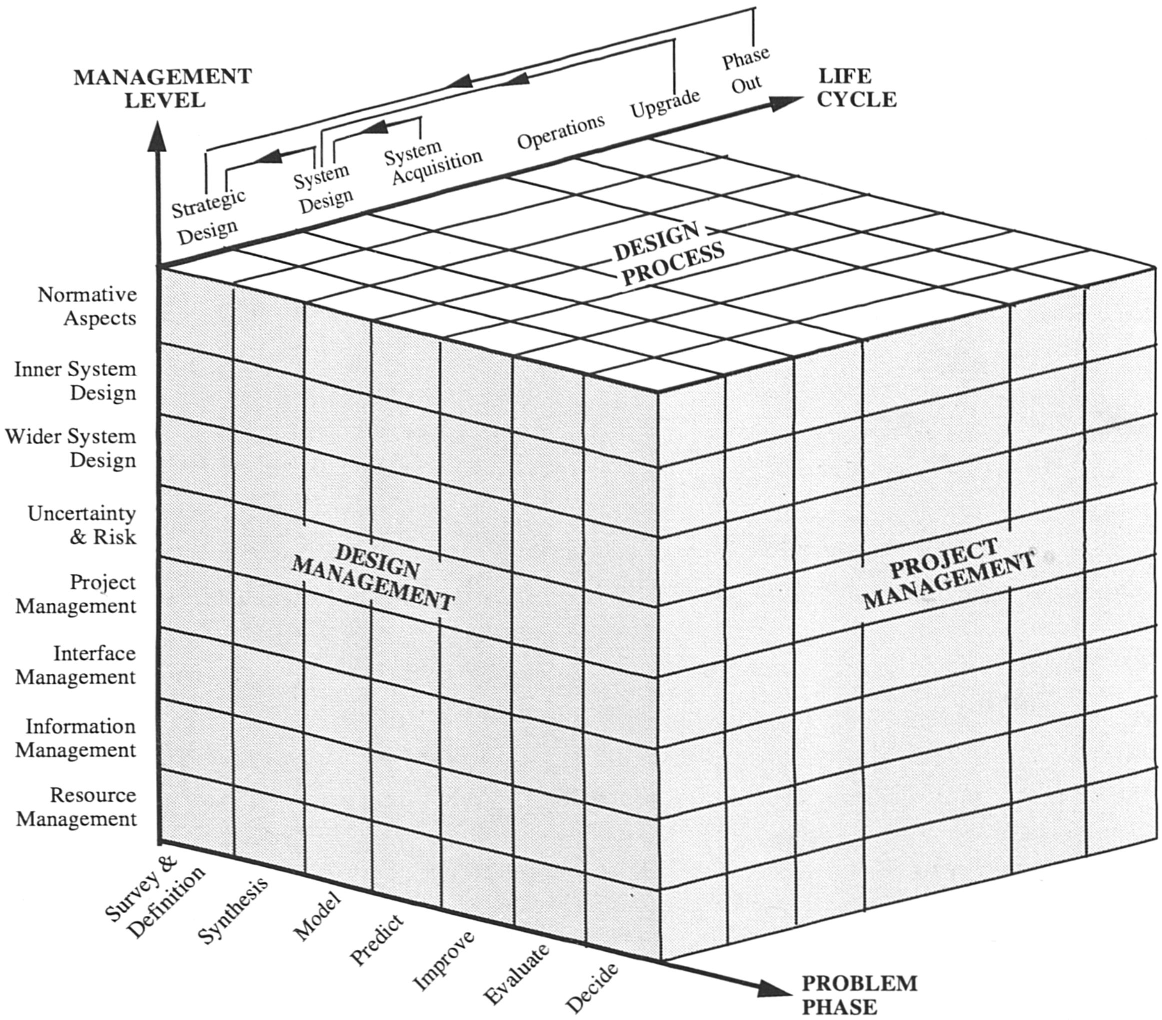

Exhibit 3.3.4 – Morphological Box for Systems Engineering

method has been introduced in an attempt to add more discipline through defining better time phases, or system lifecycles. However, systems engineering is the only systems method that imposes a time discipline through lifecycle phases.

3.3.3 Core Concepts of Systems Engineering

The essence of systems engineering, according to M'Pherson (1980), is in its emphasis on whole system design and support throughout a lifecycle This emphasis provides a framework for tackling the problems of planning, designing and managing large complex systems from inception to realisation. The core systems engineering concept is based on two main ideas; emergence and hierarchy, and communication and control (Checkland, 1981).

Emergence and hierarchy. The emergence principle states that a system exhibits properties that are meaningful only when they are attributed to the whole and not to its parts. For example, the overall control potential of an air traffic system is an emergent property of the combined management and control of airfield and terminal manoeuvring area systems, national air traffic centres, enroute centres, airline operations, and aircraft systems. The hierarchical nature of systems allows their reduction or decomposition to increase the resolution of analysis (see Flood et al, 1988), ie, conversion of the system into many simpler forms at the same time (M'Pherson, 1980).

The hierarchical property facilitates understanding of goals and objectives, requirements, system components, performance, costs and benefits, organisation, etc. Of course, the effective application of hierarchical analysis implies that the system is well ordered. Yeo (1993) noted that project management also displayed emergent properties as it derived its purpose and meaning from its organisation, component planning and control activities in creating a project according to specification, on time and within budget.

Communications and control have special significance in open systems as these systems are "open" to the effects of their environment. The design and implementation of any real-world system (or project) together with its associated project management is described as an open system (Morris, 1989). The process of communications through the timely transmission and distribution of information is necessary for the purposes of regulation and control, and the setting and maintenance of performance.

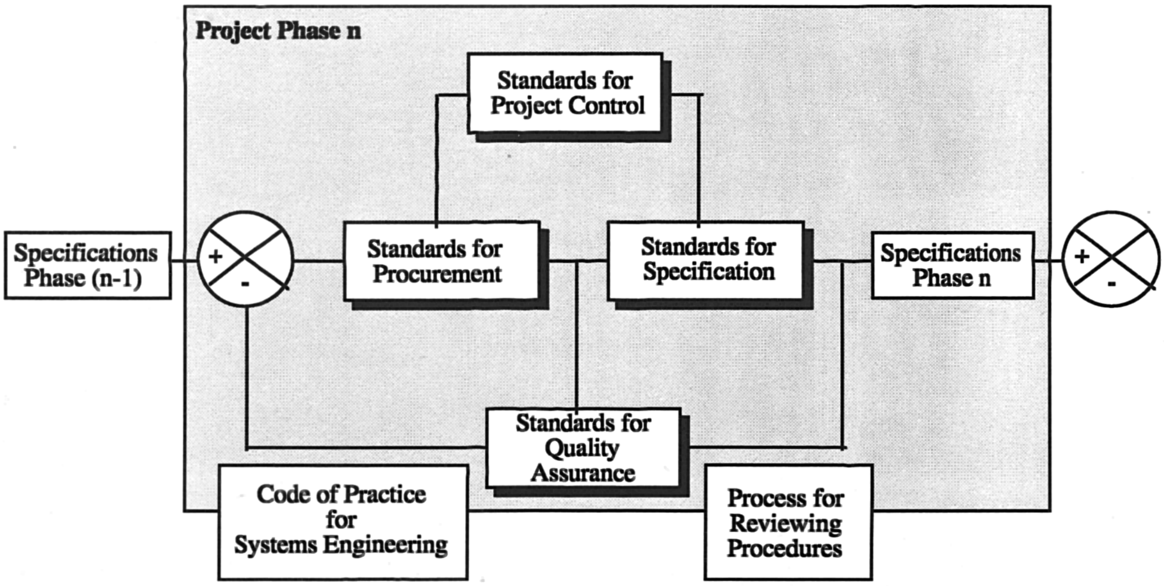

Exhibit 3.3.5 – Phase Specifications Formulation

These core concepts are applied through the application of evolving specifications, plans, schedules, standards, and procedures. These concepts according to Hitchins (1992) were applied to complex projects by controlling the process and product of each phase of the system lifecycle. The strategy is essentially to organise, correlate and manage evolving specifications (etc) effectively under project and quality control, see Exhibit 3.3.5.

Each phase within a system lifecycle has unique purpose, but standardised approaches and methods are necessary to manage and control the flow of work. According to Sage (1993), the systems engineering paradigm calls for efforts that evolve the study of issues in relation to their environment with due consideration of causal or symptomatic, institutional or organisational aspects of the problem; ie, following the 7 steps outlined by Hall (1962) – see Exhibit 3.3.3.

To undertake these steps, systems engineering employs the methods of such disciplines as behavioural and cognitive psychology, computer science, systems analysis, operations research, economics, business management, systems, and control theory. How these disciplines are used and the order in which they are used will depend upon the project. However, for the early stages in a project's lifecycle, M'Pherson (1981) has developed a model that introduces a method based upon Hall's original work (1962) and the RAND systems analysis approach. This model will be described in detail in Section 3.4.

3.3.4 System Engineering Lifecycles

The application of systems engineering is through a systems lifecycle. A system lifecycle may be conceptualised using systems engineering management or technological perspectives or a hybrid between the two. Sage (1993) stated that there was no mutually exclusive perspective, however, in general it was believed that a systems engineering management perspective was more appropriate as it would lead naturally to an organisational structure for tasks and people. This system engineering lifecycle is analogous to the project management lifecycle and a direct mapping is possible. Sage, based on earlier work by Blanchard and Fabrycky (1981), identified some eleven drivers for using a system engineering management lifecycle:

1. Encourages the identification of what the system is supposed to do.
2. Enhances the ability to establish the user, technological and management system, and requirements that are satisfied by the subsequent systems development.
3. Identifies and highlights potentially difficult technological, management, and social problem areas.
4. Encourages a thorough systematic evaluation of alternative solutions to difficult issues associated with each of the phases in the lifecycle.
5. Enables selection of appropriate processes for each phase in the lifecycle and enables co-ordination across these phases.
6. Enables planning for interaction among the various subunits of the system to be fielded, thereby enabling system integration.
7. Encourages development of lifecycle cost and benefit, or operational effectiveness, information.
8. Supports the development of project management strategies throughout the lifecycle by enabling project managers to track system acquisition efforts in an accurate manner and to identify the potential for various risks in the design, development, and implementation process.

9. Supports the development of standards and the use of these as disciplines that help ensure reliable and trustworthy systems.

10. Supports design, development, and implementation of a reliable, trustworthy, sustainable and high quality product that can be delivered on time and within budget.

11. Supports effective systems management, or management control, by enabling the institutions and organisations to be better structured and more manageable.

The use of an appropriate lifecycle model for the undertaking in hand is essential if the project is to be a success. Chapter 2 introduced a number of project lifecycle approaches and selected Kerzner's lifecycle model as the basis for this research. This model provides a general framework, but it should be noted that particular systems engineering situations will require an appropriately constructed model in order to bring to bear the required processes, but any system lifecycle configuration can be accommodated within the project management lifecycle.

M'Pherson (1990) described a simple systems engineering lifecycle as shown at Exhibit 3.3.6. The lifecycle model is important because it shows the support system and modification stages associated with operations. In reality, the modification stage could generate a full lifecycle for each major upgrade. A mid-life product upgrade is a typical example of this concept.

A mapping of this systems engineering lifecycle to the stages of Kerzner's lifecycle (in parenthesis) is quite straight forward; strategic analysis (conceptual), requirements analysis and system design (definition), system implementation and integration and testing (production), deployment and operations (operational); and phase-out (divestment).

Sage (1993) described a macro-level lifecycle comprising three super phases: system definition; system design and development; and system operation and maintenance. Within these macro-level phases, Beam et al (1987) identified no less than 22 phases of work associated with predominantly large software projects although the model could equally be applied to most hi-tech projects. The resulting lifecycle, see Exhibit 3.3.7, can be used in situations where one client or stakeholder seeks development by a vendor. In other words the lifecycle model contains all the stages of work necessary for tendering, procurement and supplier management.

The US Department of Defence (DoD) has recently denoted a software development lifecycle that divides out the hardware and software streams. This standard (DoD STD 2167-A; shown at Exhibit 3.3.8) was developed in response to the large number of military project failures experienced, and the criticisms made by the US General Accounting Office concerning the lack of standards.

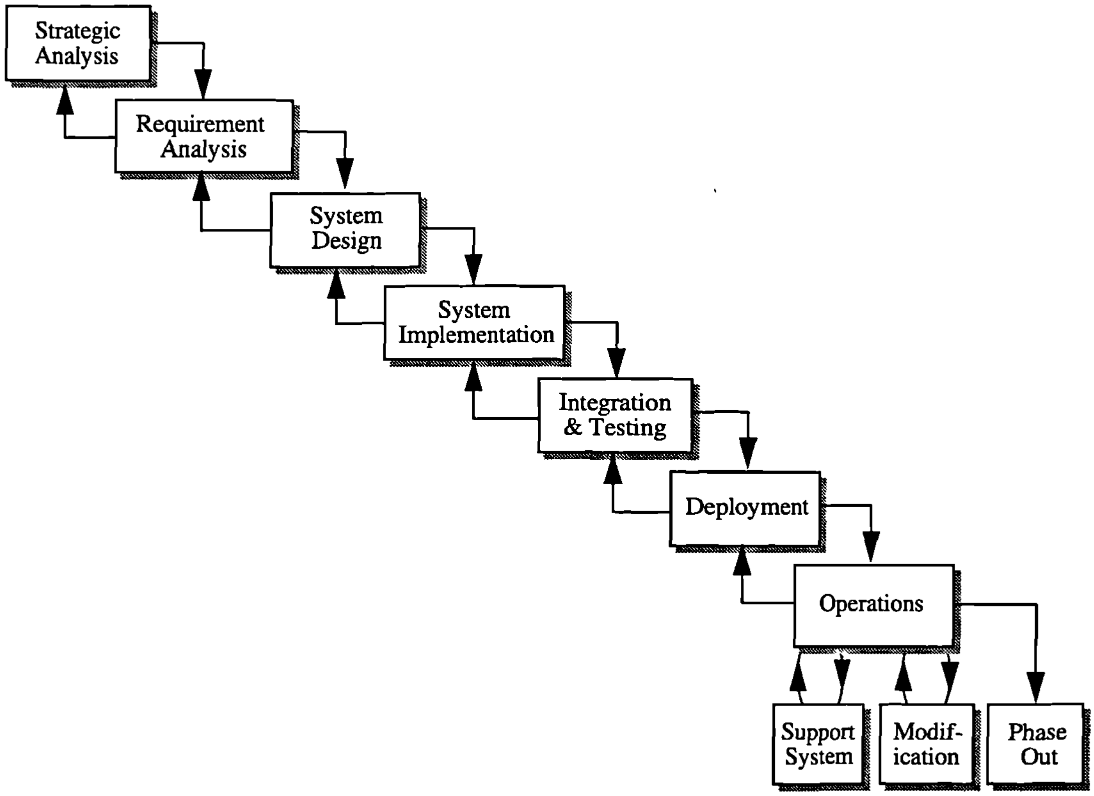

Exhibit 3.3.6 – Systems Engineering Lifecycle Model (1)

A systems engineering lifecycle model closer to Hall's original seven phase (1962) approach was provided by Hitchins (1992); see Exhibit 3.3.9. The model emulates the A systems engineering lifecycle model closer to Hall's original seven-phase (1962) need for a division between the equipment engineering and software engineering as called for in the DoD Standard[1] ; Hitchins (1992) enhanced the model to include the IEE (1992) extension for operations and retirement (Hitchins led the IEE working party for drafting).

3.3.5 Systems Engineering Processes

The processes of systems engineering evolution are illustrated for the general case at Exhibit 3.3.10 (similar to the Cleland and King (1983) framework). According to

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[1] Other models for systems engineering are described as follows:

a) DoD Systems Acquisition Lifecycle (milestones 0-V) (1987) – programme initiation/mission need decision, concept demonstration/validation decision, full-scale development decision, full-rate production decision, logistics and support review decision, major upgrade or system replacement decision.

b) The Pessimier (1966) Analytical New-Product Decision Model comprised six phases – search phase, preliminary economic analysis, formal economic analysis, full development, product testing, and communication

c) The Society of Professional Engineers (1990) also suggested six phases – conceptual phase, technical feasibility, development, commercial validation, full-scale production, and product support.

All lifecycles appear to follow the same pattern rendering further in-depth inquiry unnecessary.

Blanchard (1981) the general case would need to be "tailored" for particular undertakings, as the application of too much or too little effort could be quite costly. The Blanchard general case has been adapted in this thesis to fit the Hitchins lifecycle model. The systems engineering process evolves functional detail and design requirements with the goal of achieving the proper balance among operational, economic, and logistic factors.

Operational analysis is about understanding the needs of an organisation and documenting them in the form of an operational target or business strategy item; the output from the phase is the operational baseline for the project. In any event, all initiatives must fit in with the overall business, government or military scheme or top-level plan. The needs may arise through a market opportunity, a drive for efficiency, a military threat or a social improvement. Hitchins (1992) emphasised that operational analysis could only be effective if the wider systems were studied together and a clear definition of the system boundaries made.

Conceptual design and the associated requirements analysis forms the technical baseline for the project. A feasibility study is undertaken where the needs are analysed in terms of potential solutions, and a systems operational requirement is produced together with policies for logistics support and maintenance. A conceptual design must also consider project economics, lifecycle costs, schedule and the required resources. De Neufville and Stafford (1972) claimed that any economic treatment should consider all aspects of a project and not just those associated with the development lifecycle. Pearce (1981) put forward the view that costs should also contain an element for social impact; this supports M'Pherson's (1980) view that the "whole" system must be considered.

System definition (or preliminary system design, also referred to as advanced development) develops the technical baseline into a design baseline through formal operational functional analysis, identification of design alternatives, selection of a preferred option, and the production of a detailed design specification (Chestnut 1967, and Blanchard 1981). M'Pherson's Model for Systems Design covers this stage and hence his model can be shown in the context of this overall framework.

The operational emphasis during system definition phase ensures that the "whole" system is considered throughout and that open system concepts are judiciously acknowledged (M'Pherson 1980, and Warfield 1986 – particularly societal impacts). In parallel, the project economics, lifecycle costs, development and build schedules, and resource requirements are further refined as more information is known about the project.

A further activity to be undertaken here is risk analysis for the project and the development of a risk management plan for handling the risks should they occur. This step-wise refinement process builds confidence in the outcome of the undertakings.

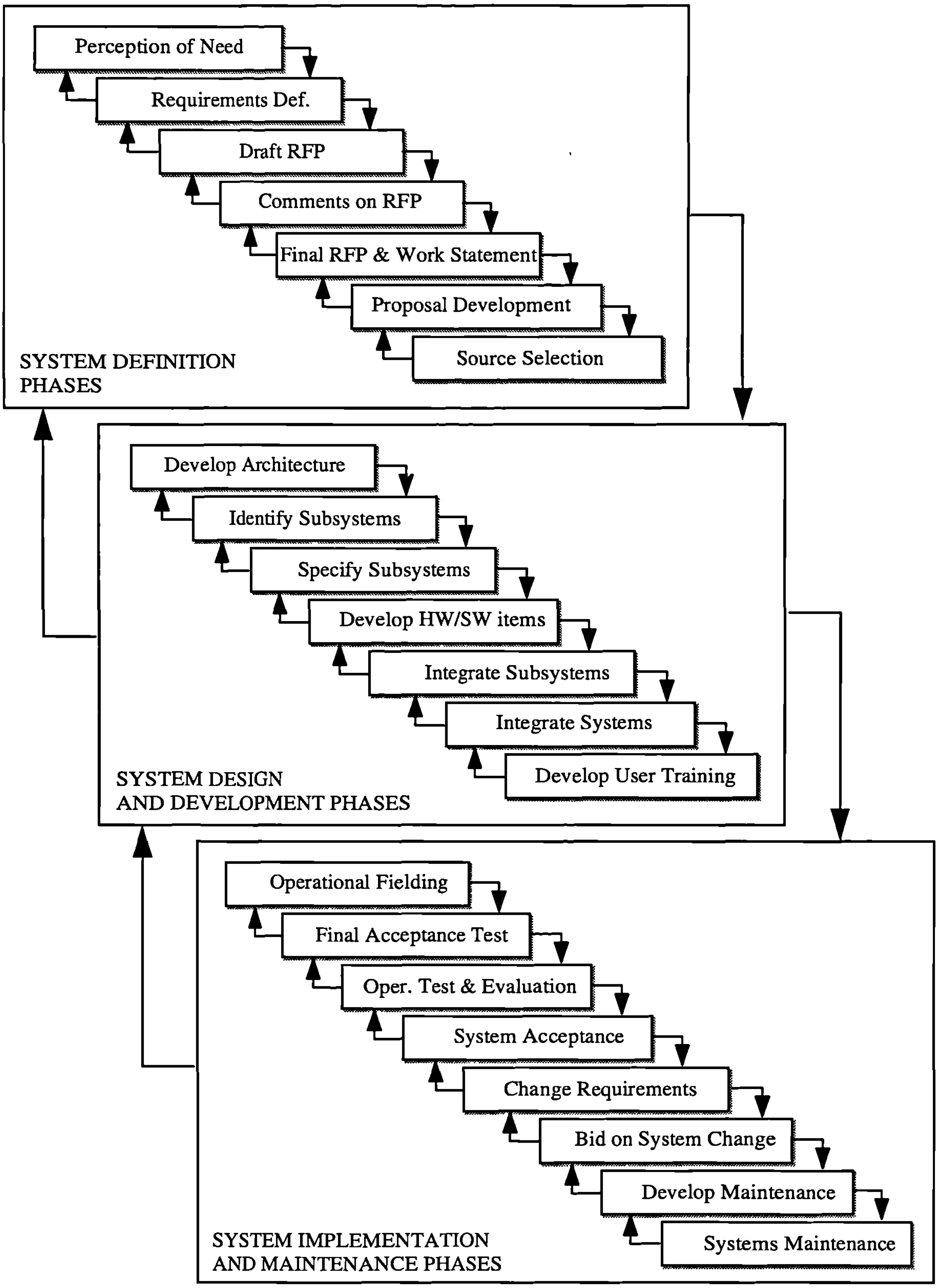

Exhibit 3.3.7- System Engineering Lifecycle Model (2)

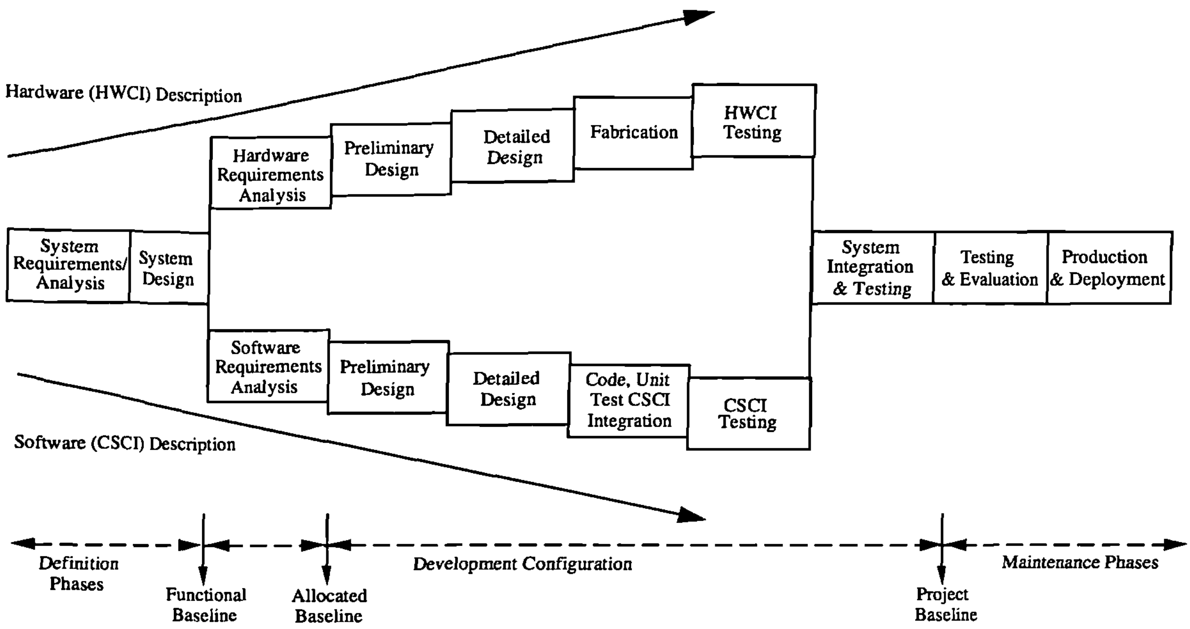

Exhibit 3.3.8 – System Engineering Lifecycle Model (3)

In preparation for project engineering economics, particularly those involving concurrent engineering, design for manufacture (DFM) and design for assembly (DFA) will need to be considered in detail. Sage (1993) developed a more comprehensive definition phase that incorporated activities for competition and

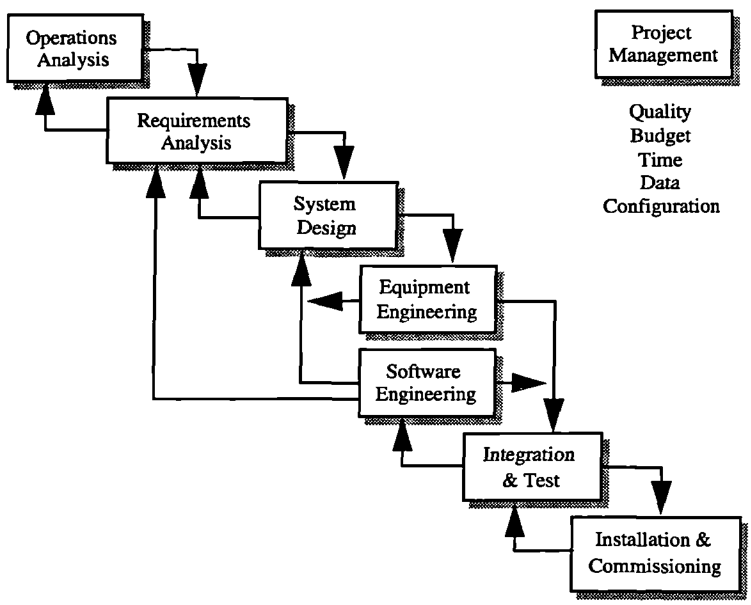

Exhibit 3.3.9 System Engineering Lifecycle Model (4)

procurement (see above). A cautionary note on the modelling activities, Hitchins (1992) quoted an example where a major military project was cancelled as the customer became dismayed on discovering that after three years only sophisticated systems engineering simulation models had been produced.

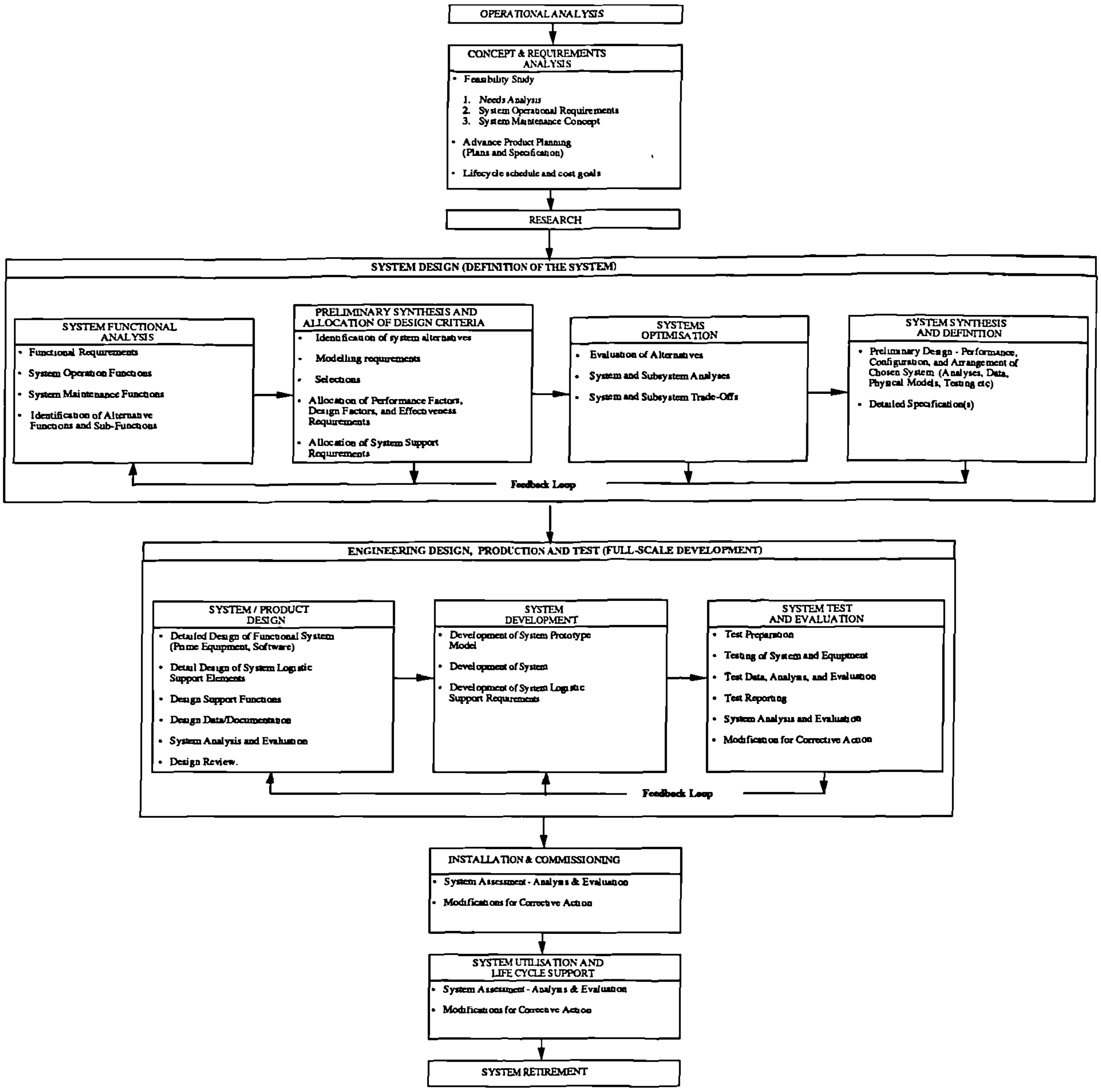

Exhibit 3.3.10 – The Systems Engineering Process

Engineering design is concerned with producing detailed specifications for subsystems, units, subassemblies, and the definition and development of software for the prime mission equipment (Hitchins, 1992). It may be deemed necessary for complex engineering projects to build a prototype or detailed simulation to test and verify preferred designs in order to assess the operational behaviour and gain insight into production issues (Blanchard, 1981). Iterative design is used to correct deficiencies noted through initial system testing.

As before, the project economics, lifecycle costs, schedules and resource requirements for production/construction are further refined as will be the requirements for maintenance and logistics support. The output from the phase will be detailed specifications for building the system that suits the whole economics of the project. Also produced will be an updated risk management plan that reflects the ever increasing knowledge about the project.

Production commences with detailed design specifications and ends with the finished product. Key concepts employed during the phase are change and configuration control and test and integration. Although first observed during the prototyping (if undertaken), performance testing will be critical and often considerable change to designs result from performance shortcomings. In order to overcome these shortcomings and those associated design errors a degree of rework will be necessary. As noted before, Cooper (1993 a, b and c) stated that this rework could account for in excess of 90% of the actual work involved in production, which in turn means that there could be a significant underestimation in effort and schedule if the amount of possible rework was not considered during the systems definition and detailed design phases. During this phase the in-service logistics and maintenance support will be finalised together with any necessary adjustments to the project's economic case.

Installation and commissioning follows the production stage of the project with its transition to operational use. Systems engineering must ensure that there is a full range of testing undertaken; this may include systems acceptance and then user acceptance testing. Furthermore, it must ensure that the organisation or community receiving the system is prepared for it. The aim is to ensure that a system start up is achieved as smoothly as possible. The transition policy is thus key to the project's success in the final stages. This policy is planned and documented during the early definition stages. Blanchard (1981) emphasised the need for early thinking on the subject and claimed that it was part of project definition.

System utilisation involves not only maintenance and logistics support, and modification and upgrade during operations, but the realisation of the economic case made for undertaking the project. Furthermore, from a project point of view, it would be advantageous to undertake a post implementation review in order that lessons can be learned. However, a key point to consider here is the cutover to the new system operation. It is important that this happens smoothly and therefore it must be planned during the definition stages. This is particularly important where there is a possibility of lost business or a reduction in operational efficiency.

System retirement is not normally considered seriously other than for projects where the retirement of a system or facility is a costly or dangerous undertaking. Plans for retirement of these types of systems will need to be developed during the definition stage in order that costs can be calculated and fed into the business case for undertaking the project.

Using the Hitchins' (1992) model, typical outputs from each lifecycle phase are identified at Exhibit 3.3.11. These phase outputs control the dynamic interfaces in the lifecycle where the project managers may monitor performance (Morris, 1989); see Chapter 2

(2.2). Furthermore, the outputs show a progressive build up of detail as the top-down design process evolves (see Exhibit 3.3.5).

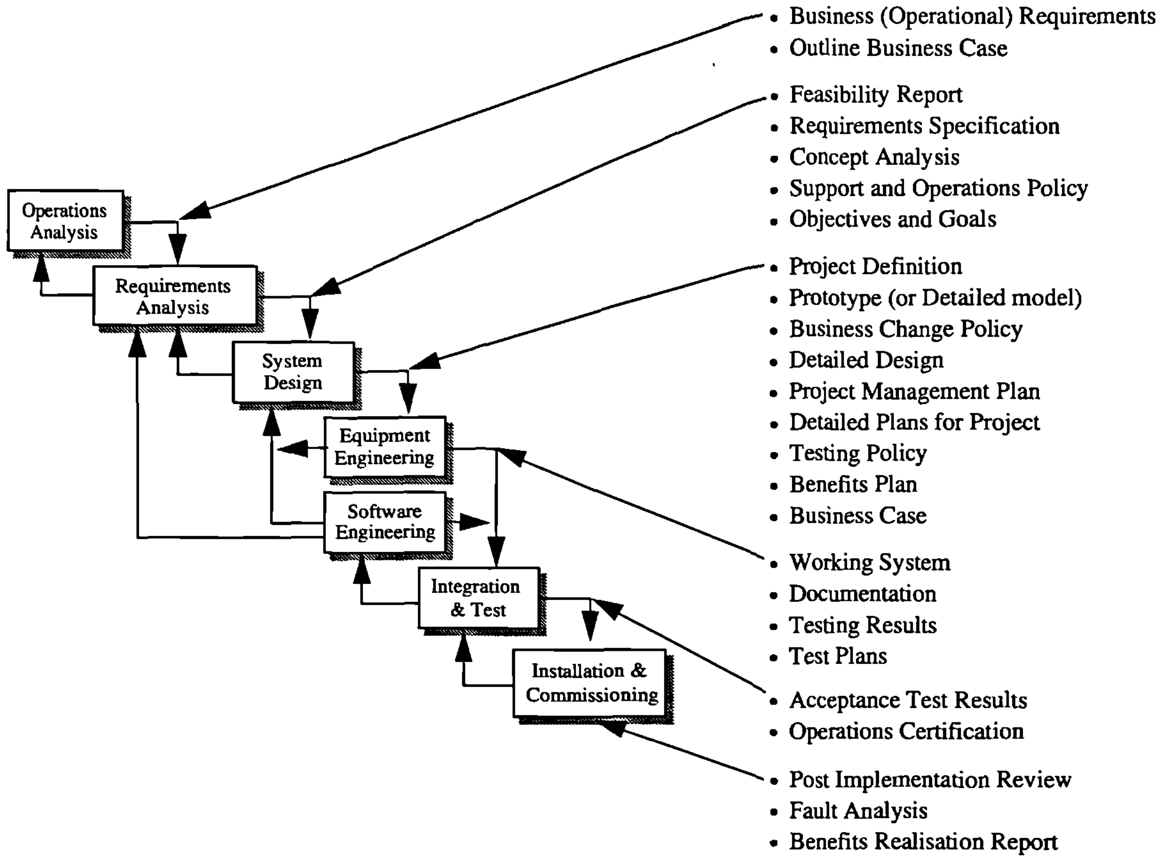

Exhibit 3.3.11 – Lifecycle Phase Outputs

3.3.6 System Engineering Support Tools

Exhibit 3.3.12 identifies the possible systems engineering "hard" tool kit that could be employed during the lifecycle (IEE, 1992), see also Chestnut (1967) where much of the pioneering work in this area was first recorded.

The tool kit presented above is only a generic identification since precise tools may be system specific or individual manager or team leader specific. Furthermore, the tool kit does not contain any soft system tools which will be addressed in Section 3.5. The whole subject will then be used during the formulation of the MM Model in Chapter 5 where a more substantial analysis of the required model types is undertaken.

3.3.7 Comment

Comparing the systems lifecycle description presented in this Section with the project management lifecycle presented in Chapter 2 it can be seen that there is agreement on the what must be done, ie, there is considerable overlap in the activities to be undertaken. However, there is an additional emphasis in the project lifecycle and on organisational and management aspects of the project, including the management of interfaces between the project and its environment; ie, managing the project as an open system. In the systems lifecycle, on the other hand, there is a more focused emphasis on the technical aspects of a project and indeed on addressing the complex but well structured problems, but more importantly there is also a method for considering and developing the project as a "whole" system; ie, technical, management, and environmental aspects as a single entity. However, there is still no method present for dealing with ill-structured problems, such as the handling of public enquiries, company board disagreements, public disagreements, project investment decisions, and the environmental or socio-economic impact of large infrastructure projects.

<table>
<tr><th>Operations Analysis</th><th>Requirements Analysis</th><th>System Design</th><th>Project Engineering</th><th>Integration & Test</th><th>Install & Commission</th></tr>
<tr><td>Solution feasibility & performance</td><td>Requirements consistency & completeness</td><td>Design options, Interfaces, tradeoffs & Specifications</td><td>Configuration compatibility, interchange, and build</td><td>Test environment</td><td>Customer acceptance</td></tr>
<tr><td rowspan="5">Scenario Models
System Boundary Models</td><td colspan="2">System Models</td><td rowspan="6"></td><td rowspan="2">Environment Simulation</td><td rowspan="6"></td></tr>
<tr><td colspan="2">Relationship Models</td></tr>
<tr><td colspan="2">Requirement Tools</td><td rowspan="2">Threat Simulation</td></tr>
<tr><td colspan="2">Human Engineering & Animation</td></tr>
<tr><td colspan="2">Logistics Models</td><td rowspan="2">Subsystem Simulation</td></tr>
<tr><td colspan="2">Risk Models</td><td>RAM/FMECA</td></tr>
<tr><td rowspan="3">Functional Decomposition</td><td colspan="2">Networks, topology, architecture</td><td colspan="3">Configuration Management Tools</td></tr>
<tr><td colspan="2">Systems Prototyping</td><td colspan="3">Interface Control Tools</td></tr>
<tr><td colspan="2">Functional / Physical Mapping</td><td colspan="3">Data Management Tools</td></tr>
<tr><td colspan="6">System Design and Engineering Framework Model</td></tr>
<tr><td colspan="6">Cost, Planning and Scheduling Tools and Models</td></tr>
</table>

Exhibit 3.3.12.- Systems Engineering Tool Kit

Therefore, Morris' (1989) statement that systems thinking had influenced the evolution of project management as a discipline as it was able to view a project as an open system is not entirely borne out by events. The high incidence of project failures identified in Chapter 2 would indicate that many project managers were not managing a project as an open system and they could not deal with ill-structured problems. This argument certainly supports Checkland (1981), and Yeo's (1993) call for a merger between the systems view (especially "soft methods") and project management[1] .

[1] There is still some considerable argument as to the need to distinguish between hard and soft systems. Traditional system advocates maintain that the so-called soft systems provide only tools and techniques that can be used to address particular issues and problems experienced as designers progress along the systems engineering time line. This research will accept this view as it is compatible with projects thinking, ie time-line based lifecycle. This research has been unable to identify any published work relating to the compilation of a comprehensive systems tool kit for project definition or systems definition.

3.4 THE M'PHERSON MODEL

3.4.1 Overview

M'Pherson (1980) also noted that too many projects were failing to be delivered to time, to budget and to specification. He commented also on a common theme for failure being a lack of due consideration for the whole system during the early project phases. As a result he developed a powerful systems engineering model that used advanced systems analysis techniques for problem solving as part of the overall system design. The "overall" or "whole" system design is taken to mean that an all-encompassing design that can address the issues of project size, complexity, technical uncertainty, schedule duration and urgency, physical and social environment, and government and politics.

Systems analysis is recognised to be a comprehensive methodology for surveying complex, multi-objective, long time horizon problems to which there are many alternative strategically feasible solutions, and for evaluating the alternatives to indicate the best solution for implementation. M'Pherson (1980) described systems analysis as a kind of large-scale search and decision analysis methodology that could form the initial phase of the systems engineering methodology. This merger has meant that systems engineering will not only address the design and evaluation of cost-effective technological systems, but will also identify the conflicts that arise due to the impacts of technology on society. This will mean that the assessment and selection of systems can be undertaken with due consideration being given to their external social and natural environments (Warfield, 1976).

M'Pherson (1981) stated that the essential structure of any effective design process was that of a cyclic decision process that iterated towards the selection of a concept whose predicted behaviour best met a given design criterion. M'Pherson's Model for providing such a structure is shown at Exhibit 3.4.1. The model is described through considering each of the 5 levels; design, design cycle, normative, forecasting, and management. Each description follows the sequence; problem survey, system synthesis, modelling, analysis, evaluation, and selection. The common starting point is "problem definition" where the customer or user defines the high-level requirement or need. In business terms, this may be an instantiation of a business strategy initiation or direction, and in military terms it may be referred to as an operational requirement.

3.4.2 Design

The design level contains the sequence of functional operations that combine the detail of the forwards design process starting from the definition of operational (or business) requirements through to the selection of the preferred candidate at the end. System performance has to be projected forward to uncertain future environments in order to cover the whole life requirements, and the design objectives must consider the wider system in the context of an open system.

The initial step in the sequence is to formulate the requirement for the system in explicit terms, and then to generate candidate solutions for satisfying the requirement. The next four steps in the sequence are concerned with iterating each candidate solution through a system design process, that concludes with an evaluation against customer set objectives and value criteria. The final design stage, System Worth, is concerned with an assessment of the system worth for each candidate, that includes:

- whole life cost effectiveness consequent on the technical design
- commercial attractiveness based on market forecasts and economic analysis (ie, the business benefit)
- social benefit of the operational system
- environmental impact of the system being introduced to the wider system
- safety of the system with regard to ongoing operations.

Final selection of the preferred option is made by the customer or user after being presented with decision information.

3.4.3 Design Cycles

M'Pherson's System Design Framework has six cycles embedded in its structure:

- **I** feasibility screening eliminates candidates that have little chance of producing the desired performance or that contravene a constraint
- **II** impact screening of candidates eliminates those that have no or only a weak impact on the objectives
- **III** research and development planning to overcome technological barriers and constraints
- **IV** is an optimising loop in which candidates are honed to achieve best performance or trade-offs between objectives
- **V** sensitivity analysis is undertaken is undertaken to ensure that the candidate is not uncontrollably sensitive to wider system changes
- **VI** this loop selects the next candidate for design.

Candidates are then ranked and subjected to a selection process.

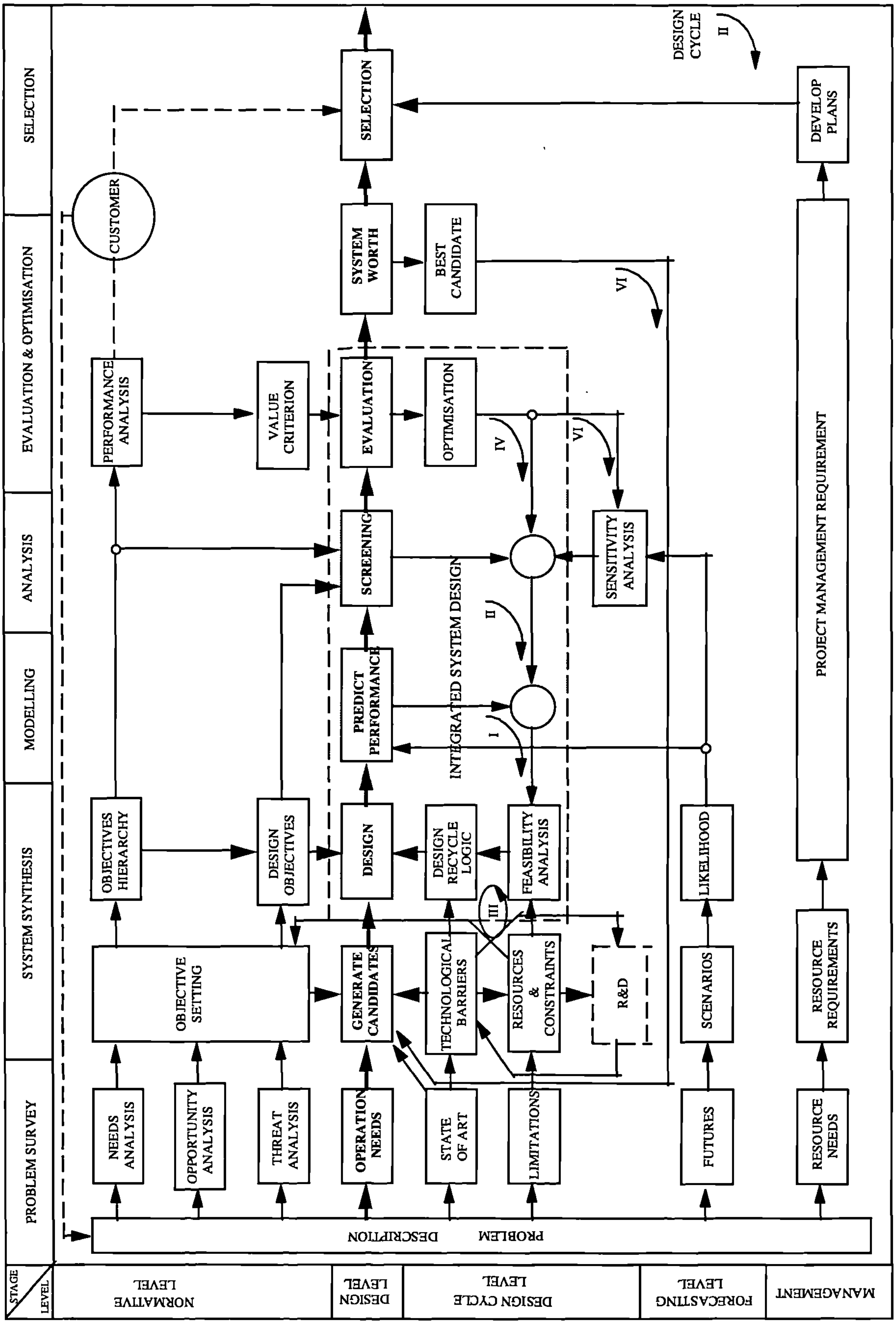

Exhibit 3.4.1 – M'Pherson's Model

3.4.4 Normative

The normative level sets out the value criterion by which the design candidates may be assessed and judged. In decision analysis terms, normative means most desirable or behaviour that the rational decision taker should follow in order to conform to accepted axioms (Sage 1992). It is at this level that the advocates of soft system methodologies claim that the hard systems methods need most help. Hitchins (1992) found that it was difficult to obtain agreement from individuals involved in the setting of objectives, the devising of objectives hierarchies (ie, priority order and groupings), and the formulation of value criteria. In nearly all large projects, especially infrastructure projects, the best that could be obtained was an agreement on compromise. However, for many projects, agreement is never reached at senior levels and this is a major cause of future project problems (see the APT case study).

In M'Pherson's Model, a prerequisite for value criterion design is a clear statement of all the objectives relevant to the project, and an agreement on the hierarchical form. The objectives are derived from a needs, opportunity and threat analysis. M'Pherson conceded that more structured objectives could only be defined using soft-system techniques such as Interpretive Structural Modelling (ISM), see Janes (1988) and Warfield (1984). Furthermore, he noted that the resultant objectives hierarchy was general and abstract at higher levels, and more precise at the lower levels. The generality means that objectives are open to interpretation, and the preciseness leads to inflexibility.

The objectives hierarchy is only a skeleton on which must be built the design objectives, the value criteria and the resulting evaluation methodology that together form the key processes for overall valuation. M'Pherson separated these processes into two groupings:

- evaluation in which the design achievements are assessed
- evaluation of the overall system's worth measured against the wider system.

The first grouping is concerned with determining the sensitivity of the design, and the computation of design outcomes, and is the province of the project's design team, ie, the project looking inwards. The second is concerned with the overall economic analysis, and is in the province of the project management and sponsors; ie, the project looking outwards (see Section 3.6 – Project Management and Open Systems). M'Pherson (1981) described in some detail the approach to assessing a system's (or project's) worth which will be considered in depth in Chapter 5 when building the MM Model; the approach is central to the theme of the new model.

3.4.5 Forecasting

Forecasting (and uncertainty) is concerned with identifying future scenarios against which design iterations (design cycles) are tested. This involves defining future operational, or business environment states, and developing models for risk assessment these states.

Using these models, designers will evaluate strategies for containing or minimising risk, for testing uncertainties and vulnerabilities, and for identifying the emergent characteristics. The models also provide a framework for obtaining a utility for preference and trade-off analysis. Forecasting is in the domain of operational research and demonstrates that systems engineering relies on a sister hard systems methodology for providing data as a baseline for evaluation.

3.4.6 Management

The management level is used, according to M'Pherson (1990), to establish the integrating mechanisms for the project to function as an open system, and to build up information on the design candidates as they develop. This level was not included in the original M'Pherson (1981) Model, but added in a M'Pherson (1990) update. M'Pherson (1990) recognised that the output from the framework must include not only the selected design description, but also information on resources needed for its implementation, a management plan for its implementation (ie, the management strategy), and a high level schedule for undertaking the work. However, it will be shown in Chapter 5 that this treatment of the management requirement is not sufficiently integrated to achieve the desired objective.

Sage (1993) referred to this information as the systems management plan. This management information together with the design information constitute the major element of the business case for proceeding the project. Getting it right at this stage is thus key to the project's success. However, the management level must also ensure that the correct level of user/sponsor/owner involvement takes place during the early stages in order to establish ownership and commitment from the outset.

The M'Pherson Model, according the Hitchins (1992), falls short of defining a project for the wider system of interest as it does not contain an approach for dealing with the interfaces with other systems and, according to Checkland (1981), could not deal with the ill-structured problems associated with problem definition objectives formulation, and the influences and prejudices of human interaction. In a wider sense, the model as it stands cannot address effectively the problems and issues associated with the real world.

3.5 PROJECT MANAGEMENT AND SOFT SYSTEMS THINKING

3.5.1 Limitations of Hard Systems

Project managers, according to Yeo (1993), use systems engineering as a frame of reference for evolving the project from its conceptual stages to its cut-over to operational service, ie, the frame of reference is time related. This framework was managed through the project lifecycle. However, as previously discussed, systems engineering and indeed systems analysis and operations research have been found to be inadequate for dealing with ill-structured problem of the real world, particularly those encountered during the conceptual and project definition stages of the lifecycle. Such problems occur where the project interacts with people, business organisations, business operations, project financing, society, government or politics. Most major projects, as has been shown in Chapter 2, experience these problems and suffer from the consequences of failure to address them correctly; cost and schedule overruns at one end of the spectrum to project cancellation at the other end. As noted earlier, Morris (1989) identified that a great many of the project problems were systematic in nature, but he did not conclude that the hard-system techniques being employed during the conceptual and definition phases of the lifecycle were unable to solve them on their own.

Focusing on systems engineering, Checkland (1983) defined three fundamental reasons why it could not cope with ill structured problems. Firstly, systems engineering faced difficulties if problems could not be expressed in terms of an objective to be achieved; ie, it had no methodology for dealing with the intellectual side of problem solving. Systems engineers claimed that this side should be dealt with by the "real-world" decision taker leaving the systems engineer free to originate the project's specifications, ie, a closed system attitude. Checkland argued that intellectual problem solving should be in the province of all concerned with a problem.

Secondly, even if these difficulties could be resolved, it was unlikely that a real-world problem situation would map neatly onto the well-structured solution emanating from systems engineering. Thus, a rail-link project could not be defined in isolation from issues associated with government transport policy, local public opinion, local authority planning, capital investment, and rail operations. Thirdly, systems engineering could deal with situations that displayed rational behaviour, but idiosyncratic irrational behaviour would be difficult to address. Using the rail-link example, an analysis of the problem in economic terms could not deal with the reasoning of a political party in power not wanting to inflame public opinion in government-held marginal seats. Checkland (1983) concluded that hard systems methodologies were wedded to logic situations where logic was not necessarily paramount.

Soft system methodologies alone are also not the panacea for systematic project problems. Currently available "soft" methods can address specific problems as they occur within the lifecycle. The choice of the method to be used for the different problem types will be addressed below; however, soft system methods do not provide a lifecycle framework for evolving the project from concept to operations through time. What is required therefore is for soft-system tools to be added to the lifecycle tool kit, with systems engineering providing the backbone for the whole project, ie, the time-related framework for the emerging system.

3.5.2 System of Systems Methodologies

Based on earlier work (Jackson and Keys, 1984) and subsequent research, Flood and Jackson (1991) categorised systematic problem types in accordance with the matrix shown at Exhibit 3.5.1. The axes of the matrix are described at Exhibits 3.5.2 and 3.5.3 respectively.

	Unitary	**Pluralist**	**Coercive**
Simple	Simple Unitary	Simple Pluralist	Simple Coercive
Complex	Complex Unitary	Complex Pluralist	Complex Coercive

Exhibit 3.5.1 – Categorisation of System Problems

Unitary

Simple- Unitary problems can often be described by quantitative or highly-structured models that simulate performance scenarios under different operational conditions. Flood and Jackson (1991) associated this category with the metaphor "machine"; engineering construct-type problems occur within this category and the associated system may be described as largely closed. Sage (1993) and Hitchins (1992) acknowledged that the majority of engineering problems associated with projects would occur within a broad interpretation of this category.

Complex-Unitary problems, on the other hand, exhibit probabilistic behaviour, and are open to or form part of the environment; ie, they occur in open systems. Flood and Jackson claimed that these problems were associated with communications and control within multi-functional and interrelated organisations (using the metaphor "organic"), and with systems that evolve over time. A large percentage of project management problems concerned with the interface between the project and the real world occur within this category. All projects, according to Morris (1989), experienced problems throughout their lifecycle at the interface between the project and its environment, and these problems were a major source of project difficulties.

Pluralist

Simple-Pluralist problems occur when there is disagreement among the participants about goals and objectives; ie, there may be cultural issues to be resolved before a project may proceed. Major infrastructure projects often experience these problems during the public enquiry; sometimes the problems are never resolved sufficiently to the detriment of the project during the build phases (see Stringer, 1991).

Complex-Pluralist problems occur when there is a lack of agreement about goals and objectives among the participants concerned and a compromise is the only way forward. Flood and Jackson used the metaphor "coalition" for these types of problems. Again, most major projects experience this category of problems during the definition stage when compromises are made when defining goals, objectives and requirements.

Simple "systems" have the following characteristics:

- a small number of elements
- few interactions between the elements
- attributes of the elements are predetermined
- interaction between elements is highly organised
- well-defined laws govern behaviour
- the "system" does not evolve over time
- "sub-systems" do not pursue their own goals
- the "system" is unaffected by behavioural influences
- the "system" is largely closed to the environment.

Complex "systems" have the following characteristics:

- a large number of elements
- many interactions between the elements
- attributes of the elements are not predetermined
- interaction between elements is loosely organised
- they are probabilistic in their behaviour
- the "system" evolves over time
- "sub-systems" are purposeful and generate their own goals
- the "system" is subject to behavioural influences
- the "system" is largely open to the environment.

Exhibit 3.5.2 – Simple/Complex Problems

Coercive

Simple-Coercive relates to the "politics" of problems where there are real differences of interest as well as of values and beliefs, and where different groups seek to use whatever power they have to impose their favoured strategy upon others, ie, the relationships between the participants is coercive. Boardroom battles can often be described under this category (as will be shown in the Advanced Passenger Train case study) and only open debate may resolve intransigence.

Complex-Coercive is where Simple-Coercive problems are concealed by a complex web of interrelationships and where the participants refuse to reveal their interests during any project analysis. These problem types are particularly damaging to the success of a project as individuals may from the start be planning to "scuttle" the project for political or personal gain. Flood and Jackson use the metaphor "prison" for both coercive types.

Unitary
- they share common interests
- their values and beliefs are highly compatible
- they largely agree upon ends and means
- they all participate in decision making
- they act in accordance with agreed objectives.

Pluralist
- they have a basic compatibility of interest
- their values and beliefs diverge to some extent
- they do not necessarily agree upon ends and means, but compromise is possible
- they all participate in decision making
- they act in accordance with agreed objective.

Coercive
- they do not share common interests
- their values and beliefs are likely to conflict
- they do not agree upon ends and means and "genuine" compromise is not possible
- some coerce others to accept decisions.

Exhibit 3.5.3 – Unitary/Pluralist/Coercive Problems

The TSR2 Project (military multi-role combat aircraft) suffered problems from both the "Simple and Complex Coercive" categories. Williams et al (1969) revealed that there was never a consensus on the need for the project within government, and on the military requirement within the Ministry of Defence. During the design and prototype stages there were political forces at work to sabotage the aircraft project. The project definition, according to Williams et al, failed to identify all the issues involved and in 1965 the project was cancelled leaving the UK without an effective nuclear strike capability.

	Unitary	**Pluralist**	**Coercive**
Simple	S-U • operations research • systems analysis • systems engineering • systems dynamics	S-P • social systems design • strategic assumptions surfacing & testing	S-C • critical systems heuristics
Complex	C-U • viable system diagnosis • general system theory • socio-tech. • contingency theory	C-P • interactive planning • soft systems methodology	C-C

Exhibit 3.5.4 – Allocation of Methodologies to Problem Types

Following on from these definitions, Flood and Jackson (1991) identified the system methodologies that could be used to address each problem category as shown at Exhibit 3.5.4. Using the Flood Jackson matrix it is now possible to allocate project problems accordingly – see Exhibit 3.5.5.

It can be seen from these matrices that most of the problem types faced by project managers, particularly during project definition, cannot be addressed by hard system methodologies alone since they exist outside the simple/unitary grid and therefore there is good reason for using the soft system problem solving methods on projects.

By using the Flood and Jackson matrices it is possible to ascribe a problem to a category as shown, and then to employ the appropriate methodology (see exhibit 3.5.4) to reach a solution. The categorisation of problem types shown is the result of a detailed analysis of project problems identified by authors referenced in this thesis. The systems engineering method will be used to guide the project through its lifecycle, calling upon the soft system methods where appropriate.

	Unitary	Pluralist	Coercive
Simple	S-U • design • performance • resource management • cost/benefit analysis • schedule setting • quality assurance	S-P • setting goals and objectives • disagreement on way ahead • disagreement on changes • public enquiries • cultural differences • antagonistic relationships • contract negotiations	S-C • gaining political support • gaining boardroom support • achieving project approval (hostile boardroom) • intransigence
Complex	C-U • risk analysis • project-team morale • communications problems • managment & organisation • gaining commitment • technical uncertainty • social acceptability	C-P • compromising on objectives • compromising on requirements • compromising on performance • design trade-offs	C-C • hidden agendas • political gains or illogical or emotional foundation

Exhibit 3.5.5 – Project Problems Related to the Flood/Jackson Matrix

The MM Model will, therefore, draw extensively on systems methodologies to address messy problem situations encountered. In effect this thesis will generate a system of system methodologies for application to projects.

3.6 PROJECT MANAGEMENT AND OPEN SYSTEMS

3.6.1 Definition of the Open System

Katz and Kahn (1966) defined open systems as "open" to the environment, as opposed to closed systems that operate independently of their environment. In open systems, events rather than elements are structured; there is a constant energy and information exchange between the system and its environment; the system organises itself to minimise entropic decay; equilibrium with the environment is achieved through a process known as homeostasis; and there is a tendency towards differentiation. A project fulfils all the requirements of the open systems definition and therefore must be treated as an open system.

3.6.2 Projects as Open Systems

In order to fully understand the scope of the management required to control a major project as an open system it is necessary to define and manage the interfaces with interacting systems. Hitchins (1992) referred to the group of interacting systems immediately surrounding a project as the "containing system", with the project being referred to as the system of interest (SOI) . Every situation will be different but, as an example, a containing system (to be referred to in this research as the "wider system of interest" – WSOI) for a major project could include: other interfacing systems, the economic climate, competitors, suppliers, the owner, project finance, government, community groups, the media, local planning, and regulatory agencies. Hitchins (1992) noted that it was not possible to undertake a project in isolation from the WSOI as it becomes an integral part of the WSOI – see Exhibit 3.6.1.

Project managers have in the past either had a "down and in" philosophy for managing projects, or had their scope limited by their controlling organisation. The resulting effect being that they have only been concerned with the project and not the project as part of the WSOI. It is not surprising then that systematic failures associated with project size, complexity, technical uncertainty, schedule duration and urgency, physical and social environment, and government and politics have occurred. These systematic issues can only be addressed comprehensively by considering the WSOI (Hitchins, 1992).

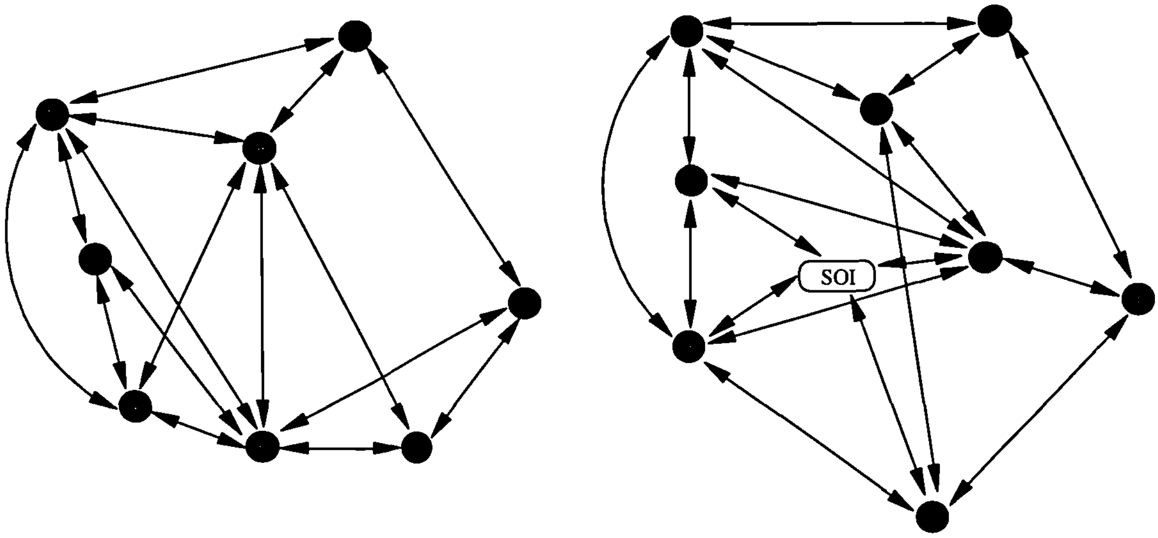

Exhibit 3.6.1 – Wider System of Interest (WSOI)

Accordingly, a project definition, as noted by both Hitchins (1992) and Morris (1989), should establish a project (the SOI) in terms of its WSOI. Furthermore, the course of the defined project can only be maintained throughout the project lifecycle if it is managed as an open system. In other words, project managers must also adopt an "up and out" management style in addition to the "down and in". The latter is sometimes referred to as the project director's role; however in this research, the roles of project manager and project director are to be considered synonymous.

3.6.3 The Three Levels of Project Management

Parsons (1960) identified three levels of management that were essential for any successfully regulated enterprise:

- the technical/tactical level (level III) design and manufactures the product
- middle management (level II) co-ordinates the design and manufacturing effort
- top management (institutional – level I) connects the enterprise to the wider system.

Morris (1989) noted that each of these levels had a fundamental role to play in managing projects (see Exhibit 3.6.2).

The distinction between levels I and II is critical since it is the distinction between the project and the outside world (the SOI and the WSOI). Levels II and III deal almost exclusively with the familiar project activities such as engineering, procurement, installation and testing; level III with a technical slant, and level II with a technical management/project management slant. Level I provides the co-ordination of the project with the outside events and institutions, ie, managing the interfaces between the SOI and the other systems in the WSOI.

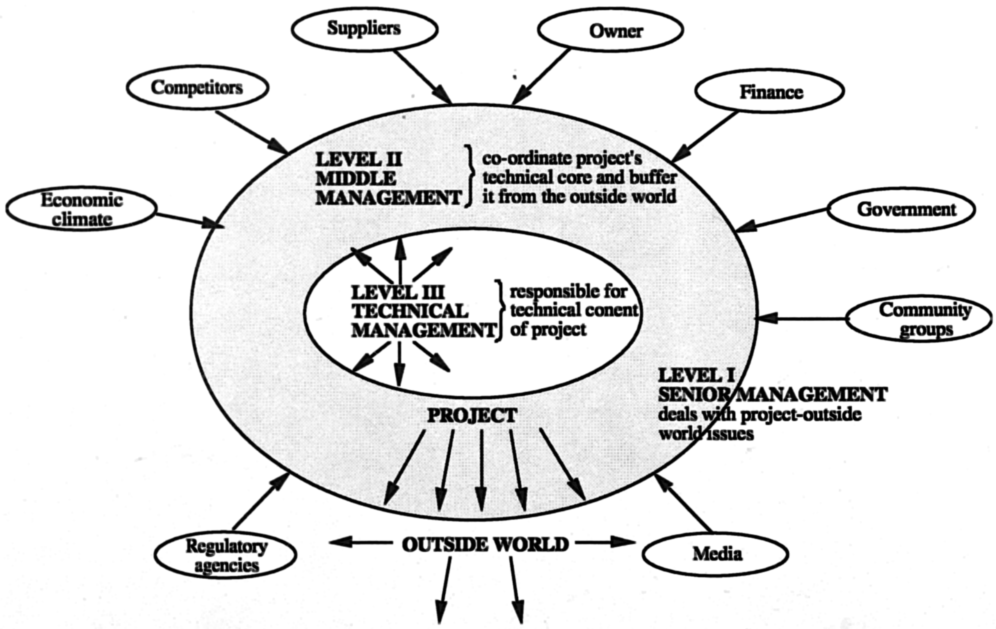

Exhibit 3.6.2 – Three Levels of Project Management

The work at these distinct levels of project management activity tends to follow a pattern that is similar on many projects (Morris, 1989). At the project to outside world level, ie, from the SOI to systems in the WSOI, the concern is to ensure that the project is commercially viable and that it is established in the WSOI in a stable manner (Hitchins, 1992). In order to achieve this levels I and II management will:

- establish the project's objectives and requirements by reference to the WSOI
- ensure that the project is defined in commercial terms within the WSOI

- define a stable organisation structure for the project within the WSOI
- define the interfaces between the project and all systems in the WSOI
- facilitate controls with other systems within the WSOI
- plan for the necessary changes within the WSOI to accept the project.

The effects of the WSOI on the project can be profound; of particular interest (Metcalf, 1974) is the problem of how organisations behave in a constantly and rapidly changing environment. Management scientists describe such environments as turbulent and call the type of systems that operate in them "multi-stable". Morris (1989) noted that large or complex projects, in particular, suffer many of the consequences predicted for multi-stable systems, such as system interaction, continuous objectives redefinition, rich internal feedback processes, high impact of external factors (often causing the SOI to have to act in an apparently less than rational way) and substantial organisational change, often of step-function size. These characteristics can be found on major projects such as the Advanced Passenger Train and the Rolls Royce RB211 (see case studies in Chapters 6 and 7).

At the internal SOI level work focuses more on delivering the project (Morris, 1989). In order to achieve this management levels II and III will:

- implement the organisational structure needed to execute the project
- realise the project definition
- provide adequate infrastructure and logistics to accomplish the project
- minimise external disruptions from the WSOI.

Problems occurring in projects require resolution within short time frames, organisational conflicts abound and compromises are inevitable. In such an environment, the boundaries can become blurred and therefore management of the interfaces within the WSOI take on greater importance (Morris, 1989). An example of this theory in action was "The Trans Alaskan Pipeline System" (TAPS) Project; it still remains one of the largest and most ambitious of recent major projects ($8bn, 1974 to 1976). Moolin and McCoy (1980) described how senior management was required to concentrate on a series of strategic interface issues of startling variation. Firstly on environmental engineering, how hot oil could be prevented from damaging the Alaskan permafrost and how the design could mitigate seismic damage. Secondly on mobilising political support for the project, the level I project management team moved to Washington DC to advise the political effort. This resulted in the 1973 TAPS Act, in an effective infrastructure being established (transportation, camps, equipment supply and union negotiations, etc), in an effective organisation being established that could cope with WSOI issues, and in conforming with appropriate environmental regulations.

The sequence of handling the issues is worthy of note: firstly, agreement on the technical concept was reached, and political support for the project was secured; secondly, an adequate infrastructure and organisation was established; and thirdly, environmental, construction, and engineering issues were resolved as they arose through the agreed organisation. This is essentially the institutional, strategic and tactical sequence already noted as typical for all projects (Morris, 1989). The level II management was centred on resolving engineering and construction problems or on issues concerning the internal project.

Morris (1989) made three important organisational observations about managing major projects as open systems. Firstly, projects require a centralised organisation during project definition in order to establish interfaces with the WSOI, a decentralised organisation during production for the control of all work but with due monitoring and control of the interfaces, and return to a centralised organisation for operations start up. Secondly, the project organisation must change according to the needs of the project's size, urgency and complexity. Thirdly, once decentralised, projects require a substantial management infrastructure to effect the necessary co-ordination in an open systems environment.

3.7 SUMMARY OF THE IMPORTANT POINTS EMERGING FROM CHAPTER 3

In satisfaction of Objective 2, a comprehensive summary to the background to hard and soft systems approaches was provided. Through an understanding of the methods and techniques of these systems, it was possible to understand how the application of the systems approach could unite with those of project management to define a project for success. M'Pherson's Model for System Design was shown to be an appropriate foundation for applying the systems approach to projects, as it comprises many of the techniques and processes required for defining projects. The model's weakness for this research, however, is that it concentrates on a project's product design thus giving less emphasis to a project's management design – both are equally important for a thorough project definition. This Chapter concluded with a discussion on why projects should be managed as open systems and it identified approaches needed to implement open system management.

From the topics covered to meet the objective five important points emerged that must be considered during the development of the MM Model:

- a project can only be evolved through a time-related development methodology as provided by systems engineering, and other hard systems methodologies such as systems analysis can assist with the design processes
- M'Pherson's Model is appropriate as the foundation for defining a projects product and for assisting with a project's management design
- hard systems methods cannot deal with the ill-structured or messy problems that are encountered though the project evolution, particularly those that occur during the project definition, and that certain soft-system methods must be employed

- the Flood & Jackson matrix for a system of system methodologies helps to select appropriate soft system tools and methods to solve project problems and thus provides a key to future success
- projects must be managed as open system if they are to be successful, and therefore the MM Model should be fully cognisant of the concepts required.

There is a need for further work, beyond the scope of this research, to develop the new IEE and IEEE standards into a formal methodology for systems engineering. Furthermore, it is necessary for an in-depth investigation to be undertaken into the successes and failures of applying systems engineering, and indeed other systems approach methodologies, within projects in order to determine how better the systems approach may be applied to real situations. Moreover, there is a need to research the application of the systems approach to world aid programmes. This latter suggestion for additional research would greatly enhance the work undertaken in this thesis and would be truly complimentary to it.

CHAPTER 4 PROJECT APPROVAL

4.1 INTRODUCTION

Projects are often initiated by individuals with a dream or vision, but in order to be successful projects must also have to be based on a solid business or public need. Assessment of the strength of the need for a project can only be achieved successfully through a formal project approval process that reviews all of the factors that either support or oppose the case for undertaking the project. The primary aim of this Chapter is to understand the decision-making activities in the project approval process in order to identify the information that must be provided from a project definition for good decision making.

This Chapter addresses Objective 3 through six major sections. The first, Capital Investment in Projects, describes Pike's Project Approval Framework which provides the thread to the business and financial part of this research. The next five sections (Investment Decisions, Public Projects, Financing of Major Projects, Quantitative Methods and Project Risk) add new dimensions and enhancements to Pike's thinking by introducing findings of other authors and researchers on related topics. It is not the intention in the Chapter to study each of the subjects in depth but with enough scope to identify activities and considerations which should be included in the project definition.

4.2 CAPITAL INVESTMENT IN PROJECTS

4.2.1 Pike's Project Approval Framework

Most capital budgeting texts place emphasis on a limited set of activities within the overall capital investment decision process such as the selection of the evaluation method, handling risk and setting of hurdle rates (rate of return). King (1975) stated that this emphasis was misplaced and suggested that a more systematic and complete project approval framework should be employed that took account of all business[1] activities involved in a structured manner. A suitable framework was later put forward by Pike (1983) which described a capital investment programme as being a well structured business system, see Exhibit 4.2.1. The information input to Pike's Framework is a qualified list of available investment opportunities that has been drawn up from an approved business strategy, and from assessments of the current business environment normally undertaken as a rolling strategy update. The seven steps in the Pike's

[1] For the purpose of brevity and to avoid confusion public and business needs will be treated as synonymous. Specifics of public sector projects will be addressed at Section 4.4.

Framework are now described in detail with appropriate comment added from other researchers.

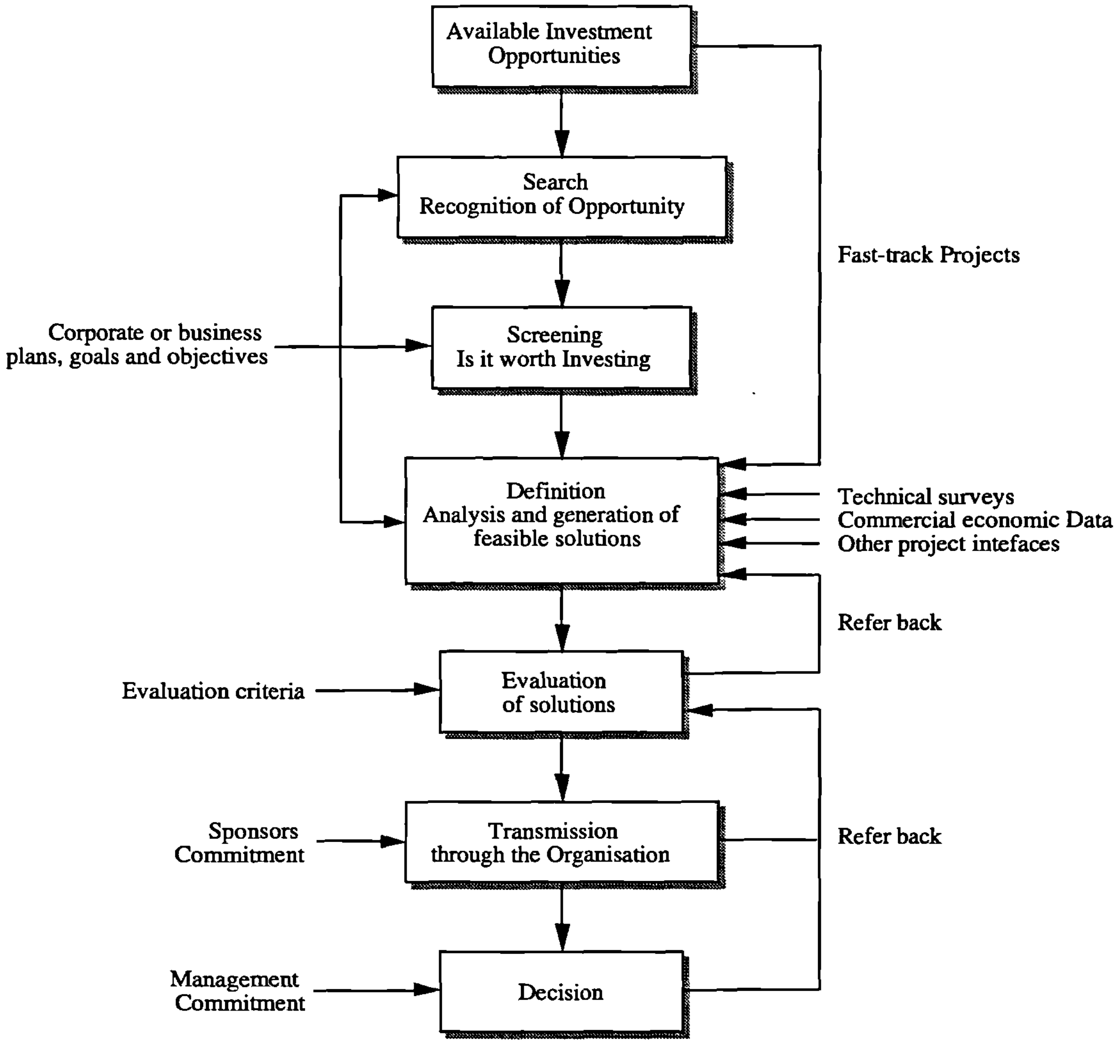

Exhibit 4.2.1 – Pike's Project Approval Framework

Search. Investment planning requires a continuous and systematic search for investment opportunities that fall within the stated business or corporate strategy of an organisation; ie, limiting the scope of the input list. Pike (1983) described effective investment planning as one that stimulated ideas and encouraged managers to generate proposals in line with corporate strategy. After all, the success of any business or enterprise depends on its abilities to identify and implement beneficial opportunities; unless a business is particularly good at this it will be on the path to failure (Barnes, 1991). However, all too often investments arise only in response to problems that a business is currently experiencing (Cyert and March, 1963). Moreover, King (1978) observed that many initiated projects could not be associated with any business or corporate goals and objectives, and that some project funding levels could not be reasonably justified in terms of the expected benefits. He also noted the existence of fault linkages between corporate plans and the projects through which the plans were being implemented, which highlighted the need for a synchronised capital investment decision process that commenced with a disciplined but innovative search activity.

Screening. Each investment proposal becomes the subject of a preliminary screening exercise where alternatives are generated and reviewed in order to identify those that are sufficiently attractive to warrant further analysis. It is neither feasible nor desirable to conduct a full-scale evaluation of opportunities at this stage. Proposals should, however, be screened to ascertain whether they are compatible with corporate or business plans, the resources required are available, the ideas are technically feasible, and the expected returns are adequate for the risks involved. In project lifecycle terms this element of work can be categorised as the Feasibility Study (Assad and Pelser, 1985). At this stage proposals or initiatives may be categorised as projects and taken forward or dismissed.

Definition. The definition of a project involves the evaluation of technical options for meeting the business requirement in terms of cost, benefit, time and risk. However, the project definition can only be meaningful if it is undertaken to meet corporate or business plans, and that goals and objectives are derived from the stated mission – in other words the project's mission must be coincidental with the corporate or business mission (Slevin and Pinto, 1987). Morris (1989) went further by stating that not only should the project's goals and objectives be clear and properly derived, but they should also be feasible. Bardach (1977) argued that setting objectives correctly was one of the most important initial activities to be undertaken during a project definition; a point later to be emphasised by M'Pherson (1980) and Hitchins (1992).

A project may also be classified for ease of evaluation (see evaluation criteria below) thus permitting it to be ranked against other projects in the competition for limited funds (Piper, 1980). A key ingredient therefore to a project's success is the project definition as it is during this activity that commercial, economic, technical solutions and risks are assessed and, more importantly, management commitment is gained. Aharoni (1966) observed that the project definition also led to implicit management commitments. He claimed that in order to collect all the required information for a project definition, it was necessary to communicate with people, to make certain decisions, and often to give tacit promises. During the project definition, commitments accumulate until a situation is created that leads inevitably to investment agreement.

Evaluation. The evaluation stage involves assembling and analysing the data from all project definitions in order to produce an optimum project mix. At this stage an organisation must decide which capital budgeting model to use for the evaluation. Pike (1983) described a good model as one which offered flexibility and was easy for managers to understand, yet sufficiently comprehensive to embody all the features necessary to produce the data for effective decision making (see also Vandell, 1973). Souder (1978) and King (1978) argued the need for a model to select a portfolio of projects that could best deliver corporate benefits as a whole. They added that it was important for the long-term future of any organisation to select only the very best projects; inferior projects, or those that did not fit within the portfolio should be filtered out as early as possible. King (1978) proposed the following criteria for identifying candidate projects; they should:

- take advantage of a strength that the company possesses
- avoid a dependence on something that is a weakness of the company
- offer an opportunity to attain advantage over competitors (Porter, 1980)
- contribute to the internal consistency of existing projects/programmes
- address a mission-related opportunity that is presented by the evolving market environment.

Sounder (1978) suggested a model for project portfolio analysis that was later enhanced by Ferns (1991) as shown at Exhibit 4.2.2. The model also provides the mechanism for addressing the resourcing complications suggested by Archibald (1976). A similar model was developed by Anderson (1994) which employs automated optimisation tools.

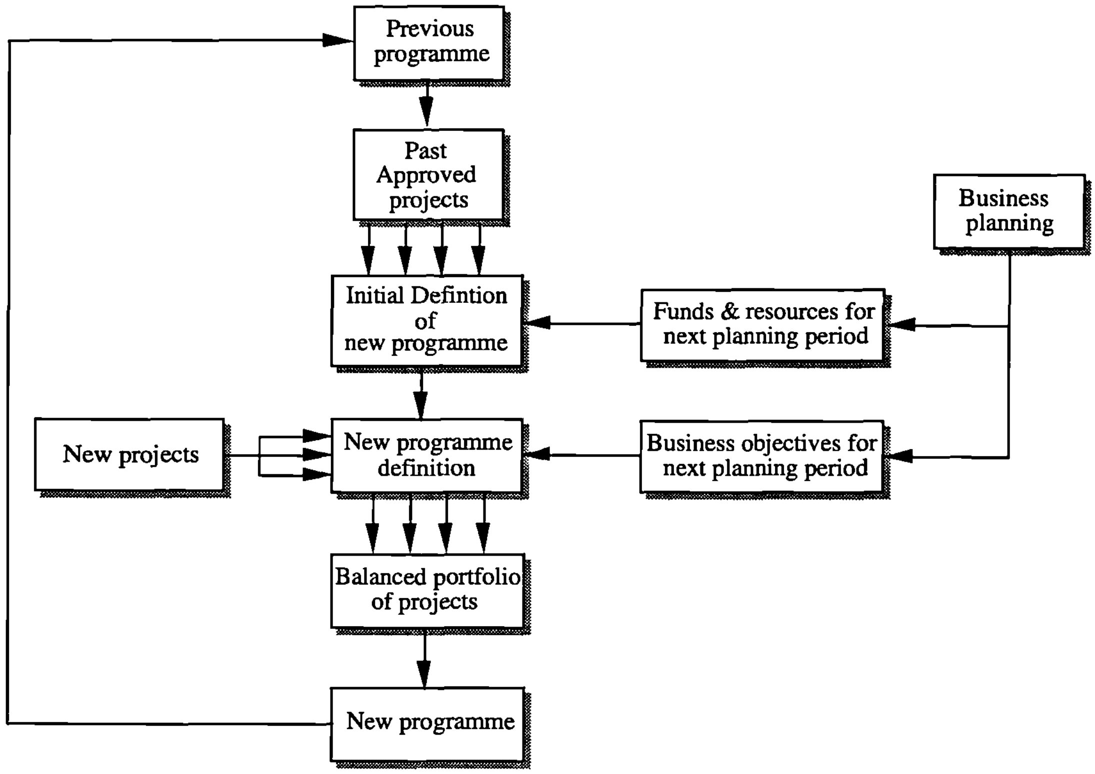

Exhibit 4.2.2 – Business Cycle Programme Management Model

King (1978) emphasised that the critical element of the evaluation approach was its use of criteria that ensured that a portfolio of projects could be integrated with the mission, objectives, strategy, and goals of the organisation together with criteria that reflected critical elements of strategy such as business strengths, weaknesses, comparative advantages, internal consistency, opportunities and policies. A project definition must provide all the necessary data for effective portfolio analysis. Archibald (1976) observed that it was rare to find a project that existed by itself without interaction with other projects. The multi-project environment (programme) commonly found in large organisations imposes resource allocation complications, and so the requirements and priorities of individual projects must be brought together in order to ensure benefits as a whole are delivered to the organisations (ie, portfolio analysis), see Anderson (1994).

Approval and transmission. Following the evaluation stage, proposals are transmitted through the organisation for approval. However, Cooper (1975) saw the approval stage for most organisations as a formal endorsement of commitments already given. This last point will be addressed again Section 4.3 – Investment Decisions. After a project has been approved, periodic reviews are required to ascertain that expectations are in line with plans. Pike (1983) noted that above all the most crucial element of the total project approval process was the human element. He further noted that a good process was one that allowed managers to make better decisions through encouraging the creative search for proposals by asking appropriate strategic questions, by providing better assumptions, by employing robust yet comprehensible evaluation models, and by providing central information and feedback on the progress of projects.

4.2.2 Assessing the Benefits of Project Portfolio Analysis

Sharp (1991) claimed that the threat to business competitiveness lay not only in the possibility that managers would select investments that turned out to be unprofitable, but that they would fail to undertake very risky, but strategically vital investments. He described a classic dilemma; if managers blindly followed the framework described above they may reject prospects that could be strategically important because the NPV analysis was not favourable. On the other hand, if they followed their instincts and experience, they might override the formal quantitative NPV analysis with the nebulous justification that the project must be undertaken for strategic reasons. The inevitable witch hunt would follow if the project subsequently experienced problems or failed.

Sharp's premise rests on two notions; well-informed, experienced managerial judgement is an excellent practical substitute for commonly accepted quantitative methods; and managerial judgements must be embedded into the formal project approval process. If managers can identify options, and if they understand the circumstances under which they would exercise them, then their judgements should be heeded. An option in this context is the ability, but not the obligation, to take advantage of opportunities available at a later date that would not have been possible without the earlier investment. These are commonly called intangible benefits as opposed to that which can be measured directly in money terms.

It is possible to think of these options as analogous to ordinary call options on securities (Myers, 1977). Security options give the owner the right, as distinct from an obligation, to buy a security at a fixed predetermined price (called the exercise price) on or before some fixed date (the maturity date). By way of analogy, a discretionary opportunity to invest capital in productive assets at some future point in time is like a call option on real assets. Like call options on securities, growth options can be applied to project investment. Indeed, Parker and Benson (1988) employed this approach to win approval for strategic information system projects that had initial negative NPVs by placing option values on information held; they referred to the concept as information economics.

Sharp (1991) described two types of options. The first type was incremental in nature; options of this type provided the business with opportunities down-stream to undertake additional profitable incremental investments. The second type of option was generated by flexibility; these options made use of investment that was already in place. The use of these options might allow the company to generate cash flows in addition to those explicitly included in the investment appraisal.

The complexity of incremental and flexibility options, their role in shaping a company's strategy, and even their impact on the survival of the organisation all demand broad analysis (Kester, 1984). An organisation must consider each project as part of a cluster of projects or as a stream of linked investment decision that extends over time. The preparation for this analysis should be undertaken during the economic evolution stage in project definition, although the cluster analysis will be undertaken during the evaluation step of Pike's Framework. Kester (1984) identified the following additional evaluation questions:

- would particular options bring the right investment opportunities in the right markets in the right time frame?
- would a company capture the option's benefits for itself or would they be available to its competitors?
- which portfolio of projects best fitted the company's overall mission after all options had been considered?

Kester (1984) also noted a key advantage of the options perspective is that it integrated capital budgeting with long-range planning. Because investment decisions today can create the basis for investment decisions tomorrow, capital allocations made in any year are vital steps in the ultimate achievement of strategic objectives. This emphasises the importance of selecting the right projects which underlines the importance of the project definition where the greater part of the analysis is performed. However, another perspective to investment decisions was given by Dixit and Pindyck (1993) where they stated that an irreversible investment expenditure closed down options for investing in future, perhaps more worthwhile, opportunities. They went on to state that the cost of investing (ie, the lost opportunity cost) should be included in the investment calculations.

4.2.3 Projects Undertaken by Project Companies

Many companies can be described as project companies, ie, their business is about contracting to build facilities or equipment for other companies or government bodies; eg, civil engineering companies, defence contractors and major electrical and electronic suppliers. These companies will tender against a formal specification for work normally in a competitive situation. A company bidding to undertake contracted projects will have to decide if its involvement in the project will yield a good return on investment. There may be a number of investment opportunities available and the company may have other contracted projects it is undertaking. Resources will be limited and therefore, like other organisations, the project company will have to decide whether the investment opportunity is worth pursuing. Following receipt of an "invitation to tender" a project company will undertake a project economic appraisal as part of a short project definition. The project definition will form part of the preparation of its tender document. Dixit and Pindyck's (1993) principles apply well to project companies in which investing in a contracting project with a low return on investment (ROI) could close down high ROI opportunities in the future owing to limited resources or funds. Dixit and Pindyck's treatise on Investment Under Uncertainty should be considered carefully for such business operations.

Following a review of a number of project company's bidding procedures, it is concluded that Pike's Framework (1983) will suffice for project companies as the same steps are followed. Indeed, to a large extent, project companies will also look at a portfolio of opportunities in a similar way described to that by Ferns (1991) and Taylor (1994).

4.3 INVESTMENT DECISIONS

4.3.1 Background

It is important to review how project investment decisions are made in order to identify management involvement in the various stages of Pike's Project Approval Framework.

Copeland et al (1983) noted that within the context of a company, modern finance theory described how capital investment decisions should be made, assuming the aim was to maximise the value of the company to its shareholders (see also Moynihan, 1994), and that strategic planning theory described how resources within a company should be allocated. However, Barwise et al (1987) discussed how both modern finance theory and strategic planning theory had evolved in almost total isolation, and neither aimed to reflect closely the actual process of investment decision making. Within the two theories, financial economics is concerned with actual investment decisions culminating in project selection within the overall company investment programme, and strategic investment decisions (SIDs) are characterised as being a once-off top management deliberation for project approval. There was also an assumption, according to Hedley (1977) that investment in projects could be subordinated to prior definitions of strategy, but Marsh (1988) argued that this assumption was not always the case which emphasised that the link between strategy and specific decisions to invest was not always clear.

When considering SIDs the organisation's structure must also be considered (Barwise et al, 1987). Many large and diversified organisations are hierarchically structured with final authority for major investments vested in corporate management. Barwise et al (1987) described a dilemma here since most strategic development originated in subordinate strategic business units (SBUs) or divisions (see Exhibit 4.3.1).

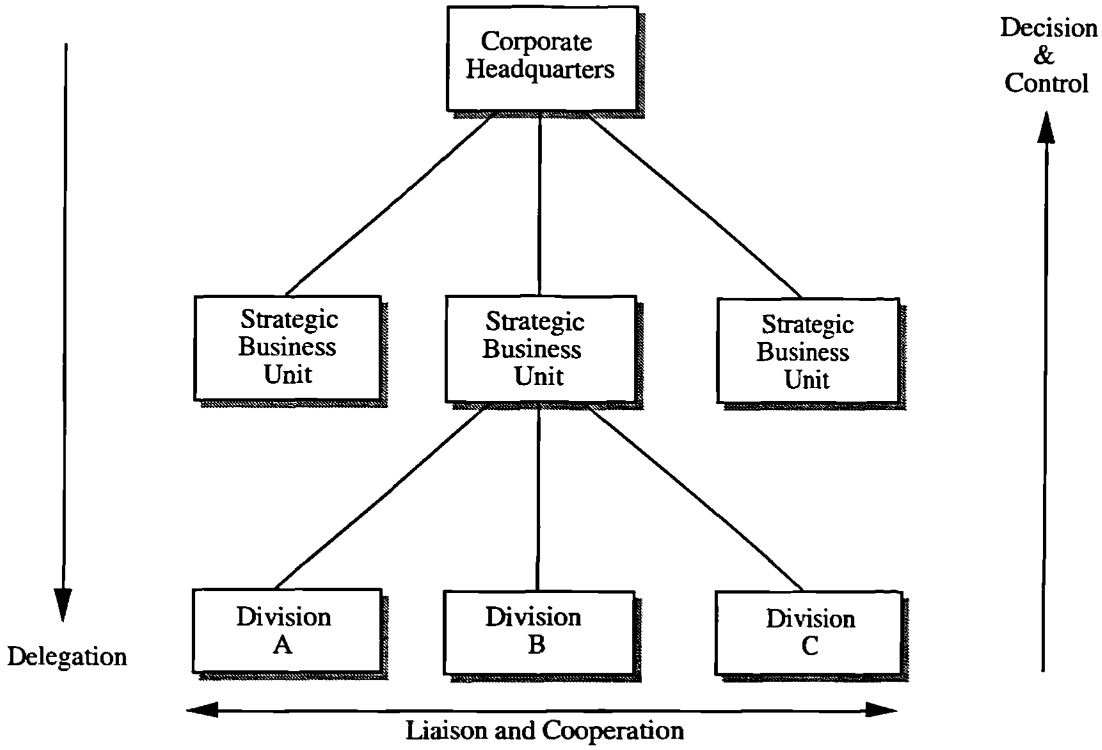

Exhibit 4.3.1 – Typical Corporate Structure

Most of the process for analysis of investment appraisal occurs at divisional level within designated project teams. However, final responsibility for the investment decision rests with corporate management, not with divisional project teams. Top management therefore faces the classic dilemma of decentralised organisations; how to delegate effectively while still retaining responsibility and control[1].

4.3.2 Early Work on Strategic Investment Decisions

The most widely cited studies into SIDs were undertaken by Bower (1970), who tracked four investment decisions in a large diversified US company, and by King (1975, 1975a) who tracked three investment decisions in two large companies. However, other authors have made valuable contributions to the mechanics of SID-making as will be noted here.

[1] The approach to investment decisions for public sector or government projects is similar to private sector projects and so the descriptions in the Section apply in general. Specifics associated with the public sector are addressed in the next Section.

These two important studies highlighted the importance of process, and they stressed that decision making was an incremental activity, taking place over an extended period of time, involving many people at different organisational levels. Bower and King (and Mintzberg et al, 1976) described models that typically viewed the decision-making process as a sequence of stages, beginning with the idea and progressing it through to final approval. This sequence tends to map onto the organisational hierarchy; although top management retains the formal responsibility for final approval, the real decisions are effectively taken much earlier, further down in the organisation.

King (1975) emphasised the critical nature of the early stages of SID-making. He identified the need to overcome manager's in-built reluctance to initiate capital projects, since these projects could mean considerable work and personal risk. Once initiated, the technical and economic characteristics of a project have to be identified and defined. King (1975) found that only one or two options were seriously evaluated, with the eventual selection being based on limited information and restricted criteria. Williams and Scott (1965) observed that a project proposal was likely to be approved unless the evaluation was very much against it. But worse, King (1975) and Sihler (1964) noted that few projects were ever rejected at the investment decision stage as this would indicate a vote of no-confidence in the judgement of those closest to the problem. This last point will be demonstrated by the British Rail Advanced Passenger Train case study.

Bower (1970) took a different view, he argued that a project progressed upwards towards funding only if a high-level manager sponsored it. The level of sponsorship would depend upon the reputations of the managers involved (Bower (1970), Williams and Scott (1965), and Aharoni (1966)). Bower continued, attitudes towards SIDs were also influenced by formal management systems, and by the way managers and businesses were monitored, evaluated and rewarded. Furthermore, these systems would be subject to management control; therefore, top managers should be in a position to manage the SID-making process through control of the organisation.

Schulty and Slevin (1975) found that the level of management support for projects was of great importance in distinguishing between their ultimate success or failure. However, Hanley (1975) showed that the degree of management support for a project was directly related to the level of ultimate acceptance or resistance to the project. Management support for a project will involve the allocation of sufficient resources (financial, manpower, time, etc), but it is also necessary for a project manager to have confidence in its support in the event of crisis (Slevin and Pinto, 1987). Furthermore, Beck (1985) saw project management as not only dependent upon top management for authority, direction and support, but as ultimately the conduit for implementing corporate strategy.

Based on the early work, Marsh et al (1988) identified three broad conclusions concerning strategic investment decisions:

1) The process was complex but could be characterised as a series of time-related stages, the earlier stages being of most importance as they established the conduct for

the remainder of the process. The traditional emphasis on the final approval stage was therefore seen as misplaced (King, 1975; King, 1975a; Pinches, 1982).

2) The process must be seen as part of a wider political context, embracing potential differences of interest between groups within the organisation, and the personal stakes of managers. Estimates and forecasts could not be isolated from the individuals and groups that provided them (Bower, 1970).

3) All stages of the process were interrelated and would to some extent be influenced by the structural context, including the formal organisation, and the systems of information, control, performance measurement and reward (Carter, 1971; King, 1975; Sihler, 1964; Berg, 1963).

Against the backdrop that the earlier studies were too limited in scope, ie, they paid little heed to mainstream financial economics and business strategy, a number of more recent broader research-based strategy studies have been undertaken. Specifically, studies by Pettigrew (1985) and Mintzberg (1987) found that SID-making was becoming a recognised process within the context of overall strategic planning.

Marsh et al (1988) in their recent research project observed that previous studies provided a useful framework for SID-making but they also had certain limitations which had to be recognised. "While they have much descriptive validity, they have more to say about process than analysis, and they play down the economic perspective". All SIDs involve analysis and will at some stage be formulated in financial terms, eg what will be the return on investment (ROI). The metrics associated with this analysis will be addressed later in this section. The Marsh research looked again at the SID-making framework, but this time with the aim of linking SID-making with the financial, strategic and organisational functions of business.

4.3.3 The Marsh, Barwise, Thomas, Wensley (1988) Research Project

This recent research project explored both the analysis and process of SID-making within three large diversified UK companies (Marsh et al, 1986). The researchers were concerned not only with how managers structured SIDs (in terms of options, assumptions and criteria), but also with the types of communication that took place, and the ways in which an emergent project changed and developed over time. The three projects chosen were large capital investments that originated in one of the organisation's divisions, but that needed board approval. In each case, the projects selected were at an early stage with many options and uncertainties still to be resolved.

The first project involved backward integration via investment in manufacturing capacity. The second was an investment in mechanical handling and packaging equipment. The third project involved the restructuring of a distribution network for fast moving consumer goods (FMCG). Based on their findings the researchers addressed four questions:

1) Did the investment decision flow from a prior strategic plan, and if not, what was the role of planning and strategy (Formal Planning)?

2) In what ways, if any, did the capital budgeting procedures adopted affect the ultimate decisions taken (Capital Budgeting Systems)?

3) Did corporate management really make the decisions, and if not, what role did they play (Senior Management's Direct Role)?

4) In what ways did the formal organisational structure/context and climate impact on the decision-making process (Controlling the Organisational Context)?

The Research Report provided a review of the conclusions reached for each of the questions posed.

Formal Planning. Explicit strategic planning, even at divisional level, had only limited impact on SIDs that were proposed and accepted. Moreover, the influence of group strategic planning was minimal. But it has been shown that SIDs should be taken within the overall strategic planning framework otherwise the resulting project's goals and objects may not be aligned with those of the business (King, 1978). This research will use King's findings.

Capital Budgeting Systems. Formal capital budgeting systems did influence reality. The systems forced those involved to be more explicit about the assumptions being made and options available in order to justify the projects. Financial analysis guided the decision process. The formal approval systems forced the pace of the project, provided the schedule for senior management reviews, identified the paths for communication and provided the project team with the basis for planning the project evaluation, and for building their personal commitment to its success. Therefore, this research will build the project definition into a formal generic capital budgeting system.

Senior Management's Direct Role. Marsh et al found that direct interventions by top management were more widespread and influential than Bower (1970) and King (1975) seemed to have observed – perhaps this was due to better management education becoming progressively more widely available over the 15-20 year period (Kelly F and Kelly H, 1986; Peters and Waterman, 1982). The researchers could not resolve the extent to which these interventions were part of a systematic approach, perhaps driven by the formal approval systems (see Capital Budgeting). Gould and Campbell (1987) have however found signs of a systematic involvement by top management. This research will build in the hooks for top management involvement during the project definition.

Controlling the Organisational Context. It was found that the organisational structure introduced several facets of parochial behaviour. Firstly, divisions tended to want to grow within their boundaries, although this implied that they might miss opportunities perceived as being outside their domain. Secondly, projects tended to favour the originating division, and project teams appeared to identify strongly with their own division's performance; thus they linked their own career prospects to that division.

Finally, growth seemed to be an important factor determining manager's morale. The very act of going ahead with new investment was seen as a positive influence on the divisional climate. What is important here is that projects may not be initiated on a firm foundation if the parochial behaviour is allowed to dominate over corporate need. In this research, the emerging project will be tied firmly to the business or corporate goals (or indeed a public need) and objectives, thereby reducing the effects of any parochial behaviour.

In conclusion, Marsh et al (1988) claimed that the implementation of business strategy through feasible projects was the key to success. Bower (1970) noted that an operational definition of strategy required a theory of implementation as a precondition. The definition of a project must therefore be within or an overall business framework.

4.4 PUBLIC PROJECTS

4.4.1 The General Case

Many large capital projects are undertaken by central government; these fit naturally into three major categories: (1) projects that support the running of the government machine, (2) projects that support the national infrastructure, and (3) projects for military equipment acquisition (Elder, 1989). In the UK, the Government's New Management Strategy (1988) and Financial Management Initiative (1983), set out financial responsibilities for all government departments including project expenditure. This Section addresses the specifics for investment decisions for UK government (or public sector) projects that are mainly associated with public accountability. The public accountability requirements in the UK are similar to those in operation in most European countries and in the USA; only UK project approval processes are considered in detail.

Controlling the expenditure of a government department is under the custodianship of that department's senior management, with a permanent secretary ultimately responsible (the Ministry of Defence has special arrangements – see below). It follows that decisions on which projects to fund and the make-up of the portfolio of projects will be made by senior management. In order to maintain public accountability, expenditure on capital projects is nearly always referred to the Treasury via the Minister responsible for that department; however, the department has powers delegated to it by Treasury to incur commitments of expenditure without specific reference to the Treasury. Projects that have a social or political impact are often further referred to the Cabinet for approval.

Capital investment decision making in government projects appears to follow the framework suggested by Pike (1983). However, each department has its own management procedures for handling projects; eg, Department of Transport (DTp) has its COBA 9 (1981) procedures, and the Department of the Environment (DoE) has its Financial Management Handbook (1990). A comprehensive list of all relevant documents in this area can be found in Stringer (1991). But central to all is the HM

Treasury's Green Book (1991). This Book provides guidance on the systematic economic appraisal of expenditure decisions. Techniques for appraisal have been developed mainly in the context of decisions on capital expenditure, but the general principles apply to any proposal for spending, saving money or involving changes in the use of resources. Two reference texts that are sympathetic to public sector economic appraisal (Misham, 1988; Pearce and Nash, 1981) spell out the necessary analysis to be undertaken during a project definition. The analysis differs in the areas of social appraisal and public accountability. Any project definition model meant for both public and private appraisals will need to take account of the differences.

For information technology projects the Central Computer and Telecommunications Agency (CCTA – an agency controlled by HM Treasury) has developed "Information Systems Guides" (1989). These Guides provide departments with the information needed to procure information systems. For the purposes of this research the interest lies in the specific Guides associated with the Feasibility Study (B2), the Fully Study (B3), and Appraisal Investment in Information Systems: Examining the Options (B4).

4.4.2 Defence Projects

Owing to the considerable sums of money involved in defence equipment acquisition, the Ministry of Defence (MoD) has developed specially focused Equipment Approvals Committee Procedures (1992). Ministers are ultimately responsible for the defence equipment programme. They have to account to Parliament for the decisions that are taken on the balance of investment within the programme; the priorities attached to particular Service requirements; the military capabilities that are developed and produced; value for money in equipment expenditure; and, if relevant, the industrial dimension, including export potential. In 1994 the value of the defence equipment programme was £34bn (NAO, 1995).

Defence equipment investment decisions have to be taken in the face of considerable uncertainty about the environment in which the equipment will operate during its life, and about the technical risks associated with state-of-the-art technology. They involve complex judgements about when to replace systems and about the mix of systems to be deployed. For these reasons, it is important that the critical facts and judgements that underlie equipment proposals are made available to Ministers and those who have delegated authority to approve equipment proposals.

No major expenditure on equipment can be committed by the MoD without first establishing by means of thorough scrutiny the military, technical, financial, and managerial validity of programmes individually in relation to other programmes and in relation to broader issues of defence policy and the resources, as expressed in the MoD's long- term costings.

The Equipment Approvals Committee (EAC) is both the highest level approving authority below Ministers and the focal point for providing advice to Ministers for equipment decisions that exceed its delegated authority. In addition, the EAC is responsible for promoting organisational procedures that allow business to be carried out efficiently and ensuring that all those with a legitimate interest in a particular project are consulted before decisions are taken. Despite the EAC's special role in defence procurement, its investment decision-making process follows the principles laid down by Pike (1983) and SIDs follow the findings of Marsh et al (1988).

4.4.3 Projects that Require a Private Bill or Public Consent

Most government projects can be managed through the procedures and guidelines in place; however, additional work and specific funding is needed for infrastructure projects that involve a private bill or public consent (inquiry), since it is these projects that are open to most scrutiny from national and local press, pressure groups, the Public Accounts Committee (PAC) and the National Audit Office (NAO). Projects in this category include major road schemes, road bridges and tunnels, rail links and airports.

Stringer (1991) claimed that the form of consent likely to be required by most of this category of projects was planning permission under the development control provisions of the Town and Country Planning Act 1971 and subsequent subordinate legislation. The project's sponsor must be aware that procedures and processes leading up to the granting or withholding of public consent are significant sources of uncertainty and delay and hence of cost and could deter otherwise viable projects. Shifts in public attitudes and changes in the consent processes themselves, add to the uncertainty. The larger the project the more likely it is that controversial issues will emerge, and the more hazardous it will be to rely solely on prior experience.

Sir Bob Reid (Reid, 1991) reviewed the difficulties facing major infrastructure projects, illustrating them from the experiences of British Rail. Such projects, he argued, were disadvantaged at the outset by the adversarial nature of British politics but the hurdles of political process were unavoidable given that the government is necessarily involved in major infrastructure projects. However, gaining Treasury sanction is never easy nor is avoiding the pitfalls of presenting a project at too high or too low an overall costing. Thus, the prudent course for the sponsor was to regard the problems of gaining consent as a vital and non-routine aspect of management based on a sound project definition.

Stringer (1991) suggested a model for the consent process – See Exhibit 4.4.1. The model comprises two phases; the Full Project Definition and the Public Inquiry. Stringer also identified the activities to be undertaken by the project definition – these are detailed in Appendix 9. The activities marked with an asterisk are those that differ from both the Morris and the M'Pherson models, and so therefore must be considered for the MM Model if it is to be used generally. The starting point in Phase 1 of Stringer's model is the basic project definition where key elements of the project are identified and assessed. It should be borne in mind that the whole of Phase 1 is aimed at getting the project definition right, in terms of public acceptability, for the public enquiry. In close harmony with the initial project definition is the specific identification of factors that could be involved in gaining consent.

In parallel to the consent factor activity, work should continue on all "other factors" such as engineering and finance. In other words, according to Stringer, the initial project definition was progressively enhanced as the consent planning process proceeded, thus making good use of information as it became available. Following an assessment of consent risks and the identification of mitigators; ie, measures that might be taken to ease consent problems, a consent strategy was formulated. Stringer made the point that no two consent strategies were the same, but experience and good preparation would assist a successful outcome. After a review of evidence the sponsor together with specialists may decide to abandon, redefine or proceed; ie, apply for consent.

The inquiry process is more linear than the definition processes and therefore can be managed to an existing framework. An important aim of the definition (Stringer, 1991) is to be complete and comprehensive in order to ease the passage of the inquiry.

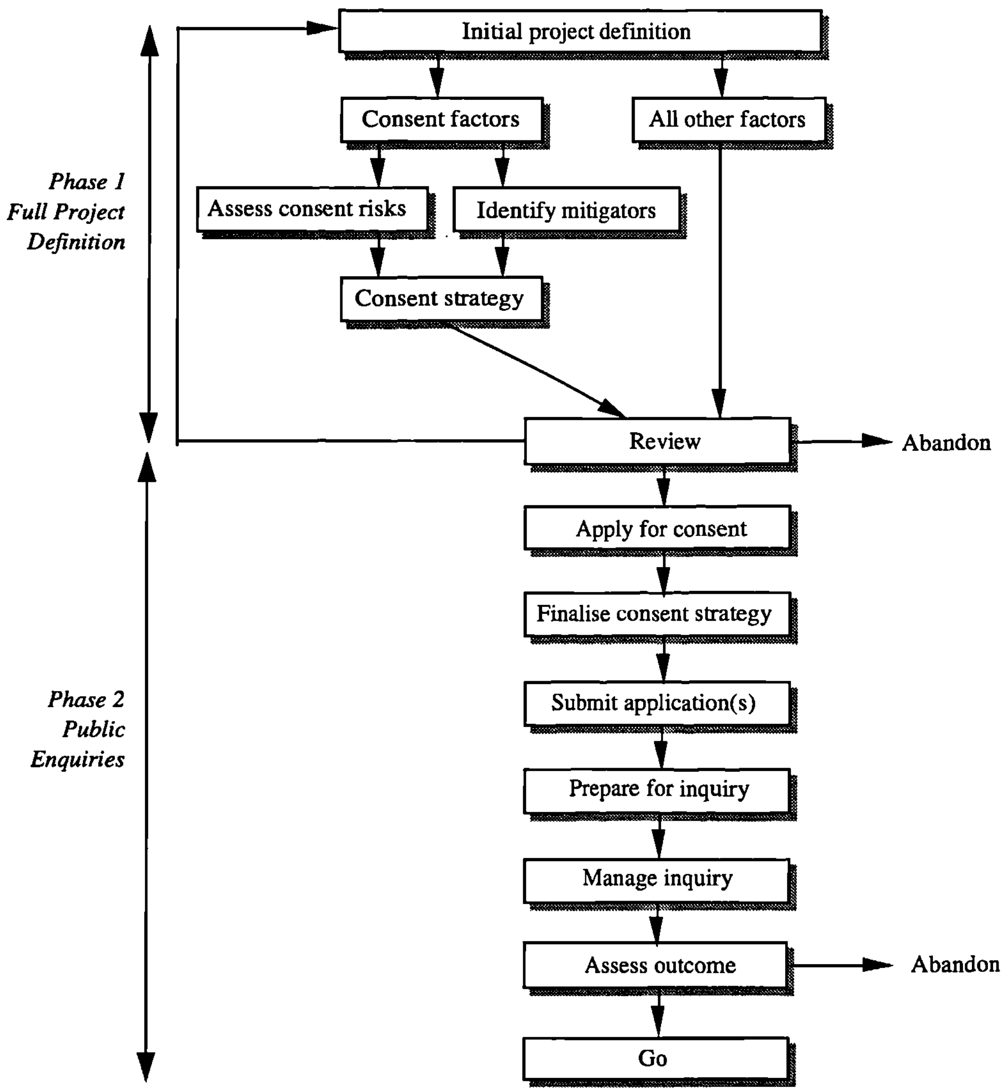

Exhibit 4.4.1 – Consent Process for Government Infrastructure Projects

4.5 FINANCING OF MAJOR PROJECTS

4.5.1 Background

A key element of the project definition is the scoping of the options for financing the project in preparation for the project approval decision. As projects become larger and often more international, the financing approach to be adopted becomes a decision driver. Projects that are company specific are often funded out of profits. However, major company projects and infrastructure projects cannot normally be financed in this way as the short-term project investment may exceed the immediately available funds. An accepted financing method is to raise funds against the benefits promised by the project or company, ie, the project is funded by debt.

In this Section the methods of financing major projects are investigated in order to identify the necessary steps to be included in the MM Model. The Section will address sources of finance, off-balance sheet financing, infrastructure project finance, and finally the criteria for successful project financing.

4.5.2 Sources of Finance

A project may be financed out of company profits or, as Merrett (1976) described it, the company could raise short-term funds through trade credit, bank borrowing, bills of exchange or deferred tax payments. For medium and long-term funds a company would turn to the capital market. Government projects are normally financed through the Public Sector Borrowing Requirement (PSBR) and hence paid for from taxation. However, for public infrastructure projects the government is increasingly looking to private financing and the use of the capital markets.

The advantages of using the capital markets, according to Simpson and Avery (1994), was that the finance would cover a longer period than would normal bank lending, that fixed interest rates were available for long-term projects giving rise to hedging benefits, and that new investors were likely to be institutional such as pension and other long-term funds, which have demonstrated an increasing interest in alternative quality fixed-income assets. To the capital market, a project financing is simply an alternative investment opportunity, and as such it must compete with other loans and investments on the basis of levels of risk, yields, terms and liquidity.

Nevitt (1989) identified three general categories of capital and loans used for projects; (1) equity, (2) subordinate debt – sometimes known as mezzanine financing or quasi-equity, and (3) senior debt which was usually secured or asset based. Brett (1987) described the debt as occurring in several layers with senior debt being the most significant.

Equity. Equity investment in project financing represents the risk capital. It forms the basis for lenders or investors advancing more senior forms of capital to the project. Equity is typically advanced as the subscription price for common or preferred stock.

Lenders look to the equity investment as providing a margin of safety. They expect the projected cash flows generated by the project to be sufficient to pay operating expenses, to service the debt and to provide a comfortable margin for contingency. Furthermore, lenders do not want investors to be in a position to walk away easily from the project; investors should have enough stake to motivate them to see the project through. The appropriate debt to equity ratio for a given project is a matter for negotiation between the sponsors and the senior lenders. However, much of the base information for this negotiation comes from the return on investment (ROI) calculations and assessment of risk that should be undertaken during the project definition.

Subordinated Loans. Subordinated debt has the advantage of being fixed rate, long term, unsecured and may be considered as equity for lending purposes (Nevitt, 1989). Subordinated loans are described by Brett (1987) as loans that rank for interest and repayment after all other borrowings of the company, ie, they are subordinate to senior debt. These loans, which are issued by banks and other financial institutions, are treated more as share capital than as borrowings. Subordinate lenders are cash-flow lenders and as such they are unsecured. If the lenders are to be repaid, the project must consistently generate operating earnings (cash flow) in order to service senior debt (principal and interest) and to build equity. Subordinate lenders are therefore sensitive to a comprehensive project definition being able to calculate, within a reasonable degree of accuracy, the expected cash flows to be generated (Morris, 1986).

Senior Debt. The largest portion of a major project's funds will normally come from senior debt (Nevitt, 1989) in which most of the borrowings will be secured through commercial bank lenders. According to Brett (1987), senior debt is not subordinated to any other liability, ie, it has first priority of payment from the general revenues of the borrower in the event of financial difficulties. Senior debt falls into two loan categories; unsecured and secured. Unsecured loans are backed by the general credit of the borrower and are not secured by perfected security interest in any asset or pool of assets. Logan (1980) stated that large unsecured loans were available only to the most creditworthy companies with good relationships with their lenders. On the other hand, secured loans were available to most projects where the assets securing the debt had value as collateral. The collateral of real property, personal property, payments due under a take-or-pay contract and assignment under contractual rights were all used for project financing. In a fully secured loan, the value of the asset securing the debt would equal or exceed the amount borrowed. A major element in the secured loan lending decision will an assessment of the likelihood of the project's success which is an output from the project definition.

Sources of project finance against the instruments used in project financing are shown at Exhibit 4.5.1 as taken from Nevitt (1989), Coopers and Lybrand (1987), Kemp (1984), and Dyer (1982).

GENERIC SOURCES	LENDERS/SPONSOR	INSTRUMENTS
1. International agencies: 2. Government export financing agencies and national interest lenders: 3. Host governments: 4. Commercial banks: 5. Institutional lenders: 6. Money market funds: 7. Commercial finance companies: 8. Leasing companies: 9. Investment management companies: 10. LBO funds: 11. Asset funds or income funds: 12. Savings and loan associations: 13. Wealthy individul investors: 14. Companies which supply a product or raw material: 15. Companies requiring the product or service producedby the project: 16. Contractors: 17. trade creditors 18. Vendor financing of equipment; and 19. Sponsor loans and advances	1. Commercial lenders a. Banks: b. Institutional investors (local markets for equity and bonds): (i) insurance companies, and (ii) pension funds: c. Commercial finance companies d. Leasing companies: e. Savings and loan associations: f. Individuals g. Investment management companies h. LBO funds, money market funds and asset funds. 2. Commercial sponsors a. Companies requiring the product or service: b. Companies supplying a product or raw material to the project: c. International agencies: (i) the World Bank, and (ii) area development banks; d. Government export financing agencies and national interst lenders; (i) export-import banks, and (ii) other government agencies e. Contractors; g. Trade creditors; and h. Vendor financing of equipment	1. Commercial bank loans 2. Supplier financing and captive finance companies 3. Export credit financing 4. Buyer credits supported by an export credit agency 5. National and international developement bank loans 6. Co-financing and complementary financing 7. Syndicated credit facility 8. Eurobonds 9. Eurodollar bonds 10. Shogun bonds 11. Floating rate notes (FRNs) 12. Stripped floating ratte notes with a cap 13. Secuirties in the US public debt and capital markets, including junk bonds 14. Leases 15. Industrial revenue bonds 16. Production payment loans and advances 17. Commercial paper 18. Short-term roll-over notes 19. Euro-commercial paper (ECP) 20. CRUFs 21. Japanese commercial paper 22. Medium-term notes 23. Caps, floors, swaptions and callable swaps 24. Private placement debt 25. Yankee bonds 26. Debentues, bonds or notes convertible to equity 27. Debt with equity warrants 28. Master limited partnerships and PIGs 29. Export credit linked swaps 30. Zero coupon bonds 31. Clip and strip bonds 32. Deep discount bonds 33. Zero coupon convertible notes (LYONs) 34. Commodity linked notes and bonds 35. Dual convertible bonds 36. Multicurrency bonds 37. Deferred payment loans 38. Research & development limited partnership 39. Debt with warrants for debt 40. Indexed rate notes 41. Canadian roll-over 42. Income share notes 43. Non-dollar debt in the United States 44. Dual currency loan 45. Stepped oupon bonds 46. Dual option warrants 47. Extendible bonds 48. Level pay floating rate notes 49. Money market preferred stock 50. Dutch auction money market notes 51. Convertiable exchangeable preferred stock 52. Leveraged preferred stock 53. Preferred stock with a dividend holiday 54. Cross-border preferred stock 55. Asset-backed securities 56. Mortgage participation and pass through certificates 57. Yield curve notes 58. American depository receipts 59. Single property schemes (SPSs)

Exhibit 4.5.1 – Sources of Project Finance

4.5.3 Off Balance Sheet Financing

The ultimate goal in major project financing is to arrange borrowing for a project that will benefit the sponsor, whilst at the same time being completely non-recourse to the sponsor; this is sometimes referred to a off-balance sheet financing (Nevitt, 1989). Nevitt claimed that this could be accomplished by using credit of a third party to support the transaction, such a third party then became a sponsor and as such would expect to benefit in some way from the project. Nevitt pointed out that there was room for disagreement between lenders and borrowers as to what constituted a feasible project finance arrangement. Borrowers would prefer for the project to be completely off the balance sheet, but on the other hand lenders did not see themselves as being in the venture capital business especially if it was unsecured.

Nevitt described the key to a successful project financing as one where there was as little recourse as possible to the sponsor, while at the same time sufficient credit support through guarantees or undertakings of a sponsor or third party in order that lenders would be satisfied with the credit risk. The optimum solution combines the undertakings and various kinds of guarantees by parties interested in a project being built in such a way that none of the parties alone has to assume the full credit responsibility for the project, yet when all the undertakings are combined and reviewed together, the equivalent of a satisfactory credit risk for lenders has resulted. A term used widely in relation to project financing is "limited recourse and financing". Haley (1992) defined this term as the finance for the project secured in part or in whole on the expectation of future cash flows from the project. Examples in the UK are the Channel Tunnel, Dartford Crossing and the Severn River Crossing.

Brett (1987) provided an excellent example of the conditions for setting up non-recourse or limited recourse project financing. Company C was set up by Companies A and B, but was not a subsidiary of either. Company C borrowed the funds it needed as a non-recourse loan, but because the loan was not guaranteed by Companies A or B no mention of it appeared in their accounts. The lender(s) were lending against the success of company C's venture and if Company C got into trouble it had no recourse to Companies A and B to get its money back.

4.5.4 Infrastructure Project Finance

Infrastructure projects are invariably expensive, complex and sometimes speculative (Snow, 1992). Such projects include bridges, roads, tunnels, airports and telecommunications systems. In the past such projects have normally been financed through the public sector; ie, out of the PSBR for UK projects. However, during the 1980s the UK government declared that certain public sector projects that could be shown to deliver sufficient post implementation benefit to pay for the project should be candidates for private sector finance. Booth (1988) stated that the most obvious cases for private sector finance involved the offer by the private sector to finance the project; in other words the projects that offered a substantial ROI (return on investment).

Budd (1988) described certain infrastructure projects as "for the public good" (hospitals, roads, prisons, etc); these would for the foreseeable future be financed from the public sector as no revenue would be generated from the project and hence they would not attract private sector finance. However, the Public Finance Initiative (PFI) (1990) took a different perspective. With the Government prepared to pay a commercially attractive rate for any service, private capital expenditure on most public sector projects could attract an acceptable ROI. In 1993, the PFI Panel was established to help in a practical way to assure the forward progress of projects. The panel sits between the Treasury, its spending departments, and the private sector in all its forms (Hogg, 1994). In 1997 two privately owned and operated prisons (Fazakerly and Bridgend) will be commissioned, two privately owned National Health Hospitals are being planned, and in 1998 the Channel Tunnel rail link between London to Dover will be opened. These public sector projects can be considered in the same way as infrastructure projects.

An important method of financing and managing "profitable" infrastructure projects is to employ the BOOT (Build-Own Operate-Transfer) approach. Haley (1992) described the BOOT arrangement as shown at Exhibit 4.5.2.

Build:	• design • manage project implementation • carry out procurement • construct • finance
Own:	• concession • franchise
Operate:	• manage and operate plant • carry out maintenance etc. • deliver product/service • receive delivery payment
Transfer:	• hand over plant in operating condition at the end of the contract period

Exhibit 4.5.2 – The BOOT Arrangement

Other variants of the BOOT concept are Build-Operate-Transfer (BOT) and Build-Own-Operate (BOO). Under PFI some projects are termed "Design, Build and Operate" (DBO). However, for the purposes of this research, only the BOOT concept will be considered as the other variants are similar as far the project definition processes are concerned, they are just different business propositions (McCarthy, 1991).

Limiting and spreading risk is an important element of BOOT financing which can lead to a large number of stakeholders being involved (often as many as 20 in £400 – £500m projects). Equity is essential, the amount being dependent upon the market's perception of the scale of the risk; with unlimited non-recourse financing it is often as high as 25%. Apart from equity financing, other conventional sources of finance include subordinate financing and junior debt (preference shares, warrants, convertible bonds); senior debt (commercial medium to long-term bank loans arranged through banks); and leasing (where the owner can claim capital allowance for rolling stock and other equipment, and offset them against corporate taxation). McCarthy (1991) described the BOOT project structure as shown at Exhibit 4.5.3.

The structure involves the creation of a special-purpose joint venture company in which the contractor, operator, and banks have a share. This concession company borrows money to fund the construction, on the security of the revenue that the lending banks believe will be generated by the project. All financial obligations must be serviced within the life of the concession. Franchise financing is therefore most akin to limited or non-recourse project finance, except that the revenues are received under licence. The project is approached in a similar way to limited recourse project financing in which the risks are isolated and allocated to those most qualified to bear them. At the end of the concession period, the ownership of the project and the right to operate it reverts to the government which may then choose to either grant a new concession or to operate the project itself.

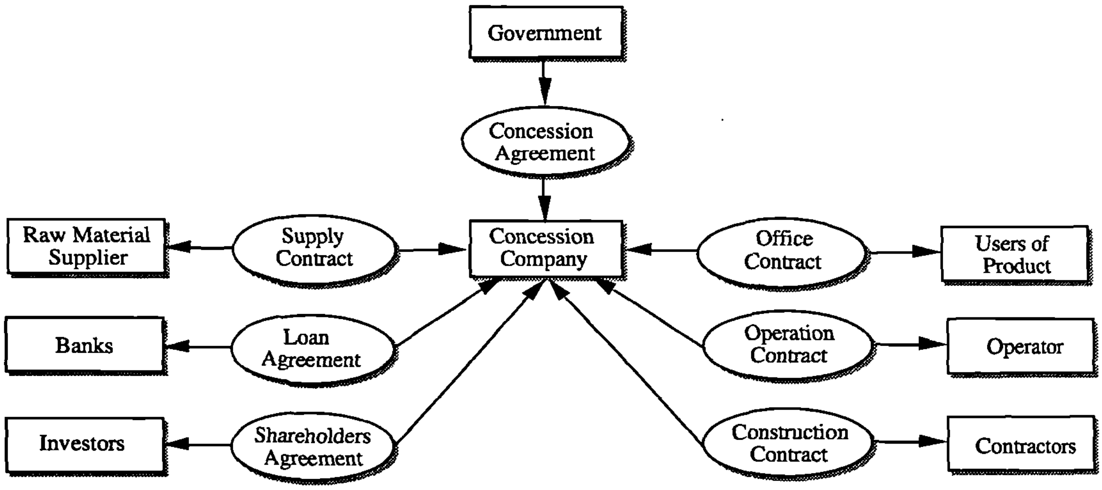

Exhibit 4.5.3 – BOOT Project Structure

Haley (1992) claimed that it was theoretically possible to finance a BOOT project entirely from debt without there being any requirement for equity. This means that what would otherwise be equity risk is channelled through one or more of the contracts. In the case of the Dartford Crossing in Kent, the limited recourse risks were passed on to the debt providers who would take the risk that the tolls will not be sufficient to repay the debt by the end of the concession period. Haley (1992) advised that is was normal for the debt to equity ratio to be 30% to 70% respectively. To complete the Dartford Crossing case, De Pelet (1988) stated that the finance was structured in three main tranches: (1) a 20 year subordinated loan stock to the amount of £34m subscribed by City institutions; (2) a further tranche of £30m subordinated loan stock; and (3) £85m plus £20m contingency of senior debt in the form of a syndicated bank loan facility led by the Bank of America. The equity risk was borne by the subordinated loan stock holders.

Snow (1992) observed that finance was a competitive business. Ultimately, according to Snow, resources, whether provided by the private sector directly through the capital market or by governments, must have an impact on the capital market. If competition for funds was acute, marginal projects or those with inadequate definition would not attract finance. Furthermore, projects whose outcome was uncertain or whose sponsors lacked credibility would be considered by banks and financial institutions as having too high a risk. A key step, therefore, in the financing case is a comprehensive project definition as it is the definition outcome that will form the selling material to prospective financial backers (McCarthy, 1991).

A point to note when defining infrastructure projects is that providers of finance are wary of undertakings being planned for politically unstable countries as the risks that the debt could not be serviced are too high (Wylleman, 1992). This level of risk aversion does not bode well for third world and the emerging Central European counties who may well rely on the BOOT philosophy to modernise their ailing economies; particularly through upgrading antiquated communications systems. Tai-Lan Lo (1992) noted that these governments needed to understand the nature of project financing, especially the perspective and expectations of the private sector.

Criteria for Successful Project Financing

The financial viability of a project must be shown during the project definition (Morris, 1986; Nevitt, 1989). Cash flow projections must be sufficient to service any planned debt, to provide for cash needs, to pay operating expenses, and to provide adequate contingency. Nevitt (1989) identified example models for cash flow projection which are shown at Exhibit 4.5.4 and Exhibit 4.5.5.

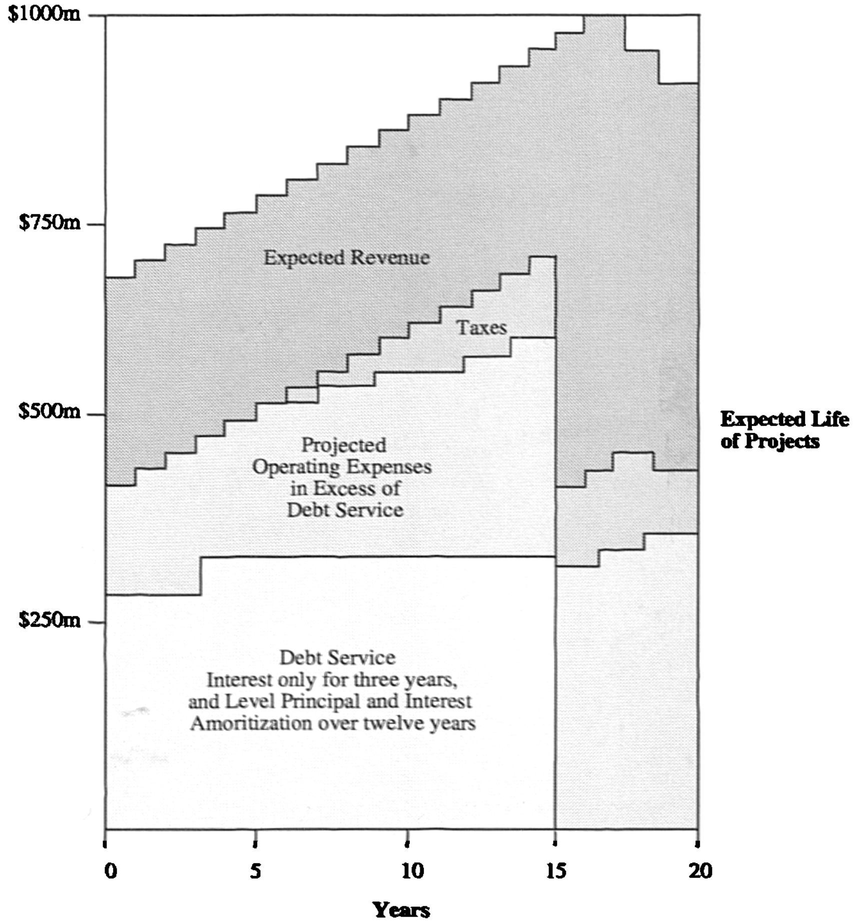

Exhibit 4.5.4 – Revenues, Operating Expenses, Taxes and Debt Service Adjusted for Inflation and Escalation

Lenders will examine projections in order to determine debt coverage over the loan life. According to Nevitt (1989) lenders might expect 2:1 coverage over the project life, and 1.5:1 over the loan life (also see Knapp, 1988). Nevitt advised that the cash flow models used during the project definition must be realistic with particular attention being given to worst case scenarios and the inclusion of adequate contingency. Measures to be used in modelling should include return on equity (ROE), return on investment (ROI) and return on Assets (ROA).

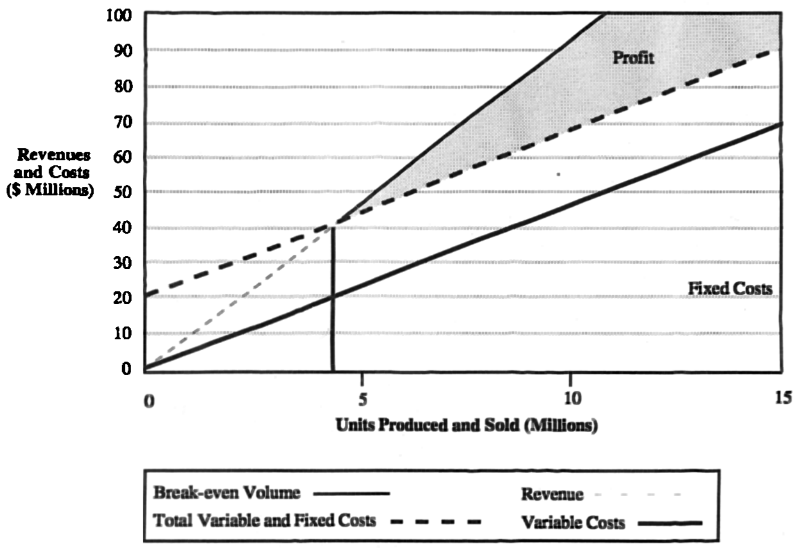

Exhibit 4.5.5 – Calculation of Break-Even Volume

Nevitt (1989) described a further model that will prove useful in the project definition stage, this model is shown at Exhibit 4.5.6. This model will inject the process into the project definition for assessing the alternatives for project financing. This action will be necessary from the simplest project to the comprehensive BOOT project.

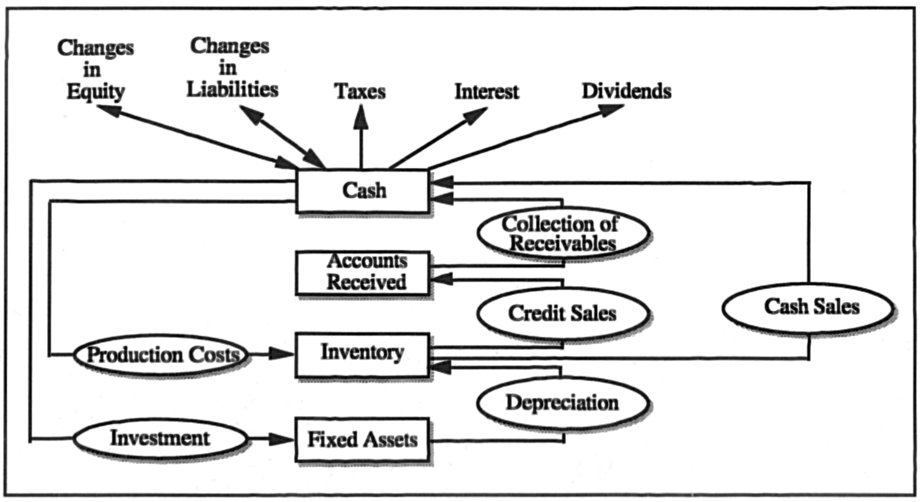

Exhibit 4.5.6 – Assessment Model of Alternatives for Project Financing

4.6 QUANTITATIVE METHODS

Companies have become more systematic over time in their approach to capital budgeting (Pike, 1983), and more sophisticated in using the discounted cash flow (DCF) approach (Klammer and Walker, 1984). In addition to DCF, many companies have augmented their analysis with the use of payback and accounting rate of return (ROI). What is important though is that any analysis metric for major projects should be used under conditions of uncertainty. Pike (1983) alluded to this problem when he commented on errors in the application of DCF.

This section builds on the basic methods of project appraisal, net present value (NPV), internal rate of return (yield) and benefit/cost ratio in order to introduce advanced techniques for appraisal under conditions of uncertainty. This is particularly important for projects that will rely on debt for their financing (Haley, 1992).

4.6.1 Basic Methods

DCF expresses the net incremental cash flows of a project in terms of their present value. By considering the amount and timing of these cash flows (after tax) an investment appraisal can be made against a common base thus avoiding normal accounting conventions. Lucey (1980) identified the more commonly used DCF techniques as the net present value (NPV), the internal rate of return (yield), and benefit/cost ratio. A brief overview of these techniques is presented below.

Net Present Value. According to many writers (eg, Merrett and Sykes, 1976; Lucy, 1980; Bierman and Smidt, 1961) the traditional methods of investment appraisal use the NPV. The present value of any project is found by discounting the company's cost of capital and all future net cash flows to their present value equivalent, hence:

$$P = \sum_{i=1}^{i=n} \frac{Ai}{(1+r)^i}$$

where A represents the end-year cash flows and r is the company's cost of capital, ie, the discounting rate. The NPV is found by subtracting the capital cost of the project; the equation can thus be rewritten:

$$NPV = \sum_{i=1}^{i=n} \frac{Ai}{(1+r)^i} - C$$

Where the net cash flows arising from a project are risk free (or adequately reflected in the rate of discount) and if the NPV is positive, the project can be considered acceptable. NPV represents a company's prospective increase in wealth from undertaking the project (Merrett and Sykes, 1976). Moreover, it is the maximum value the company could place on its rights to exploit the project, and the maximum amount it could borrow for distribution to its shareholders and break even by the end of the life of the project.

Internal Rate of Return (Yield). This technique obviates the need to decide upon a discounting rate, as the solution is the discounting rate which would give a nil NPV (Lucy, 1980). Mathematically the yield on an investment is given by the equation:

$$C = \sum_{i=1}^{i=n} \frac{Ai}{(1+r)^i}$$

Under conditions of uncertainty, when the solution is greater than the company's cost of capital, the project is acceptable. More accurately, a project should be accepted if the degree of risk is held to be adequately compensated for in the resulting yield.

Benefit/Cost Ratio. In its simplest form the ratio between the discounted sum of the benefits and the costs can be expressed:

$$\text{Benefit / Cost Ratio} = \frac{\sum_{i=0}^{i=n} Ri(1+r)^{-i}}{\sum_{i=0}^{i=n} Di(1+r)^{-i}}$$

The above formula, according to Lucey (1980), did not net the benefits thus giving misleading results. It is preferable to use the ratio that compares total benefits to total costs, where R represents the cash receipts and D the cash disbursements of a period.

4.6.2 General Criticisms of the Basic Techniques

It has been suggested by Pinches (1982) that there was a bias against new technology both in the banking community and in business, and that the current practice of appraising investment might not be appropriate. Specifically, it has been alleged that the traditional appraisal methods, ie, payback techniques whether discounted or not and the DCF techniques of NPV and IRR, undervalue the long-term benefits of investments. Pinches further suggested that the techniques assumed a far too static view of future commercial activity by under-rating the effects and pace of technological change. Furthermore, there were many benefits from investments which were difficult to quantify and were often ignored in the appraisal process. Moreover, it was claimed that the systems of management often employed by large organisations compounded the bias against those investments that reap all rewards vital for long-term viability. The last point was also identified by Pike (1983) and echoed by Quinn (1985) when they drew attention to the corporate need to report a continuous stream of quarterly statements that proved disruptive to the long time-spans of major projects. Quinn went on to say that such pressures often made publicly owned companies favour quick marketing fixes, cost cutting, and acquisition strategies over process, product or quality innovations that would yield much more in the long term. All this would seem to point to the need for a different approach to investment appraisal.

Senker (1984) supported this argument, he attacked the use of the payback technique whether discounted or not. His objection was that it ignored all cash flows after the desired payback period, and thus it did not take account of the long-term advantages of potential investments. He thought it was surprising that payback was still regarded as a serious tool for financial analysis. However, Ashford et al (1988) described the payback technique as a simple rule of thumb; its attraction was its simplicity and robustness for making judgements on possibly optimistic costings and uneasily quantified business risks. Ashford, and Haley and Schall (1977) claimed that the payback technique was an inadequate appraisal technique and should never be used alone.

They all concluded that NPV and IRR were appropriate ways of valuing cash flows, but care should be exercised in applying a fair discount rate since any bias in application was due to a systematic use of too high a discount rate, but this could be avoided by correct analysis. Assumptions about the future could lead to bias if an over-optimistic picture of the no-investment position was taken, but again this was an avoidable pitfall (Dixit and Pindych, 1993). Where benefits cannot be quantified, they should nevertheless be stated in order that they can be given proper consideration during investment decisions. According to Ashford et al (1988), the biases of capital-investment appraisals could be avoided, but with one difficulty; new technology invariably led to greater complexity. This complexity was traditionally handled in the capital-investment process by an unrealistic increase in the discount rate being employed which led inevitably to a bias against change.

Hodder and Riggs (1985) stated that discounting procedures were not inherently biased if management set realistic hurdle (discount) rates and examined carefully its own assumptions. Unfortunately, many DCF analyses of risky projects were overly simplistic and ignored three critical issues that managers and decision makers should consider: the effects of inflation, the different levels of uncertainty in different phases of the project, and management's own ability to mitigate risk. Hodder and Riggs advocated that different discount rates should be used for different stages of the project, after all, they argued, risk usually declined as the project proceeded through its prescribed stages. Furthermore, they pointed out that for long running projects inflation and hence interest rates fluctuated, and managers tended to assign a safe discount rate to cover all contingencies.

In their conclusions, Hodder and Rigg blamed DCF procedures for short-sightedness, biased perceptions, excessive risk aversion, and other alleged management weaknesses. However, understanding the pitfalls in the casual use of the DCF techniques could both improve the analysis of capital investment projects and place these techniques in a more appropriate perspective. The views of Hodder and Riggs will influence the formulation of the MM Model.

Turning now to the those capital projects of the BOOT type that rely on senior and subordinate debt, and equity financing. Nevitt (1989) identified that lenders wished to ensure that a project had a satisfactory economic incentive as measured by ROE, ROI, and ROA. This is particularly so where a company is charged with the "operate" element of BOOT, since it is during this stage that debt will be serviced and dividends paid against equity. ROE, ROI and ROA are key financial ratios for assessing the viability of a firm. Fanning and Pendlebury (1984) defined the ratios as follows:

$$\text{Return on equity} = \frac{\text{Net profit after taxes}}{\text{Stockholders equity}}$$

$$\text{Return on investment} = \frac{\text{Net profits after taxes}}{\text{Investment}}$$

$$\text{Return on assets} = \frac{\text{Net profits after taxes}}{\text{Assets}}$$

The calculated ratios evaluate the current performance of a company against previous years, or against other companies in the same industry.

4.6.3 A Further Technique for the MM Model

Using the findings of Hodder and Riggs (1985) and Ashford et al (1988), this research will use of DCF techniques subject to the following qualifications; the effects of inflation are adequately catered for, different levels of uncertainty for different stages of the project are used, and an assessment is made of the risk management plan in order to judge management's own ability to mitigate risk. This last point will be addressed in more detail in the next section which looks at project risk in particular. The MM Model will also accept Nevitt's (1989) requirement for the use of company performance ratios for assessing risk associated with limited recourse project financing.

There is, however, another interesting approach to financial assessment that could be employed within project definition. When a company gets into trouble, lending banks do a "staying power" analysis. It is a conservative way to assess the company resources available to repay loans under distressed circumstances. Arnold (1986) suggested that company managers could undertake a staying power analysis before embarking on a capital investment project in order to ascertain if the company could withstand financial setbacks. He also suggested that the technique could help managers to decide on the size of an important capital expenditure.

To conduct a staying power analysis, a manager must understand the lender's viewpoint. Arnold stated that a cardinal rule of credit was to have two sources of repayment. The primary source was always the business' cash flow, and the secondary was the liquidation value of assets. Arnold (1986) described the processes of staying power analysis as follows:

1) Forecast the financial performance that would result from the most hostile business environment that might reasonably occur.

2) Translate the description of the hostile operating results into financial results.

3) Quantify the duration of the hostile period and the currency magnitudes, and in particular focus on each account's erosion potential.

4) Estimate the worst case working capital requirement for the project.

5) Anticipate what cash conservation programmes the company would implement when financially distressed.

6) Assume the worst case scenario for sales but hold in line with historic levels.

Management should then answer 4 questions. (1) Does the company need external financing to get through the bad period? (2) Do lenders have to supply any net new money? (3) Can the company stay in compliance with its borrowing base? (4) What are the costs of lender assistance?

4.7 PROJECT RISK

4.7.3 Overview

The whole of business, said Harvey-Jones (1991), was about taking acceptable risk. In a major project a substantial proportion of the cost is committed early, and the scope for cost overrun can be large. It is important, therefore, to address the risk of overrun from the earliest stages of a project.

Greater management awareness of project risk has been stimulated by the well documented project problems of the 60s, 70s and 80s, by the growth in external project financing and by the formal analysis of risk required in contracting (Morris, 1992). The first comprehensive analysis of project risk is carried out during the project definition (Morris and Hough, 1987) where risks are identified, their impact assessed, and possible management measures defined. The resulting work forms the first instantiation of the project's risk management plan (Chapman, 1979). This section is structured to address three topics; risk identification, risk modelling and risk management measures.

4.7.2 Risk Identification

Analysis of project problems has shown that project managers have gained a generally poor reputation for coping with risk on projects (Albino, 1988). However, Morris and Hough (1986) argued that poor project definitions were the primary cause of risk problems as it was during this stage of the project lifecycle that drivers of risk should first be addressed. Nevitt (1989) agreed by emphasising that a full risk assessment should be part of the project financing case; the project definition is the process that gathers the evidence for this case. Berkeley et al (1991) identified pointers for good risk management practice that included the following:

- project risks should be identified during the earliest project phases, ie during feasibility and project definition
- no major project decisions should be made unless those risks having the greatest impact are clearly understood
- no project risk should be ignored or dealt with in an arbitrary way.

The need to anticipate the possibility of occurrence of risks and to understand their likely impact on the project has led to much work aimed at identifying risk drivers. Humphreys (1990) described these drivers as an observable phenomenon that was likely to drive up the possibility of some risked consequence whose future occurrence depended, in part at least, on this phenomenon. He warned against trying to identify all project risks as firstly time would not permit this, and secondly it would not be possible to assemble and interpret the data collected. Glahn and Borg (1988) stated that the goal for risk identification was, therefore, to define a limited set of key risk drivers that applied to a particular project, according to its type, its environment and its stage of development. Cash et al (1983) claimed that only if this could be achieved would it make sense to proceed to assess levels on the identified risk drivers in order to evaluate their likely effects.

4.7.3 Risk Model

Williams (1993) identified a need for a risk management model that had two fundamental features: a mechanism for ensuring that risks were identified, analysed and managed; and a means of communicating across a complex project structure thus providing a common currency for understanding and for ensuring the co-ordinated monitoring and control of risk (see also Charette, 1989). Berkley et al (1991) and Cooper and Chapman (1987) identified procedures for risk analysis which were used by Stupples and Hatfield (1993) to develop the generic model at Exhibit 4.7.1 to represent the two features. Williams (1994) developed a systematic approach to risk analysis specifically for use in project definition.

The first stage of Stupples and Hatfield's model was concerned with identifying risk drivers as described by Humphreys (1990) and Beidleman et al (1990). The list of drivers shown is not comprehensive but represents the major areas required for the MM Model. The drivers are then used to identify risks against project elements in order to form a risk register. Humphreys (1990) identified project elements as phases of the project lifecycle, the management of the project, technology, business requirements, transition or migration to operations, project interfaces (see also Morris, 1989), etc. The resulting list will be a comprehensive risk register with probably several hundreds of entries. Morris (1992) claimed that many companies had developed "risk books", which were lists of risks associated with classes of projects. Eberlein (1983) stated that many companies updated their risk books from the results of case studies; "the benefit of hindsight is often better than sophisticated quantitative techniques".

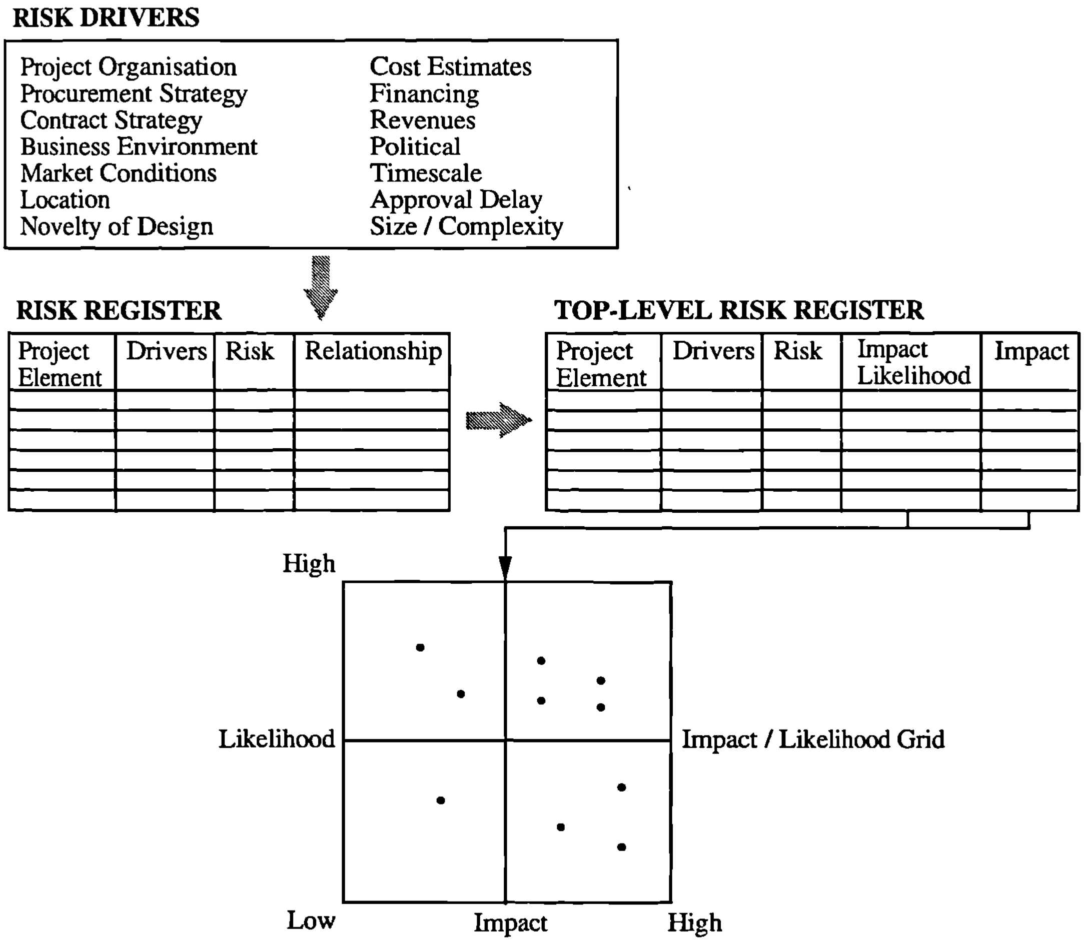

Exhibit 4.7.1 – Risk Analysis

Morris and Hough (1987) studied project success and failure in depth and produced a useful list of the risk drivers for general projects – see Chapter 2 of this research. A similar list was produced by Ashley (1987) for construction projects.

After the risk register has been formulated all risk entries must be analysed and assessed. It is here that the combining factors and the weightings applied can become difficult. Stupples and Hatfield (1993), Humphreys (1990) and Morris (1992) agreed that the objective was to identify from the risk register a small set of major risks (Top-Level Risks) that could be managed. Glahn and Borg (1988) claimed that if an attempt was made to manage all perceived project risks then the intrusion on the project would be so great that little productive work would ever get done. Usually, according to Morris (1992), the risks were assessed into major risks and non-major ones, though generally this was done on a project by project basis. Humphreys (1990) agreed with Glahn and Borg (1988) when he stated that only a limited number of risks on a given project were really significant. Other risks should be monitored in case their impact became significant. Techniques for combining and evaluating risks (Morris, 1992) include expert panels (conducted along the lines of Delphi, but generally without the questionnaire base), influence diagrams, successive estimating and, most commonly, Monte Carlo. Cooper and Chapman (1987) have developed more sophisticated techniques involving risk responses and semi-Markov uncertainty analysis which tracked progress as it developed, see also Norris (1992).

The final process of the model is to form the Impact/Likelihood Grid. It is important that the risks be appraised qualitatively as well as quantitatively. Although it is logically correct to express their impact in common units, their nature can be fundamentally different. Their probabilities and impacts, both direct and consequential, can be so different that a sudden change in a qualitatively different risk set can catapult a low priority risk into a high priority position.

4.7.4 Risk Management Measures

The measures selected to reduce or contain the effects of risk must not only be technically effective but also cost effective (Stupples and Hatfield, 1993). Using information from the Top-level Risk Register the authors assessed the changes to Impact/Likelihood profile that may be brought about by introducing risk management measures, see Exhibit 4.7.2.

Quantifying the risk in order that a cost/benefit analysis can be applied to selecting the appropriate risk management measure is essential to the process. Thedeen (1979) explained how difficult this was; he noted that the perceived effects of risk would increase when rated in general frameworks, and made the suggestion that there was a close connection between risk assessment made using these frameworks and decisions on whether projects were worthwhile. A study by MacCrimmon and Wehrung (1986) defined standardised risk situations, and described how managers qualified risk and selected options for addressing risk. The study also compared the effectiveness of various risk measures in these standardised situations. The study concluded by considering how managers adjusted to risk by hedging, ie, keeping options open, or delaying until more information was available, rather than opting for a specific measure; there are over 300 references in the study. Straw and Ross (1992) found that some companies had separated the risk of personal failure from that of the project in order to encourage managers to make decisions regarding risk; especially if a decision was required to "pull the plug" on the project.

Presumably, these difficulties prompted Morris (1992) to promote the thesis that expert panels (using Delphi) should be used to assess risk. Sharp (1991), as noted above, claimed that there was no substitute for experienced management judgement. This point was also made by Hertz (1979) when he acknowledged that there was no substitute for management judgement in both input estimation and decision. However, Devaney (1991) thought that some managers' over commitment to projects often clouded their judgement on risk. In many cases there was a psychological temptation to try to recoup what had already been expended. This temptation often gave rise to the "doubling up" syndrome of roulette players; the Delphi technique should even out the findings through group thinking.

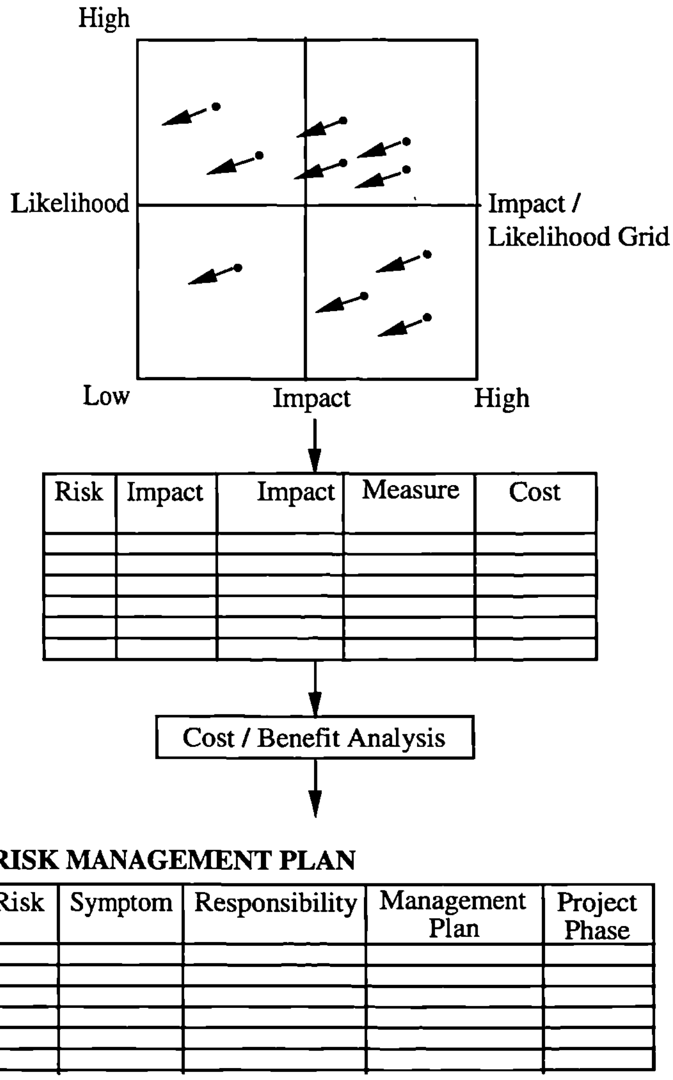

Exhibit 4.7.2 – Producing the Risk Management Plan

Thornton et al (1985) stated that for projects, risks affect time, quality and cost; all of which could be measured in terms of money. However, Braithwaite (1989) outlined the need for broader thinking and pointed out the human, corporate and environmental costs of accidents and mistakes if they were not prevented by a strategy for handling project risk. He cited the examples of Bhopal, Seveso, Piper Alpha, Three Mile Island and Chernobyl. This research will look specifically at the Advanced Passenger Train and Rolls Royce RB211 Aero-engine projects where this broader thinking proved to be lacking.

Once costs can be attributed to the effect of a risk occurring, and to an associated risk management measure then a cost/benefit analysis can be undertaken. Stupples and Hatfield (1993) suggested that a range of management measures should be considered in order to identify the most cost effective. It may be the case that it is not worth putting any risk management measure in place as the measure may cost more than the effect of the risk, and therefore contingency action would have to be defined.

Allocating the various risks to the project phases in which they are most likely to occur (Beidleman et al, 1990) is the key ingredient to making projects successful. However, Morris (1992) suggested that wherever possible risks should be assessed during the project definition and suggested that there were essentially three options; eliminate, lay-off (onto for example insurers or contractors) or manage. The project definition should decide which of the three options should apply to each risk. The project definition would, therefore, seem the ideal place to formulate Braithwaite's risk strategy.

4.7.5 Risk Management

Risk management uses the information from the risk analysis to provide the foundation for decisions on how to improve the probability of the project meeting its objectives (Norris et al, 1992). Effective risk management on projects requires that the project manager is able to anticipate the risks to the project and to design suitable organisational structures within the project in order to minimise their impacts, ie, to establish the risk management plan (see Exhibit 4.7.2). Humphreys and Berkeley (1992) stated that in order to achieve this the project manager needed to examine what sort of project risk intelligence was needed, ie, what will be the symptom. Cooper and Chapman (1987) looked at the need to apply corrective measures at the first signs of a risk occurring. Indeed, Chicken (1994) noted that whenever gross cost escalation occurred then it was possible to detect at least some weakness in the risk management area.

Elder (1989) found that the use of "hassle management" with the risk management plan was an effective combination. Hassle management, see Exhibit 4.7.3, is concerned with looking for the very early symptoms of problems and dealing with them in order avoid hassle at the end of the project.

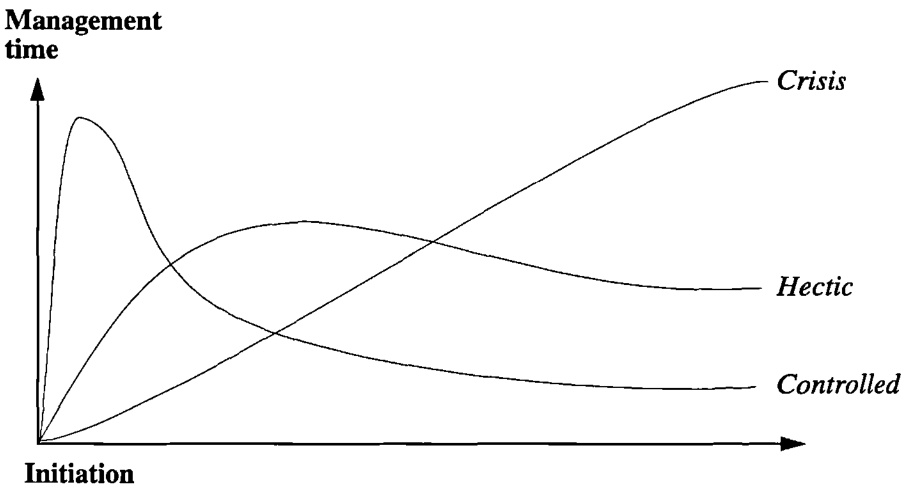

Exhibit 4.7.3. – The Hassle Graph

Implementation of the risk management plan should be through specific activities incorporated into project schedules, and well documented risk management measures should be in place for immediate use should the effects of a risk occur (Stupples and

Hatfield, 1993). Sweet (1986) suggested that risk tracking should be made part of milestone management as it forced a discipline into the process. Weinburg and Freedman (1984) maintained that milestone tracking was not enough in itself and suggested that risks should also be part of the quality assurance process. Best practice in project management has confirmed that both are used, and for very large projects sophisticated tools for managing risk are used (Morris, 1992).

4.8 SUMMARY OF THE IMPORTANT POINTS EMERGING FROM CHAPTER 4

In satisfaction of Objective 3, a full understanding of the decision making activities within the project approval process was developed. This understanding involved the adoption of Pike's Project Approval Framework which enabled the project definition to be positioned within a well structured business system; ie, it provided the project definition with a business frame of reference. Once the Project Approval Framework was in place the Chapter went on to discuss the rationale for investment decisions; the special needs and considerations of public projects; how projects may be financed, with a special emphasis on infrastructure projects; the quantitative methods available for a project's financial appraisal; and the application of risk assessment methods.

From the topics covered to meet the objective, six important points emerged that must be considered during the development of the MM Model:

- through the use of Pike's Framework senior management commitment to a project may be secured in a structured and focused manner
- a project's objectives need to be derived from business or public strategic objectives
- the MM Model must be able to define projects for both the private and public sectors, including those projects that need public consent
- the MM Model must be able to address the options for project financing as an integral part of its design process
- the pitfalls of poor application of DCF techniques must be fully addressed
- formal risk assessment must also be an integral part of the design process.

There is a need for further work, beyond the scope of this research, to develop a formal approach to project economic analysis of BOOT-type projects or those associated with the UK Government's Private Finance Initiative (PFI). Such an approach would compliment the MM Model.

CHAPTER 5: FORMULATION OF THE MM MODEL

5.1 INTRODUCTION

This Chapter together with its companion chapters 6, 7, and 8 are concerned with the formulation of the MM Model. The formulation follows the five major steps shown at Exhibit 5.1.1 which together specifically address research objectives 4 and 5, ie: to combine the Morris Model, the M'Pherson Model and other methods and techniques identified in this research to formulate the MM Model, together with an associated tool kit, for major project definition; and to test the MM Model against a specially developed and comprehensive compendium of project success criteria, and against three case studies selected for their combined ability to exercise all elements of the new model. The five steps are arranged to conform to a modified systems analysis approach tailored for this research.

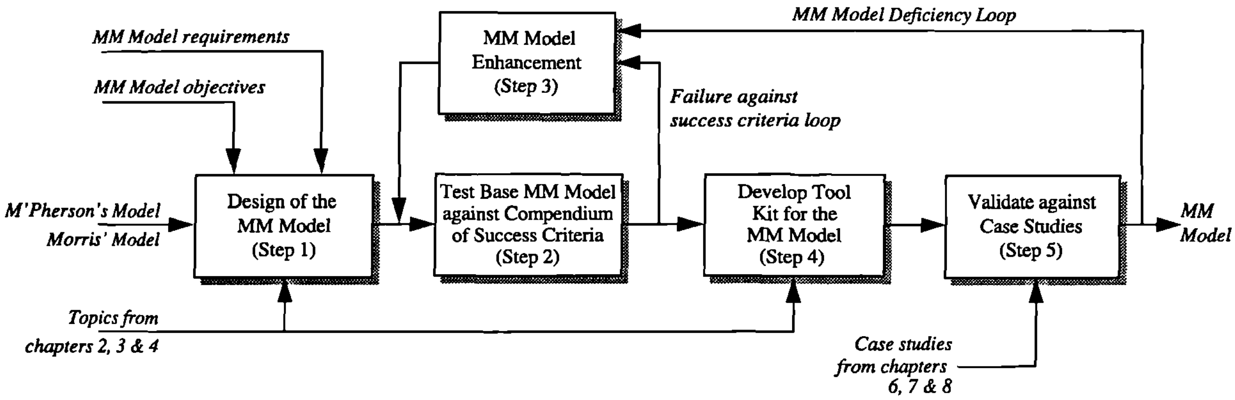

Exhibit 5.1.1 – Formulation Steps to the MM Model

The first step (Section 5.2) concentrates on the design of the MM Model through the incorporation of the Morris Model into the M'Pherson Model and augmenting the result, as appropriate, with methods and techniques introduced in chapters 2, 3 and 4. The MM Model is reconciled for the purposes of this research with Pike's Framework as it is this framework that links the project definition to a typical business system; a weakness with current project definitions (Morris, 1986; et al). The second step (Section 5.3) sees the Model tested against the Compendium of Project Success Criteria specified at Section 2.4. The MM Model (Step 3) is iterated through test loops until it satisfies these criteria. The loops are labelled according to the Compendium's headlines; ie, project size, complexity, technical uncertainty, schedule duration and urgency, physical and social environment, government and politics, and management. As the tests identify weaknesses and deficiencies in the model additions and modifications will be made according to processes, procedures or methods described in chapters 2, 3 and 4; only the results of the final iteration through all the loops is documented. Once the MM Model satisfies the success criteria a suitable tool kit (Step 4) is specified (Section 5.4) for use with the Model; the tools were drawn mainly from chapters 3 and 4. The tools and techniques identified will be generic types as described in this research. The choice of specific tools and techniques will be left to users of the MM Model.

The final step in the formulation of the MM Model is undertaken in chapters 6, 7 and 8 where it will be fully exercised against three major project case studies; the Advanced Passenger Train (APT), the London Water Ring Main (LWRM) and the Rolls Royce RB211 Aeroengine. The case studies have been carefully selected in order to provide the greatest range of tests. If the model is found to be deficient by any of the case studies it will be iterated through one of the enhancement loops at Step 3. Any tool kit modification will be undertaken as part of the iteration process; again only the final iteration will be documented. Section 5.5 introduces the case studies by describing why each was selected, the format used for documentation, and the conduct for the research. A summary of the Chapter is provided at Section 5.6.

5.2 DESIGN OF THE MM MODEL

The formulation of the MM Model is described under eight headings: Objective of the MM Model (5.2.1), Statements of Requirement (5.2.2), The MM Model Reconciled with Pike's Framework (5.2.3); Three Perspectives of a Project (5.2.4); Coverage of the Requirement by the Morris and M'Pherson Models (5.2.5); Harmonisation of the Morris and M'Pherson Models (5.2.6). Understanding the Product Design Process (5.2.7); Incorporating the Project Management Design Process (5.2.8).

5.2.1 Objective of the MM Model

The objective of the MM Model is ***"to facilitate the definition of a major project in terms of the product to be delivered, its specification, its cost, its benefits, its schedule, its risks, its financing needs, etc, and the management needed to successfully deliver the specified product to time and to budget to the sponsoring organisation for operational use".***

5.2.2 Statements of Requirement

The requirements for the MM Model can be directly related to the Compendium of Project Success Criteria (see Section 2.4) developed as part of this research. The rationale being that the compendium is comprehensive under the systematic headings of project size, complexity, technical uncertainty, schedule duration and urgency, physical and social environment, government and politics, and management, and is supported by other considerable research into project success and failure. Furthermore, the compendium has been produced in requirement format for practical project application. For the purposes of MM Model formulation, the compendium has been reproduced at Appendix 10 in table format with additional columns for use within this Chapter.

5.2.3 The MM Model Reconciled with Pike's Framework

Pike's Framework (see Exhibit 5.2.1) provides the frame of reference for the MM Model within a typical business system (see Section 4.3) in order that a project may be integrated with the formal appraisal process, and linked to an organisation's business strategy or policy. Positioning the project definition in this way ensures that it not only becomes part of the executive decision process but also part of a wider communications process – ie, all individuals responsible for managing the firm are kept informed of what is happening in other departments (Marsh et al, 1988). This positioning approach also satisfies Morris' (1986) dictum that the project definition is the best way of securing high-level management commitment and ownership. Pike's Framework also identifies the formal interfaces between the project and the business system (Marsh et al, 1986) and hence will highlight the necessary information flows, particularly those required to secure management commitment to the project.

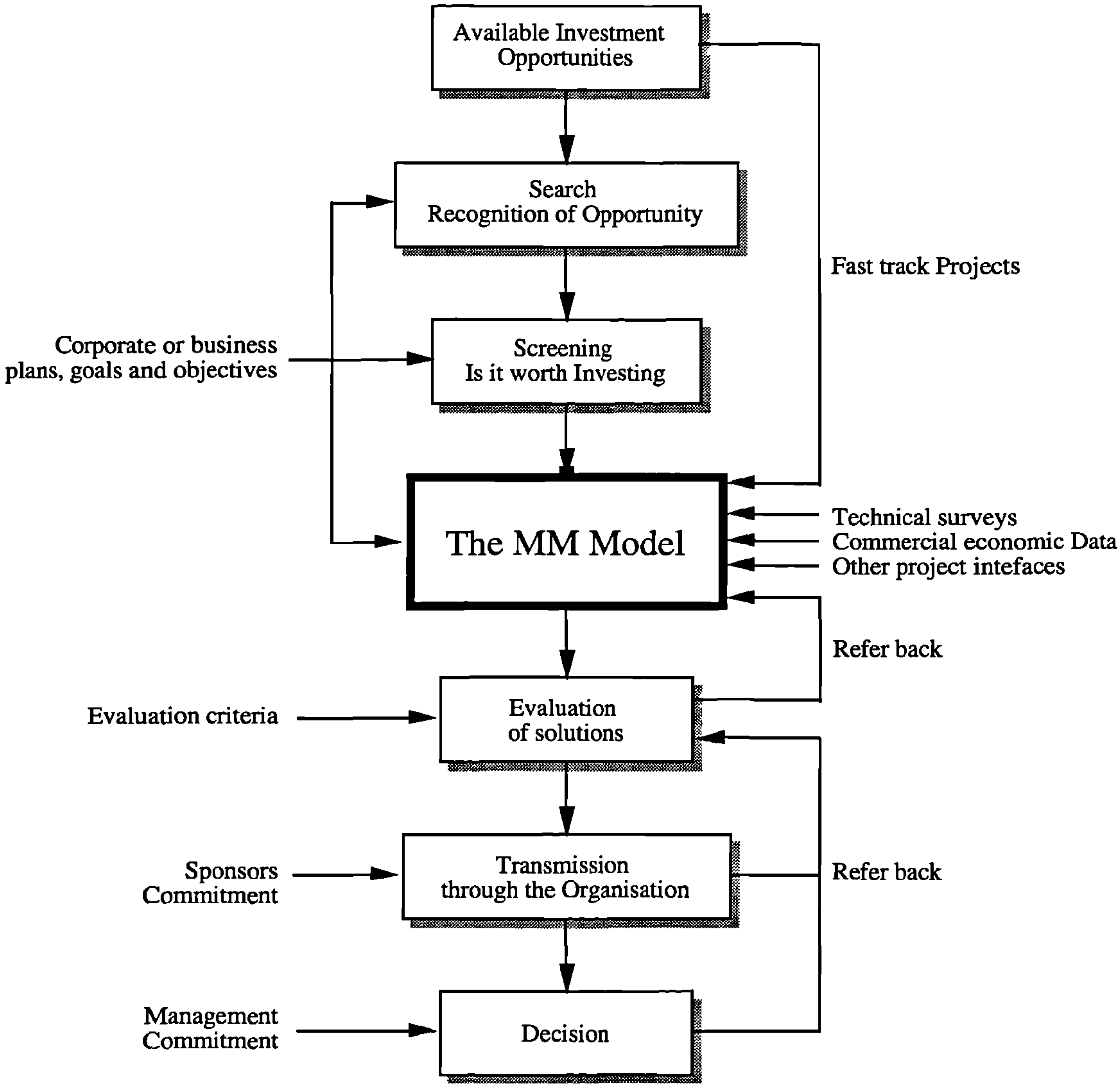

Exhibit 5.2.1 – Overall MM Model Reconciled with Pike's Framework

The investment appraisal or strategic investment decision for the project is made during the "Decision" activity of Pike's Model after commitment has been secured from key members of the organisation. It is essential, therefore, that the output from the MM Model is a comprehensive description of the product to be produced together with its associated plans, costs, benefits, and risks, and of the management approach to be adopted (Morris, 1985). Any missing or questionable information will cause the project to be referred back to the project definition, and so further feedback loops exist outside the MM Model.

5.2.4 The Three Perspectives of a Project

In his 1980 paper, M'Pherson addressed systems engineering as an approach to viewing a project as a system. He presented three essential and powerful perspectives from systems engineering that represent the ingredients of a project; organisation, system design, and system planning (see also Sage, 1993). To formulate the MM Model it is necessary to understand these perspectives in detail.

Organisation (Perspective 1)

The first perspective is about designing the project, or as M'Pherson described it, "designing the design"; ie, the organic process that has to be conceived, organised, and managed as a whole. M'Pherson recognised that projects could go wrong, become unstable, or fail if they were not designed properly so this perspective specifies what has to be managed in overall organisational terms. The scope of the management extends beyond the project into the wider system of influence (WSOI) and hence views the project as an open system (Hitchins, 1992). M'Pherson (1980) developed a schematic representation of the first perspective which is shown at Exhibit 5.2.2, incorporating minor modifications for the purposes of this research.

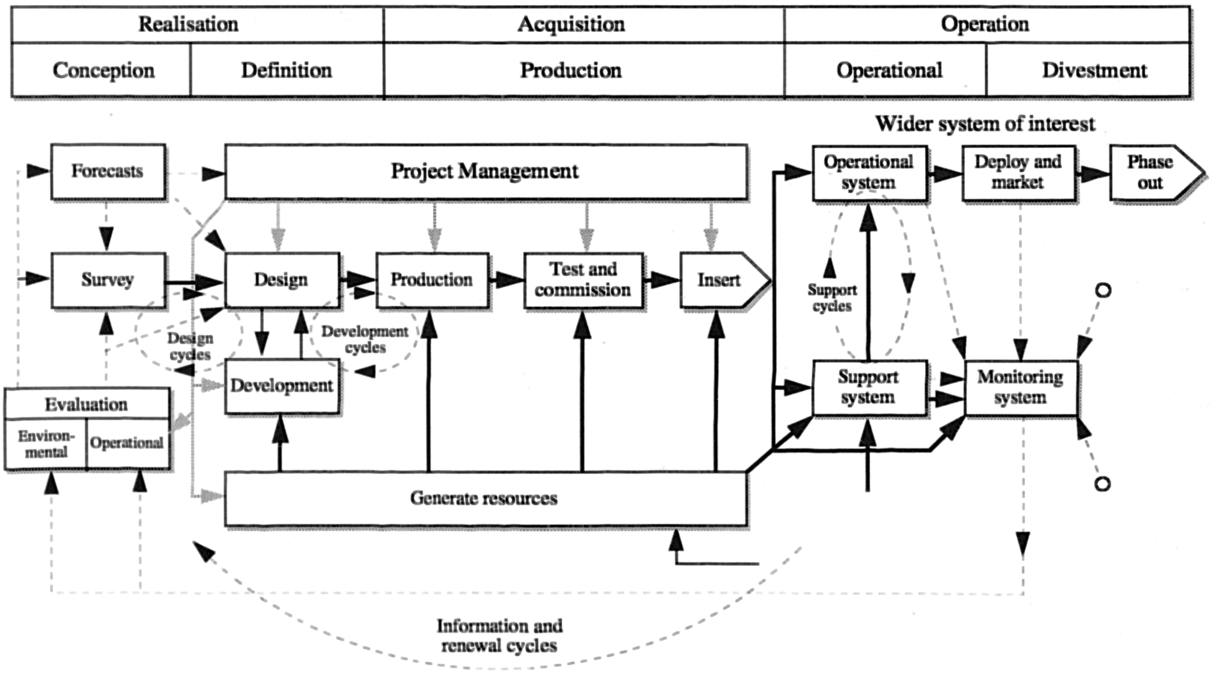

Exhibit 5.2.2 – M'Pherson's Organisational Perspective

The perspective shows the project in lifecycle terms (using Kerzner's Model – see Exhibit 2.2.4). External influences are controlled and monitored through the Wider Management which equates to Morris' (1989) Level I Management – see Exhibit 3.6.2. M'Pherson (1980) also observed that the emergent organisation was multivariable, and multiloop and hence would display dynamic behaviour that would require control to maintain its stability. This observation would indicate that Systems Dynamic Modelling could be used to assess the risks associated with different organisation options (Cooper, 1993 a, b, and c).

System Design (Perspective 2)

The second perspective is about getting the product or the required system right at the right time – ie, it has to meet the customer's needs in terms of functionality, performance and commercial acceptability, and it has to be matched to the operational environment and to the social and natural environment. The last two points are concerned with the WSOI. M'Pherson (1980) provided a conceptual model for "whole" system design which is reproduced at Exhibit 5.2.3 (this conceptual model is the foundation for the M'Pherson Model used as the basis for this research).

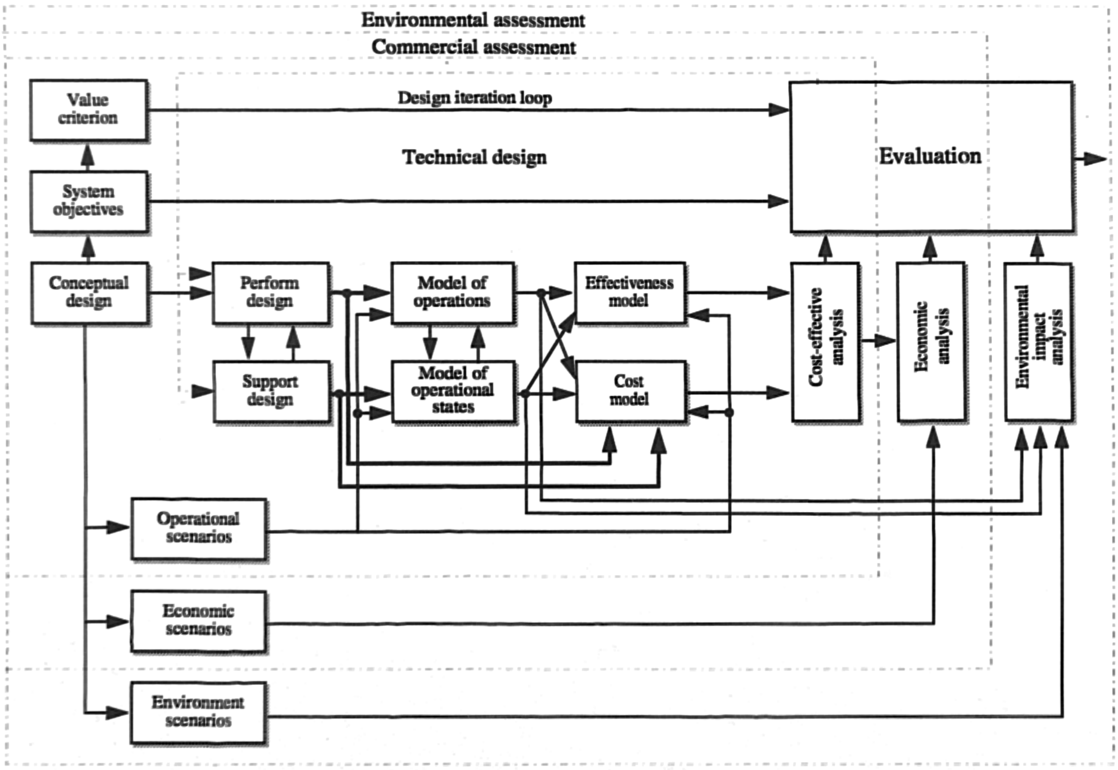

Exhibit 5.2.3 – M'Pherson's System Design Perspective

This perspective, which represents the design element in the Organisational Perspective, culminates in an evaluation process that relies for its integrity on the qualification and quantification of objectives – an area of extreme difficulty according to Hitchins (1992). M'Pherson (1980) also acknowledged the difficulties that could be encountered, emphasising that all too often there was conflict between objectives.

The outcome of system design is a design for the whole system not just the "system of interest" (SOI), ie, a design that includes and emphasises the WSOI. M'Pherson's (1980) WSOI representation of a major engineering undertaking or project is reproduced for this research at Exhibit 5.2.4 to provide an indication of the scope of design needed if a project is to be described in terms of an "open system".

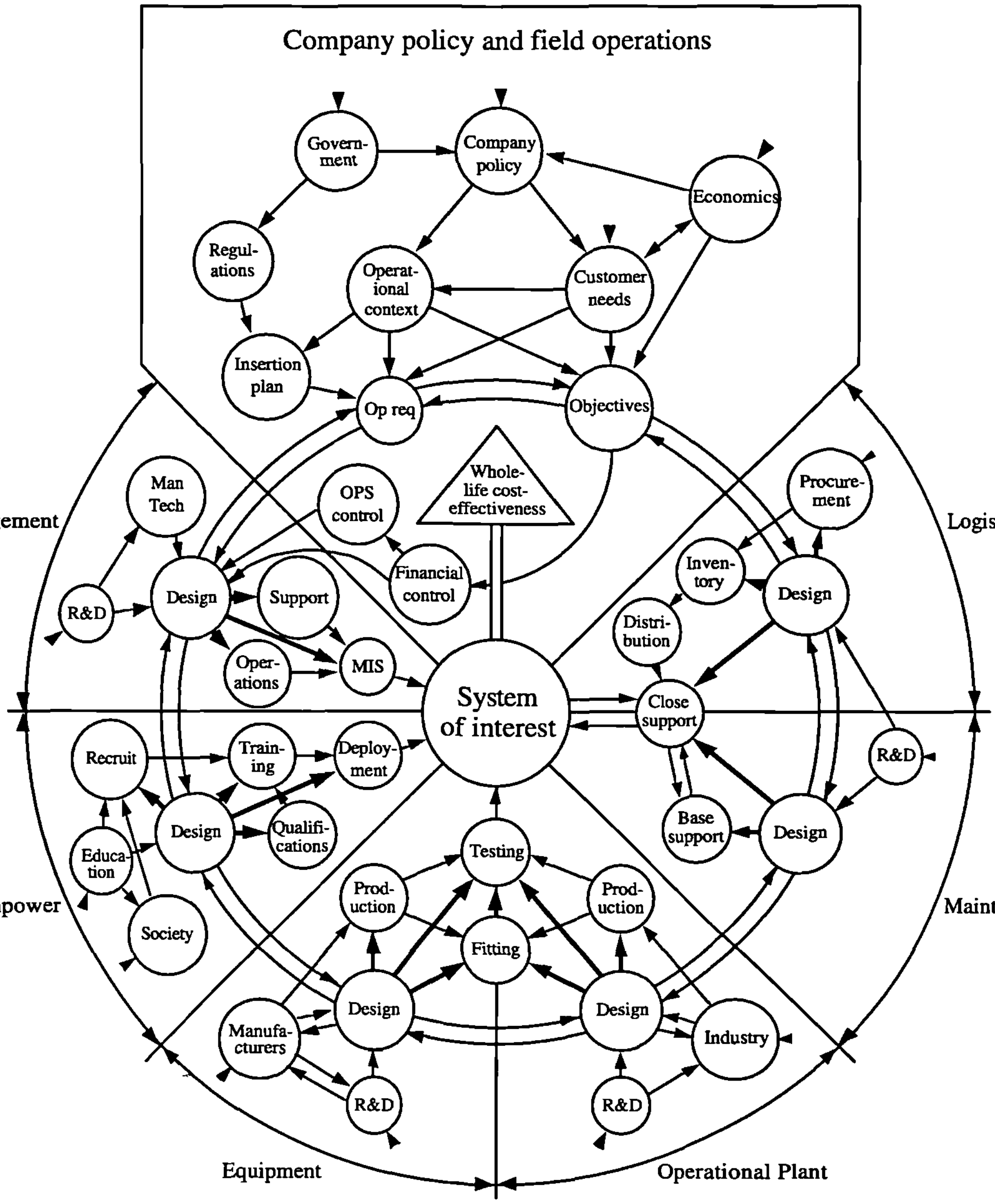

Exhibit 5.2.4 – M'Pherson's Wider System of Interest

All elements combine to produce a system that meets the objectives agreed for the project at the outset. For the purposes of this research, M'Pherson's published WSOI is viewed to comply with Hitchins' (1992) definition of the WSOI as it can be considered to be the "containing system" for the project, and it also satisfies Morris' requirement (1989) for the Level I Project Management role in the project (see Exhibit 3.6.2). Hitchins (1992) referred to the group of interacting systems immediately surrounding a project as the "containing system", and this provides detail for defining project boundaries in terms of management responsibility. M'Pherson's suggested WSOI is a representation or starting framework and as such would have to be adapted or even reconstituted for each project situation, in particular the nature of each external link will almost certainly be different for each project, and therefore it will be necessary to construct a specific WSOI for each undertaking.

However, a danger to be avoided will be the temptation to formulate a WSOI design for a particular project with undefinable interacting systems, or those systems that, under normal circumstances, would be considered too remote to have a measurable impact. Pragmatism will be required in order to avoid the situation quoted by Hitchins (1992) regarding a project cancellation relating to too much "upfront" modelling and definition.

System Planning (Perspective 3)

The third perspective is about system planning and applied project management. According to M'Pherson (1980) the developed project plan must schedule, co-ordinate and integrate the tasks of each sector of the WSOI in order that the system may become reality. M'Pherson's representation of a project plan for a project definition is shown at Exhibit 5.2.5.

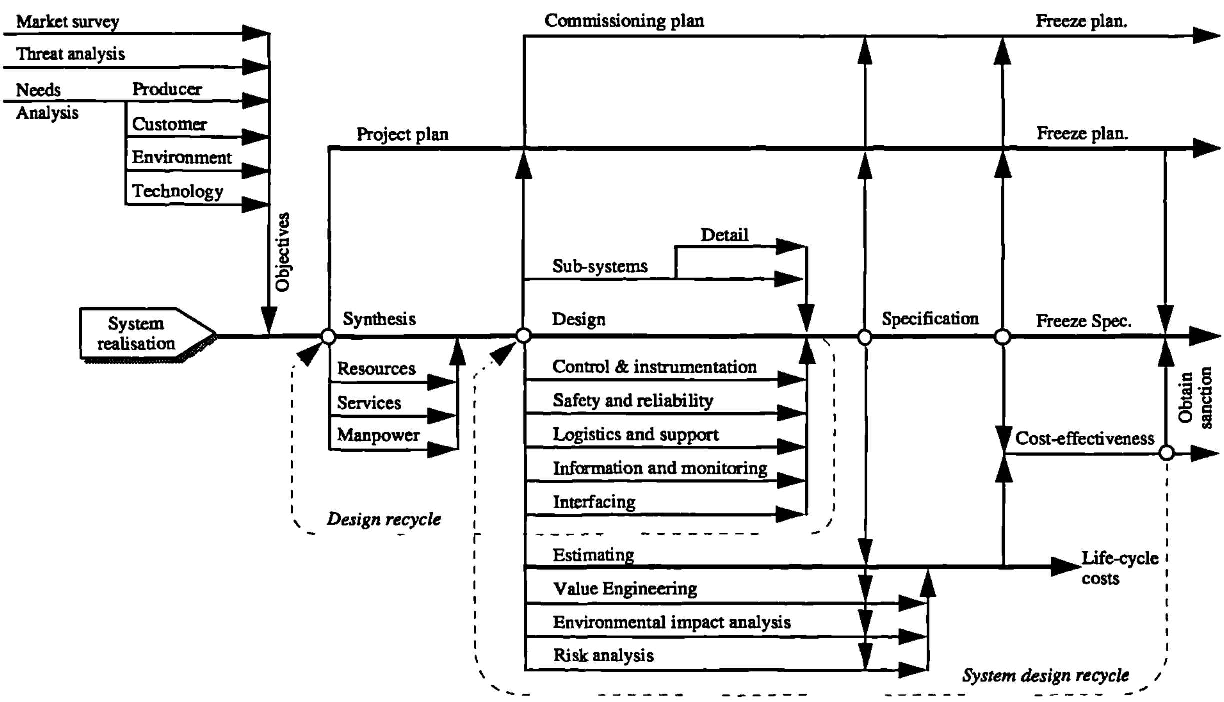

Exhibit 5.2.5 – Outline Project Plan for a Project Definition

It will be during the project definition that such plans are developed for the implementation of the whole project. The plans will need to reflect the product option selected and the management requirements for all project interfaces identified by the WSOI. This emphasises the importance of formulating a truly representative WSOI for the project during systems design and why effort should be invested in getting it right. It will be the project management task to guide the project as directed by the project plan. The plan will be a costed and resourced plan and hence any deviation or late achievement of milestones could mean a cost and time overrun for the project.

5.2.5 Coverage of the Requirement by the Morris and M'Pherson Models

Having developed the statements of requirement, it is necessary to determine the degree of coverage achieved by the Morris and M'Pherson Models in terms of the systems engineering perspectives outlined above. In order to achieve this, the first step will be to assign one or more perspectives to each requirement, and then to establish the degree of coverage that the M'Pherson and Morris Models offer.

Assignment of Perspectives to the Requirements

One or more of M'Pherson's systems engineering perspectives has been assigned to each statement of requirement in column 3 of Appendix 10. Each assignment was based on a match between the perspective's description and that of the requirement. In many instances, two or three perspectives cover a single requirement and this indicates that only an integrated systems model which addresses all three perspectives will suffice. A non-integrated approach would result in individual statements of requirement being addressed by different models which may not use the same base data and may prove to be very difficult to harmonise into a meaningful output.

Assessment of the M'Pherson and Morris Models Against the Requirements

Following a detailed analysis of M'Pherson's (1981) Model, it became clear that it concentrated on the second perspective, in order to focus the System Design Framework on the product design (the system to be delivered). The model generated the base data required to address all three perspectives, but for design the first and third perspectives were implied rather than specifically covered. This point was discussed in detail with Professor M'Pherson (1994), who commented that the audience for his papers (1980 and 1981) was primarily of a technical orientation and, in order to focus the papers accordingly, it was necessary to assume that the organisation design and systems planning would be undertaken. He also agreed that the organisational and system planning perspectives could be integrated with the core model rather than residing as a new level (see Exhibit 3.4.1) if organisation and planning optimisation were to be addressed.

The great strength of the M'Pherson Model lies in its adherence to systems theory principles and its well-structured processes for design. The M'Pherson Model was, therefore, chosen as the foundation for this work as it could be evolved into the MM

Model through new research-based processes derived from Morris' work. Exhibit 5.2.6 presents the results of an analysis of the Morris Model that demonstrates that it has the potential to cover perspectives 1 and 3. The exhibit also shows clearly that whilst the M'Pherson Model covers the product design process, it does not address specifically the management aspects that Morris (1986) identified as being the essential elements for project success.

Morris Model	M'Pherson Model	Perspective
Management Attitudes		
Attitudes and Commitment	Not addressed	1,3 and Pike
Project Definition		
Comprehensive scoping	Project Scoping Covered	1, 2, 3
Good design management	Partially covered by processes	1, 3
Finance		
Financial analysis of risks	Covered but needs enhancing	1, 2
Organisation & Contract Strat		
Project organisation	Not addressed	1
Contract strategy	Not addressed	1
Owners involved in contract	Not addressed	1
Resources/Management		
Effective leadership & mgt	Not addressed	1
Efficient team working	Not addressed	1, 3
Good communications	Not addressed	1, 3
Adequate resources	Not addressed	3
Consistent labour practices	Not addressed	1, 3
Human Qualities		
Coping with human error	Not addressed	1, 3
Team attitudes	Not addressed	1, 3
External Factors		
Effects of external factors	Addressed but not how managed	1, 2, 3
Political support	Addressed but not how managed	1, 2, 3, and Pike
Local community factors	Addressed but not how managed	1, 2, 3
Scheme		
Good planning and schedules etc	Not addressed	1, 3
Recognition of risks of urgency	Not addressed	1, 3
Recognition of concurrency risks	Not addressed	1, 3
Communication and Controls		
Project controls	Not addressed	1, 3
Quality assurance and auditing	Not addressed	1, 2, 3

Exhibit 5.2.6 – Analysis of the Morris Model

It would not be useful at this stage to undertake a detailed test of an adhoc combination of the Morris and M'Pherson's models against the statements of requirement as the Morris Model only addresses perspectives 1 and 3 in terms of topic headings; ie, the topics have no formal process structure associated with them – they are more in the form of checklists. However, a first review comparing column 3 of Exhibit 5.2.6 against column 3 of Appendix 10 would indicate that a good coverage is possible. In addition, Pike's Framework supports two of Morris' topics.

It should also be noted that neither of the models covers full risk analysis, project financing and project investment appraisal, although the M'Pherson Model provides the means for preparing for the latter under the heading of System Worth. The MM Model will need to address these requirements if it is to be comprehensive.

5.2.6 Harmonisation of the Morris and M'Pherson Models

Project definition, or Strategic/Systems Design in Hall's (1969) terminology, is about designing the whole system as a project; ie, the product or system to be produced together with the project management and company resources required to deliver that product or system (Morris, 1989; Sage, 1993; M'Pherson, 1981; Hitchins, 1992). To achieve this, it is necessary to design a project in an integrated and top-down manner in order to establish and preserve its consistency and integrity (Hitchins, 1992). Therefore, simply adding uncoordinated activities as new levels to M'Pherson's Model (as first suggested by Hall, 1969) will not enhance it for project definition purposes. Specifically, a new management module is required that is fully integrated within the existing M'Pherson Model; ie, evolving the model in a structured manner in order for it to address project definition.

M'Pherson's Model holds the key to its own evolution as illustrated by Exhibit 3.4.1. The model has two main elements; a "Containing Framework" that is essentially an analysis module that provides and receives both business and design data, and a "Framework for Integrated System Design" that essentially addresses the product design and resides as a module within the Containing Framework (ie, the shaded area). The MM Model concept is shown at Exhibit 5.2.7 with two design modules; the Integrated System Design for the Product" (M'Pherson's Framework for Integrated System Design) and the "Integrated System Design for Project Management". The new module will represent the management aspects of the Morris Model, and thus will address the missing first and third perspectives. Combining product and project management design aspects into a single integrated module would be difficult to achieve as the processes involved are essentially different and are undertaken by different individuals with different skill sets, albeit the individuals may be members of a multi-functional project definition team. Operating as two discrete teams, one for project design and one for product design, would not yield a harmonised view of the overall system. Harmonisation is further achieved in two ways; firstly, the "Containing Framework" will be common to both design modules and secondly, the two design modules will be able to interact in a structured manner in order that the management module can react to the emerging design.

Harmonisation in this manner is justified for the following four reasons. Firstly, it satisfies Checkland's (1981) principle of emergence and hierarchy in that a project exhibits properties that are meaningful only when they are attributed to the whole system and not to the sum of its parts; ie, the project management aspects cannot be considered separately from the product. Secondly, Yeo (1993) noted that project management also displayed emergent properties as it derived purpose and meaning from the product of a project.

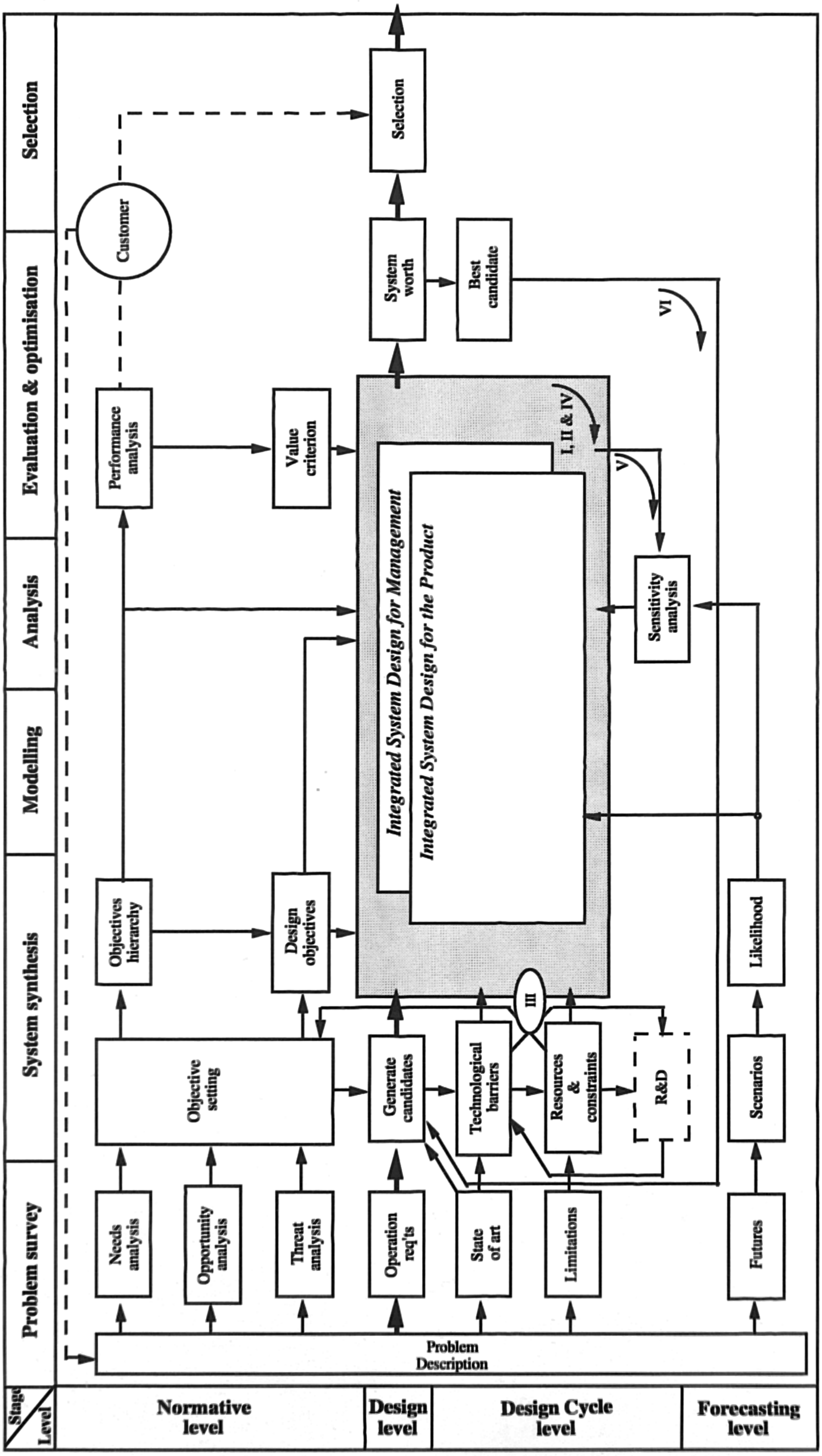

Exhibit 5.2.7 – The MM Model Concept

Thirdly, the whole project must be defined within the wider system of interest if it is to be successful (Hitchins, 1992; M'Pherson, 1981); also, the product can only be defined in terms of its management and its surrounding environment (Morris, 1989) thus conforming to the three levels of management required for open systems (see Exhibit 3.6.2). Fourthly, M'Pherson's (1981) three perspectives of systems engineering can be addressed fully in an integrated manner.

5.2.7 Understanding the Product Design Process

In order to understand how to incorporate project management aspects, it is first necessary to understand how the product design is achieved. M'Pherson's (1981) Framework for Integrated System Design (designated Product Design for this research) is shown at Exhibit 5.2.8.

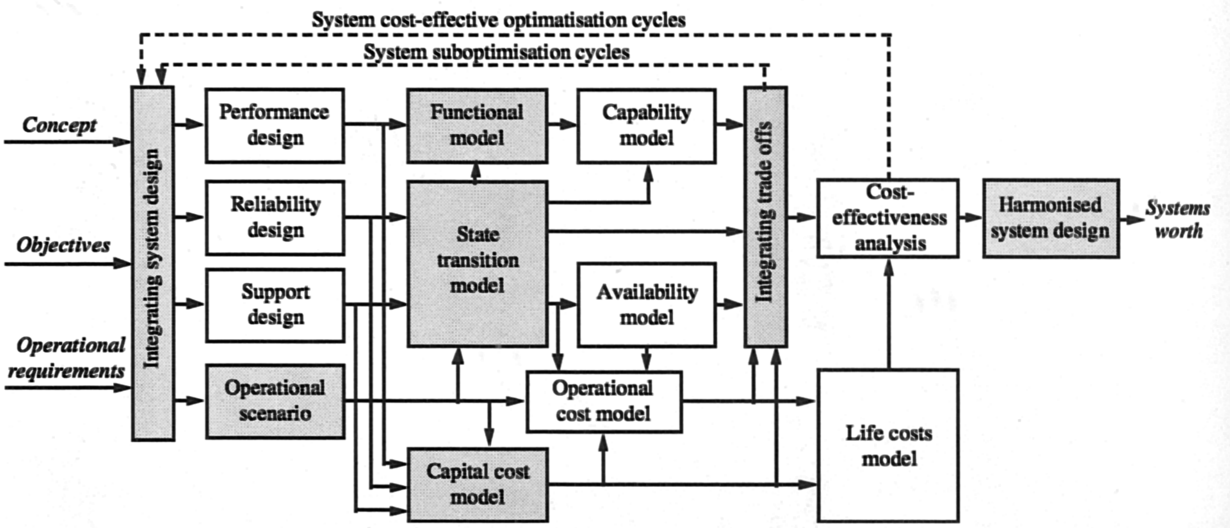

Exhibit 5.2.8 – Integrated System Design for the Product

The product system design is described in detail by M'Pherson in his 1981 paper, and is covered as a complete subject by Sage in his book (1992), but suffice to say here that it follows a classical development approach that is tailored for each situation. The general case commences with an Option Design (Integrating System Design) that is progressed through Performance Design, Reliability Design and Support Design in order to produce Functional, Transition, Capability and Availability models. The Operational Cost Model and the Capital Cost Model provide data for the Lifecycle Cost Model (see Exhibit 5.2.9) for areas covered by lifecycle costs.

Following the collection of cost, capability, and availability data, a trade off analysis is undertaken against operational objectives. The Integrating System Design activity provides the design detail for the SOI in the context of the WSOI (see Exhibit 5.2.4) as reference data for the ongoing product design, and the management design. Furthermore, the integrated system design will also take full account of the manufacturing requirements for new products including the need for concurrent engineering (or simultaneous engineering), design for manufacture (DFM) and design for assembly (DFA) (Parnaby, 1995).

The design cycles (iteration loops) I, II, IV, and V of the M'Pherson Model have been identified together with the interfaces both to the Containing Framework (by line arrow) and the Project Management Design Module (interfacing modules are shown shaded). It should be noted that it would not have been possible for the capital costs within M'Pherson's original model to be calculated without a detailed project planning exercise being undertaken (perspective 3) and, therefore, a key input from the Integrated System Design for Project Management will be formal cost information that has been directly calculated from an actual project schedule and its associated plans.

Capital costs	
Realisation costs................................	
Feasibility Study	
Project Definition	
Acquisition costs...............................	
Development	
Manufacturing	
Assembly	
Test	
Deployment	
Training	
Capital charges	
Operating costs	
Operating system costs	
Equipment:	Resource use, (Support), Modifications, Renewal, Phase-out
Personnel:	Wages, Benefits, Training, (Support) Retirement
Operations:	Dues, Licences, Facilities
Marketing:	Research, Advertising, Sales Personnel
Intelligence:	Equipment, Personnel
Support system costs	
Personnel:	Victualling, Transport, Health, Recreation, Lodgings
Maintenance:	Personnel, Monitoring + Diagnosis, Scheduled Maintenance, Equipment, Facilities, Downtime costs
Logistics:	Personnel, Spares & Stores inventories, transport, facilities, Procurement
Ethical costs	
Safety:	Monitoring + alarms, equipment, personnel, damage, liability, insurance
Environment:	Amenity, public relations, pollution abatement

Exhibit 5.2.9 – Lifecycle Cost

An additional activity, the “Harmonised System Design”, has been added to M'Pherson's Framework for Integrated System Design to bring together both the product and the management as an integrated "whole" in preparation for an assessment against "Systems Worth" (part of the original M'Pherson Model).

5.2.8 Incorporating the Project Management Design Process

Olsen (1971) defined project management as a collection of techniques and supporting tools to direct the use of diverse resources towards the accomplishment of a unique complex one-time undertaking within time, cost and quality constraints. Each project requires a particular mix of these tools and techniques structured to fit a particular situation. Project management has six objectives (Turner, 1993): managing scope; managing organisation; managing quality; managing cost; managing time; and managing risk. It is the purpose of the project definition (according to King and Cleland, 1978) to determine, through formal structured analysis, the full scope of the project and how each of the above management objectives can be met by assessing how particular techniques and tools can best be brought together to address the objectives. Furthermore, the project definition provides an opportunity for an organisation or firm to review its original initiative in terms of risk, benefits and fit within an ever changing business strategy.

The top-level Integrated System Design for Project Management is shown at Exhibit 5.2.10. The 5 major processes shown are based upon project definition approaches identified by authors such as King and Cleland (1983), Sage (1992), Turner (1993), Morris (1987 and 1989) and on accepted published best practice, with a sequence added to focus on the needs of both improved project definition and the MM Model's objectives; Exhibit 2.2.5 (for project definition) represents the sequence employed that was first suggested by King and Cleland in 1978. The sequence shows feedback paths for re-evaluation and rework in order to formulate a balanced Integrated Management Plan.

The aim of the Project Management module is to identify and specify an appropriate design for the project, together with a management approach for delivering the project that includes acceptable schedules and plans. The module therefore specifically addresses M'Pherson's first and third perspectives and is formulated to fully represent the incorporation of the Morris Model into the M'Pherson Model. However, it is important that the Product Design, Project Management Design and the Containing Framework together address M'Pherson's three perspectives in an integrated manner in order that all of the system's emergent properties can be realised; ie, the whole is greater that the sum of its parts.

Interfaces to the Product Module and the Containing Framework are also shown at Exhibit 5.2.10, and identified specifically (in parenthesis) by the detailed descriptions that follow. The Project Management Design takes full cognisance of the WSOI at each stage as it is this element that ensures that the emerging management design is developed to deal with an open system (Hitchins, 1992), and hence it will be able to deal with all impacting project interfaces (Morris, 1989).

The first two processes; Project Baseline Analysis and Project Analysis, qualify and quantify the project's scope through a consolidation of all impacting elements. The consolidation exercise involves developing a management view of the product to be delivered, the business and project environment in which the product will be developed,

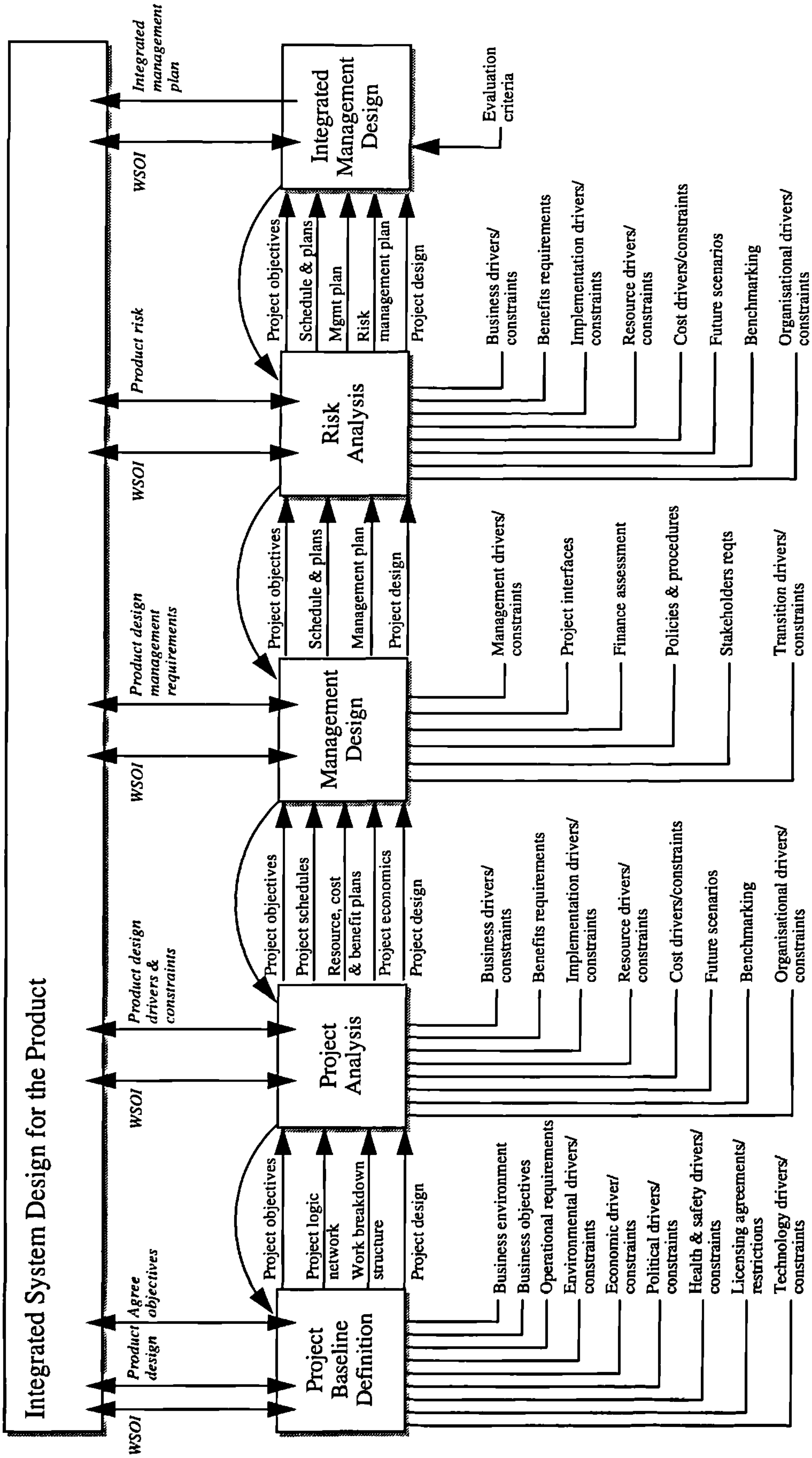

Exhibit 5.2.10 – Integrated System Design For Project Management

implemented and operated, and the work content and logic of each phase in the lifecycle. Management Design identifies the organisation, controls and all resources required for realising the project, and the Risk Analysis identifies the level of contingency and possible mitigating measures needed to maintain the project's quality, schedules and plans. The final process, Integrated Management Design, is concerned with testing the emergent management design against evaluation criteria from M'Pherson's Containing Framework, and the harmonisation of the various process outputs into an Integrated Management Plan. The Integrated Management Plan (the documented Integrated Management Design) and the Integrated Product Design are harmonised into a full systems engineering approach to project definition in the Design Module prior to the Systems Worth Analysis within M'Pherson's Containing Framework. Systems Worth analysis is described in outline for completeness at the end of this section.

The intent will be to produce an Integrated Management Design for each of the feasible product designs. In reality, however, there will be a limited number of feasible product designs and from a management viewpoint there would exist a significant number of common features and therefore iterations through the design loops should not result in project management designs starting from the beginning each time; indeed a significant proportion of the management design work will be essentially the same. Furthermore, it may be decided that the full project management design should only be undertaken for the most technically feasible product.

Project Baseline Definition

The aim of the Project Baseline Definition is to specify a constitution for the required project in harmony with project objectives, an appropriate break down of the work required to deliver the product, an acceptable work sequence design (ie, a project logic network), and a suitable design for the project (M'Pherson's design of the design) – see Exhibit 5.2.11).

The initial baseline analysis reconciles the WSOI and agreed objectives with key external factors that will have a significant impact on the project's setting and conduct, which includes consideration of both the physical and social environment of the project; eg, national and local politics (including any nationalistic aspirations), licensing, health and safety, legislation and bylaws, and the ecosystem. Furthermore, the baseline analysis will determine the level of political support needed for the project if it is to be successful, together with identification of where such support would be forthcoming. The aim will be to identify how the project interacts with its WSOI, and the behaviour of the project and its direct environment as a result of perturbations that may occur on the interfaces as the project progresses along its timeline (Hitchins, 1992). The Project Baseline Analysis also provides the description and initial definition of "why the project is needed and what the project is about"; ie, the base specification needed to set up the project to successfully deliver the required product at the right time and at the right price within a given business or operational environment. Furthermore, the baseline analysis will identify special planning requirements such as those associated with public inquiries (Stringer, 1991), and defence procurement projects (Equipment Approvals Committee, 1992). These special planning requirements will involve additional activities to be included into schedules, and more onerous organisational and planning procedures to be adopted. For projects with a significant manufacturing element, the baseline analysis reconciles the project with company systems strategies and policies covering design, manufacture and integrated logistics support. Such policies may cover a defined product introduction process (PIP) and acceptable practices for concurrent engineering (Parnaby, 1995). The project's constitution is set up to reflect the type of procedure involved whether it be company or government imposed.

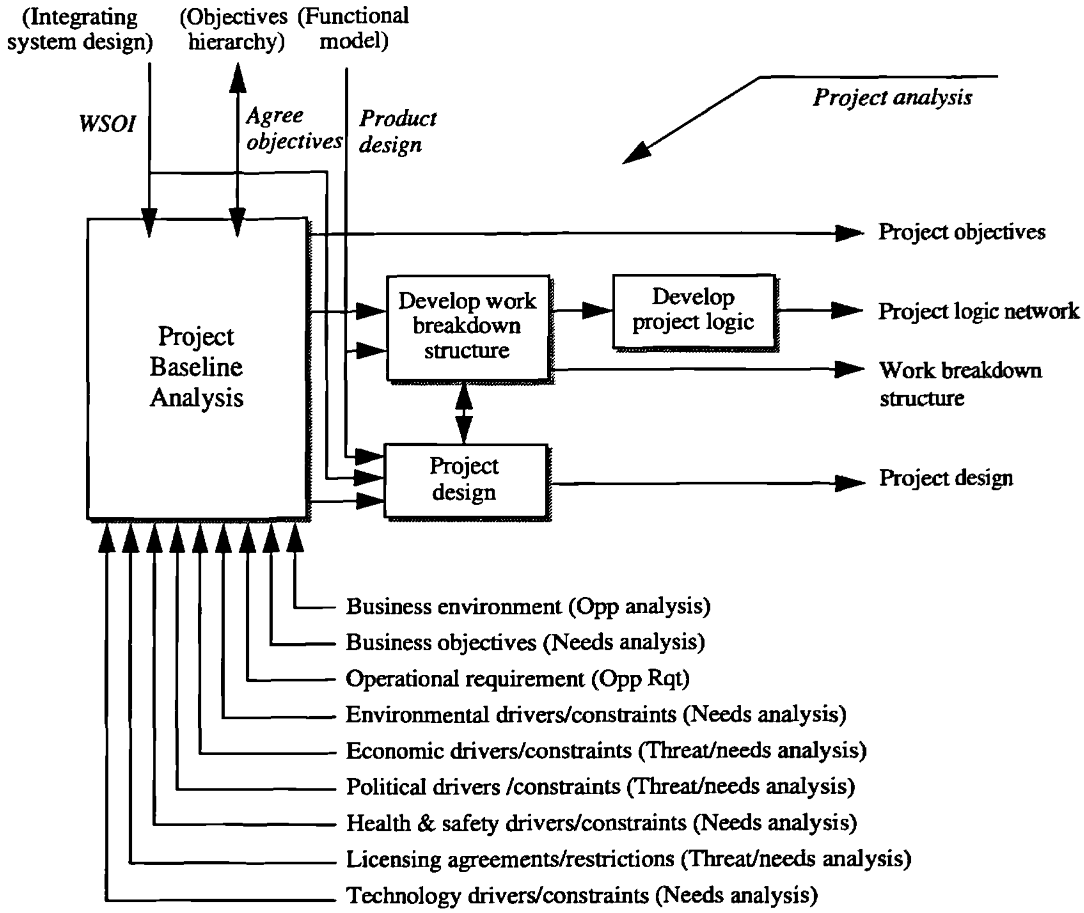

Exhibit 5.2.11 – Project Baseline Definition

Project related critical success factors (CSFs), associated key performance indicators (KPIs) and appropriate performance measures are derived directly from the project's objectives and are key to managing the project's performance over time, and for judging its overall success (of course the term success must also be defined, see Paul (1982), and the RB211 aero engine case study). It is essential for the project's objectives to be aligned with business objectives and to be clearly communicated and agreed with the owning organisation, ie, all senior managers involved and key players on the project team;

commitment and a universal agreement on what will be delivered, the timeframe and cost are necessary ingredients for success (Marsh et al, 1988).

The process provides a disciplined and systematic identification and breakdown of the project into work packages and associated deliverables that contribute to producing the product; input to this activity will be required from the functional model (Integrated System Design of the Product) in order to provide design detail on the product. It is at this stage in the process that the size and complexity of the project first become apparent. During the project definition stage it will not be possible to produce a comprehensive WBS but it will need to be taken to a depth where an acceptable level of confidence can be attributed to the costs, resource requirements and duration estimates; Turner (1993) stated that at the sanction stage (project approval) it was necessary to decompose the project to the work package level (ie, not activity level) in order to determine the project's parameters. The WBS will also provide the means by which major project deliverables can be identified and defined in order to address Morris' project dynamic interface issues; ie, to identify where natural break points in the project occur to determine an appropriate structure for the project (Morris, 1989).

Following the production of a WBS to an acceptable level for project definition, a network is produced which logically connects each of the WBS work packages. Duration and resource requirements will be allocated to work packages by the next process. An analysis of the work breakdown structure will yield dynamic interfaces, and the project design will yield static interfaces; ie, those associated with the WSOI (see Morris, 1989 and Hitchins, 1992). From this information, and the adoption of an appropriate project lifecycle model, it will be possible to develop a project design (M'Pherson's first perspective see Exhibit 5.2.2 above). This project design will be refined as the management design progresses through the next four processes.

The Project Baseline Analysis provides the foundation information for those activities that satisfy the incorporation of the Morris Model elements into the MM Model and as such does not address any specifically.

Project Analysis

Following the project's baseline definition, the emerging project structure and its constitution are analysed to determine their full scope and the extent of the complexity with the aim of designing a project that is achievable in terms of cost, time, functionality and benefit. Complex public infrastructure projects involving public consent (Stringer, 1991) will require particular attention owing to the large number of additional activities to be undertaken, as will the extent of media exposure the project will face. The process for achieving the detailed analysis is shown diagramatically at Exhibit 5.2.12.

The Balancing Activity develops, using appropriate formal tools and techniques, a project schedule and associated plans from the work breakdown structure (WBS) and logic network by iterating them through the illustrated design loop to balance available resource (logistics included), acceptable cost, required benefits and functionality. The balancing activity is achieved against a backdrop of parameters from M'Pherson's Containing Framework and design detail from the Product Module; it is important for the whole system to emerge in unison (Hitchins, 1992). An external input may be used for providing valuable benchmarking information on similar projects. Complexity can only be contained if the scope of the project is fully realised and planned from the outset, and the risks associated with schedule urgency and concurrent activity are fully understood and compensated for, especially where technical uncertainty is present (Morris, 1986). There is also a need to identify clear and substantial milestones against which the project performance can be measured.

It may be necessary at this stage to reduce, phase or defer functionality in order to make the project achievable (particularly if the project faces political uncertainties), but this can only be undertaken in conjunction with the product design, benefits analysis, and to satisfy business and operational objectives. For large capital projects, or those with significant technical uncertainty, it will be necessary to build contingency for rework into the schedules if the project is to have integrity (Cooper, 1993a, b and c). The schedule and plans must also take account of the work required to define, design and manage interfaces hence all work will be done under the auspices of the WSOI.

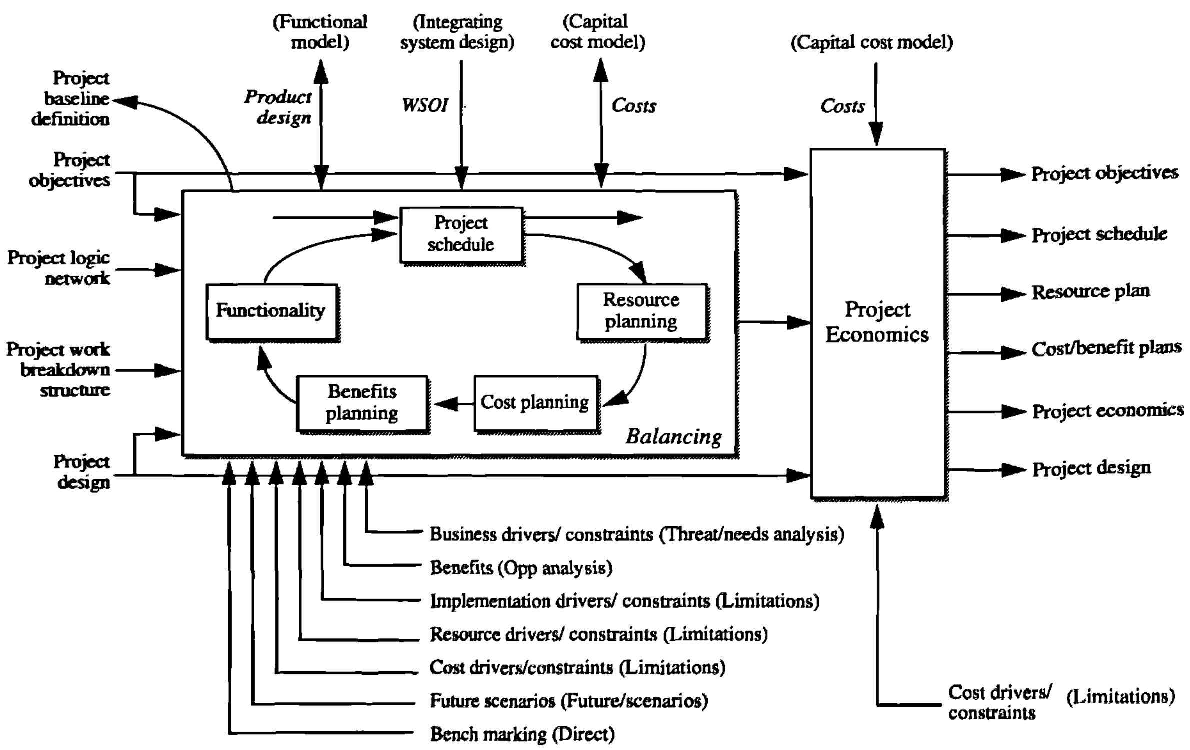

Exhibit 5.2.12 – Project Analysis Process

Project Economics identifies the overall cost (from the Capital Cost Model) of the project, and assesses how the project is to be financed progressively (not sources of finance) throughout the lifecycle, possibly to meet political or company constraints on funding, and the value of the benefits from the project and when these benefits are to be realised. An analysis of the expenditure profile will allow the development of a matching or possible advantageous income profile and, if the project is being provided through contract, what quantum of cash is required for different milestone points. Indeed, the design of the project and the planning of the project will be dictated to a large extent by payment milestone positioning. A degree of sensitivity analysis will need to be undertaken for each milestone in order to ascertain the project's profit or loss out-turn for schedule variations. The process will consider what impact price, inflation, regulation, technical development, government and corporate changes, and political short-termism could have on the success of the project, and will build in necessary financial compensating factors. Furthermore, possible economic incentives could compensate negative factors.

For BOOT, BOT, BOO, and DBFO projects it will be necessary to assess a project's economics in terms of a business undertaking; ie, will the revenues from operations service the debt, provide an acceptable return on equity, and deliver an acceptable profit to the operator before the end of any concessionary period.

Project analysis addresses the Morris Model elements concerning comprehensive scoping, good planning and schedules, recognition of the risks of urgency, recognition of the risks of concurrency, and adequate resources.

Management Options

A governance review looks at the control options open to the emerging project. Full consideration is given to the project's constitution, its size, complexity, technical uncertainty, schedule duration, schedule urgency, physical and social environment, and government and politics which are qualified in order to surface all control issues. In particular, project interfaces, both dynamic and static (from the project design and WSOI) are assessed for controllability; any that are found to be uncontrollable or difficult to control indicates the need for reassessment of the project's baseline (Morris, 1989) or its positioning in the WSOI. Once the full scope of the project is realised and options for governance considered, an integrated set of management requirements for the project are developed. In keeping with Hitchins' (1992) findings, these requirements are compiled against the WSOI background in order to ensure that the management is not parochial to the internal project, and it satisfies Morris' (1989) and Parsons' (1960) philosophies for a three-level management model (see Exhibit 5.2.16).

The management requirements are described under the topic headings of project organisation and culture, control and reporting, project communications, contracting and procurements, quality assurance and control, transition management, project interface management, environment, and financing options; see Exhibit 5.2.13. These topics reflect the incorporation of the management elements of the Morris Model into the M'Pherson's Model and the observations raised by Kershaw (1978) concerning large international projects that span a wide geographical area. Each topic will require a specific study although not in isolation as the connecting bar represents. Work to be undertaken within each of the study topics is described under the appropriate headings below, although this description should be read in conjunction with more detailed theories developed as part of this thesis.

Project Organisation and Culture. The organisation to be developed must implement the governance required to direct and manage the project as part of the WSOI with clear and unambiguous reporting lines and authority levels. Furthermore, the organisation must be appropriate not only to the complexity of the project but also to its scale, its geographic distribution and contracting arrangements (Millar and Rice, 1967). Moreover, the organisation must a be appropriate to that of the parent body, to the project's owner and to any participating stakeholders, and single point responsibility must be established for each function (Cleland, 1990). It should be noted that because of their non-monolithic nature, government agencies or public bodies involved should be kept to a minimum with their function and authority carefully defined (Morris, 1986).

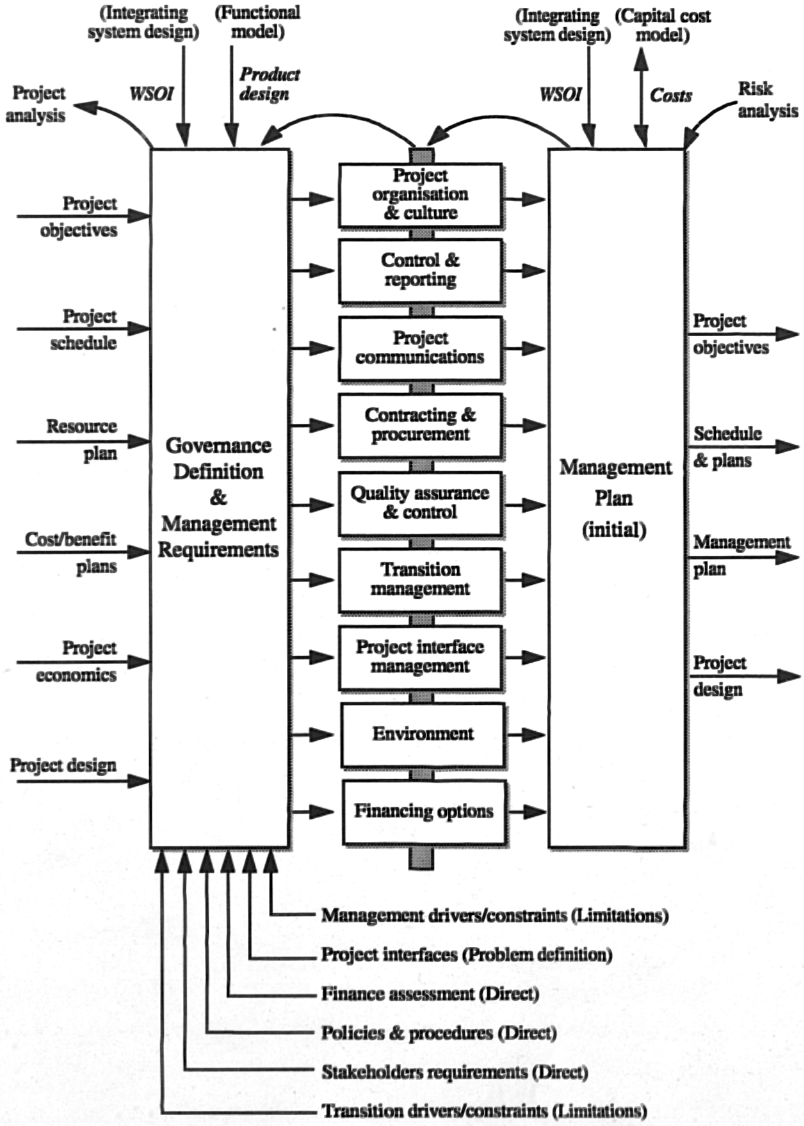

Exhibit 5.2.13 – Management Options Process

It is not possible to design or propose a required project culture directly, but it is possible define the values and behaviours to be adopted by the project to suit a particular environment (Firth, 1995); ie, local needs, laws and customs, the requirements for schedule urgency, and the needs of the project team (location, hardship, etc). Furthermore, the proposed values and behaviours must recognise the need to develop and maintain acceptable project attitudes from all involved (see also project communications), and to enable the project to develop its staff through team working (Leeper, 1995). An effective team can solve issues collectively that would be beyond a single team member's ability (Ketzenbach and Smith, 1993). Leadership will ensure that the required values and behaviours are established and maintained throughout the life of the project. The project's culture will emerge as a result of practising the values and behaviours prescribed; if a change of culture is necessary then the leader will need to change the values and behaviours accordingly and wait for the new culture to emerge (Firth, 1995).

Control and Reporting. This topic is at the heart of the day-to-day project management and it is difficult to implement effectively retrospectively, ie, when the clock starts running for implementation. During project definition it is necessary to identify how the project will be formally and comprehensively controlled to meet its governance requirements, and how management complexity can be minimised at each level, especially where contractual and geographical boundaries with international participants are involved (Kershaw, 1978). It will also be necessary to determine which influences are controllable and which are uncontrollable in order to implement appropriate management measures. For all projects it is necessary to control a product's configuration throughout its development and production, and therefore this study needs to define a configuration management approach together with suitable change control procedures (IEEE, 1994). It is through these procedures that the integrity of the product together with its schedules and plans can be maintained. The study will identify the projected information flows in order to ascertain the management information systems needed to support the control and reporting function. Furthermore, to ensure collective ownership of decisions, project boards, task or topic related management committees, and working groups will be identified and appropriate terms of reference drafted. Control and reporting administration and other project support functions are traditionally delegated to a project office (project organisation).

Project Communications. This is an essential part of securing and maintaining commitment and involvement of all concerned (Sykes, 1982; et al). It will entail making visible the essential elements of the project together with progress and highlights to the community of interest; ie, within the project and with all interacting organisations. Furthermore, communications is an essential ingredient to building and maintaining teams, and raising the general awareness of major issues as they arise (Katzenbach and Smith, 1993; Morris and Hough, 1985). On controversial projects or those associated with major infrastructure, such as those requiring public consent, it will be necessary to counter possible press and public criticism or pressure groups, and run articles supporting the project's objectives in order to mitigate against future problems. However, for all major projects it will be necessary to develop a Communications Plan appropriate to the nature of the project; ie, in line with its constitution. A communications activity can be run by the project office, but for major projects it is often necessary for a PR company to be involved which will entail additional capital expenditure.

Contracting and Procurement. This study, which will include the identification of possible legal frameworks, will assess the options for implementing a project. Considerations for the study will include although not exhaustively: what if anything is to be contracted; if contracted should it be through a prime contract (where all risk is laid off and usually the project is fixed price), a managing contract (where a contractor is engaged to manage the project on behalf of the customer, possibly through fixed price arrangements) or time and materials (where the customer and contractor share the risk and no fixed price is involved). Infrastructure projects, or substantial public sector projects, may be considered for Private Finance Initiative (PFI) arrangements (possibly as a Build Own Operate Transfer (BOOT) project – or a similar derivative), and appropriate contracting and procurement, organisation, and financing arrangements will need to be considered (Haley, 1992). Types of contract, particularly those which are incentivised, must be considered and linked to the findings of the project economics analysis, project organisation and control and reporting. Contracting and procurement should also adopt the simplest path in line with the project's needs in order to reduce or contain organisational complexity. With international contracts, it is important to constrain national aspirations if parochial behaviour or "favoured contract status" is to be avoided, and to ensure that consistent labour practices are employed. Finally, the type of contract identified should be acceptable to both the contractor and the customer if future disputes are to be avoided.

Quality Assurance and Control. The scope and responsibilities of the necessary quality assurance and control function will depend largely upon the project size, complexity, technical uncertainty, schedule duration, schedule urgency, physical and social environment, government and politics, and the nature of the project within its WSOI. The quality assurance and control study will produce a quality plan that documents the rules, procedures and standards that ensure that the product is designed, developed, tested and brought to operations to meet its agreed specification, and that the project is managed in accordance with the agreed management plan (Dickson, 1985). The organisation study will identify where the quality assurance and control function exists within the project and how it will interface with any customer or sponsoring bodies' equivalent function. Such functions will also need to interface with their equivalence in other systems in the WSOI if overall integrity is to be maintained.

Transition Management. This requirement is concerned with the management of moving the product from a fully tested state to its operational state in accordance with the operational requirement and the integrated system design. This study will produce a transition management plan that describes how the SOI will mate with the WSOI at the appropriate time, and all management actions necessary to make it happen. Transition management will need to work on each side of all relevant interfaces to be effective and, therefore, may need to be synchronised with other projects and operational systems.

Project Interfaces. Following an analysis of the emerging project design and the WSOI it is possible to identify and specify each of the project interfaces. Morris (1989) observed that only when project interfaces (both dynamic and static) were managed effectively could the integrity of the project be preserved. During project definition, therefore, a management approach is specified for each interface. The dynamic interfaces, as described in Chapter 3, occur when a project is in transition from one lifecycle stage or phase to another and therefore specific management activities will be identified and defined before the transition is made; however the project definition will need to provide a framework for this management in order to provide consistency throughout the life of the project. Furthermore, the framework will be concerned with controlling the evolution of system specifications (through configuration management) as the project moves stepwise along its timeline. Static interfaces are those interfaces that exist between the project and its WSOI; ie, those elements or bodies that are external to the project, but affect the project. For each static interface a management approach is identified and agreed with the element or body concerned in order that a common approach is adopted; on international projects it may also be necessary to use interface management to constrain nationalistic aspirations. The output from the study will be an interface management plan that will form part of the overall project management plan.

Environmental Study. For projects that impact the socio-economic aspects of public life, and most major projects (especially infrastructure projects) will have some impact, there is a moral obligation to establish and confirm the real need for the project from a public viewpoint. Without this confirmation it will be difficult overcome public resistance and possible hostility to the project's implementation. To achieve this aim it will be necessary to examine the cultural diversity of the area in which the project is to be sited and judge whether it is appropriate to undertake the project at that time in that place. In preparation for the risk analysis, and in conjunction with the project economic assessment, there is a need to assess the environmental impact of both the project and the resulting product, and to identify measures for containing or reducing the impact (this element of the work will be coordinated with the communications plan), this may include formulating environmental and community packages that leave an area no worse off than before the project began. The output from the study is an Environmental Plan (integrated with other associated plans) that addresses all issues relating to the environment and how the project management organisation will deal with them.

Financial Options. This study element looks at all of the options for financing the project as discussed in Chapter 4, ranging from on-balance sheet financing, through debt, equity, to off-balance sheet financing (see Nevitt, 1989; McCarthy, 1992). The financing required will depend upon the nature of the project, the cost of the project, the return on investment from the project, the business environment, whether the project is being built under BOOT (or other derivatives) or PFI arrangements. This study will need to identify the best and least complex option for a financing package for the project in line with the findings from the Contracting and Procurement Study and with the Economic Analysis completed as part of the previous process. Furthermore, for international projects, especially those for third-world development, the study will need to understand and build into the findings local fiscal policies (eg, taxation and pay considerations) as they affect the project.

Initial Project Management Plan. This plan draws together the plans from each of the study elements and harmonises them into a management directive (ie, its mandate) for the project. It sets out how the project is to be managed and will be used to create the environment within which project control is exercised. If such a plan is not created at this time much effort will be wasted in pursuit of conflicting courses of action, uncoordinated work, clashes of responsibility, and inadequate information transmission. A key issue to acceptance of the plan is the involvement of senior management who must be committed to the plan from the beginning (through Pike's Framework). By stating clearly what has to be done, by when, by whom, and how, the plan allows problems to be highlighted early and the necessary action to be taken. The plan is also the vehicle to obtain consensus and commitment to the project. Included in the plan will be a restatement of the business objectives and a clear definition of project targets.

The Management Options Process overall addresses the Morris Model elements concerning attitudes and commitment, good design management, project organisation, contract strategy, owners involved in the contract, effective leadership management, efficient team working, good communications, consistent labour practices, coping with human error, team attitudes, effects of external factors, political support, local community factors, project controls, and quality assurance and auditing (see Exhibit 5.2.6).

Risk Analysis

The activities for the risk analysis are shown in the process at Exhibit 5.2.14. The sequence of the activities is based on research undertaken by Stupples and Hatfield (1993) – see Chapter 4.

By assessing the emerging management design, the drivers and constraints from M'Pherson's Containing Framework and the emerging product design it is possible to identify a super set of risk drivers (in the context of the WSOI – Hitchins, 1992). A key input to this activity will be the company or organisations' standard risk register. Appropriate risk drivers from the super set are selected for the project in question, and qualified and quantified for impact (likelihood and cost) – see matrix at 4.7.3. Risks occurring in the top left, top right, and bottom right quadrants (see Exhibit 4.7.1) are all candidates for management action. This action could take one of three forms:

- firstly, it could require changes to the product design or management design within the project definition

- secondly, it could require mitigating action or contingency (either one will entail additional cost) for the ongoing project
- thirdly, it may be decided to ignore the risk until it happens then to invoke a predetermined management measure.

Risk measure options are generated for each risk in question and a cost/benefit analysis is applied accordingly. In many instances, large projects will affect both the physical and social environments and therefore specific considerations may be necessary to reduce public and political concern. Furthermore, special consideration may need to be applied to very large-scale infrastructure projects (or the so-called mega-projects – see Merrow 1988) that impact the whole macro economy of a nation (eg, a telecommunication project resulting from a national deregulation and modernisation strategy that could cost in excess of 30% of the host nation's GNP); political and financing risks associated with these projects are high. A risk management plan is prepared that will cover identification of threats, probability of the event occurring and impact if it does occur, contingency plans, risk reduction actions, and roles and responsibilities in risk management.

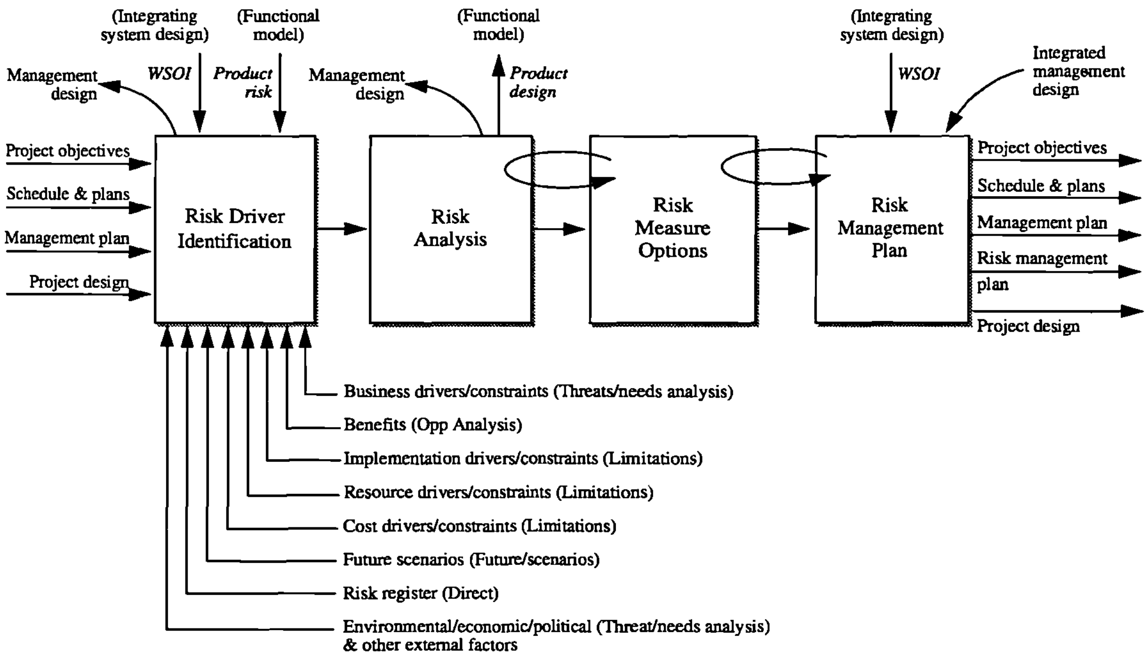

Exhibit 5.2.14 – Risk Analysis

It is often necessary to include in the project schedules activities that will look for symptoms of risk in order that proactive action may be taken. This process will specifically address the Morris Model element concerning financial analysis of risks, but it also addresses the shortfall from the analysis of both models where it was noted that neither really covered risk assessment and management effectively.

Integrated Management Design

The aim of Integrated Management Design is to produce an Integrated Management Plan which, together with the Integrated System Design, defines the SOI within the WSOI. The process has two activities which are shown at Exhibit 5.2.15.

The first activity ensures that the project objectives, schedule and plans, the initial management plan, the risk management plan and the project design are brought together to form an Integrated Management Design. This design will be tested against the product design, the evaluation criteria (from M'Pherson's Containing Framework) and the WSOI for management capability and effectiveness. The full dynamics of the management environment will need to be understood and if necessary modelled to identify gaps and weaknesses. The management design at this stage will need to satisfy Morris' (1989) and Parson's (1960) requirements for project management at three levels if the project is to managed as an open system (Hitchins, 1992). Morris' 1989 model for open system management is repeated at Exhibit 5.2.16. Note, only a limited number of WSOI elements are shown in the outside area.

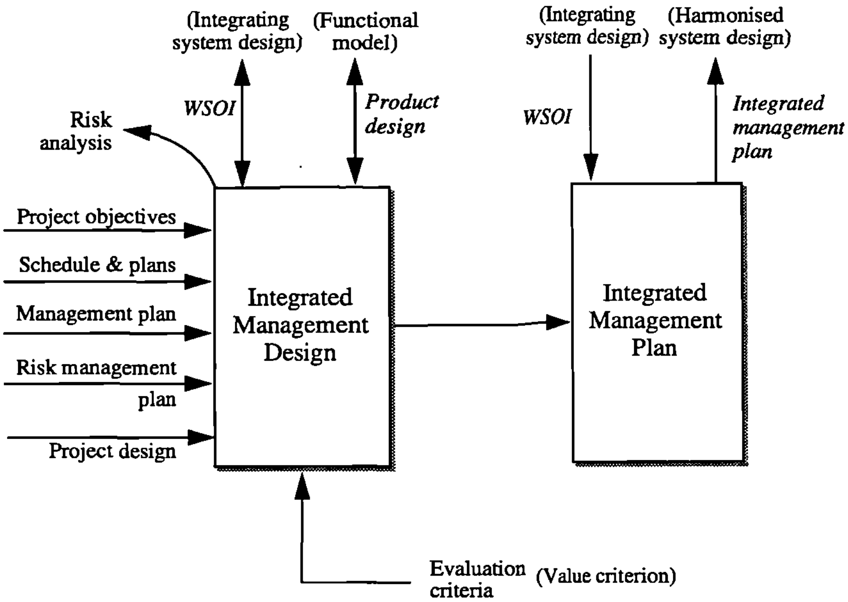

Exhibit 5.2.15 – Integrated Management Design Process

Following confirmation that the integrated management design satisfies its requirements, a comprehensive Integrated Management Plan (containing the Risk Management Plan, Schedule, Cost Plan, Resource Plan etc, and Project Design) is formulated. This Integrated Management Design, together with the Product Design, can be evaluated by M'Pherson's System Worth process in the Containing Framework. The overall system design satisfies M'Pherson's three perspectives and therefore can be evaluated as a whole system with all the emergent properties visible. At this stage the Morris Model has been fully integrated in a structured manner into the M'Pherson Model.

Systems Worth (Containing Framework)

M'Pherson observed that dimensions of system "goodness" were the value attributes of the system that constitute what the customer, user, sponsor, financier, contractor, regulator, environmentalists, and authorities acting on behalf of society (for example) would regard as mandatory and desirable objectives. A system design is examined for its contributions to those objectives; the overall aggregate of the contributions is termed the system's "worth".

A project emerging from definition requires M'Pherson's "worth" test as part of its overall evaluation. The objectives (the value criterion) will have already been analysed as part of the baseline definition in order to set the project's objectives as part within the project management design, but this exercise does not assess the worth of the whole system in aggregated terms and, therefore, does not obviate the need for the M'Pherson process, but merely assists by adding focus from a project's viewpoint. The normative level of M'Pherson's Containing Framework formally specifies the value

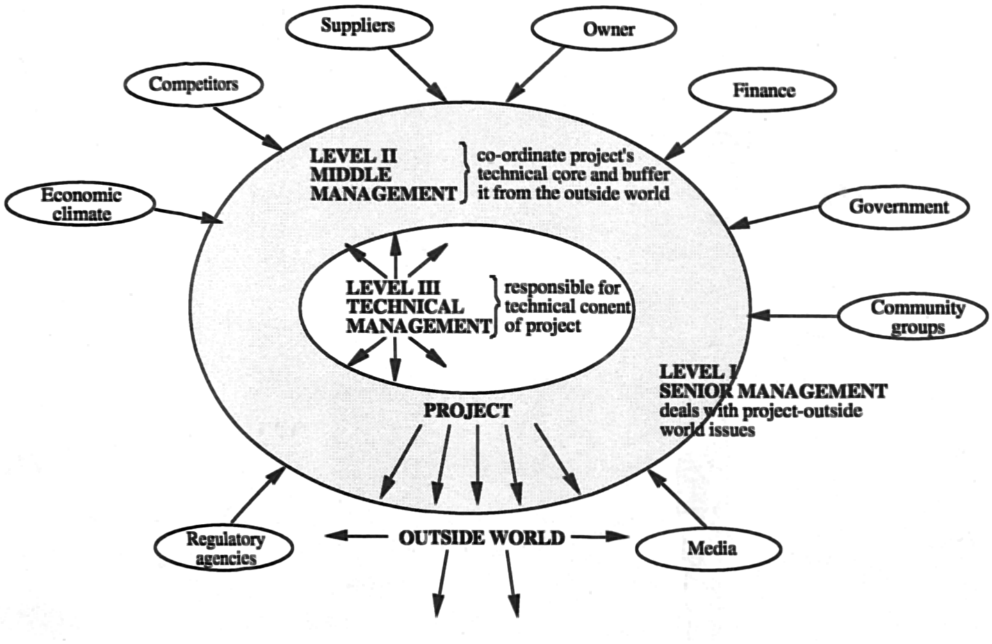

Exhibit 5.2.16 – Three Levels of Project Management

criterion by which the candidate project designs are assessed and judged as described at Section 3.4.4, and in detail by M'Pherson (1981) and Sage (1993). These descriptions are adequate for the MM Model and can be used directly. However, a difficulty emerges with complex projects (Hitchins, 1992; Morris and Hough, 1987) with firstly setting, formulating and agreeing the objectives, and then determining an objectives hierarchy in order to provide structure, and to show relationships and dependencies. M'Pherson acknowledged that when objectives were "fuzzy" (or messy in Checkland's parlance, 1972) soft systems techniques and tools will have to be used to resolve issues and conflicts.

For major international infrastructure projects where there are many stakeholders, including governments acting in the roles of authority, customer, regulator and paymaster (with the implications of short-termism, national aspirations, and political over interference), problems associated with objective setting could be "coercive" in nature (see Flood and Jackson, 1991) and special resolution techniques will be required. This topic will be addressed again is Section 5.4.

5.3 TESTING THE MM MODEL AGAINST THE COMPENDIUM OF PROJECT SUCCESS CRITERIA

In order to test for validity, integrity and completeness, the MM Model is tested against the requirements stated in column 2 of Appendix 10 (ie, the Compendium of Project Success Criteria) under the table headings of project size, complexity, technical uncertainty, schedule duration, schedule urgency, physical and social environment, government and politics, and management. The results of the final iteration are recorded in column 4 of Appendix 10. Results of the very many intermediate iterations are omitted for brevity and clarity.

The MM Model's features (activities) are recorded against one or more of the requirements. The host module of each feature is shown in parenthesis; Integrated System Design for the Product (ISDP), Integrated System Design for Project Management (ISDPM), or Containing Framework (CF). An analysis of the tables reveals that there is a complete coverage of the requirement (using Pike's Model which hosts the MM Model and provides the business framework) although the techniques and tools to be employed (generic representations) have yet to identified (see below). The configuration of the MM Model to be used for a particular project definition, ie, the study areas required for a particular project, is stipulated during the problem definition stage (M'Pherson's Containing Framework), and during the Baseline Analysis (where the full nature of the project is realised). In the case of large infrastructure projects, all study areas will be required as the management plan generated will need to cover the majority of recorded requirements.

5.4 DEVELOPMENT OF A TOOL KIT FOR THE MM MODEL

The tool kit identifies both tools and techniques (to include methodologies) using Flood and Jackson's (1991) "system of system methodologies" approach in order to give structure and formality to the identification process, and to harness the combined power of hard and soft systems methodologies; a unison called for by Yeo (1993). Flood and Jackson (1991) categorised systematic problem types in accordance with the matrix labels of Exhibit 5.4.1; brief descriptions of these problem types are provided at Section 3.5.2, with full descriptions presented in Flood and Jackson's reference book[1]. For this research, project problem types have been specially related to Flood and Jackson's matrix[2] (see Exhibit 5.4.1).

	UNITARY	PLURALIST	COERCIVE
SIMPLE	S-U • design • performance • resource management • cost/benefit analysis • schedule setting • quality assurance	S-P • setting goals and objectives • disagreement on way ahead • disagreement on changes • public enquiries • cultural differences • antagonistic relationships • contract negotiations	S-C • gaining political support • gaining boardroom support • achieving project approval (hostile boardroom) • intransigence
COMPLEX	C-U • risk analysis • project-team morale • communications problems • managment & organisation • gaining commitment • technical uncertainty • social acceptability	C-P • compromising on objectives • compromising on requirements • compromising on performance • design trade-offs	C-C • hidden agendas • political gains or illogical or emotional foundation

Exhibit 5.4.1 – Project Problems Related To The Flood/Jackson Matrix

Using the "system of system methodologies" codes (shown in the Matrix cells at Exhibit 5.4.1) the MM Model's requirements, and hence its activities, have been categorised (see column 5, Appendix 10) against the types of problems that may be experienced during the project definition (shown in the matrix). Categories in bold are designated the primary problem types, but it should be noted that the secondary problem types may also be significant and therefore a combination of tools and techniques will be required. A detailed analysis of the problem types at Appendix 10 reveals that much of the work to be performed by the project definition clearly falls within the "simple unitary" categorisation and, accordingly, the traditional hard systems methodologies will suffice. However, the analysis also reveals that a proportion of the work, specifically that associated with management design and objectives setting, falls within the other categorisations, and therefore attracts Checkland's (1972) "messy (real world) problem" label. These problems can only be effectively addressed by soft system methodologies.

This research has, through the rigorous analysis of numerous project problems, found that a great many of the fundamental causes can be traced to poor project definitions, and that some of the causal problems therein can be further traced to "messy" management issues.

[1] Flood and Jackson's research is still relatively new and needs to be given a more practical focus if it is to be introduced for general use. This research has accepted this concept and used it to assist with the categorisation of project problems and to identify tools and techniques for problem solving. However, care was used in the application of the concept in order not to introduce complexity into the project definition process through the use of esoteric methods.

[2] As a cross check a reference was made with earlier published work by Jackson and Keys (1984) which was much more practical in order to ensure that the results correlated.

However, despite this, this research has been unable to identify any general use of soft systems tools and techniques to address these issues; a finding also echoed by Sage (1993) and Yeo (1993); Sage noted that the soft systems movement was more influential in Europe than the US, but the methods were still not widely used in Europe.

Flood and Jackson (1991) in their research identified groupings of system methodologies (using both hard and soft approaches) for each of the problem types (see Exhibit 5.4.2); their research results provide the foundation for this research task. Authors such as Sage (1993), Hitchins (1992), Flood (1993), and Checkland (1993) and various international standards, such as the IEEE standard on systems engineering (1994), have all gone some way to defining tools and techniques for project and systems design although most limit their definitions to a few highly generic timeline examples. Using this knowledge base, and the project problem categorisations recorded at Appendix 10, a tool kit for the MM Model has been formulated.

	UNITARY	**PLURALIST**	**COERCIVE**
SIMPLE	S-U • operations research • systems analysis • systems engineering • systems dynamics	S-P • social systems design • strategic assumptions surfacing & testing • interpretive structural modelling	S-C • critical systems heuristics
COMPLEX	C-U • viable system diagnosis • general system theory • socio-tech. • contingency theory	C-P • interactive planning • soft systems methodology	C-C

Exhibit 5.4.2 – Allocation of Methodologies to Problem Types

The tools and techniques required are identified in table format under the three MM Model areas; Containing Framework (Exhibit 5.4.3), Integrated System Design for the Product (Exhibit 5.4.4), and the Integrated System Design for Project Management (Exhibit 5.4.5). In each case the tools and techniques, together with their problem-type categorisation codes and their purpose in the context of the MM Model, are shown against discrete processes or specific process groupings. The tools and techniques are indicative of the class, however substitutes are acceptable so long as they meet design support needs. The more general operations research and systems analysis tools and techniques are taken as read and have not been included in the exhibits as they would be used as and when required within all of the processes.

Exhibit 5.4.3 shows that Checkland's "messy" problems occur when groups of individuals become involved in design or decision activities that cannot be defined with a precise description. The area of most concern in the Containing Framework is objective setting and its related activities; also identified by Hitchins (1992) as the exercise that is most often performed badly resulting in serious down-stream project difficulties. A suitable technique for defining objectives under normal circumstances is Interpretative Structural Modelling (Janes, 1988), supported by the Soft System Methodology if it is found that compromise is necessary, and Critical Systems Heuristics if agreement is stalled at the political level. A recent example of this last point was the difficulties associated with gaining political support for the Channel Tunnel Rail Link project (Department of Transport, 1995), where political agreement on the objectives was not forthcoming owing to the public opinion fall-out from the public inquiry, and from the adverse local socio-economic impact on areas in the direct vicinity on the rail link. Government ministers, together with members of parliament from the area in question, believed that their interests and political aspirations were being undermined.

Process (or Process Groupings)	Tools and Methodologies	Purpose
Problem Survey	Problem Analysis (S-U)	Defining the problem
	Interpretative Structural Modelling (S-P)	Getting agreement on problem
	Requirements Definition Tools (S-U)	Formulation of Requirements
	IDEF (S-U)	Requirements relationships
	Computer Assisted Requirements Definition (S-U)	Requirements specification
Objective Setting	Interpretative Structural Modelling (S-P)	Need analysis/objectives/goals
	Soft Systems Methodology (C-P)	Compromising
	Critical System Heuristics (S-C)	Gaining political support
	Threat Simulation (S-U)	Business analysis
	Structured Objective Design	Designing discrete objectives
Criterion Design	Interpretative Structural Modelling (S-P)	Getting agreement and criterion
Research	Systems Worth Model (S-U)	Cost/benefit analysis
	Stupples & Hatfield Model (S-U)	Risk assessment for uncertainty
Scenario Generation	General Simulation (S-U)	Simulation of Scenarios
System Worth	Cost/Benefit Models (S-U)	Cost/benefit analysis
	Stupples & Hatfield Model (S-U)	Risk analysis
	Social Systems Design (S-P)	Social benefit/cultured diversity
	Multi-Objective Decision Analysis (S-U)	Environment impact
	Utility Theory (S-U)	Overall evaluation of SOI
		Alternatives assessment
Selection	Decision Trees (S-U)	Assisting with selection
	Decision Support (S-U)	Assisting with complex decisions
	Descriptive decision models (S-U)	Assisting with selection

Exhibit 5.4.3 – MM Model Tool Kit for Containing Framework

Systems engineering, systems analysis and operations research tools can address a substantial part of the design support requirements of the Integrated System Design for the Product (see Exhibit 5.4.4). However, it should be noted that structured software design tools and techniques may require the support of soft systems such as Interpretive Structural Modelling as early design activities involve a requirement for the instantiation of business requirements into software requirements; an area of major problems in software definition (Charette, 1989). In response to Hitchins' (1992) criticism that

Process (or Process Groupings)	Tools and Methodologies	Purpose
Integrating System Design	Viable Systems Model (C-U) Interaction Matrices (S-U) Tree Structures & Hierarchical Structures (S-U) Structural Software Design Models (S-U)/(S-P) Causal and Influence Diagrams (S-U) Computer Assisted Design (S-U) IDEF Diagrams (S-U) Cognitive Ergonomics Models (S-U) M'Pherson's System Design Framework (S-U) Design for Manufacture (S-U) Design for Assembly (S-U) Quality Function Deployment (S-U) System Prototyping (S-U)	Definition of the WSOI System design support System design support System design support System design support System design support System design support System design support System design support Manufacturing Design Manufacturing Design Requirements Compliance Testing concepts for viability
Performance Design	Performance Simulation (S-U)	Simulation to test and optimism designs
Reliability Design	RAM/FMECA Simulation/Models (S-U)	To rest reliability, maintainability and acceptability
Support Design	Lifecycle Support Models (S-U)	To identify product support requirements
Operational Scenarios	Simulation Models (S-U)	To evaluate various scenarios
Functional Model	IDEF Diagrams (S-U) Structure Software Design Models (S-U) Functional/Requirements Model (S-U) Functional/Physical Model (S-U) Causal and Influence Diagrams (S-U) Quality Function Deployment (S-U)	Functional representation Functional representation Upwards harmonisation Downwards harmonisation Functional design Requirements compliance
State transition	Systems Dynamics (S-U) State Transition Models (S-U)	Dynamic transition analysis Development of state transition representation
Capital/Operational/ Lifecycle Costs	Cost/Benefit Models (S-U) Computer Assisted Design (S-U)	All cost modelling and support Design representation
Capability	Simulation Models (S-U) Prototyping Models (S-U)	Capability analysis Capability testing
Availability	RAM (S-U)	Availability assessment
Integrating trade-offs	Use of Models identified for Integrating System Design/Functional Model/Cost/Benefit Models (S-U)	Trade-off analysis
Cost Effectiveness Analysis	Cost/Benefit Models (C-U)	Cost/benefit of the emerging system design

Exhibit 5.4.4 – MM Model Tool Kit for Integrated Product Design

traditional systems engineering did not view a system potentially as an "open system" (ie, the SOI developed did not take a wide enough perspective), the WSOI for the MM Model should be developed using tools and techniques that can deal with open systems definition. The Viable Systems Model is appropriate for this task supported by

Interpretive Structural Modelling and Soft Systems Modelling where agreement on its structure is needed; particularly for major infrastructure projects where both public consent and the necessary political will are required.

Process (or Process Groupings)	Tools and Methodologies	Purpose
Project Baseline Definition	Viable Systems Model (C-U)	Establishing the constitution/whole picture
	Viable Systems Model (C-U)	Interface design/project design
	Interpretative Structural Modelling (S-P)	Projects needs/objectives/goals
	Critical System Heuristics (S-C)	Gaining high-level approval/ commitment
	Cost, Planning & Scheduling Tools & Models (S-U)	Project planning/work breakdown
Project Analysis	Cost, Planning & Scheduling Tools (S-U)	Project planning/project scoping/project design
	Economic Models (S-U)	Project economic modelling
	Systems Dynamics (S-U)	Project scoping/identification of rework
	Cost Accounting & Budgeting Models (S-U)	Cost/benefit analysis
Management Option	Viable Systems Model (C-U)	Project organisation and culture Control and reporting Project communications Contracting & procurement Quality assurance and control Transition management Project interface management Environmental study
	Economics Models (S-U)	Financing options
	Project Financing Models (S-U)	Financial options
	Cash Flow Projection Models (S-U)	Financial options
	Staying Power Analysis (S-U)	Financial options
	ROA, ROI & ROE Analysis (S-U)	Financial options
	Soft Systems Methodology (C-P)	Option analysis
Risk Analysis	Stupples & Hatfield Model (S-U)	Whole risk modelling
	Systems Dynamics (S-U)	Re-work cycles
	Project Network Models (S-U)	Schedule simulation
	Contingency Theory (C-U)	Alternative analysis
Integrated Management Design	Evaluation Models (S-U)	Evaluation of management approach against criterion

Exhibit 5.4.5 – MM Model Tool Kit for Integrated Project Management Design

As with the Containing Framework, the use of soft system tools and techniques for management design will have a significant positive impact. The Project Baseline Definition will face many difficult design issues relating to formulating and agreeing a constitution for the project with the various and many organisations and individuals who will become involved, and subsequently formulating and agreeing the project objectives. Management design will benefit from methodologies such as the Viable Systems Model in identifying and structuring management options with Checkland's Soft Systems Model assisting with options analysis and final selection. The use of these models will add clarity that hitherto has been absent.

The tool kit presented in this thesis demonstrates formally that the combined use of hard and soft systems tools and techniques will support project definitions of large and complex projects, particularly those associated with infrastructure or those that have significant political involvement. The tool kit specified satisfies Yeo's (1993) plea for the use of soft system methodologies for complex projects.

5.5 VALIDATION AGAINST CASE STUDIES

5.5.1 Criteria for Selecting the Case Studies

In order to provide a comprehensive and balanced test for the MM Research Model and to provide the feedback for the necessary enhancements through Step 3 in the development process, real and suitable projects must be identified. These case study projects must satisfy the following six selection criteria in order to qualify as suitable:

1. Each case study should involve a major project in terms of its management demands; ie, because of its size, complexity, technical uncertainty, schedule duration and urgency, and because of the impact on the physical and social environment, and government and politics.
2. There should be a good spread of project types covering nationalised and private industry, high and low technology, differing project appraisal methods, and differing approaches to project management.
3. Each case should be well documented in terms of both company literature and external assessment literature.
4. Key individuals from the original project staff should be available for interview.
5. One case study should have been the subject of an in-depth study in order to provide this research with a frame of reference to anchor ideas an concepts.
6. One case study should be concerned with a failed project, one a successful project, and one a project which has experienced an undefined outcome.

Case studies that satisfy these selection criteria are briefly described below.

5.5.2 The Case Studies

Each of the three case studies satisfies the first 4 criteria, and between the three case studies criteria five and six are satisfied.

British Rail's Advanced Passenger Train (APT). British Rail's (BR) APT can only be described as a project failure. The project began life in 1969 in response to the airlines' threat against BR's West Coast London/Glasgow service. The journey time of 6.5 hours was considered to be unacceptable; BR needed a journey time of less than 4 hours in order to remain competitive. Throughout its 16 year life, the project was dogged by technical difficulties, lack of senior management support, wildly varying political enthusiasm, union disagreements on future working practices, media ridicule, and a continuous decline in public confidence. The project was cancelled in 1985 with a sunk cost to the taxpayer of £100 million. The case study is an excellent example of a project failure; could the failure have been predicted during project definition, and could the project have been set up for success?

The London Water Ring Main (LWRM). The London Water Ring Main Project is the largest capital project to date undertaken by any of the recently privatised water companies. The aim of the project was to improve the flexibility and efficiency of water distribution and reduce operating costs for the capital's water supplies. The project commenced in 1989, with a planned completion date in 1996; benefits from the project were being realised progressively as the schedule advanced and so parts of the main became operational prior to completion of the whole main. The planned project budget was £250 million, which is entirely privately funded. The progress of the project was excellent; all tunnelling was completed in February 1993, approximately 21 months ahead of schedule, and the whole project was completed in 1995, 1.5 years ahead of schedule. The project can be described as a good example of success. The MM Model will show that this project was set up for success, ie, it had all of the correct ingredients from the start.

The Rolls Royce RB211 Aero-engine. In a little under three years, Rolls Royce Ltd sank from the zenith of what was hailed as the greatest technical and commercial success by a British company in this century, to the ignominy of bankruptcy and total collapse (Edmonds, 1975). The principal cause of this collapse was the contract in 1968 to design, develop and build the RB211 aero-engine for the Lockheed CL1011 Tristar medium-haul airbus. The size, cost and technical complexity of the engine, coupled with the terms of the contract with Lockheed, exposed structural and management weaknesses inherent in the company. Furthermore, it exposed shortcomings in the company's approach to defining projects, as the MM Model will show. The project problems affected the UK and USA, six of the worlds major airlines, two of the worlds most prestigious companies, and in excess of 100 suppliers. Ironically, the RB211 engine went on to become a highly successful product.

5.5.3 Case Study Format

Each of the three case studies is divided into two main parts. The first part is concerned with providing a detailed background to the project being analysed. This background will cover all the major events and difficulties encountered and successes achieved.

The second part is concerned with an analysis of the project using the MM Model. The analysis will consider for the main part the published material on the project, ie, that material used to compile the background, but this will be augmented by interviews with key individuals associated with the project, and inspection of unpublished company information where it still exists. The rationale for this approach is that people often hold the information of why things were or were not done. Interview information is corroborated with documentary information where possible.

The analysis of each project will be presented under the MM Model's main headings of the Containing Framework (problem definition, business analysis, objectives analysis, operational requirements, research and development/technical barriers, constraints, scenarios, and system worth), Integrated System Design for the Product (integrating system design, product design, product modelling, cost modelling, trade-off analysis, and cost effectiveness analysis), and the Integrated System Design for Project Management (project baseline definition, project analysis, management design, risk analysis, and integrated management design).

5.6 SUMMARY OF THE IMPORTANT POINTS EMERGING FROM CHAPTER 5

In satisfaction of Objective 4, the MM Research Model has been formulated to combine the Morris Model, the M'Pherson Model, and other techniques and tools identified in this research, to define major projects for success. The MM Model satisfies the compendium of project success criteria (developed for this research and used as a requirement for development) and provides the only complete and integrated approach to defining projects for success based on systems techniques and tools.

To test the new MM Model in a practical way, three case studies were selected for their combined ability to exercise all elements of the new model. The case studies were well documented and access to knowledgeable individuals was assured. The analysis documented in Chapters 6 and 8 shows that had the MM Model had been available and used on the Rolls Royce RB211 project and on British Rail's APT project, a very different set of circumstances would have occurred benefiting the project and nation overall. Chapter 7 shows that although an adequate definition was undertaken for the London Water Ring Main project this was not as comprehensive and well structured as that advocated by the MM Model.

A clear area for further research is in the use of specific soft system methodologies for solving project problems; particularly for project management design and objective setting. The research will need to be practical and based on a wide range of real-world case studies.

CHAPTER 6: CASE STUDY 1 – THE ADVANCED PASSENGER TRAIN

6.1 BACKGROUND

In the early 1960s, in the face of increased competition from motorway and airline networks, and following significant investment in the electrification of the West Coast Main Line (WCML), British Rail (BR) was forced to review its long-term strategy. The Beeching report (1962) defined the role of the railways, emphasising particularly the importance of meeting demands of travellers over distances of between 100 and 500 km. It was this market that BR wanted to capture, and so it focused its efforts on developing high speed trains.

In 1962, it was decided to reorganise BR research and development, centralising it at Derby. Sidney Jones, a scientist/engineer with experience of research and development gained at the Royal Radar Establishment at Malvern and in industry, headed up the new research organisation. He recruited a specialist team of scientists and engineers, some of whom came from BR's engineering organisation and some from the aerospace industry. The team was given the task of studying and modernising various technical equipment in operation in the railway system with a view to developing the technology for high-speed travel.

6.1.1 The APT Concept

The main obstacle to shorter journey times was the oscillation of vehicles, coupled with high wheel maintenance costs, which occurred at higher speeds. The team therefore concentrated on understanding the dynamic behaviour of a wheelset as it ran along rails. Their findings enabled them to develop a mathematical model that could be used to identify important track and suspension parameters and, thus, ways of increasing the critical speed at which oscillation occurs. This model was used to design a suspension unit for a high speed freight vehicle that achieved a critical speed of 224km/h, both on laboratory test rollers and track. Subsequent tests using prototype vehicles over distances in excess of 160,000km continued to show much improved stability at high speeds and, in addition, lower wheel and track maintenance requirements.

Since approximately half of BR's major routes comprise curved track, half of which is relatively small radius, it was considered particularly important to increase curving speeds in order that a significant increase in average journey speed could be achieved. Curving speeds were mainly limited by passenger comfort which suffered as a result of slippage between the track and the rail at speeds in excess of 160km/h. The researchers found that, by tilting the passenger car body as a function of speed using an active role suspension system, a 40% increase in curving speed could be achieved for the same passenger comfort level. This research was augmented by studies into vehicle response to curves and track irregularities, bogies, suspension, braking system, transmission system

In 1966, in the light of advances made as a result of the research undertaken, the Research Organisation put forward a proposal to build a single experimental Advanced Passenger Train (APT), incorporating a tilt mechanism in order to facilitate higher curving speeds. The proposal was greeted with hostility from the BR Board, particularly among the more traditional mechanical and electrical engineers. However, it was finally agreed that, if the £3million required for the experimental APT could be found outside BR, then the programme could go ahead. Three years of lobbying followed, resulting in an undertaking by the Department of Transport to put up 50% of the funds.

In 1969, the BR Board was faced with the decision of how best to invest in the way ahead. Studies looking abroad revealed that other railway administrations in countries such as Japan, France and Italy, had invested primarily in building new track for trains that used existing technology but higher power. BR's rail network was the result of massive investment in the Victorian era. Although this track was rather sinuous and, in many places, in poor condition, BR decided that it would be too costly in terms of money, time and political difficulties to construct new tracks or major new alignments.

The decision was taken, therefore, to concentrate on the design of improved suspension systems to allow high speed trains to travel on existing tracks. BR then had to choose which type of train should be developed to be the cornerstone of its high-speed strategy. BR authorised the construction of two trains; the Advanced Passenger Train (APT) and the High Speed Train (HST). The APT was to pioneer advanced performance, through a higher curving ability and higher maximum speed. The technical innovation and associated risk of the APT project resulted in an extended timescale for development and the HST was conceived to be an interim solution to the desire for reduced journey times on inter-city routes, extrapolating existing technology in order to achieve higher speeds on the straighter routes, such as the East Coast Main Line (ECML).

The APT programme (Project Initiation Report, 1969) had the following eight business objectives:

- to achieve a maximum speed of 250km/h, 50% higher than existing trains
- to increase the existing maximum curving speed by 40%
- to operate on existing tracks within the limits of existing signalling systems, clearance, tunnels, stations, etc
- to maintain standards of passenger comfort
- to achieve efficiency in energy consumption
- to conform to safety and environmental standards, eg; noise levels
- to maintain current levels of track maintenance
- to operate at a cost per seat-kilometre similar to that of existing trains.

The APT programme was divided into three phases of diminishing technical risk, as follows:

1. Experimental phase for research and development to prove the novel technical concepts.
2. Prototype phase in which the novel features were to be integrated into the total train design facilitating tests of the technical, operational and finally the commercial performance, as the train entered limited public service.
3. Production phase for the consolidation of all developments into a final train design for series production and fleet operation.

6.1.2 Experimental Phase

The authorisation of the APT programme included the construction of experimental trains, the building of high technology laboratory facilities at Derby, and the preparation of a test track between Melton Junction and Edwalton.

In September 1971, the first experimental vehicle (APT-E), in the form of a 2 car articulated Power-O-Power (POP) train driven by gas turbines, began track trials in order to test coach tilt, suspension and bogie mechanisms. The POP train was tested using a Unimog road/rail vehicle to haul the train. The BR Publicity Department, excited by the first running of an APT-related vehicle, arranged for a film crew to visit Old Dalby in order to see the train in action. After filming the painfully slow progress of the train as it crawled along behind the Unimog, the senior engineer present was questioned about the disappointing lack of speed. His response, "What do you expect when it's being towed by a lorry?" This exchange was to mark the beginning of the rather ill-fated publicity that the APT would receive during its lifetime.

The APT-E was officially unveiled on 16th December 1971. A series of instrumentation and control system tests were then undertaken, followed by braking trials, before the APT-E moved under its own power for the first time on 29th June 1972.

Four drivers were trained to operate the train in preparation for the forthcoming main line runs. Commissioning of the train often continued late into the night and was severely hampered by a myriad of electrical faults. The start-up procedure was particularly complex; it consisted of a 6 page checklist that often took 2 hours to complete, mainly as a result of a series of phantom fault indications in the cab due to an unreliable electrical system.

On schedule, 25th July 1972 marked the first main line run from Derby to Duffield. The train successfully ran to Duffield at 40km/h and was cleared to return at 80km/h. Unfortunately, a variety of electrical problems resulted in cancellation of a second scheduled run, ruining most of the photograph opportunities planned by the press. In addition, the driver chosen to face the barrage of media at the end of the run was a rather shy, quiet man, not suited to the task in hand. Once again, the publicity of the APT was poorly managed.

Almost immediately after this successful first run, the APT-E was blacked by the drivers' union, ASLEF. ASLEF had been negotiating with BR for some time for double manning and increased pay for the added responsibility of driving high speed trains and intended to use this blacking to put pressure on negotiations. The ban imposed by ASLEF covered both driving and shunting the train. After spending 4 months in a siding, exposed to the elements, it was decided that the APT should be moved in order to prevent the occurrence of structural damage to the train. A shunter driver, very unhappy to go against the line taken by his colleagues, was ordered to shunt the train back to the locomotive works. The ASLEF executive met immediately in order to decide the action that was to be taken in response to defiance of the ban. A 24 hour national rail strike was called for the following day. Negotiations were later resumed and agreement finally reached in April 1973.

In August 1973, after one year of being immobile, the APT restarted trials. A number of modifications had been made to the train and performance was notably better. On 21st September, the train achieved 160km/h on the Dalby test track, followed by 200km/h and 243.7km/h in October 1973. There were, however, a variety of problems to be ironed out, such as horns jammed, doors stuck and, more significantly, failures in the tilt and brake systems.

On 12th February 1974, the APT was given clearance for high speed testing on the Midland Main Line. The train had only run 5389km in 20 months. October 1974 marked the first main line run above line limit (144km/h). The APT-E reached 160km/h and the braking systems performed well. A series of test periods followed. Williams (1985) noted that, by July 1975, the train had reached 218km/h, even though it had been designed for 250km/h. Its running time between Leicester and St Pancras was still only that which was usual for an InterCity train. He added, however, that "for the APT team, the achievements were real and the testing had laid solid foundations of technical knowledge for the design of the prototype trains".

The first scheduled 240km/h run took place on 27th July 1975 on Western Region, between Uffington Loop and Goring. Apart from a few problems caused by the tracks, the APT ran very well, setting a new BR speed record of 240km/h, receiving, at long last, extensive complimentary publicity. In October, the APT completed the journey between St Pancras and Leicester in 58.5 minutes, at an average speed of 158.6km/h (the fastest service train took 84 minutes at an average speed of 113.3km/h). Over the next few months, a number of VIP visits were arranged to Old Dalby and the train continued to perform well.

During its four year life, the APT-E completed 37,694km, exceeding 241km on only three occasions. This must be viewed as a rather poor performance in the light of the 320,000km and 1,000 runs at over 250km/h achieved by the French TGV over the same period. Nevertheless, Williams (1985) wrote that, in April 1976, "the team spirit and sense of identification with the project seemed as strong as ever".

6.1.3 The Prototype Phase

The prototype phase of the programme was conceived as the test bed for novel suspension and braking systems (Boocock and King, 1976). Authorisation for the phase, which included the construction of 3 prototype (APT-P) trains, was given by the BR Board in October 1974. The cost of the phase was estimated to be £50 million, with financial support coming from the Department of Transport.

The APT-P phase of the programme began with reorganisation of the team that was to work on the project. The Research Department's role in the project diminished and responsibility for the APT was transferred to the CMEE's Department. As it became clear that only a small number of the original team would be allowed to continue working with the project, many of the people who had joined specifically in order to work on the development of the APT left, while the remainder transferred to the CMEE Department. The changes took their toll on the spirit of the new team.

Although there was no change in the basic design requirements, the APT-P trains were different to the APT-E in a number of ways. The primary change, from diesel to electric traction, was prompted by the 1973 fuel crisis. Other modifications, such as the more aerodynamic shape, articulated train configuration, active tilting mechanism, advanced lightweight bogie suspension and coaches and auxiliary friction brakes to hydrokinetic brakes, were made in the light of the APT-E results. The train was intended for use on the WCML, since this offered the best commercial potential for an APT service. In the light of WCML passenger forecasts, it was decided that the train should comprise 12 passenger coaches, and so 2 power cars would be required. In order to provide adequate current collection, these power cars were positioned centrally in the train, thus effectively dividing the train in half necessitating duplication of catering and other facilities.

In 1977, Derby Locomotive Works completed the first two prototype power cars, followed in June 1978 by the first trailer rake which was produced by the Carriage and Wagon works. One APT-P was equipped with instrumentation to monitor important aspects of the train's performance. The second APT-P was used in an intensive programme of driver training. The third, completed in March 1980, tested the endurance and reliability of the train in runs between Glasgow, Preston and London.

The test programme did not start until February 1979, due to a series of industrial disputes. Progress was once more disrupted when, during a VIP journey in early 1980, an axle broke, resulting in derailment of a wheelset, as the train travelled at 200km/h. Following a few months of revision of the assembly and inspection procedures, testing was resumed, but a variety of problems, including heat build-up due to dragging brakes and doubts about the running clearances of the train under certain tilt failure conditions resulted in the suspension of further runs for 12 months. The APT's entry into passenger service scheduled for October 1980 was also cancelled.

It was not until March 1981 that the first of the fully modified prototypes began track testing again. By Autumn 1981 the three APT-Ps had accumulated over 200,000km, but system failures and breakdowns remained a daily occurrence and modification an ongoing process. The trials also produced heartening findings. Loadings from the APT-P at a cant deficiency of 9 degrees were shown to be almost identical to those from the HST at a deficiency of 4.5 degrees. The hydrokinetic braking under adverse track conditions achieved a braking distance at 210km/h equal to that of the HST at 160km/h.

The revised date for the introduction of the APT into passenger service was set for 7th December 1981. It was decided that, initially, one APT would make the round trip between Glasgow and Euston three times each week, with the possibility of a more frequent service as operational experience increased. Two reserve trains would be available to cover breakdowns and workshop overhauls, modification and development testing.

The APT's inaugural run took place on the appointed day, although past performance led to the somewhat strange BR decision to despatch an empty train behind the APT in case of breakdown! The train behaved impeccably, completing the journey from Glasgow to Euston at an average speed of 152km/h in 4 hours 13 minutes, arriving 2 minutes early. One rather worrying observation from a number of passengers was that they had experienced motion sickness. This was a minor problem to BR compared with the almost universally scathing press coverage of the trip. "The unique tilt made a few people feel queasy", The Express. "It was like driving over cobbles until south of Motherwell", The Times. A tilt failure "spilt drinks and food across the floor and jammed electrically operated doors", The Telegraph. "Why did the train not reach its design speed?" The Times (1981). "One minute early and fourteen months late", The Express. Over the next few days, the APT received extensive media coverage as the "accident prone train" failed to run or broke down during the journey. Williams (1985) wrote, "at the end of the second week, it was obvious that if the coffee was cold in the restaurant car, it would provoke front page headlines in some papers".

On 24th December 1981, only 16 days after the first commercial run, the Transport Secretary announced that the APT must prove itself in commercial service before the Government would put up funding for a fleet. Against this background, the BR Board decided to withdraw the train from passenger service until the problems could be solved and a more reliable service guaranteed. In the April 1984 issue of the BR house journal, an article on InterCity sector management stated: "APT is clearly a non-starter in its present form, having survived less than a week when placed in revenue service in December 1981".

6.1.4 The Production Phase

It was at this stage that a number of calculations were made, that should have taken place much earlier in the project. BR reassessed the business requirements for the WCML. The findings suggested that best returns on total investment would be achieved with lower powered, shorter trains. BR decided to limit the number of trailer vehicles to ten, the level that could be handled by one power car, thus rendering a vast amount of research and testing unnecessary. It is interesting to note that a 1+10 APT formation carries only 30 fewer passengers than the 2+12 which involves power cars in the centre of the train. Williams (1985), noting that it was unfortunate that this arrangement had not been used from the start, suggested that it was due to "the victory of commercial pressure over engineering expediency". He attributed this situation to the APT design team's position outside the railway establishment and BR's desire to get the project off the ground at all costs.

Articulation had always been one of the cornerstones of the APT concept. It provided reduced weight, lower noise and a good, stable ride at a very reasonable cost. There were two main drawbacks of this system. Firstly, if a single coach failed, the whole train had to be withdrawn until repair had taken place. In addition, since the articulated bogie resulted in fewer axles, each axle had a very substantial braking duty to perform and thus an increased risk of wheelslides. The development of the BT12 conventional bogie provided a superior ride quality to the existing articulated bogies and was, in many ways, the last straw in the decision to scrap the articulated bogie for the production (APT-U) trains.

Another first claimed by the APT concept was the application of the hydro-kinetic brake to trains. These brakes had still failed to achieve the braking distance to enable the APT to travel at 250km/h. They also proved to be both expensive and unreliable. The reduced braking duty of each axle resulting from the use of conventional bogies, coupled with the decision to limit the APT's maximum speed to 225km/h, enabled the APT's required braking distances to be achieved by conventional axle-mounted disc brakes. Following these modifications, the braking performance of the APT-U was superior to that of the APT-P.

The study that really threw the whole APT concept into question was commissioned in 1983. Although it was known that conventional trains could negotiate curves safely at a 9 degree cant deficiency, BR had always limited the cant deficiency to 4.25 degrees for the comfort of passengers, although on the continent a deficiency of 6 degrees was permitted. A series of runs was finally undertaken in order to identify the exact cant deficiency at which passengers experienced discomfort. The study found that passengers could tolerate a cant deficiency of up to 6 degrees when standing and 7 degrees when sitting. The APT was designed to run at a cant deficiency of 9 degrees but, operating at the 200km/h speed limitation, the additional speed gained at this level resulted in a saving of only 15 minutes between London and Glasgow and less than 5 minutes on the most lucrative stretch of the route serving Liverpool, Birmingham and Manchester. The costly research and development of the APT tilting mechanism had been unnecessary for this programme.

Even at this stage, it was decided that an InterCity train designed for operation at 225km/h, without the need for modifications to the overhead power and signalling systems, would provide sufficient time savings over the current 200km/h Class 89 trains to justify design and construction costs. It was calculated that basic coach and bogie design would enable use of the train in both tilting and non-tilting form on the WCML and the ECML would enable the initial investment cost to be offset against large continued revenue from the lines.

A lack of engineering resource meant that the non-articulated tilting coaches were designed and constructed first, followed by the power car two years later, in 1989. It seems strange that these constraints were imposed on the APT when, at the same time, five prototype HSTs were being constructed in order to replace those taken out of service in order to be fitted with electric traction facilities. At this time, BR had also commissioned the design of a non-tilting, double cabled electric locomotive which was expected to operate on the WCML until superseded by the APT in 1990. It was soon realised that the double cabled locomotive was superior in performance to the single cabled HSTs under development and so the latter were cancelled!

The changes in the APT-U led to press speculation that the APT had been scrapped. BR was quick to point out that, the APT had not been scrapped but, in a final effort to combat the dreadful publicity that had always surrounded the APT, BR re christened the APT-U the "InterCity 225".

6.1.5 Why Did the APT Fail (The Public Case)?

The APT had been heralded as the flagship of the BR high speed strategy, poised to revolutionise rail travel in the 1980s far into the future. By 1985, however, the APT had taken 25 years and £50 million to become a potentially successful, but still commercially and in many ways technically unproven, concept. What had gone wrong?

In December 1981, the main concern raised regarding the APT as it entered commercial service for the first time was the project timescale. Although much time had been lost as a result of industrial disputes, the 12 years that the APT took to enter into commercial service was considered to be far too long. The experimental phase had been designed to collect sufficient knowledge in order that only features successfully proved on the APT-E would be incorporated into prototypes, resulting in a short, cost effective prototype phase. In the event, the experimental phase ran for seven years, but only 1600 km, before the start of design work on the prototype. The prototype phase lasted for over 10 years and produced 3 very expensive APT-Ps that were totally different to the APT-Es and quite unrepresentative of the proposed production trains. It seems incredible that BR should construct 3 expensive prototype trains of this nature when "the object of having a prototype train is to test the strengths and weaknesses of the design" (BR 1982). In defence of the timescale, BR noted that the project had involved design, testing and modification of many new components and systems, but this did little to allay the criticism, especially in the light of the HST's successful entry into commercial service after just 6 years.

Throughout the project, there were continual design changes to every aspect of the APT, often without spending the necessary time for the development of appropriate modifications. Major changes were made to the tilt system in order to "fine tune" it, allowing negligible time to assess the impact of these changes and improve the system's reliability. Reasonably low technology tread brakes on the APT-E were replaced by elaborate, unreliable high technology brakes on the prototype. The swinging arm articulation bogie was replaced by a new bogie after just one run on the APT-E. The result of these constant changes was vast expense in terms of time and money and considerable frustration among the team.

There were a variety of risks associated with the project. The large amount of technical innovation required to develop a train with a faster curving ability and higher maximum speed resulted in high risks and an extended development timescale. As goals and objectives for the train were continually not achieved and revisions made, it became clear that the original project definition had been insufficiently thought through.

A particularly worrying question was whether the APT was really necessary. The original mandate given to the Research Team in 1962 was to study and modernise various technical equipment in operation in the railway systems. The objective was broadened in the light of initial findings, eventually becoming the 8 objectives of the APT project approved in 1969. Concern has since been raised that these objectives may have been developed with a technical focus that did not take sufficient account of the commercial aspects of the project.

The question of commercial feasibility was particularly poignant in the light of studies in 1981 that showed that speeds as high as 250km/h were no longer commercially viable on the WCML or ECML. The APT, which had originally been designed for the WCML, was found to be unable to run at above 200km/h on that route unless major reworking to the signalling and overhead power line systems took place. Existing overhead equipment had been designed for 160km/h operation and, so, upgrading would be necessary for speeds above 225km/h with a single pantograph or 200km/h with pantographs at each end. The main limitation to speed was the braking distances achieved by the APT. Although designed to stop the train from 250km/h within the existing signalling limits on the WCML, the brakes had only demonstrated ability to stop the train within these limits in good conditions and not under the conditions at which BR braking distances are calculated.

It appears that doubts regarding the necessity of the APT have fuelled much of the negativity that has surrounded the programme. There have, however, been a number of other reasons for the generally unhelpfully critical attitude towards the APT project. Five groups of people will be discussed below: BR organisation, unions, Government, media, and general public.

BR Organisation

From the beginning of the project, there was suspicion among the BR establishment regarding the expansion and centralisation of the research department and, more particularly, the number of non-railway personnel recruited to work there. Sidney Jones noted "the greatest problem that existed (in 1960s) was that of introducing modern technology into an established industry". In trying to modernise a traditional industry 2 problems emerge:

- the level of technical understanding in the established industry is very poor
- the attitudes of minds are extremely different from those in the high technology industries and there is a big resistance to change.

The proposal to build the APT-E in 1966, was greeted with hostility by the BR Board and finally only accepted on the understanding that financing would come from outside BR. After 3 years spent promoting the APT concept, Williams (1985) observed, "the project would not have been started but for the perseverance of the Research Director". The BR Board continued to express doubts about the APT, with mechanical and electrical engineers openly strongly opposed. Boocock (1976), in describing the project team at Derby, noted the "great enthusiasm and spirit of co-operation between builders and designers". This spirit was vital to the project, since the only support that the project team received came from the Research and Passenger Departments. The disunity, however, led to instability and slow progress in the project as a whole.

The APT-E trials, with their associated numerous small hitches and difficulties added weight to the scepticism of the "established" railway engineers. The trials made very slow progress and this was exacerbated by BR Management pressures. Months of negotiation with a wide variety of BR personnel were necessary before the APT-E was permitted to run above line limit on tracks other than the test track. The APT was forced to conform to a series of BR regulations that were a ludicrous legacy of history and section politics. An example of this is to be found in the in train communication system. The train supervisor would give running instructions via an intercom to the field trials representative in the rear cab who then relayed them via cab-to-cab telephone to the inspector in the front cab who repeated them to the driver. This system was laborious at the best of times and quite useless in an emergency, as the project team discovered to their cost.

The data collected by the team following these trials convinced them of the viability of the APT, but the Chief Executive of the BR Board initiated an independent critical analysis of the viability of the APT. This independent analysis took 6 months to complete, further delaying the project and confirming the distrust existing between the BR Board and Research Department.

At this time, the BR Board also decided that responsibility for the design and construction of the APT-P should be given to British Rail Engineering Limited (BREL). BR decided that the team that had been formed to work on the APT-E should be disbanded and only selected members be transferred to BREL to continue work on the project. The rationale for this reorganisation was stated to be improved lines of communication between the research group and engineering organisation. In practice, the change resulted in the loss of team spirit and identification with the project which had been such an important driving force in the project to that time.

Although the trials were fairly successful, the BR Board was once again ruffled by the embarrassment caused when an axle broke and a bogie was derailed while the APT-P travelled at 200km/h carrying VIP passengers.

Fiercely critical media coverage of the APT inaugural run and subsequent array of problems proved to be the final straw to the APT saga. The BR Board, fed up with bad press regarding the APT and trying to rekindle public support lost during negotiations with the unions, withdrew the APT and began to re-examine its policy with respect to the future of high speed equipment.

Relationships with the Unions

Throughout the APT project, the relationship between the BR Board and the unions, particularly the drivers' union ASLEF, was frosty. The focus of concern was the pay and conditions of drivers of high speed trains. The APT, being the epitome of high speed vehicles, was to some extent used by ASLEF as a lever for negotiations.

In July 1972, directly after the APT-E's first main line run to Duffield, the APT was blacked by ASLEF. It was not permitted to move, either under its own power or through shunting. The team was forced to leave the APT-E outside in the sidings to rot. Eventually, after 7 months and no end of the dispute in sight, the team insisted that one of the drivers shunt the train into the Locomotive Works. It was a very difficult decision, since both the team and the driver knew that his actions would alienate him from his colleagues and cause uproar within ASLEF. The project added a few more enemies to the ranks, some of whom belonged to the general public who were rather irritated by the all out one day strike called by ASLEF the day after the APT-E was moved. In all, 12 months of testing time was lost to the project. The dispute was finally settled in ASLEF's favour and trains running at speeds in excess of 160km/h were required to be manned by 2 sets of drivers. This policy considerably increased the costs of operating these trains.

It is interesting to compare the attitude of the BR drivers with that of the French SNCF drivers. In France, TGVs are single manned and regard the ability to drive these trains to be career enhancing, rather than a threat.

The Government

The Government, although supporting the project financially at the experimental and prototype phases, had never been a totally reliable source of support. The Government pledged chunks of support, but never enough long-term investment to enable BR to confidently plan a long term strategy. The result was a somewhat piecemeal approach, with a number of projects running in parallel. Once again, when looking abroad, a very different picture emerges, as governments in Europe and Japan invest vast sums in their railway systems.

The Media

The media played the major role in shaping the attitude of the general public towards the APT. Unfortunately, it appears that BR did not realise the importance of the media until it was too late and the media machine was not on their side. From the first disappointing filming of the APT being hauled along at snail's pace by a road-rail vehicle, to the cancelled second main line run for the benefit of photographers, to the clumsy negotiations with the unions, to the derailment as the train travelled at 200km/h carrying VIPs and the final laughable accounts of the series of failures of the APT, press coverage had been no less than a catalogue of disasters.

The Public

For many people, the first introduction to the APT came in July 1972, when it was blacked by the drivers' union, ASLEF, and again in November 1972, when its movement to the locomotive works in defiance of the union ban, resulted in a one day all-out strike. The majority of the general public, however, had no idea of the existence of the APT or thought that the HST and the APT were the same, until 1981. At this time, the HST was already well established as a commercial and technical success and the APT ostentatiously arrived on the scene as a commercial and technical failure.

The reports were heavily laden with the negative aspects of the project, with almost no coverage of the positive technical innovation and successes of the project. With the press almost unanimously pouring scorn on the APT project, it is hardly surprising that the majority of the general public turned against the venture. The general public are the customers for BR's service and BR knew that, at the end of the day, without their support, the APT would always be a non-starter.

6.2 RESEARCH ANALYSIS

The basic research material used for the background to the case study was augmented for the full research analysis by the internal British Rail project definition study for the Advanced Passenger Train (called Project Initiation Document, 1969) and early working papers from the research stage. Interviews were undertaken with Sir Richard Marsh, formally Minister for Transport (1968 to 1970) and Chairman of British Rail (1971 to

1976); Mr R Meecher (1994), formally a development engineer on the APT-E and APT-P now with ABB; and Mr T Burrows formally a senior line manager from BREL during the APT era[1] .

6.2.1 MM Model – Containing Framework

Sir Richard Marsh (1995) commented that the APT project was a "problem child" during his tenure as Minister for Transport (1968 to 1970), and throughout his Chairmanship of BR (1970 to 1976)[2] . During his time at Transport, the project was being defined for both the BR Board and government approval. Marsh acknowledged that considerable work had been undertaken to prove feasibility, although with hindsight he though that more attention should have been paid to the whole concept (the WSOI in terms of this thesis) rather than focusing on specific technical problems and looking for a strictly technical solution to a business problem.

Marsh's top-level insight into the project was valuable as it identified that the fault lines that eventually led to the project's failure could be traced directly to insufficient and misleading information being presented to both the BR Board and government for project approval. He stated that BR at the time had not understood the full business and commercial implications of introducing the APT and the viability of such a complex project. It should have been known at the project definition stage that the railway's infrastructure would need considerable modernisation to accommodate train speeds of 250 km/h; ie, rework to the signalling, overhead power line systems, and significant stretches of track.

A review of the project definition study report (1968) reveals that very little consideration was given to the impact of the APT on the existing infrastructure; it seemed to assume that the train would be designed and built to use the existing infrastructure. A recent Times report (June, 1995) estimated that the WCML modernisation programme was estimated to cost £3bn and BR was looking for private investment to meet some or all of the bill.

Marsh advised that the business case for the project was not sound and there was little consensus on the BR Board for such a revolutionary undertaking. However, the government was keen for the project to go ahead as it demonstrated commitment to rail travel. He agreed that had BR qualified and quantified the commercial impact of the project it would have been doubtful that investment approval[3] would have been forthcoming. Furthermore he agreed that the objectives for the project were based on a technical solution rather than a commercial need. Analysis of the APT against the MM Model's Containing Framework is provides at Exhibit 6.2.1.

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[1] Now retired

[2] Also now retired

[3] Similar approval procedures to those employed by Central Government

Problem Definition	BR understood and defined its worsening competitive position with airlines poised to make major in-roads into its lucrative long-distance Inter-City services.
Business Analysis	The business analysis identified that in order to maintain the commercial viability of the WCML route in the face of airline competition, BR needed to reduce the journey times between London and Glasgow to less than 4 hours.
Objectives Analysis	The objectives were clearly stated but they were technically focused and did not take sufficient account of the business and commercial aspects of the project. This resulted in overly complex technical solutions. Furthermore, the objectives were never universally accepted by influential bodies in BR and never formally translated into design objectives.
Operational Requirements	The operational requirement reflected the objectives and drove the project to identify unnecessarily complex technical options that did not take sufficient cognisance of the lessons learned on other railways (particularly in the areas of cant and braking systems).
RandD/Technical Barriers	No single technical innovation would have crippled the project; but the combination of new braking mechanisms, tilt mechanisms, articulated bogies, the number of power cars, and high speed pantograph operation; coupled with the sinuous, poorly maintained track and ageing signalling systems, were too much for one project to manage.
Constraints	The project did not take account of a number of significant and varied constraints; existing railway infrastructure was not geared for high speed travel, BR had insufficient technical resource to develop both the APT and HST concurrently, the BR Board, BREL and the unions were hostile to the project, and government funding was unpredictable.
Scenarios	Operating scenarios were not undertaken until 1981, when studies showed that speeds as high as 250km/h were not commercially viable on either the WCML or the ECML because of the infrastructure upgrading work required. If this had been known by the project definition, it seems very unlikely that approval would have been granted.
Systems Worth	According to the project definition study report, only a very simple cost benefit analysis using NPV was undertaken. A Systems Worth analysis would have yielded the project's non viability; especially when the full cost of infrastructure modernisation was taken into account..

Exhibit 6.2.1 – Analysis Against the Containing Framework

6.2.2 MM Model Integrated System Design for the Product

Sidney Jones prescribed that the design of the APT should include an extended experimentation phase and thus he decided that only limited design would need to be undertaken during the project definition (Meecher, 1994). This approach reflected his RandD background at RSRE Malvern where business and commercial pressures were not generally considered but scientific excellence was. According to Meecher (1994), the technical design at the definition stage consisted of the compilation of earlier technical studies that were aimed at solving specific problems associated with the already chosen solution. The result being that the project definition confined itself to the SOI only which led to the infrastructure issues being ignored until 1981. Analysis of the APT against the MM Model's Integrated System Design for the Product is provided at Exhibit 6.2.2.

Integrating System Design	The analysis shows that the system design that was undertaken focused on the SOI, and only one solution was considered seriously; the twelve coach, two centre power car configuration, using hydrokinetic braking, 9 degree cant and articulated bogies.
Product Design	The product design for the selected solution was comprehensive but only after the experimentation stage; during PD it comprised the results of focused research papers written and published between 1965 and 1968[1].
Product Modelling	Again, most of the modelling occurred during the experimentation stage.
Cost Modelling	No realistic cost modelling could have been undertaken during PD as the product design was not advanced enough to support the analysis required.
Trade-off Analysis	By considering the SOI only, and accepting from an early stage the configuration described above would be the final solution, the need for trade-off analysis did not arise at the PD stage. However, throughout the experimental stage and the later prototype stage a number of trade-offs were considered as designs failed to live up to expectations.
Cost Effectiveness Analysis	This analysis would not have been effective without the other analysis being undertaken[2].

Exhibit 6.2.2 – Analysis Against the Model's Integrated System Design for the Product

Burrows (1994) commented that the project team saw the investment appraisal for the APT as a three stage process with only enough detail being provided for the next approval. Marsh (1995) complained that it was this staging that denied the BR Board and the government the information that would have described the APT as an overall concept in terms of the whole BR business, certainly the impact on the infrastructure would have been realised in 1969 and a more appropriate investment appraisal decision made.

[1] The product modelling was based on the premise that new technology appeared to offer an answer to a commercial problem. There was no evidence found to support a hypothesis that various technologies were seriously considered.

[2] In any case no comprehensive cost-effectiveness analysis was found and furthermore, no systems-worth analysis had been undertaken.

6.2.3 MM Model Integrated System Design for Project Management

Analysis of the APT against the MM Model's Integrated System Design for Project Management is provides at Exhibit 6.2.1.

Project Baseline Definition	No attempt was made to understand the project's WSOI, and hence the serious impact from the infrastructure was not realised until the project became troubled. There was no plan to organise sound political support which resulted in it being patchy at best. Furthermore, the project's objectives strongly reflected the Experimental Phase as opposed to the whole project which essentially were purely technical. Moreover, as a result of poorly defined project objectives, the project design focused on an experimentation type project and not on a project that was required to deliver a product that would address BR's worsening competitive position in a realistic timeframe. The WBS and the associated project logic network did not reflect the size and complexity of the whole development.
Project Analysis	Project plans and schedules did not reflect the high-technology elements of the project, particularly those areas that needed a significant level of R&D, even though a significant amount of time was allowed. Furthermore, rework cycles were underestimated for the amount of R&D involved, the availability of skilled resource was wrongly assumed, and the concurrency with the HST was not allowed for. The plans reflected a luxurious timescale for experimentation and prototyping rather than the urgency of the commercial situation. Project economic analysis was undertaken but, with incorrect project data, the output was meaningless.
Management Design	The project was run by the R&D department and not as normal by BREL. Despite this more unusual and remote way of handling a significant and important BR project, no special management requirements were identified; the project organisation did not reflect a high-risk project; inadequate schedule and cost control were put in place; an inadequate communications plan was developed; quality assurance was not considered for special treatment; the WSOI was not considered and therefore the external interfaces were not identified and hence not managed.
Risk Analysis	Risk identification and the subsequent analysis work singularly failed to recognise, qualify, and quantify the systematic risks associated with project size, complexity, technical uncertainty, schedule duration and urgency, government and politics, and management. It was the combined effect of significant risks in each of these areas that caused the APT project failure. An inadequate Risk Management Plan was produced, and the schedules reflected the required-by date not the achievable date.
Integrated Management Design	A management plan was produced but it only addressed organisation, control and reporting, and authority levels. An integrated management plan of the type called for by the MM Model was not produced.

Exhibit 6.2.3 – Analysis Against the Model's Integrated System Design for Project Management

Project management design for the APT did not follow traditional BR policy for projects developed through the experience of BREL (Burrows, 1994) instead it was developed specifically for an R&D project that reflected an experimentation culture. There was no sense of urgency displayed by the project team; for them their focus was to ensure that the new technology being employed was perfect. In the end, there was too much new technology being developed for the resources available, and development was taking place in isolation from the real world (the WSOI). The project ran out of time! The HST, developed using BR's more classical approach to projects, achieved BR's stated aim of maintaining its competitive position in the inter city travel market and hence obviated the need for the APT.

6.3 SUMMARY OF THE IMPORTANT POINTS EMERGING FROM CHAPTER 6

The APT case study proved useful for the development of the MM Model in that it was exercised by a project that experienced all of the classic systematic problems described by Morris and Hough (1987). An analysis of the project using the MM Model shows that had a systems-based approach (eg, classical systems engineering) to project definition been used the symptoms of the systematic problems experienced could have been identified during the project definition and addressed accordingly. The BR approach to project definition for the APT concentrated on obtaining project approval and not understanding the project and accordingly designing it for success.

The project definition had singularly failed to identify the WSOI and hence the external interfaces were allowed to adversely impact the project with no strategy in place to address problems in a proactive manner. The lack of a systematic approach to project definition, no perceived need to design with knowledge of the wider system, and no specified way of managing interfaces between the SOI and SWOI were the root causes of failure. Other project problems could be described as occurring as a result of these failures.

The APT project also uncovered weaknesses and shortcomings in the MM Model in the areas of project objective setting, communications design and media management, and managing project objectives. The MM Model has been modified accordingly.

CHAPTER 7: CASE STUDY 2 – THE LONDON WATER RING MAIN (LWRM)

7.1 BACKGROUND

Historically, getting good drinking water to London has always been a challenge since, although the city straddles a mighty waterway, the Thames is contaminated with tidal salt water in its lower reaches. Water therefore has always had to be drawn from stretches above Teddington Lock or from the Lee Valley and in the 17th century a "new river" was built from springs in the Lee Valley to the River Head.

Londoners depended for their water supplies on an ageing network of trunk mains that radiated across the city from treatment works in the Thames and Lee Valleys. Nobody knows exactly how long this network was and, because much of it was more than 100 years old, it required increasing maintenance and repair. Since it used electricity to pump water distances of up to 50km, it was also saddled with very high running costs.

Rather than carry out further patchwork repairs and make ad-hoc additions to the existing system, Thames Water opted to create an entirely new system. In this it was assisted by the fact that London stands on clay, which is traditionally seen as the "tunneller's friend". Clay is easy to work, creates minimal settlement, and its strength and impermeability prevent leakage and contamination. However, the new system was confronted with other obstructions, both above and under ground. Above ground buildings, roads and traffic hampered access; below hung an inverted landscape of piles and foundations, tube tunnels and telephone connections. For these reasons Thames Water chose to site the new ring well below the existing services, building foundations and transport, at depths of 40 and sometimes 75m (the main averages 45m).

The London Water Ring Main Project is the largest capital project to date undertaken by any of the recently privatised water companies. The aim of the project was to improve the flexibility and efficiency of water distribution and reduce operating costs for the capital's water supplies. The ring main forms part of a larger programme of construction and development being undertaken by Thames Water in an attempt to boost drinking water sales. It is, therefore, not simply aimed at increasing the volume of water supplies, but also the quality of water.

The main comprises an 80km ring running from reservoirs by Heathrow Airport, west along the two major loops of the main to meet at a point between Battersea and Barrow Hill, see Exhibit 7.1.1. The main, which is essentially a 2.5m diameter tube, has the capacity to provide 285 million gallons of water per day, equivalent to 50 percent of the Capital's existing demand. The reservoirs that feed the ring main are themselves fed by five water treatment works in West London.

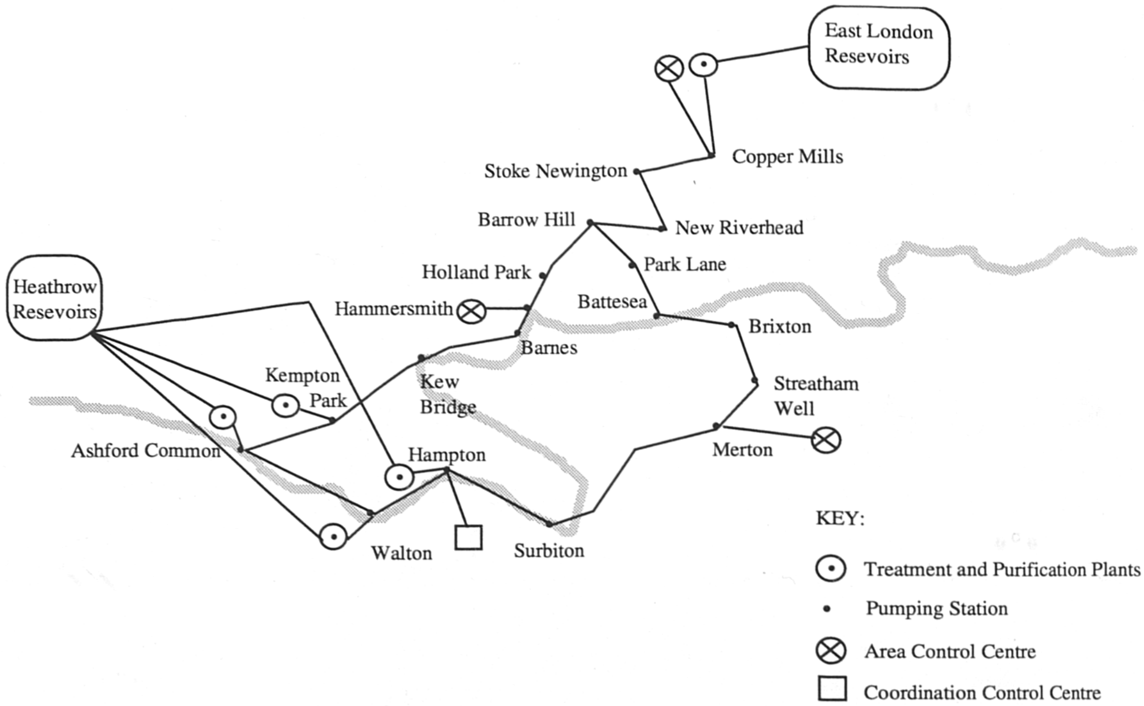

Exhibit 7.1.1 – The London Water Ring Main

The project commenced in 1989, with a planned completion date in 1996; benefits from the project were to be realised progressively as the schedule advanced and so parts of the main became operational prior to completion of the whole main. The planned project budget was £250 million, which was entirely privately funded. The progress of the project was excellent. All tunnelling was completed in February 1993, approximately 21 months ahead of schedule; indeed the Southern loop of the ring main was supplying water to Southern, South East and Central London in 1993. In addition, the project cost less than the original estimate. Despite this, some difficulties were experienced in the areas of water engineering and contracting; some 250 different contracts were involved. The project was completed early in 1994.

The background to this case study covers the following areas; the LWRM concept, technical aspects, the commercial case, organisation and management, cost and finance, performance and project schedule, and Thames Water's view of the project. Reference material for the case study includes; Kuras (1993), Snow (1992), Bell (1992), Water Supplement (1993), Thames Water (1993), and Contract – London (1991).

7.1.1 The LWRM Concept

The idea behind the project was quite straight forward. Water from rivers is stored in raw reservoirs near Heathrow Airport and in the Lee Valley. When water is required for the ring main, it is piped to four treatment plants for purification before the water goes underground. The four plants are located at Ashford Common, Kempton Park, Hampton, and Walton; a fifth treatment plant at Coppermills, will be added when the ring main is complete; see Exhibit 7.1.1.

The water travels downhill from the reservoirs to the treatment plants to maintain pressure in the main bore; the ring main overall is 44m below the treatment works that supply it. Water from the ring main is drawn through 12 vertical shafts to the existing surface distribution mains; the shafts are 12m in diameter and can each supply enough water for about two million people. Pumps are used to raise the water 45m to the surface. Shaft controllers at each pump-out shaft handle the pump start-up and shutdown sequences, and synchronise the delivery valves to pump operations. Sensors in the shafts keep a check on the environment, and will set off alarms or shut down the plant if there is a build-up of gas. All the electrical equipment is housed in a control room on, or close to, the surface of each shaft.

Tunnel		
Length:		80km
Diameter:		2.5m average
Depth		40-75m; on average 45 metres
Flow		up to 1,300Ml per day (MLD)
Pumpout Shafts		
Number:		12
Diameter:		11.9m reducing to 10.3 at top
Flow:		60Ml per day
Water treatment works		
Number:		5 (Hampton, Ashford Common, Coppermills, Kempton Park, Walton)
Examples of upgrading (peak daily flow in megalitres per day):		
	Pre-1987	**Post 1987**
Hampton	525	790
Ashford Common	410	690
Coppermills	480	680

Exhibit 7.1.2 – LWRM Technical Specifications

The local control and interlock panel (LCIP) in the control room co-ordinates pump and valve operations, but each shaft also has a number of autonomous microprocessor-based controllers that interface with the LCIP. These controllers maintain water levels and pressures, and monitor plant condition. Controllers gather information from sensors that monitor flow, pressure , water level and water quality. They also monitor pumps and collect electricity consumption data. The controllers run the pumps according to programmed 24-hour schedules or set points, but they can also be configured from one of the three area control centres (ACCs). Exhibit 7.1.2 outlines the technical specification of the LWRM.

7.1.2 Technical Aspects

There were problems using conventional traversing survey methods in the streets of central London owing to the pressure of traffic and pedestrians and the length of sight lines. Traversing surveys were needed to position the underground main with respect to shaft positions. For the early phases of construction a roof-top traversing method was employed with all the staff costs, inconvenience and delays that entailed. For the surveys for stages 4 and 5, a satellite survey system was used, the Global Positioning System (GPS). GPS uses the Navstar Satellite Constellation which has been in use for transport navigation for the past 7 years and is being increasingly used for civil engineering projects. A portable receiver picks up signals from at least four satellites. Each point surveyed is referenced first to the satellite global co-ordinate system and then to local co-ordinates. At each shaft site, bearings were taken from three survey stations and transferred to the bottom of the shafts. The tunnel-boring machine was then aligned and set off on the correct bearing. One surveyor could set up to receive and collect the data, and within a couple of hours define the position to $\pm$ 1cm.

Thames Water also redesigned the wedge block tunnel linings invented in the 1950s by the Metropolitan Water Board. Blocks were made from unreinforced, pre-cast concrete segments which were pushed against the smooth bored stiff London clay and held in place by a "key" wedge block. No grouting, secondary lining or bolting was needed, and the system was typically one-third of the cost of bolted linings. Thames Water improved the wedge block by reducing the number of segments per section, including the key, from 12 to 8, lengthening it from 0.68m to 1m and increasing its weight from 170 to 500kg. All blocks were handled mechanically whereas before they were sized to suite manual lifting. The result was a significant increase in the speed of tunnelling, a decrease in number of access shafts and a cut in tunnelling costs by 30 per cent. Moreover, the segments were interchangeable with the bolted segments, which were sometimes necessary for wetter or more sandy conditions.

Water runs into the ring main from the water treatment works using gravity; the ring itself is always full and hence pressurised during operation. Previously water was pumped by electrical motors for up to 50km. The new system therefore brings savings of around £1.6 million per annum through reduced energy costs. The only points at which pumping occurs is in the shafts that connect the ring to the existing mains. Since the shafts are quite broad they posed siting difficulties requiring innovative solutions to be devised; eg. the traffic island at Park Lane houses one of the biggest pumpout shafts. For environmental reasons, all structures, including a large switchroom, are below ground and the site grassed over once construction was completed. Advanced information technology played a large part in the project, ranging from computer-aided design (CAD) and modelling in its earliest phases to the use of various systems for monitoring, controlling and managing the project. The application of IT provided the key to effective control during the operational phase.

7.1.3 Control of the Ring Main

Thames Water undertook a review of the potential LWRM control and monitoring strategies during the definition phase of the project. Because of the size of the project and the investment it represented, the strategy took into account projected needs for the next century, not just the present and immediate future.

Under the strategy, London was divided into three sectors, each with an area control centre (ACC); Thames Valley (Hammersmith ACC), Lee Valley (Coppermills ACC) and South London (Merton ACC). The pinnacle of this hierarchy is a coordination control centre (CCC) at Hampton, south London; see Exhibit 7.1.1. The primary objective of the CCC is to coordinate the three ACCs and maintain an effective relationship between the demand and supply of potable water. The Hampton installation is the core of the control of the entire London water network. It is built around the world's largest water supervisory control and data-acquisition (SCADA) system and is able to control and monitor a quarter of a million data points. Machine hardware for the ACCs and the CCC has been standardised in order that there is a fast, streamlined interchange of data, and graphic display systems are uniform across the network in order to standardise training, and to facilitate job mobility. There is also a free movement of information, so that Coppermills, for example, can gather material from the Thames Valley, and operators in different locations can simultaneously monitor the same data on their displays.

The monitoring and control system has four tiers. The lowest tier is the local control and interlock panel (LCIP), from where local processors manage individual shaft pumps. At the next tier, control and monitoring of all shaft functions is provided. There is dual redundancy at this point, with each shaft having two controllers. Each controller is connected to its shaft pumps – there will be at least six main pumps, and a tunnel drainage pump – through dedicated processors, so that a single failure will result in the loss of only one discrete element and will not affect the ability of a shaft to deliver water.

Shaft controller functions include; monitoring the destination of pump water (reservoir or direct into supply), flood protection, fire and security monitoring, plant-condition monitoring, and operational control through pre-determined schedules. This operational function is a 24 hour schedule downloaded from the ACC, allowing the shaft controller to manage pump behaviour over a 24 hour period using predictions of the volume of water that will be taken out of an individual shaft at any one time. Like the LCIP, the controller is stand alone and, in the event of ACC failure, will pursue its last instruction and continue pumping.

On the penultimate tier are the three ACCs, each staffed on a 24 hour basis with the responsibility for day-to-day activity. The CCC is positioned on the final tier and it has the responsibility for co-ordinating overall water demand by each ACC and balancing this with the water to be drawn from each of the five treatment works. The LWRM is part of a similarly tiered London water control network, enveloping the abstraction of river water, storage in raw water reservoirs and treatment centres. When fully completed, it will allow Thames Water, for the first time, to control the passage of London's water from river to tap under a common system. Thames' hope is that it will bring to the public tangible benefits of privatisation, and change public perception of the water company during the few hot days in July.

7.1.4 Commercial Aspects

Until 1989 Thames Water was a public utility whose role amounted to little more than meeting its statutory duties of providing clean water and removing effluent. Its privatisation in that year was a key act of Mrs Thatcher's administration. Like the other privatisations it had two political aims; firstly, it provided an extension of shareholding to classes of society that were previously untouched by it; and secondly it led to the exposure of the utilities to competition from market forces with the consequent achievement of gains in efficiency and flexibility. The latter led to substantial staff reductions as the efficiency drive identified over-staffing, and new technology required fewer operators. However, the government also had a hidden agenda; it wanted to empower the water utilities to secure the funding necessary to upgrade their seriously under capitalised infrastructure of which London's water supply network was a prime example. London's water infrastructure was crumbling and in urgent need of a large cash injection to address the quickening decay. Prior to privatisation this money could only have been raised through the PSBR, direct taxation, or a higher water or local rate; all of these options were thought to be politically unsafe.

The impact of privatisation on Thames Water has been marked. It has shown good profitability and strong growth in turnover and capital investment (see Exhibits 7.1.3 and 7.1.4). Thames Water's capital investment programme has without a doubt been greatly assisted by privatisation and its associated freedom from the shackles of government-allocated year-by-year budgets. The capital investment programme has grown from £102m in 1987 to £392m in 1991 with most being funded from profits, as the outstanding debt graph shows (see Exhibit 7.1.3).

All this has led to what Thames Water's 1990-91 Annual Report termed "a starburst of activity" but as the Annual Report also comments, "the danger of a huge acceleration of activity in any company is loss of control". To avoid this tight managerial and budgetary controls were imposed for operations, and effective project management implemented in order to ensure that projects were delivered on time and within budget. These could be said to form part of a larger managerial revolution; a new incisiveness and motivation is reported with organisational patterns inherited from its public sector disappearing fast, project responsibilities and accountability for performance replacing functional duties. These organisational changes were introduced against a growing demand for water in

London with a 1985 report projecting 15 per cent growth in demand to 2006 (see Exhibit 7.1.5).

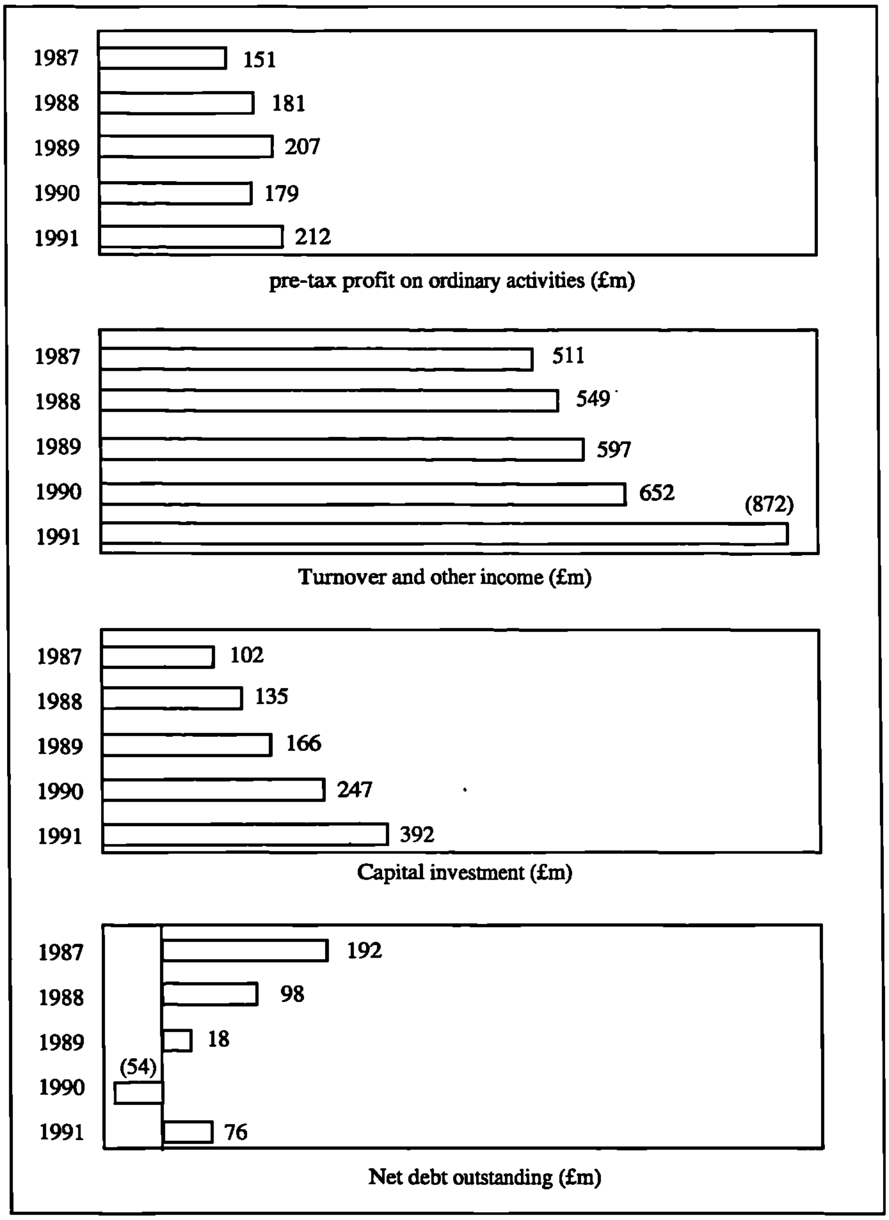

Exhibit 7.1.3 – Thames Water: Recent Financial Performance

An additional factor in the LWRM Project was an increased emphasis on water quality, spurred by world environmental concerns and specific EC pressures. The LWRM Project improved the quality of the water through the creation of a smaller number of more efficient water treatment works. Thames Water stated in its 1990/1991 Annual Report that it already satisfied World Health Organisation limits for pesticide levels in water and was investing £400m in advanced water treatment (AWT) facilities to achieve the virtual zero limits set by the EC. In addition to removing pesticides the advanced treatment process would also provide additional benefits by improving the taste and colour of the water. The AWT Project involves installing a number of the new plants throughout the whole of the Thames region, two of which, Walton and Ashford Common will feed the LRWM.

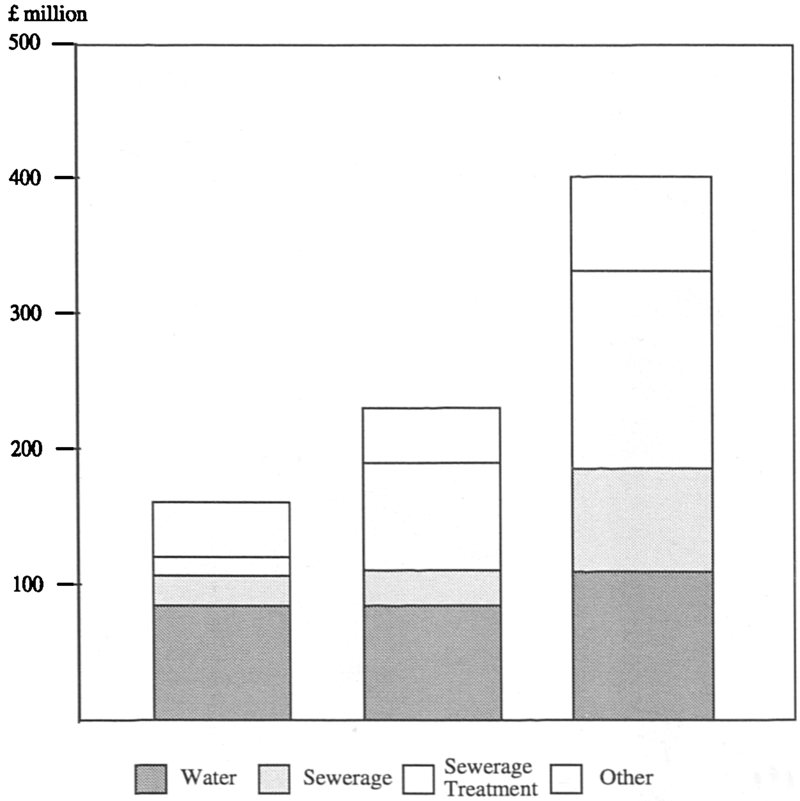

Exhibit 7.1.4 – Thames Water Capital Expenditure 1988/91

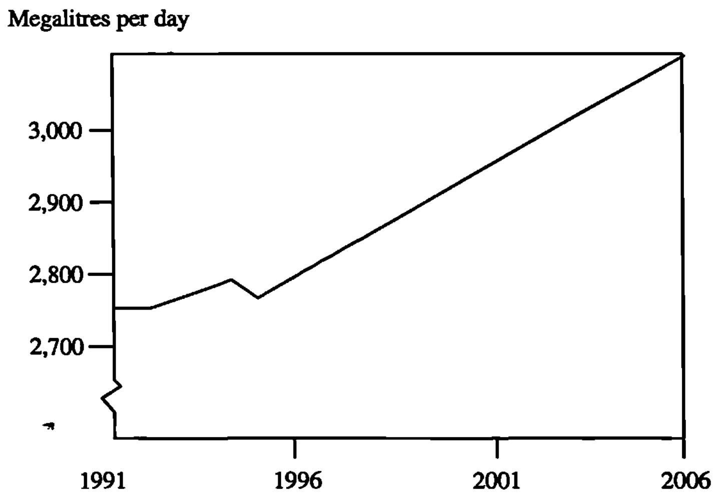

Exhibit 7.1.5 – Demand For Water 1991 – 2006

7.1.5 Organisation and management

Responsibility for the LWRM Project rested with Thames Water Utilities Limited (TWUL), the company's main operating arm (which also inherited the previous statutory obligations to provide clean water and remove effluent). The group structure of TWUL is shown at Exhibit 7.1.6. The management structure of the engineering department is shown at Exhibit 7.1.7.

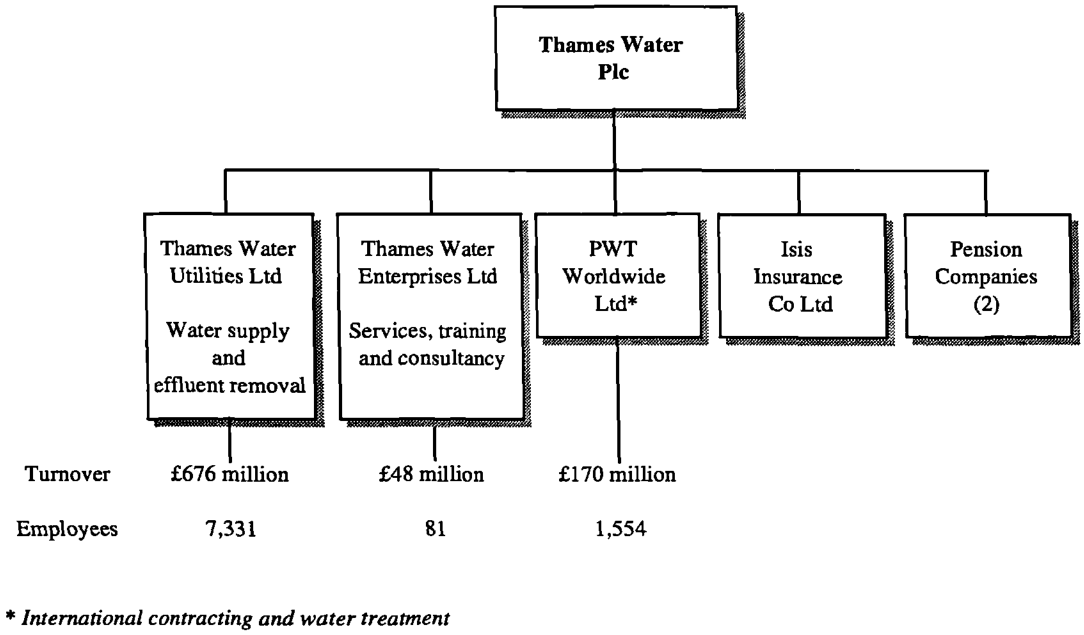

Exhibit 7.1.6 – Thames Water Group Structure

As a major project, LWRM combined three very important features: short, clear lines of authority and reporting to TWUL's Engineering Director; a project team approach; and backup from an array of functional and specialist expertise. These features were replicated within the LWRM project team itself (see Exhibit 7.1.8). As a project structure this had the advantages of being standardised and therefore easily extended, of flexibility and of combining freedom of action at the operating level with adequate overall control.

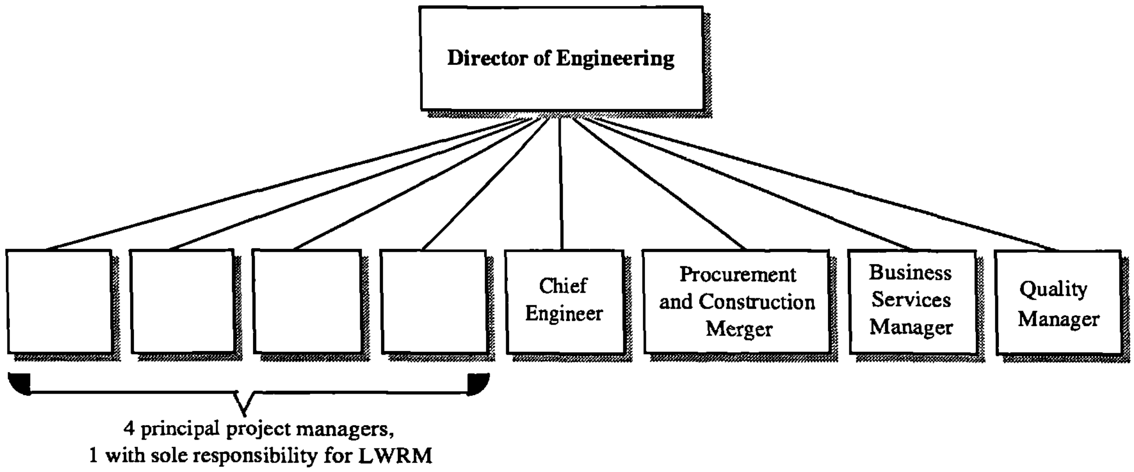

Exhibit 7.1.7 – TWUL Engineering Department: Management Structure

The Engineering Director commented that "in such a fast moving yet lengthy project full and effective control and monitoring is vital. Its very nature demands that Thames Water gets it right first time and that we minimise costs at the very beginning – at planning and design where the potential for cost reduction is greatest. Once costs are incurred at this stage, they cannot be eliminated".

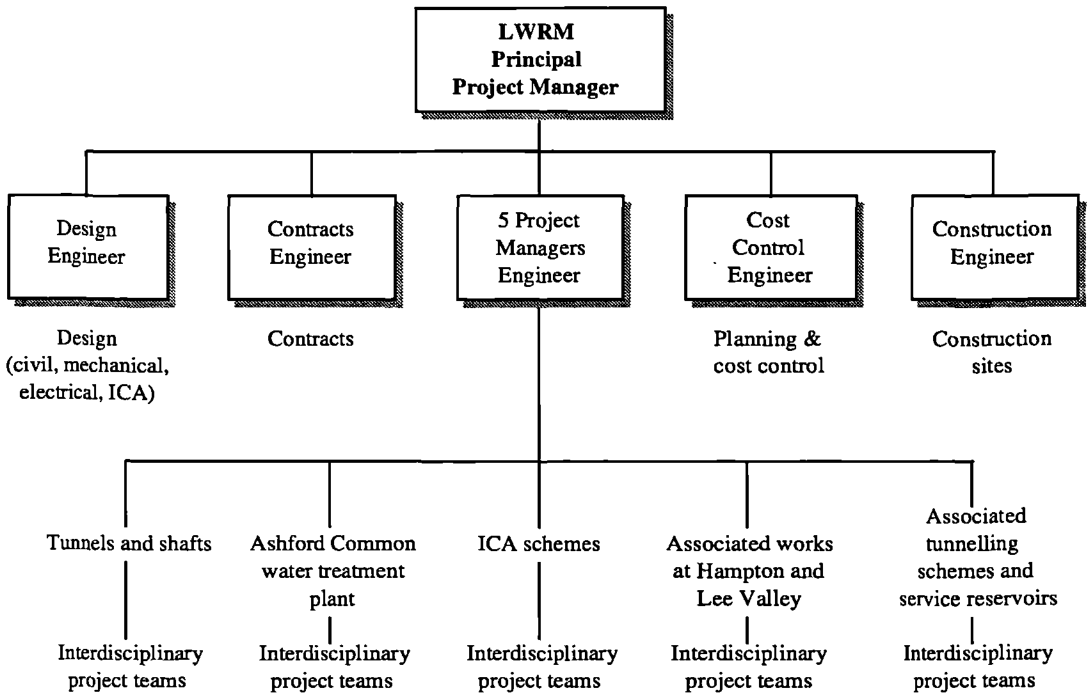

Exhibit 7.1.8 – TWUL Project Management Structure

This demonstrated not just Thames Water's proactive stance, but a larger shift within major projects – what is often referred to as the "downstream-upstream evolution". By this is meant a movement from focusing on tail-end, user problems to preliminary planning which reduces risks and avoids problems later on, ie, the project definition.

Planning and monitoring had three dimensions: time, performance and cost. To ensure proper control of time and scheduling, Thames used a computer software package called Trackstar. This carried out critical path analysis, projects end date calculations, and set standard milestones in progress towards both major and minor objectives. It also drew up recovery and contingency plans so the project can be got back on course even if difficulties and delays are encountered.

Continuous performance audits were built into the process. A "Quality Manager" reported directly to TWUL's Director of Engineering, and a continuous programme of internal quality audits ensured adherence to procedures and systems. Each department carried out its own quality audits, supplemented by a series of "spot" audits.

In addition to forward planning and continuous monitoring, retrospective assessments also took place to ensure the company learned fully from past experience. Each project is subject to a post project review in two stages; the project managers write an interim assessment for the client; the Department of Engineering then carries out a detailed post-mortem of every aspect of the project for the Board.

If a more proactive management stance is typical of LWRM, then so also is a more interventionist and participatory approach. Whereas a sharper interventionist role can lead to greater confrontation and contractor-client tensions, in the case of LWRM it has taken a much more collaborative form.

Thames Water now favours IChemE Target Cost Control contracts over ICE fifth contracts. Using Target Cost Control the contractor plans the resources and completes the detailed design where necessary, with clear incentives to help reduce costs through profit sharing arrangements. Thames also helps the contractor's management to optimise work schedules and reduce costs. Thames has found this form of contract especially useful for tunnelling work with its often undetectable obstacles and unpredictable rates of progress. Overall, this has fostered greater teamwork, facilitated fast-track design and construction, and created a high level of cooperation between client, contractor and subcontractor. The IChemE Target Cost Control Contracts have also avoided the disputes and claims over largely subjective matters that often occur with ICE fifth contracts.

A further feature illustrating Thames Water's interventionist approach is its willingness in certain cases to manufacture directly rather than buy. It has established a joint venture with Taylor Woodrow Construction to manufacture wedge block segments using part of the former Channel Tunnel facilities on the Isle of Grain. It has also purchased three tunnel-boring machines from a Canadian company for £1 million each. By spreading costs over the construction of overall tunnels, Thames aims to reduce the several costs of the programme.

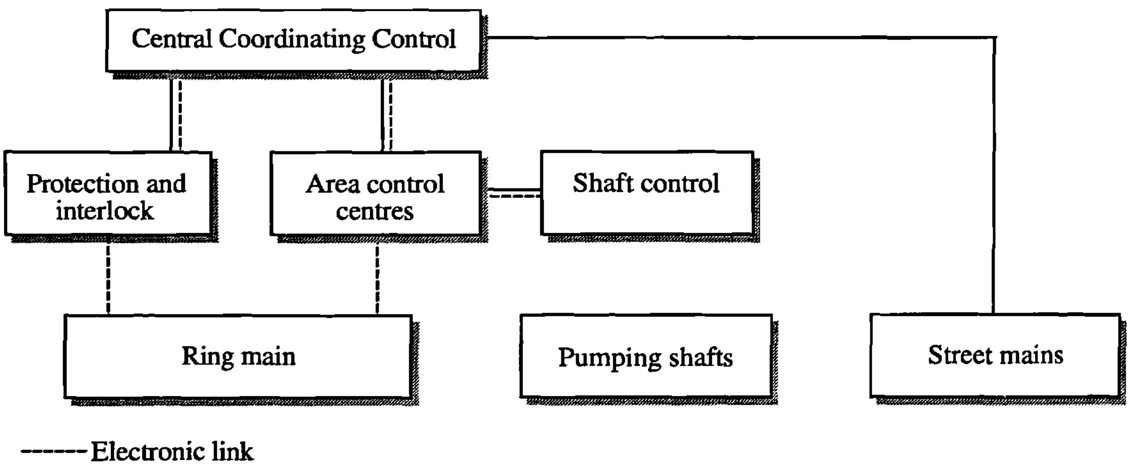

Exhibit 7.1.9 LWRM: Final Operational Structure

On completion, Thames Water switched to a final form of management for the operation of the LWRM. As described earlier, operations have four levels of engineering control (see Exhibit 7.1.9). The CCC coordinates the overall flows in and around the ring main, collects data for analysis, and sets the parameters for the ACCs, which in turn supervise the shaft controllers. The shafts themselves are unmanned, and high-technology monitoring and communications play an important role in coordinating the operation of these structures. The investment in technology attracts a substantial payback through manpower savings in operations.

7.1.6 Cost and Finance

On completion the LWRM had cost £250 million (at 1991 prices) and as such was the largest element in Thames Water's projected £4 billion investment programme. Pre-privatisation, the project was funded by the government but from 1989 it was funded part by loan and part from profits, although it was becoming funded more from profits as the project proceeded thus minimising debt finance. Furthermore, by phasing the project to become progressively operational, the project became almost self funding which reduced still further the need to raise debt capital. The amounts Thames Water has raised externally in recent years to fund all projects including the Ring Main have risen substantially as the capital programme has got under way. Internal and external funds are compared at Exhibit 7.1.10 for the years 1990 and 1991 in order to show how self financing was becoming more prevalent.

	Funds Generated		% Increase
	1990	1991	
Internally	£198.5m	£243.4m	23
Externally	£66.1m	£87.6m	33

Exhibit 7.1.10 – The Ratio of Internal Funds Against External Funds

However, these borrowings remain well within the sphere of manageability given Thames Water's record of profitability and the annual level of demand for its services.

The controls exercised throughout the project on budgets were as tight as in other managerial areas. A key element in project control was the capital expenditure or CAPEX Committee. The Committee comprised the Group Chief Executive and the Utilities Directors of Operations, Finance and Engineering, it was involved at several points in the project's life, for example at 30 per cent design report and at tender invitation stages. Costs were controlled to the day, month and year. Estimates were both global and specific and are further divided by project group, individual project, contract, down to the level of specific order, estimate or contract variation. To monitor all this information Thames developed a computer system called PROFISY (Project Financial Information System) that not only monitored costs (linked to ledger records of payments) but also produced financial forecasts.

7.1.7 Performance and Projected Schedule

During this project Thames Water set a number of construction tunnelling records. For instance, a UK record of 55 wedge block rings were installed in a single shift in the Merton to Battersea section; helped by the innovation with larger wedge blocks.

However, a number of unforeseen problems were encountered, notably the inundation of a tunnelling machine at Tooting Bec Common in South London. The drive had to be abandoned and air locks which had previously been installed were strengthened and locked down. The tunnelling machine entered a sand pocket and water flooded into the tunnel. The tunnelling machine was recovered by sinking a new shaft which involved freezing the ground to -18 C. The remaining 1.3km of tunnel was completed using an Earth Pressure Balance Machine designed specifically to cope with the conditions in the Thanet Sands which contained water at 4b pressure. At Pimlico the tunnelling machine encountered piles some 40m below a four-storey office block. These had not been shown in any of the records and resulted in the machine having to be manoeuvred around the obstacle.

Despite such setbacks the LWRM finished ahead of schedule, within budget and performance specifications. Indeed progress on certain tunnels was between three and twelve months ahead of schedule. The reward could be an even greater role for the ring main and the result that it might supply even more than 50 per cent of London's water.

7.1.8 Thames Water's View of the Project

The LWRM has been a model major project in terms of achieving its targets of deadlines, budgets and quality and an illustration of the growing sophistication of major project management. Among the factors contributing to its success were:

- a strong proactive management posture; an emphasis on anticipating problems at the planning stage and setting up mechanisms in advance to cope with them
- tight monitoring and control throughout and the creation of a learning loop, feeding back experience and knowledge into the project
- appropriate deployment of advanced technology, both in the implementation of the project (eg. satellite surveying) and its modelling and monitoring (Trackstar and PROFISY)
- effective use of project managers and teams incorporating or supplemented by specialist and functional expertise and a strongly interventionist role in relations with contractors (eg. in contracts) but one that succeeds in achieving participation not confrontation.

Among other larger factors contributing to the project's success were the confidence created by the sound financial bases of the company and the project; also the financial flexibility and managerial incisiveness resulting from privatisation.

7.2 RESEARCH ANALYSIS

The basic research material used for the background to the case study was augmented for the full research analysis by Thames Water's Project Definition Study Report for the LWRM. The Project Manager, Roger Remington, provided most of the detailed background information (1994). A telephone conversation was held with Peter Hemmings (1994), who was the Project Manager for the early stages of the project between 1986 and 1989. It was during this time that the project definition was undertaken and Hemmings provided much of the background to Thames Water's transition from public to private ownership.

7.2.1 MM Model – Containing Framework

Analysis of the LWRM against the MM Model's Containing Framework is provided at Exhibit 7.2.1. The project definition undertaken did not have the benefit of a well-structured systems model, such as the MM Model; however, a number of analysis activities were undertaken as part of the pre project definition stage which had common attributes with the MM Model. The results of the analysis were fed directly into the project definition.

Problem Definition	Thames Water realised that its water main infrastructure for London was more than 100 years old and was in urgent need of extensive repairs, it would not meet the predicted 15% growth in demand for water by 2006, and would fail to satisfy the new EC standards on water quality. It was decided that a new ring main was required.
Business Analysis	In 1989 Thames Water developed an aggressive business plan to improve the flexibility and efficiency of water distribution and reduce the capital costs of London's water supplies. Its ultimate goal was to boost drinking water sales and, at the same time, meet EC standards on water quality. The new London Water Ring Main was an essential part of this business plan as it provided the infrastructure on which the whole of the business development would be based.
Objectives Analysis	Based on the business analysis, clear business objectives were defined. Within these business objectives it was possible to identify those directly related to the LWRM.
Operational Requirements	The operational requirements for the LWRM were clearly stated and focused particularly on the management and operation of the ring main post installation.
R&D/Technical Barriers	There was no major R and D required, but a certain amount of technical development was undertaken to improve tunnelling speed and efficiency. There were some technical barriers that needed to be overcome including traversing surveys and the use of technology to minimise operational staffs.
Constraints	Owing to the "inverted landscape" the water tunnels had to be sited an average of 45m below ground level in order to avoid disruption of other services. In addition, in order to avoid attracting criticism on ecological grounds, the project planned to minimise adverse environmental impact.

Scenarios and Likelihood	Considerable scenario analysis was undertaken into the demand and flow rates, such as the impact of positioning of pumping stations and reservoirs.
Systems Worth	In the sense of the MM Model, the Systems Worth analysis undertaken was quite basic. However, a full cost-benefit analysis was undertaken which included an assessment of the value of the new ring main to the people of London and the programme as a whole.

Exhibit 7.2.1 – Analysis Against the Containing Framework

7.2.2 MM Model Integrated System Design for the Product

Analysis of the LWRM against the MM Model's Integrated System Design for the Product is provides at Exhibit 7.2.2.

Integrating System Design	Thames Water understood well the LWRM in the context of its WSOI. In order for this project to be successful Thames Water needed to be able to define and manage the very many interfaces between the SOI and the WSOI. In particular, it needed to address the specific interfaces with local councils and communities as a whole as the work to be undertaken would seriously impact everyday life.
Product Design	The basic engineering concepts involved were quite simple; however, the realisation of the concept required some high technology components and difficult environmental factors. The Project Definition document showed that Thames Water had considered all aspects of the product design, in particular those relating to the overall system and its operation. Evidence exists that Thames Water understood in detail how the LWRM would function as an infrastructure in terms of its interfaces with all surrounding systems.
Product Modelling	Hemmings (1994) advised that Thames Water had necessarily undertaken advanced modelling of the systems operation in order to ensure that a high reliability product would be developed. The emphasis was on the assessment of capability and availability in order to ascertain how the cost saving business objective could be achieved. The design of the LWRM relied very much on the outcome of this modelling.
Cost Modelling	Thames Water employed advanced cost modelling techniques as it was important to have a firm grasp of the life costs of the ring main. The rigour in this area was dictated in part by Thames Water's need to demonstrate to its shareholders that it had a firm grasp of its finances and shareholder value would be paramount.
Trade-off Analysis	Trade-off analysis was undertaken, but the overall design was dictated by parameters that would not accommodate too many options. There was some flexibility in design, but this did not call for sophisticated trade-off analysis.
Cost Effectiveness Analysis	Again, within the confines of the limited options, trade-off analysis was undertaken.

Exhibit 7.2.2 – Analysis Against the Model's Integrated System Design for the Product

Thames Water did not follow a structured system design methodology as suggested by the MM Model, but it did cover the fundamental features. In the case of the LWRM, a sophisticated system design approach was not critical as the overall system concept was relatively simple. However, certain aspects of the project called for sophisticated design, for example systems control, and in these areas the use of the MM Model could have provided a better insight into the transitional difficulties and testing that Thames Water experienced.

7.2.3 MM Model Integrated System Design for Project Management

Analysis of the LWRM against the MM Model's Integrated System Design for Project Management is provides at Exhibit 7.2.3.

Project Baseline Definition	Although not referred to as the WSOI, Thames Water took great cognisance of all interfacing systems as the LWRM impacted nearly every aspect of life in London. During the planned 7 year implementation all interfaces external to the project were identified and a management approach defined. Moreover, the project was designed to reflect an extensive tunnelling undertaking which inevitably would disrupt London's everyday life (both commercial and domestic). The WBS and the associated project logic network reflected the size of the project and specifically the interfaces that had to be managed.
Project Analysis	Project plans and schedules reflected the project and specifically where the rework cycles were thought to reside. Thames Water could be accused of being over generous with the time schedules but, in their defence, it should be stated that tunnelling is notoriously unpredictable and major obstacles can often dramatically impede progress (the Channel Tunnel is an example; see Stannard, 1990). In the event only two incidents occurred with the LWRM; at Pimlico and Tooting Bec. Considerable work was undertaken on project economic analysis and the project was a model of how self-financing could be applied, hence minimising senior debt.
Management Design	Thames Water prided itself on its team working culture and, accordingly, the LWRM project organisation was set up to build on this culture in a way that was appropriate to a project of this size. Control and reporting was designed to be interventionist, but only when circumstances dictated this approach. The project control systems defined were in line with a project of this size and complexity. Project communications were designed specifically to cope with the enormous disruption that this project would cause to London. An appropriate contracting and procurement strategy was put in place to deal with the expected 250 contracts within the project. Special consideration was given to quality assurance and control and, as mentioned before, the project interface management was well designed. Owing to the potential environmental impact of this project, specific studies were undertaken with the aim of mitigating the impact. Thames Water, being a newly privatised company, looked aggressively at the LWRM financing options in order to maximise return.
Risk Analysis	Risk identification and subsequent analysis were rigorous and appropriate risk management plans were devised which looked to manage risks proactively.

Integrated Management Design	A management plan was produced and addressed all of the topics called for by the MM Model. In keeping with Thames Water's management culture this plan, together with the product design, was signed off by senior management and hence full commitment to the project was assured.

Exhibit 7.2.3 – Analysis Against the Model's Integrated System Design for Project Management

7.3 SUMMARY OF THE IMPORTANT POINTS EMERGING FROM CHAPTER 7

The MM Model has shown that Thames Water's "downstream-upstream evolution" approach to project definition worked; this confirms the findings of this research that time spent working through the project definition processes as suggested is the only way of setting up the project for success. Remington (1994) confirmed that Thames Water had expended considerable effort in project definition and had presented the results for project approval through an appropriate business system not dissimilar to that suggested by Pike (1983). He also confirmed that similar processes suggested by the MM Model were followed, but acknowledged that a more structured approach would have been helpful. Furthermore, Remington (1994) supported the use of systems tools and techniques and confirmed that Thames Water had used some hard systems methods. He maintained that the soft systems approaches were unnecessary for the LWRM since, in his opinion, this project did not face any ill structured (messy) problems.

A further analysis of this project provides some indication of why it was successful:

- it was an extremely well planned and designed project from the outset
- the project's objectives were well understood and not over ambitious
- the complexity was minimised and only a small amount of new high technology was involved (mainly relating to systems control)
- the project was defined in terms of its wider system of influence (supporting M'Pherson 1981 and Hitchins 1992)
- the project did not face any significant ill-structured, messy problems
- the project communications were excellent.

The LWRM project uncovered no shortcomings or weaknesses within the MM Model, in fact it confirmed that the processes and structure of the model were entirely appropriate.

CHAPTER 8: CASE STUDY 3 – THE ROLLS ROYCE RB211 AERO-ENGINE

8.1 BACKGROUND

This case study background maps the progress of the RB211 aero-engine from its concept, through its turbulent development period, including causing the collapse of the Rolls Royce Company, to its recovery as one of the world's most successful jet engines. Four main references have been widely used, the first two of which are major research works in their own right: a government Command paper (1972); a study into the failure of the project (Edmonds, 1975); an autobiography of the RB211 rescue engineer (Hooker, 1984); and a case study into major project failures (Bignall and Fortune, 1984). Various aviation journals are also referenced together with Rolls Royce internal documents.

8.1.1 Overview

As a result of the Plowden Report (1966) on the aircraft industry in the UK, Rolls Royce Aero-engines acquired Bristol Siddeley Engines Ltd (BSEL) for £67m to form the largest aero-engine company in Europe and the third largest in the world, behind General Electric (GE) and Pratt and Whitney (Pratt) both of the USA.

The new company employed some 80,000 staff with an annual turnover of £321m ($700m); the profits were calculated to be £12.25m (Plowden, 1966). The annual turnover of GE and Pratt was $1400m and $2100m respectively. This meant that the new Rolls Royce company had only 20% share of the world aero-engine market but, what is more important to the case study, Rolls Royce had only an 8% share of the commercial aero-engine market; its market was predominantly for military aircraft, and therefore much of its business relied on government contracts. By 1967 it was realised that the new company was too large for its current share of the aero-engine market, with the chief executive advising that Rolls Royce was in danger of being taken over by one of the US aero-engine giants unless Rolls Royce broke into the new US wide-bodied airliner market. The government at this stage actively encouraged Rolls Royce to acquire more commercial business as it was concerned that a national asset would become controlled by a foreign country (Edmonds, 1975).

Commercial aero-engine technology was changing, with Pratt exploiting Sir Frank Whittle's proposition that engine efficiency would be greatly increased by utilising a higher bypass ratio. The Pratt JT3D was the normal choice of power unit for the Boeing 707 series of airliners. The Lockheed C-5A Galaxy and the Boeing 747 "Jumbo Jet" used a new generation of high bypass ratio (HBPR) engines; GE's TF39 and Pratt's JT9D. The new breed of HBPR engines essentially used an existing type of engine core with a downstream turbine added to drive, through a long "back-to-front" shaft, with a large fan at the front of the engine. This fan, in essence a multibladed propeller, supercharged the entire air flow entering the core engine thus greatly enhancing the overall efficiency of the engine.

Rolls Royce viewed the medium-haul airbus market as the opportunity it needed to absorb its over capacity. The medium-haul airbus concept originated in Europe in 1965 with the advent of the Hawker Siddeley "Bident", a two-engined larger development of the in-service Trident airliner. However, the government refused to support the Bident since it preferred, for cost reasons, to join a consortium instead of going it alone. Also, the Bident offered only 170 seats and most European airlines considered that 250-300 seats was optimum. The European market would be for 100-200 aircraft with the possibility of a greater number for the US market. For Rolls Royce this would mean 800 to 1000 engine units; enough to keep the newly formed Rolls Royce Company viable.

In 1967, after one year of debate, it was agreed that a European Airbus venture would be set up to build the A300 (300 seats), with design leadership surrendered to the French for acceptance of the Rolls Royce's RB207 propulsion units. The RB207 was planned to be an HBPR engine of 50,000lbs thrust but it was still at the concept stage. At Rolls Royce, the development of a new engine followed a three stage process (Webber, 1994) as shown at Exhibit 8.1.1.

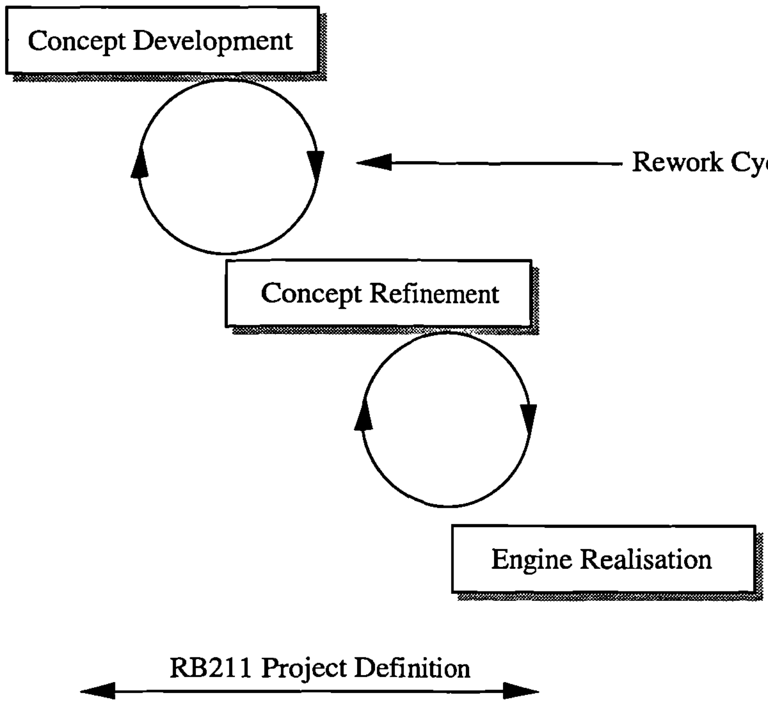

Exhibit 8.1.1 – Three Stage Development Process At Rolls Royce

The first stage covered the basic research into the various technological options available to meet a particular gas turbine requirement. During the second stage, the basic concepts were developed into firstly a prototype engine and then into a working version of the target engine. In the case of the RB211, the new concepts required for the HBPR "three-spool" approach were first tested and developed on the RB178 prototype and the second stage was used for identifying the manufacturing processes required for production. The third stage was concerned with building the engine through development versions to the eventual product. Version development overlapped, known as scarfing, in order that the programme timing could benefit from concurrency (see Exhibit 8.1.2).

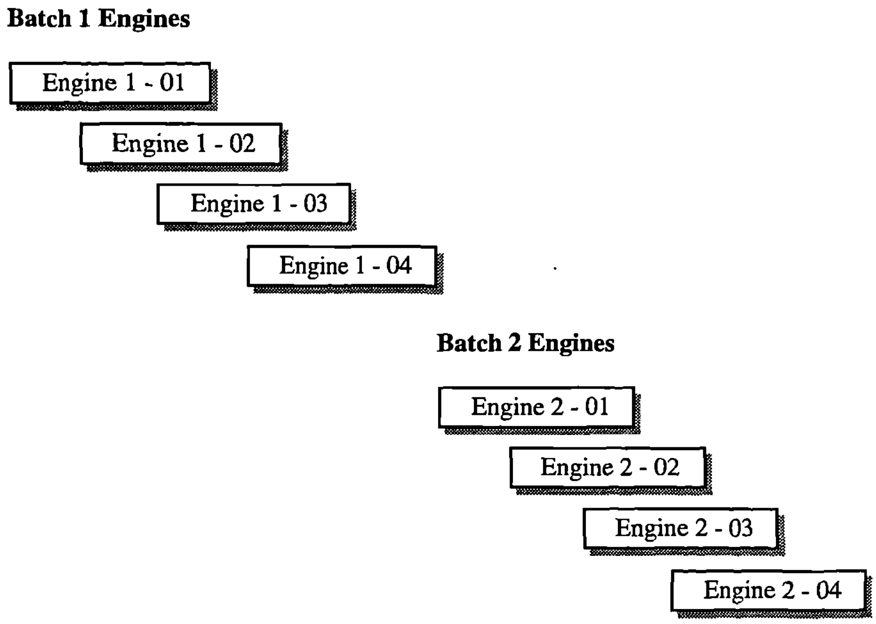

Exhibit 8.1.2 – Scarfing Process

The project definition was undertaken during concept refinement and the early phases of engine realisation. For a matter of record, the launch cost of the engine comprised 20% for running, 40% for staff and 40% for parts.

The RB207 was planned to be a development of a Rolls Royce private venture initiative – the RB178. In effect, the RB178 was described by Rolls Royce as the prototype for all of its HBPR engines. However, the UK did not have a good track record on European collaboration; the Anglo-French variable geometry fighter had been abandoned amidst considerable bitterness, the Concorde project was progressing from one political crisis to the next, with costs escalating out of control, and the Airbus project still had difficulties despite a memorandum of agreement being signed. Moreover, the Rolls Royce Board at the time did not view Europe alone as providing the increased market that it needed. At the same time as the drive to provide the RB207 engine for the A300, Rolls Royce and the government were pursuing a much bigger prize; the US medium-haul market. Many in both Rolls Royce and the government had been incensed by the US decision not to accept UK engines for either the Boeing 727 or the early 747s, and therefore it was becoming a matter of principle for one of the new range of US medium-haul aircraft to be powered by a Rolls Royce engine.

The government had recognised that, if Britain's aerospace industry as a whole was to be competitive with the USA, a foothold had to be gained in the US market. The only chance of this happening outside the specialist military markets (eg, the Rolls Royce (ex BSEL) Pegasus for the Harrier Jump Jet; or as it was known at the time the P1127) was through advanced technology commercial aero-engines. The government was committed to Rolls Royce's prestige and viability as demonstrated through collaborative projects such as the Jaguar, Concorde, and the A300.

The US target for Rolls Royce was the Lockheed CL1011 TriStar, since McDonnell Douglas was already in the advanced stages of selecting the GE's CF6 engine for its DC 10. GE, also seeing the A300 as a prize, launched a development programme to enhance CF6 from 33,000lbs thrust to 50,000lbs thrust; the CF6-50. This development was a fundamental cause of the RB211's later project problems as it indirectly forced Rolls Royce from the European Airbus Consortium and for many years out of contention for what was to become a world-accepted airliner. The original thrust specification for both the TriStar and the DC 10 was 33,000lbs, but this figure was uprated to 42,000lbs for both airliners before any contracts were signed. However, the promised availability of GE's CF6-50 meant that McDonnell Douglas could offer a heavier DC 10 for long-range routes; this heavier version became the main option available and out sold the TriStar.

It should be stated here that the original RB211 concept design was for an engine producing 33,000lb thrust. The original project definition estimates for cost were based on this concept. The TriStar weight increased as its design matured and Lockheed required an engine of 42,000lb thrust. According to Bignall and Fortune (1984), Rolls Royce agreed to increase the thrust without increasing the price of the engine.

Thus, from the outset, Rolls Royce was in an inferior marketing position (Edmonds, 1975). It was striving to build an engine of 42,000lbs thrust in competition with a much larger US rival that was offering engines up to 50,000lbs thrust. However, Rolls Royce offered two key features with the RB211; a three-spool layout, and hyfil fan blades. The former meant that the fan, the IP compressor, and the HP compressor could be driven by independent turbines at optimum speed, and the latter reduced the weight of the fan through using carbon fibre rather than steel. Both new technologies promised better fuel efficiency and lower overall weight (Edmonds, 1975).

The government had openly acknowledged that the RB211 contract for the TriStar would be the largest export order ever won by the UK, and it would significantly contribute to the UK's balance of payments. It agreed, therefore, to make available facilities in Washington for lobbying the US Congress, to provide launching aid for the RB211, and it promised both Rolls Royce and Lockheed that if the RB211 was selected for the TriStar then it would contribute to the development costs. Lockheed had read this promise to mean that the UK government would underwrite any loss that Rolls Royce incurred in developing the RB211 (Edmonds, 1975). A contract was signed with Lockheed on the 29 March 1968. As a result of the contract Lockheed went ahead with large launch orders for the TriStar from Eastern Airlines, PanAm, TWA, and with a specially formed British financial group called Air Holdings whose purpose was to underwrite 50 of the US jets for sale to non-US carriers.

During the time of the negotiations, Rolls Royce continued the development of both the RB207 and the RB211 in order to keep Rolls Royce's options open; that is one foot in the A300 camp, and the other in the TriStar camp. Development on both engines continued until December 1968, when the government withdrew from the A300 consortium, as Rolls Royce accepted that it did not have the resources to develop both engines simultaneously (Hooker, 1984). The effective cancellation of this engine caused political problems between France and the UK on the partnership for the A300 Airbus Project, and perhaps more importantly, allowed GE into the European market with the CFS6-50 (Hooker, 1984). This powerful engine later became the standard for the DC 10, with only the long range version being offered; a market disadvantage for the TriStar.

A number of considerations suggest that during the period of negotiation leading up to the Rolls Royce/Lockheed contract, the government was closely involved in the venture and now fully committed to it, but in face to face discussions with Lockheed, the government appears to have abdicated responsibility to Rolls Royce executives. When the RB211 contract was announced, the Minister of Technology claimed close association with Rolls Royce's success, "it was an interesting example of a partnership between government and industry which has made this possible". In the House of Commons, help given by the government towards winning the contract was described as "the highest possible".

8.1.2 Extent of government Involvement

For many years before the RB211 project, Rolls Royce had been a government orientated industry (Edmonds, 1975). It was a symbol of British technology, and engineering genius; "one of the nation's vital assets" claimed Tony Wedgewood-Benn, Labour Minister of Technology; and it was "one of the world's most famous companies", (HC Deb 1970). For years, governments had made Rolls Royce the king-pin of a long-term strategy for the aerospace industry and within the UK and the rest of Europe. Rolls Royce had, in consequence, become a quasi-non-government organisation, rather than a private corporation.

All of Rolls Royce defence development contracts were totally government financed, and there was substantial government launching aid to develop "promising" civil aero-engines; half of the cost of preliminary design work, pure and applied engineering research, plus direct capital grants and use of the facilities at the National Gas Turbine Establishment, the National Physics Laboratory, and the Royal Aircraft Establishment were provided.

The government strengthened Rolls Royce's competitive position by sacrificing overall design leadership of projects to Britain's European partners in exchange for Rolls Royce leadership in the development and production of aero-engines. This stance, according to Edmonds (1975), attracted severe criticism from among others the avionics manufacturers who felt that their world leadership was being sacrificed in the interests of the "albatross", Rolls Royce. By 1968, of all major collaborative ventures that used Rolls Royce engines, only one had UK design leadership. Moreover, there was close collaboration between the government and Rolls Royce in research into the whole medium-haul airbus market; Rolls Royce had secured government finance for development work on all major national and collaborative programmes and for research into advanced technology engines.

Finally, the government was involved throughout the negotiations with Lockheed regarding the financing and underwriting of the RB211 project (Flight, 1968a).

8.1.3 Contract Between Rolls Royce and Lockheed for the RB211

It is essential to have an understanding of the nature of the RB211 contract in order to test the strength of the Rolls Royce/government relationship, and the degree to which the government had delegated responsibility for the contract to Rolls Royce.

Rolls Royce agreed with the Lockheed Aircraft Corporation to provide the RB211-HBPR advanced technology engine for the CL1011 "TriStar" medium haul airbus. Rolls Royce negotiated the contract for 450 engines (150 aircraft sets) and 96 spares for delivery from September 1971 fully certificated at 42,000lb thrust. The first 100 engines would be at the fixed price of £354k ($550k, the contract price was quoted in dollars at an exchange rate of £1 = $1.59) each, which included adjustments for customer requested modifications, a fixed inflation factor, and a narrow band currency fluctuation limit. If either currency moved outside this band the disadvantaged party could negotiate a compensating figure. The contract (483 pages) under US Law was signed on the 29 March 1968.

The government openly congratulated Rolls Royce on being awarded the contract because of the vital contribution to the economy and to the national defence interest. However, it should be noted that an important factor in Lockheed's acceptance of Rolls Royce's tender was a commitment by the government to guarantee that Rolls Royce, with government financial backing, would not fail to meet its side of the contract, and verbal assurances to that effect were given to Lockheed by senior members of government in late 1967 (Flight, 1968b).

It was Rolls Royce's usual practice to define the brochure performance and forecast technical problems for a new engine by a synthesis of performance achieved on individual test rigs of its aerodynamic components, and then to add to that estimated performance a deterioration of approximately 1.5% specific fuel consumption. Experience with the RB211 suggests that this was an inadequate method of estimating performance and forecasting technical problems for a fixed price contract with penalty clauses that exceeded the total company assets. The government, according to Edmonds (1975), was aware of these penalty clauses and encouraged the contract to be accepted even though a significant national asset was to be put at risk. Both Rolls Royce and the government must have known of the risk since an engine of this type had never been built it the UK. Edmonds (1975) thought that Rolls Royce was naively arrogant.

The price of $550k per engine was, according to the CEO of Lockheed, unrealistically low, and it was suspected that the British government was involved in order to hold down the price. The contract price was in fact lower than competitors even before the sterling devaluation in 1964. The penalty clauses required that each engine was to be delivered on time and to specification. The only contract flexibility was for alterations in contract price to cover the effects of inflation. General experience suggests that fixed price contracts for development and production of advanced technology products above certain scale should be avoided (Edmonds, 1975).

8.1.4 Initial Funding and Cost Estimates

The original cost estimates for launching the RB211 were £65.5m of which the government agreed to contribute 70% to a maximum of £47.1m (HMSO Command Paper, 1972). Launching aid (Government Procedures, 1960) is an interest free financial contribution to the launching costs of civil aircraft or aero-engines to cover in part design and development, production jigs and tools, and "learner costs" (ie, the higher labour costs incurred in the early production stages. Full production costs are financed through engine orders, and in return the government receives a share of the profits once they reach agreed levels. This left Rolls Royce to raise £18.4m through bank organised senior debt arranged through the Bank of England, Midland and Lloyds, with Lloyds being the lead bank.

To demonstrate why such a large investment is needed to launch a new aero-engine, it is important to understand the lead time within the cost-cycle for a large engine development – see Exhibit 8.2.3 (Puttick, 1993).

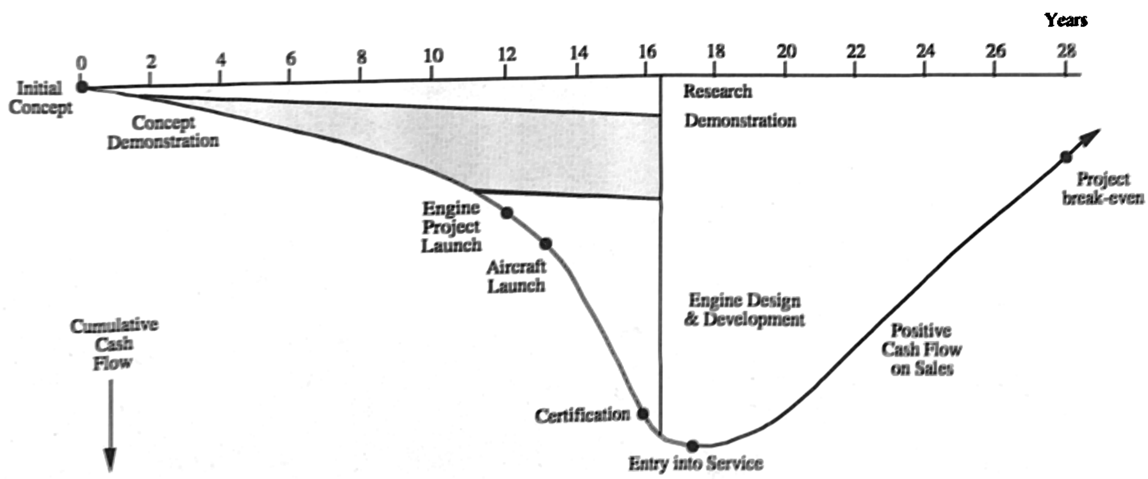

Exhibit 8.2.3 – Cost Lifecycle for Engine Development at Rolls Royce

From "engine project launch" the timescales agree with the project time of the RB211. However, research and demonstration were very much shortened, ie, 4 years rather than 12 years in order for Rolls Royce to enter the US airbus market. This short time in research and development did initially save money but, as will be shown, the cost of short-cutting was very high to both the project and the company. Launch aid covered the engine to "entry into service".

The government had already provided significant funds for research and concept demonstration into the RB207 and RB211 HBPR engines; this work was undertaken mainly on the RB178 testbed (Edmonds, 1975). The RB207 was planned for the A300 European airbus and the original CL1011 two-engined concept. This funding is thought to have been around £1.5m. Furthermore, the government had also funded a market study into the potential world airbus market which concluded that 700 to 800 aircraft with a seating capacity of 200 to 250 would be needed by the end of the 1980s (Edmonds, 1975).

Indirect government financial aid was also made available to the project (Edmonds, 1975). In late 1967 the government gave a commitment to Air Holdings Ltd, a private leasing and selling agent for civil aircraft, that it would cover in part an Air Holdings undertaking to purchase 30 TriStar aircraft with options on a further 20 for sale outside the USA. This arrangement was to ease pressure on the US balance of payments with the UK in order to pre-empt any questions that may have been raised in the US Congress; this is formally known as an off-set agreement. Air Holdings was liable to Lockheed for £15m should it not sell any aircraft, but this risk was covered in the City where it was considered that the RB211 was considered to be a good risk. Edmonds (1975) thought that City analysts based their judgement on Rolls Royce's hitherto track record of delivering engines on time and to budget.

Rolls Royce also had confidence in the launch figures as it had developed its last major engine, the Spey, to time and to budget. However, this experience led Rolls Royce to a false sense of security as the Spey benefited from tested technology and production techniques from two previous successful engines; the Rolls Royce Conway and the Rolls Royce Medway. Rolls Royce's methods of estimation were based on a policy of gradual technical development rather than large step development. In the case of the RB211 this policy was not adhered to and the development risks were not appreciated.

The RB211 was twice as powerful as any engine that the company had developed before, it had novel design features that required new materials, and the final production engine was required to run at much higher temperatures than had before been experienced. Furthermore, according to Hooker (1984), the operating pressures were outside the company's previous experience, and the size of the fan blades, castings and rings was more than double anything seen at Derby previously.

8.1.5 Project Organisation

Another element that must be considered was that during the initial stages of the project the Rolls Royce engineering department at Derby was completely reorganised. The new organisation, as noted by Bignall and Fortune (1984), was project orientated and matrix based, with each project group led by a chief project engineer. The matrix concept had deprived the RB211 project of the continuity of experienced design engineers with the result that they lost day-to-day contact with issues as they were developing. Furthermore, the Derby engineering department was experiencing resourcing difficulties through being committed to the design and development of two HPBR engines simultaneously; the RB207 and the RB211. It was decided to stop work on the RB207 in order to concentrate effort on the RB211 (Hooker, 1984).

In July 1967, during the project definition, Derby's Director of Engineering (Adrian Lombard) died. He was reputed to be (Bignall and Fortune, 1984) a brilliant engineer; he provided dynamic leadership on developing concepts for HBPR engines, and he had a firm grasp of the new technologies required by the new engine. It was not until much later in the project (February, 1971) that he was replaced by another outstanding engineer – Stanley Hooker. Hooker, the retired chief engineer from Bristol Siddeley Engines Ltd, reviewed the project in 1971 he produced a appraisal report which is included at Appendix 11. Reference to the report at this point is made in order to provide a technical description of the engine for the case study.

8.1.6 The RB211 Project Until the Rolls Royce Receivership

Aviation Week and Space Technology (1969) reported that from March 1968 (the contract date) until June 1969 the RB211 project had proceeded to plan. The only significant problem had been with the Hyfil carbon-fibre blades which had encountered difficulty with rain erosion and brittleness when tested against bird strikes. However, Rolls Royce was not unduly concerned as it had a fall-back strategy to use titanium blades, although this option would attract a weight penalty. In fact, Rolls Royce as part of its contingency planning had already ordered the titanium blades from a German supplier (Hooker, 1984). Aerospace Week reported that the first engine (RB211-06) had been tested during August 1968, and Flight (1969) reported that the eighth engine of the 06 series had been tested by the end of July 1969.

What was not being reported was that during this period the development of the new engine was exceeding its planned budget by a significant margin. Bignall and Fortune (1984) recorded that progress on the engine design was slower than had been expected, but production dates demanded that designers released drawings to the workshops knowing that the designs might well prove unsatisfactory. Other designs were passed to manufacturing before all of the necessary tests had been carried out. The result was that many manufactured parts had to be scrapped and re-made when the need for modifications became clear. Rolls Royce had implemented the scarfing process (see

Exhibit 8.1.2) without ensuring that the designs were robust, perhaps a result of the shortened research and development period for the engine. It is also a good example of the adverse effects of uncontrolled concurrency – see Morris (1986).

The Rolls Royce Chairman's Report to Shareholders in 1969 gave the first public warning of the troubled times ahead when he announced that some additional cash would be needed for the RB211 development. In response, the Labour government asked the Industrial Reorganisation Corporation (IRC) to investigate this cash crisis at the end of 1969, and as a result it undertook to make an unsecured loan to Rolls Royce of £20m, £10m in 1970 and a further £10m in 1971. Furthermore two accountants were appointed to the Rolls Royce Board which hitherto had been predominantly engineers. One of these accountants (designated deputy chairman – Ian Morrow) reported to the Minister for Technology in August 1970 that the development costs of the RB211 were set to rise yet further with the result that the Minister ordered a full-scale technical investigation (Government Command Paper, 1972).

The technical investigation revealed in September 1970 that the engine development could be completed successfully, that the manufacturing task to meet the contract terms and conditions was difficult but achievable, and that the new overall cost forecast was acceptable. However, this cost estimate was referring to the revised estimates submitted to the government also in September 1970. This new estimate had revealed that the launching costs had risen to £135m (as compared with the original £65.5m, and the £118.5m when the new Conservative Administration had come into office in June 1970), and that there was an expected loss on production of £45m. Furthermore, there would be a loss of profits arising from a reduction in expected sales of other engines, and the withdrawal of investment grants; both amounting to some £33m. As a result, the company expected a cash short fall of some £60m in the years 1971 and 1972 after taking account of the first £10m IRC loan (Government Command Paper, 1972).

As a result of high-level discussions, the government agreed to provide an additional £42m of launch aid, and the three banks involved a further £18m. In November 1970, Cooper Brothers (Chartered Accountants) was asked to conduct a study into the long-term position of Rolls Royce. It is important to note that the release of the new finance would be dependent on the results of the accountant's findings. In January 1971, the company indicated that the cash flow requirements would be very much greater than previously forecast, because of the technical difficulties being encountered on the RB211 project, the financial penalties that would be incurred because of schedule slippage, and because of escalation in production costs.

An internal technical appraisal undertaken by Stanley Hooker, the replacement Director of Engineering, revealed that the remaining technical problems with the engine were capable of being solved but a 6 month slippage in the programme was necessary in order to overcome the difficulties. The delay was due to the large number of modifications to the design that were still emerging at a time when the engine should have entered full-scale production (Hooker, 1984). This was reported to the new post of Minister for Aviation and Supply on the 22 January 1971. The dilemma was that Rolls Royce could expect contract penalty claims of £40m to £50m for delay in the contract, but much higher claims if the programme was stopped.

It was reported to the Prime Minister (Ted Heath) on the 25 January 1971 that the RB211 project and the company itself were at serious risk, and that further intervention by the government was necessary in order to protect defence interests. On the 26 January the Rolls Royce Board confirmed that the launching costs had risen by a further £24m to £159m and were likely to rise further to £180m, and the production loss had risen to £90m from £45m. As a result, a further £110m cash flow would be required; a £50m increase on the September 1970 figure. It was concluded that the RB211 could not be completed within the resources available to the company, and that the company had little option but to stop the project.

On 4 February 1971 the Rolls Royce Board announced that it was unable to fulfil the RB211 contract with Lockheed, and had placed Rolls Royce in the hands of the Official Receiver. The following reasons were given:

- the time limits specified in the Lockheed contract would have to be overrun if Rolls Royce was to meet both the technical specification and the minimum performance requirements, resulting in Lockheed invoking the severe penalty clauses written into the contract
- the increased launching aid agreed with the government and the banks in November 1970 had still not been released because of the length of time that Cooper Brothers had taken to compile its report
- the earlier estimates of losses on the production of the RB211 were expected to be too low owing to the nature of the fixed price contract.

The net result, according to Aviation Week and Space Technology (1971), was that the liabilities of the company exceeded its tangible assets, and would be so whether it chose to continue or to terminate the contract. Either way, Rolls Royce would be liable for a £300m penalty.

8.1.7 The Rescue of Rolls Royce and the RB211 Project

On the 5 February 1971, the UK Prime Minister advised the US President and the US Secretary for Defense of the Rolls Royce situation and explained the UK's legal position, and the implications for both Rolls Royce and Lockheed; both companies were major defence suppliers. In the UK the implications of the Rolls Royce demise were widespread in terms of jobs, the survivability of associated industries, and defence; National pride had also taken a severe dent. Such was the importance of the situation that the Prime Minister appointed the Secretary of State for Defence to co-ordinate all of the activities.

The government needed time to investigate with all of the interested parties the possibility of negotiating a fair contract for the RB211 engine. As a consequence the Official Receiver was asked to maintain work on the RB211 for a limited period with the government indemnifying the necessary expenditure. In the meantime, the government initiated legislation through Parliament that would enable it to purchase Rolls Royce. Purchase of Rolls Royce's gas turbine business was completed by April 1971; Rolls Royce's car business was sold off privately.

Following the appointment of the Receiver the government appointed three eminent engineers to undertake a further project review in order to ascertain what resources were needed to complete the project. Their report of the 18 February 1971 concluded that the remaining technical problems could be overcome, with a 6 month slip in the programme (ie, broadly in line with Stanley Hooker's report). They estimated that over and above the £100m launch costs already incurred, a further £120m would be needed; this figure included a provision for contingency. Furthermore, production losses would amount to £80m.

Lockheed engineers studied the technical and financial forecasts and were of the opinion that the government estimates were too high. They stated that in their view the remaining development expenditure need not exceed £60m, and that insufficient account had been taken of the likely profit from future sales of spares. This diversity of opinion illustrated the reasons why Rolls Royce found itself in such a difficult position since different teams of well qualified engineers were still coming up with vastly differing estimates even when there was a large amount of information known – much more than would have been known during the project definition. As will be shown later, the complexity of the project was the major cause of the failure.

Lockheed was asked by the UK government to back its judgement,; the latter would be prepared to provide the additional £60m, but if this proved to be insufficient Lockheed would be asked to provide the extra funds required. Furthermore, a joint company owned 50/50 by Rolls Royce(71) and Lockheed would be set up to manage of the RB211 project. The two companies would therefore share in the profit or loss of the engine. Moreover, the price of each engine would be increased by an average of £150,000. However, in order to make this proposal work, penalty clauses under the original contract would be waived, and mutual warranties arranged whereby each party could be assured that the other would complete its share of the project.

Lockheed advised that it would be unable to obtain the financial backing necessary for it to be able to participate in the RB211 programme as suggested by the UK government, but would be willing to waive the penalties for a delay of up to 6 months, and to accept an increase of £40,000 per engine. The government was thus faced with stark options of financing the whole of the remaining development or cancelling the project. Provided that it could get assurances on the future of the TriStar, it decided to continue with the project.

On the 10 May 1971, it was announced in Parliament that the government would finance Rolls Royce (71) in the development and production of the engine, and to enable it to maintain support facilities throughout the life of the RB211 engine. For its part, Lockheed agreed to pay an additional £50m for the 555 engines (the equivalent of £90,000 per engine), and to annul the penalties under the old contract for delay in the delivery of the engine. For its part, the US Administration agreed to ask the US Congress to guarantee up to $250m of additional credits for Lockheed in order to assure the continuity of the TriStar project.

On the 11 May 1971 Rolls Royce (71) and Lockheed signed a new contract for the RB211 under English law. On the 23 May Rolls Royce (71) took over from the Receiver, and on the 9 September the US Congress agreed the additional credits for Lockheed. On the 14 September the RB211 project was given the final go ahead by the UK government.

For the 14 September decision, Rolls Royce (71) prepared a full re-estimate of the remaining finance required for its RB211 commitment. In short, the company would require £125m to complete launching, and it expected to make a loss of up to £45m on producing 555 engines, after allowing for the £50m price increase agreed with Lockheed and the airlines. Thus, the total estimated cost to the government would be £170m. The government had already invested £47m and the banks £18m, and therefore the RB211 engine project was to cost £235m as opposed to the original proposal of £65m – a 3.6 fold increase.

8.1.8 Where Did the RB211 Project Begin to Go Wrong

A good starting point for this analysis is the Official Investigation Report undertaken by inspectors appointed under the Companies Act by the Department of Trade and Industry. The inspectors noted that the company had skilled and experienced engineers and could call on outside help of the highest quality. Its banks and the government had confidence in it and its reputation was second to none. Yet one product caused its collapse because the size, complexity, cost and schedule had been seriously underestimated. Once the contract had been signed it was found that the project management could not deliver the engine to time, to budget, and to requirement. The RB211's project definition had singularly failed to identify the problems that were ahead, and the project team, based on its experience of the Rolls Royce Spey, had believed that it could deliver the engine within a £65m budget.

It should have been understood during the definition phase that the size and technical complexity of the engine introduced a significant risk that should have been considered, not only when setting the price and timescale, but also when negotiating the terms and conditions of the contract. Rolls Royce, according to Edmonds (1975), was already losing money on fixed-price government contracts and, although a clause was incorporated into the Lockheed contract to allow for inflation in material and labour costs, this was based on an engine price that was already too low. The contract negotiators must have had confidence in the original price quoted for the engine as, surely, they would not otherwise have agreed to such harsh penalty clauses. Edmonds (1975) argues at length that both the government and Rolls Royce senior management must have wondered why the price should be so low when both the technical and marketing departments of Rolls Royce were expounding the engine's performance superiority.

Initially, Rolls Royce priced the RB211 at some $100,000 less than either GE or Pratt. A short time later, for some extraordinary reason, it reduced the price of each engine by a further $50,000. This low price was all the more surprising since the competitor engines from both GE and Pratt had significant flying hours.

Rolls Royce's belief in its own technical superiority seems to have affected its overall attitude towards the contract. It appears that the project definition singularly failed to inject commercial reality into the project. Edmonds (1975) commented that too many design engineers and scientists as opposed to market facing commercial managers were in influential positions. Had an investigation been undertaken into the RB211 project, it would have found good reason to conclude that the project would fail within a short space of time (Edmonds, 1975). The Command Paper (1975) also identified that such an investigation would have identified that the company would fail – no company would enter into a contract where the cost of development of a product, or the penalty clauses, exceeded the tangible assets of the company.

It is therefore possible to state that a comprehensive project definition would have set the project up for success. However, would Rolls Royce and the government have continued with the project had both known that the launch costs were in the order of £235m? To have recouped this order of launch cost, the price for each engine unit would have been in the order of £1m (definitely not competitive with GE or Pratt).

However, if Rolls Royce had not taken the decision to enter the US commercial market at that stage, it would probably not have been viable as a company and possibly it would have been absorbed by either GE or Pratt, with all of the associated political fall-out. Large projects of this type will almost always have a political influence, so a project definition must consider this when evaluating a commercial position.

8.2 RESEARCH ANALYSIS

The basic research material used for the background to the case study was augmented for the full research analysis by the internal Rolls Royce project definition study for the RB211 (called the Initial Concept Study, 1967) and early working papers from the Concept Demonstration (1967 and 1968). Interviews were undertaken with Mr C Webber (1994), Head of Engine Audit at Rolls Royce (formally a development engineer on the RB211), and Mr R Turner (1994) formally a senior project engineer on the RB211 (now retired).

8.2.1 MM Model – Containing Framework

Analysis of the RB211 against the MM Model's Containing Framework is provided at Exhibit 8.2.1.

Problem Definition	The problem for Rolls Royce was defined and clearly understood in its business strategy; in order to survive it needed to penetrate the US commercial aircraft engine market for the new medium-haul airbus because the newly enlarged company had too much capacity.
Business Analysis	From working papers it was clear that Rolls Royce undertook considerable business analysis. It correctly assessed that the only opportunity for "breakout" was the Lockheed CL1011, but at the same time kept its options open for the A300. What it did not assess correctly was the threat posed by GE's CF6 -50; in the event it was this engine that played a large part in the failure.
Objectives Analysis	Objectives for the new engine developments were set, but these did not reflect the threat posed by the new GE CF6-50 engine and therefore performance planned for the initial RB211 was flawed from the outset.
Operational Requirements and Candidate Generation	The original requirement for 33,000lb thrust had been uprated to 42,000lbs thrust during the PD without all the necessary re-assessment being undertaken. Also poor market analysis by Lockheed had failed to identify the real threat from the long-range version of the DC10 using the GE CF6-50. As part of candidate generation, RR failed to design an initial WSOI and therefore had no idea of the system's true interfaces.
R&D/Technical Barriers	The technical barriers to entry into the HBPR engine market were well understood, but RR underestimated the R&D required to produce the RB211 with its novel 3-spool configuration and hyfil compressor blades. RR based its R&D assessment on the RR Spey engine which used standard technologies; thus leaving the risk assessment exposed.
Constraints	RR seriously misread the constraints on producing the RB211 in the required timeframe. It was concurrently developing the RB207 HBPR (50,000lbs thrust) for the Airbus A300 but available engine R&D and design effort were insufficient for major concurrent developments. Although this shortfall was known it was ignored; "only good news was welcome news".
Scenarios and Likelihood	The scenarios for bringing the engine into service were well modelled and the new engine's operational environment was fully understood and well documented.
Systems Worth	The systems worth assessment was flawed as at this stage it should have acknowledged the value of the engine to RR's survival. The issue was that the economic price of the engine was either not known or the true cost was hidden from the directors of the company, and that the UK government expected (probably through ignorance) the engine to be commercially viable; ie, not underpinned by public money.

Exhibit 8.2.1 – Analysis Against the Containing Framework

Although Rolls Royce appeared to undertake all of the necessary work called for by the Containing Framework, albeit there was considerable underestimation in several important areas, none of the processes involved were integrated and hence much of the work was stand alone; ie, it did not benefit from the whole picture emerging to show inconsistencies and inaccuracies. The investment appraisal that was undertaken had insufficient information from the project definition to make a valid business decision.

8.2.2 MM Model Integrated System Design for the Product

Analysis of the RB211 against the MM Model's Integrated System Design for the Product is provided at Exhibit 8.2.2.

Integrating System Design	The SOI was concerned with the engine, the engine management system, and the aircraft environment. The SOI was well understood and documented. What was not understood was the WSOI and the impact that some interfaces would have on the development process; including schedule urgency, lagging R&D, market forces for a more powerful engine, concurrency with the RB207 and the complexity.
Product Design	The performance design, reliability design, support design and the operational scenarios were all undertaken, but the starting point was based on the premise that the RB211 was an evolution of the Spey engine – itself a development of the earlier Conway engine. This false starting point led to the underestimation of the size and complexity of the development task. This underestimation had a knock-on effect through the project definition thus invalidating its findings.
Product Modelling	Rolls Royce employed advanced modelling techniques and was well able to employ them effectively. The problem was that its estimation techniques could not cope with fixed-price projects.
Cost Modelling	The capital cost modelling had seriously underestimated the cost of the overall development programme; ie, £65.5 million as opposed to the eventual outturn cost of £235 million. This underestimation was a direct result of poor project estimating and the failure to properly assess the rework required for a high technology development. Rolls Royce had based its previous engine development estimations on small stepwise evolutions; the RB211 was a revolutionary step forward. The errors from the capital cost model were reflected in the lifecycle costs and hence downstream decisions were based on erroneous data.
Trade-off Analysis	Rolls Royce's processes for trade-off analysis were sound. The problem was that the inputs to the analysis were flawed; although it must be said that the trade-off between the various engineering options appeared to be effective.
Cost Effectiveness Analysis	The cost effectiveness analysis should have shown that Rolls Royce should not have contracted to build this engine for the offered price without greater government financial backing; the RB211 would then have been a political decision.

Exhibit 8.2.2 – Analysis Against the Model's Integrated System Design for the Product

Rolls Royce's project definition processes for product design were both comprehensive and logically structured. The weakness was in the analysis data being provided and the misapprehension that the company was capable of any engine development in unrealistic timescales because it had the "best" engineers. The root of the RB211's problems can be traced to a poor understanding of the commercial situation; Rolls Royce appears not to have had an approach that linked a commercial assessment with a design assessment. The Containing Framework of the MM Model specifically addresses the commercial aspects and if used it would have surfaced these issues.

It should be noted that all of Rolls Royce's defence development contracts were totally government financed and there was hitherto substantial government launching aid for "promising" civil aeroengines. The problem was that Rolls Royce did not have mature commercial assessment processes and the company was predominantly design driven; ie, it had few market facing managers who had influence on the company. By way of illustration, commercially aware companies would not enter into a contract where the cost of product development, or indeed the contractual penalty clauses, exceeded the tangible assets of the company.

A fixed price development of this nature should have raised warning flags during the business analysis process (in threat analysis) identifying that a project failure would be so devastating that the company itself was at risk and objectives set accordingly. Hence the design processes would have been undertaken to satisfy these objectives. This provides a clear indication as to why an integrated project definition model such as the MM Model is necessary.

8.2.3 MM Model Integrated System Design for Project Management

Analysis of the RB211 against the MM Model's Integrated System Design for Project Management is provided at Exhibit 8.2.1. The approach to managing engine projects at Rolls Royce was to form a project team, designers and project staff, dedicated to the engine in question. The team would remain together until the end of Concept Realisation when the development moved to full production. The project definition was premised on this organisational approach remaining in force throughout. The change to a project matrix structure deprived the project of some of its dedicated design staff and this had the effect of slowing development and increasing the rework cycle times. Thus issues were taking progressively longer to resolve with the observed detrimental effects on the project's performance.

The project definition was not revisited to ascertain the impact of such a fundamental change on the RB211 development. Working papers indicate that the organisation change occurred to satisfy the resource demands of two major projects, the RB211 and the RB207, but failed to observe that the two projects were at approximately the same point in the lifecycle and therefore had calls on the same staff at the same time. Work on the RB207 was not stopped until December 1968, ie, some 10 months after contract award for the RB211, by which time the unresolved rework was seriously affecting progress on the all important early design activities, the impact of which was not fully realised until mid-1968 when the programme reached an irrecoverable position.

Project Baseline Definition	It appears that no attempt was made to understand the project's WSOI, and hence any impact from external factors was not realised until the project became troubled; eg, political support for such an important survival project was not organised to be on-going. Furthermore, the project's objectives did not align with the business objectives; ie, company survivability versus a high quality, profitable and saleable product. Moreover, the project design reflected a typical UK government funded engine development, rather than a fixed price international project that was more than three times the size and complexity of any previous RR project. The WBS and the associated project logic network did not reflect the size and complexity of the engine development, especially the R&D required.
Project Analysis	Project plans and schedules did not reflect a high-technology project with such a significant level of required R&D. Furthermore, rework cycles were underestimated, the correct availability of skilled resource was wrongly assumed, and the concurrency with the RB207 was not allowed for. The plans were produced to reflect a commercial price for the engine rather than a derived price; hence from the outset the plans were unachievable. Project economic analysis was undertaken but with incorrect project data the output was meaningless.
Management Design	The project was assumed to be the same as other projects undertaken by RR and therefore no special management requirements were identified: the project organisation did not reflect an international high-risk project; inadequate schedule and cost control was put in place; the US contract (with its harsh penalty clauses) was accepted to win the business (business objectives) rather than to satisfy the project (project objectives); and no project interface management was identified.
Risk Analysis	Risk identification and the subsequent analysis work singularly failed to recognise, qualify, and quantify the systematic risks associated with project size, complexity, technical uncertainty, schedule duration and urgency, government and politics, and management. It was the combined effect of significant risks in each of these areas that caused the RB211 project failure and the subsequent collapse of the RR Company. An inadequate Risk Management Plan was produced, and the schedules reflected the required-by date not the achievable date.
Integrated Management Design	A management plan was produced but it only addressed organisation, control and reporting, and authority levels. An integrated management plan called for by the MM Model was not produced.

Exhibit 8.2.3 – Analysis Against the Model's Integrated System Design for Project Management

Project management design for the RB211 engine concentrated on developing schedules, cost and resource plans for Concept Development. Estimating techniques used historic data typically used for a stepwise development rather than a fundamentally new concept. There appears to have been no attempt to incorporate enough contingency to cope with risks arising from project size, complexity, technical uncertainty, schedule duration and urgency, government and politics, and management. However, some contingent measures were included to address risks associated with the 3-spool layout and the hyfil blades; basically Rolls Royce considered that the engine core was a stepwise development of the R-R Spey.

The project organisation reflected past development projects not a project of the size and nature of the RB211. The RB211 would have benefited from the integrated project management design called for by the MM Model as most of the weak areas observed in this review would have been highlighted effectively (as shown at the exhibits above). There was no evidence found that Rolls Royce employed many of the available systems tools to assist with the necessary analysis tasks; at that time these tools would have been hard systems tools covered by "simple unitary" in Flood and Jackson's terminology.

8.3 SUMMARY OF THE IMPORTANT POINTS EMERGING FROM CHAPTER 8

The Rolls Royce RB211 case study proved useful for the development of the MM Model in that it was exercised by a project that experienced all of the classic systematic problems described by Morris and Hough (1987). An analysis of the project using the MM Model shows that had a systems-based approach (eg, classical systems engineering) to project definition been used the symptoms of the systematic problems experienced could have been identified during the project definition and addressed accordingly. The Rolls Royce approach to project definition concentrated on project sizing using traditional methods and a limited project analysis which proved inadequate for the size and nature of the RB211 project.

The RB211 project uncovered significant shortcomings and weaknesses within the MM Model associated with where Risk Analysis should be undertaken and how M'Pherson's Containing Framework should interact with the Integrated System Design for Project management. The former issue caused the Risk Analysis to be positioned after Management Design in order for a risk assessment to be undertaken on the whole project design. The latter issue caused the enhancement of the Baseline Analysis to ensure that a project's constitution was fully understood prior to designing the project. An understanding of a project's constitution is essential for highly complex projects that involve international participation.

CHAPTER 9: CONCLUSIONS

9.1 OVERVIEW TO THE RESEARCH

Project management as a formal discipline was introduced as a result of the Atlas space and Polaris nuclear submarine programmes, although project management as an informal technique was first recorded in ancient Egyptian literature on temple building programmes at Luxor; originally Thebes or Tapet (West, 1989). Numerous other examples of the use of project management techniques have been recorded through the centuries particularly throughout the 19th century. Despite the fact that project management has matured in developmental terms over the past 30 years, the performance of major projects has continued to disappoint owners, sponsors, project managers and the like, with some writers arguing that the performance on major projects overall has deteriorated as undertakings have grown in complexity.

Substantial research into project performance has acknowledged that the application of project management, although weak on many projects, was not the primary cause of poor performance, but rather the occurrence of systematic problems associated with project size, complexity, technical uncertainty, schedule duration and urgency, physical and social environment, and government and politics. Furthermore, poorly conducted project definitions, where these systematic problems should have first be addressed, were considered to be the root of the poor performance. Systems practitioners have advocated that systems methods and techniques, both soft and hard, should be employed during the definition stage of the project lifecycle in order to address potential systematic problems and hence improve overall performance.

This thesis has combined Morris' project management model for defining projects for success with M'Pherson's systems engineering model for systems design, and augmented the result with other related business, project and systems methods and techniques to formulate the MM Model for Project Definition. A reader's quick guide to the development of the MM Model is presented below:

- the Morris Model is described at Section 2.5 and is shown in diagrammatic form at Exhibit 2.5.1, the M'Pherson Model is described at Section 3.4 and shown in diagrammatic form at Exhibit 3.4.1
- appropriate systems tools and techniques were selected using Flood and Jackson's System of System Methodologies (see Sub-Section 3.5.2 and Exhibits 3.5.4 and 3.5.5)
- the relationship between projects and business was defined using Pike's Project Approval Framework. This framework is described at Sub-Section 4.2.1 and shown in diagrammatic form at Exhibit 4.2.1

- a systems analysis approach was used to formulate the MM Model as shown at Exhibit 5.1.1
- the MM Model's requirements are specified at Appendix 10 under the headings of Project Size, Complexity, Technical Uncertainty, Schedule Duration, Schedule Urgency, Physical and Social Environment, Government and Politics, and Management
- the concept for developing the MM Model is described by Sub-Section 5.2.6 'Harmonisation of the Morris and M'Pherson Models'
- the incorporation of the project management design process into the MM Model is described by Sub-Section 5.2.8 and is shown in diagrammatic form at Exhibit 5.2.10
- the development of a tool kit for the MM Model is described by Section 5.4 and the tools within the kit are identified at Exhibits 5.4.3, 5.4.4 and 5.4.5
- the detailed MM Model is shown in diagrammatic form at Appendix 12 which includes MM Model Framework, the Integrated System Design for the Product and the Integrated System for Project Management.

The MM Model was tested firstly against a comprehensive compendium of project success criteria in order to validate it against important published research on project success and failure. The Compendium was specially prepared for this research by combining other authors' findings and enhancing them using the results of work undertaken in this research. Secondly, the MM Model was tested against three case studies; British Rail's Advanced Passenger Train (APT), Thames Water's London Water Ring Main, and Rolls Royce's RB211 Aeroengine in order to create real project test environments with real systematic problems.

The three studies were specifically selected for their combined ability to exercise all elements of the MM Model. The Model exposed strengths and weaknesses within the test projects, but at the same time the APT and the RB211 projects exposed deficiencies in the MM Model that caused change to its structure.

The model applies the systems approach, through a structured sequence of processes, to the definition of a major project for successful implementation in terms of a suitable project design, a required implementation specification, and an implementation plan. Furthermore, the model's outputs will form a major element of the business case for project approval. Moreover, for tender submission the model may be used to prepare a detailed response where the submitted cost, schedule and design reflects reality.

This concluding chapter now addresses the achievement of the research against the stated objectives (Section 9.2), the contribution to knowledge (Section 9.3) and future research work needed (Section 9.4).

9.2 ACHIEVEMENT OF OBJECTIVES

Achievement against each of this researches five primary objectives is presented below under appropriate headings. In each case, the objective being addressed is repeated at the outset for clarity.

9.2.1 Achievement Against Objective 1

To understand the foundation and nature of major projects, to develop from various published works a compendium of project success criteria, and to introduce Morris and Hough's Research Model for Preconditions for Project Success (to be called the Morris Model).

An investigation was undertaken into the foundation and nature of major projects by establishing the processes used and the management demands and challenges that emerged (Sections 2.2 and 2.3). This was achieved by researching a significant number of independent study reports and national audit reports into major project success and failure. The reports cover between them some 3500 major projects undertaken world-wide between 1960 and 1995 and therefore represents a comprehensive survey of project issues experienced.

This thesis concludes (Section 2.3.4). that problems experienced were systematic in nature rather than directly attributable to inadequate project management, and that these systematic problems can be described under the headings of project size, complexity, technical uncertainty, schedule duration and urgency, physical and social environment, and government and politics. Furthermore, this thesis confirms the findings of other published work by demonstrating that the root cause of these systematic problems can be traced to poorly conducted project definitions (Section 2.3.4).

From the independent published study reports and national audit reports researched, particularly those published by Baker et al (1988) and Morris and Hough (1986), it was possible to compile an initial compendium of project success criteria under the headings of project size, complexity, technical uncertainty, schedule duration and urgency, physical and social environment, and government and politics; ie, to draw the success criteria under the systematic problem areas (Section 2.4). Through further analysis of the study material it was also possible to add further success criteria under the new group heading of "management". The compendium was enhanced still further with information derived from some 40 independent major project audit reports produced by the PA Consulting Group. These audits were undertaken between 1988 and 1995 and hence represent an up-to-date and rich source of data. Various other published research findings on project success criteria were reviewed as part of the overall research undertaken and the results used to confirm or further enhance the work, thus the Compendium presented in this thesis is considered to be the most comprehensive currently available.

The Morris and Hough research model of Preconditions for Project Success (the Morris Model) was introduced in preparation for the formulation of the MM Model Section 2.5). In a discussion with Dr P Morris (1992) it was agreed that the model, in its published form, was a first attempt at defining projects for success. He further confirmed that the model comprised a set of activity lists under general topic headings, and that if the model were to be developed as a template or route map for project definition, formal design processes ordered in a logical manner would need to be added. He concurred that systems methods and techniques would provide a suitable addition.

9.2.2 Achievement Against Objective 2

To understand how the application of hard and soft system methods and techniques can combine with those from project management to define a major project for success. As a part of this understanding, M'Pherson's System Design Model was introduced and described.

The development of an understanding of the application of the "systems approach" to the definition of major projects initially arose from the need to address the systematic problems that contribute to poor overall project performance (Section 3.1). A survey (Section 3.3) into the "hard system" approaches confirmed that systems engineering was the ideal starting point as it was complete and robust enough to address many of the systematic problems identified, and it was based on lifecycle processes analogous to those in the project lifecycle. M'Pherson developed a comprehensive system design model (or framework) employing systems engineering methods, supported by advanced systems analysis techniques, that suited the product design aspects of a project definition (Section 3.4). A combination M'Pherson's Model and Morris' Model provided a comprehensive solution to successful project definition.

However, it was recognised by the majority of systems practitioners that "hard systems" could not deal with the "messy" or ill-structured problems experienced by major projects, particularly those problems that occurred when agreement was necessary from diverse groups of individuals on objectives and requirements setting, and on issues arising from management and product design (Section 3.5). A survey of the many and varied "soft system" approaches discovered that Flood and Jackson had developed a "system of system methodologies" that identified system methods for solving different generic categories of hard and soft problems (Section 3.5.2). Although the system of system methodologies' concept is new and requires further development, it nevertheless provides a valuable input to the MM Model development. As part of this research, real project problems were profiled against the Flood and Jackson generic categories thus identifying specific hard and soft system approaches, for project problem types (Section 3.5.2).

Finally, against this objective a project was viewed as an "open system" and its interfaces with its environment or "wider system of interest (WSOI)" were researched.

Accordingly, systems methods and techniques for specifying and managing the WSOI were identified (Section 3.6).

In completing this element of the thesis a full understanding was achieved on how the application of "hard" and "soft system" tools and techniques could combine with those of project management to define a major project for success. Moreover, through new work emerging from systems theory and practice it was possible to identify specific tools and techniques for project problem solving, which proved directly applicable to the formulation on the MM Model.

9.2.3 Achievement Against Objective 3

To understand the decision-making activities in the project approval process in order to identify the information that must be provided from a project definition for good decision making.

To achieve this objective it was first necessary to identify a suitable project approval framework to host the MM Model (Section 4.2.1). Pike's Framework was selected as it offered the required decision processes encompassed in a well structured business system model. The framework defines clearly where a project definition stage fits into a business system, and what information flows are required between the project definition and the business system; particularly those information flows relating to the harmonisation of project objectives with overall business objectives. It was also confirmed that an organisation's adopted financial analysis approach guided the decision process, and that the approval framework dictated the pace of a project definition (Section 4.3.3). A review of various Central Government project approval procedures (Sections 4.4.1 and 4.4.2) , confirmed that the principles of Pike's Framework apply equally to public projects, including defence projects, and those projects that required a private bill or public consent (Section 4.4.3).

Selecting a financing approach to a project together with appropriate instruments for finance is a key element in the approval process (Section 4.5.1). A review of the possible approaches and associated instruments of project finance was undertaken in order to identify what information would be required from a project definition to secure finance (Sections 4.5.2 and 4.5.3). Furthermore, the financing needs of infrastructure projects, particularly those qualifying under Private Finance Initiative arrangements (eg, build-own-operate-transfer projects – BOOTs) were studied, together with the special project organisation considerations for BOOT (or derivatives) projects; eg, a separate organisation may need to be established and financed as a stand alone company (Section 4.5.4).

It was argued within this study that effective decision making would require an economic analysis of the project to be part of the project definition (Section 4.6). This research reviewed appropriate quantitative methods for project appraisal, including those methods considered suitable for BOOT projects. Furthermore, the sister subject of project risk assessment was reviewed in some detail, and a suitable approach for the MM Model identified (Section 4.7).

In addressing this objective it was possible to identify all of the important sources of business information required from a project's definition stage for good project approval decision making.

9.2.4 Achievement Against Objective 4

To combine the Morris Model, the M'Pherson Model and other methods and techniques identified in this research to formulate the MM Model, together with an associated tool kit, for major project definition.

The formulation of the MM Model followed a structured and research-based development process. The first step (Section 5.2.1)was concerned with identifying a formal objective for the MM Model; ie, "to facilitate the definition of a major project in terms of the product to be delivered, its specification, its cost, its benefits, its schedule, its risks, its financing needs etc, and the management needed to successfully deliver the specified product to time and to budget to the sponsoring organisation for operational use". The next step (Section 5.2.2) involved defining statements of requirement for the MM Model that were derived from the Compendium of Project Success Criteria. Pike's Framework provided the reference for the MM Model within a typical business system in order that a project may become part of a formal appraisal and decision process, and subsequently part of the ongoing business system for control and reporting (Section 5.2.3).

The starting point for harmonisation was to assign to each statement of requirement one or more of M'Pherson's three systems engineering perspectives; ie, organisation, systems design, and systems planning. These three perspectives view the whole project as a single system entity with the M'Pherson Model predominantly focused on perspective two and the Morris Model predominantly focused on perspectives one and three (Section 5.2.4). The assignment activity together with a comparison analysis between the M'Pherson and Morris models showed that a complete coverage of the requirement could only be achieved if the two models were considered together as neither one covered the full requirement. However, if the two models were to be harmonised to form the MM Model it would need to be achieved in an orderly and structured manner as there was a high degree of commonality in the base information required for all design processes involved, and some commonality of purpose (Section 5.2.5). Furthermore, if the MM Model was to have integrity it would need to satisfy the systems theory principles of emergence and hierarchy, and communications and control, and therefore a formal structure was essential.

The M'Pherson Model held the key to a structured harmonisation as it satisfied the systems theory principles, and it already comprised well structured processes for design based on a formal systems discipline, unlike the Morris Model which comprised action points under topic headings. If an integrated system design for project management (satisfying the Morris Model requirements) could be developed to reside as a parallel stream of work along side and co-operating with M'Pherson's integrated system design for the product (the original inner framework of M'Pherson's Model – Section 5.2.6) using M'Pherson's Model's containing framework (see Exhibit 5.2.7), then a harmonisation that satisfied both the requirement and system theory principles was possible.

Using the Morris Model's topics it was possible to identify, and compile processes, in a sequence order proposed by King and Cleland (1978), to address the project and project management designs required for a project definition (Section 5.2.8). The processes drew on the techniques described in this research. A new Integrated System design for Project Management was developed as part of this research and fully harmonised with M'Pherson's Model thus evolving it to become the MM Model. Employing the results of research by Flood and Jackson (1991) it was possible to specify a tool kit for the MM Model that identified hard and soft system tools and techniques for solving specific project problems (Section 5.4). This work, which has not been attempted before, addressed a number of observations by leading researchers calling for the use of soft systems methodologies for project problem solving.

The result being the formulation of a complete model together with a systems tool kit for defining major projects for success derived from an in-depth research into all aspects projects including why some are successful and why others are not. The MM Model appears to be the only complete system model available for project definition. Process diagrams for the whole MM Model are shown at Appendix 12; comprising the Containing Framework from M'Pherson's Model, the Integrated System Design for the Product from M'Pherson's Model, and the Integrated System Design for Project Management. The latter being a development of the Morris Model.

9.2.5 Achievement Against Objective 5

To test the MM Model against a specially developed comprehensive compendium of project success criteria, and against three case studies selected for their combined ability to exercise all elements of the model.

The MM Model was thoroughly tested against the Compendium of Project Success Criteria in order to ensure that all attributes of the Compendium were covered (Section 5.3). Full compliance with the Compendium was essential to the Model's overall integrity since the Compendium was itself derived from a significant number of research studies and reports on major projects that were either successful or had experienced systematic problems associated with project size, complexity, technical uncertainty, schedule duration, schedule urgency, physical and social environment, and government and politics. The tests involved iterating the evolving MM Model through test loops until it complied fully with the Compendium's elements. Several of the iteration loops resulted in a restructuring of the Integrated System Design for Project Management in order to integrate it effectively with the M'Pherson Model, and to ensure that the whole model had commonality of purpose.

The first real-project test for the MM Model was British Rail's Advanced Passenger Train (APT) project (Chapter 6). The project formally started in 1969 amid high expectations for a new fast rail service on the West Coast Main Line to rival the airlines' new scheduled services, and was cancelled in 1985 after failure had been accepted by the British Rail board. The test case showed quite conclusively that had a comprehensive project definition been undertaken by British Rail using the MM Model the difficulties experienced could have been foreseen and action taken accordingly. The APT project also uncovered weaknesses and shortcomings in the MM Model in the areas of project objective setting, communications design and media management, and managing project objectives that resulted in change to the MM Model.

The next real-project test for the MM Model was Thames Water's London Water Ring Main (LWRM) project (Chapter 7). The aim of the project was to improve the flexibility and efficiency of water distribution, and to reduce operating costs for London's water supplies. The project commenced in 1989 and finished in 1995, eighteen months ahead of schedule and below the anticipated budget of £250m. The MM Model showed that the project design had been excellent, an entirely suitable project management system had been implemented, and that the product design had been systematically considered. The LWRM project uncovered no weaknesses or shortcomings in the MM Model.

The final real-project test for the MM Model was Rolls Royce's RB211 Aeroengine (Chapter 8). In 1968 Rolls Royce contracted to build a new generation jet engine for the Lockheed CL1011 Tristar wide-bodied airliner. In 1971 the project caused the collapse of Rolls Royce as a company and forced the British Government to rescue the company thus saving face for the UK. The RB211 went on to become one of the most widely used high bypass jet engines in aviation history. The MM Model showed that Rolls Royce had not set-up the RB211 undertaking as a project that could deal with systematic problems; significantly, the management organisation, the control and reporting and the management of project interfaces were flawed, and technical uncertainties were not addressed until much later in the project. Furthermore, an effective risk analysis was not used for final schedule design.

However, the RB211 project uncovered shortcomings and weaknesses within the MM Model associated with where risk analysis should be undertaken and how M'Pherson's Containing Framework should interact with the Integrated System Design for Project management. The latter issue caused the enhancement of the Baseline Analysis to ensure that a project's constitution be fully understood prior to designing the project. An understanding of a project's constitution is essential for highly complex projects that involve international participation.

Comprehensive testing of the MM Model against the Compendium of Project Success Criteria, and against the 3 real-life projects has shown, after suitable enhancement to weak areas, the Model to be both robust and complete. A "Snapshot" test against a basket of other projects experiencing difficulties further shows the validity of the approach.

9.3 CONTRIBUTION TO KNOWLEDGE

Many authors and eminent researchers have identified the project definition as the most important stage in the project's lifecycle as it is during this stage that the full impact of the project is first realised in detail. The results of the project definition are used to gain both approval for the project to proceed, and the necessary commitment from senior individuals and appropriate public bodies and authorities to support the project for the duration. It has been recognised that poorly conducted project definitions have been the root cause of a great many projects that either experienced severe difficulties or eventually ended in failure. The weakness being that approaches to project definitions have been unable to address the systematic problems associated with project size, complexity, technical uncertainty, schedule duration and urgency, physical and social environment, government and politics

This research has contributed to knowledge by developing a research-based approach for improving the definition stage of major projects by harnessing systems tools and techniques within a well structured process model (the MM Model) to address the identified systematic project problems. In developing the MM Model a number subsidiary contributions to the body of knowledge were achieved:

- through a detailed analysis of published work on project success and failure it was confirmed that the vast majority of major project failures were associated with systematic problems related to project size, complexity, technical uncertainty, schedule duration and urgency, physical and social environment, and government and politics
- a Compendium of Project Success Criteria was developed from existing published work and enhanced through additional research to be probably the most comprehensive available
- through the use of Flood and Jackson's System of System Methodologies it was possible to first categorise generic project problems in accordance with Flood and Jackson's complexity matrix and hence identify the type of systems tools and techniques (both hard and soft) for solving these problems. This element of the research responded to the call from a number of authors for systems practitioners to employ systems science to solve systematic project problems
- through the use of Pike's Business System Model it was possible develop the MM Model in a manner that would suffice for all major project types including those undertaken directly by government. The assertion was confirmed by researching the various approaches employed by central government organisations and agencies to project investment appraisal and approval.

The MM Model, being part of a formal business system, will enable an organisation to determine comprehensively and more effectively the nature of a project together with all necessary information on which an investment appraisal can be founded. Based on a wide literature search it is believed that the MM Model is the only model that can define in a systematic manner the product of the project in harmony with a specific project design and the project management required to deliver the product. The MM Model completely satisfies M'Pherson's three perspectives for system engineering, Hitchins' call for the wider system of interest to be used in order to establish the project as an open system, and Morris and Hough's requirement for defining successful projects.

9.4 FUTURE WORK

9.4.1 Defining Soft Projects for Success

There is a need for further research work to understand the special needs of the so called "soft" projects as these projects have been found to have a higher failure rate than the more traditional "hard" projects, and they are notoriously difficult to manage. Soft projects for instance can be associated with major business change programmes where firms are changed in character and in organisation to meet a newly defined role or set of business objectives, or associated with social aid programmes such as the eradication of an epidemic or the relief of famine in war stricken areas in third world countries.

The scoping of such projects has proved difficult owing to little or no historic data for reference purposes, ie each project is a unique undertaking, and there is an absence of a generic lifecycle to act as a design framework. Furthermore, the setting of agreed objectives by all parties involved has proved difficult or in some cases impossible. The MM Model has been formulated as a general project definition model but with an emphasis towards hard engineering projects and will, therefore, need to be tested against a representative sample of soft projects in order to ascertain whether the model has weaknesses in dealing with these projects and enhanced accordingly.

9.4.2 Further Systems Engineering Research

There is a need for further work to develop the new IEE and IEEE systems engineering standards into a formal methodology for systems engineering; ie, to enhance systems engineering from being a theology (quoting Hitchins) to a universally recognised methodology in a scientific sense.

However, there is a more pressing need for an in-depth investigation into the successes and failures of applying systems engineering and other systems methodologies to projects in order to determine improvements achieved. This investigation would need to identify a successful project that used the IEEE systems engineering standard and then benchmark other projects against it. The objective would be to catalogue the strengths and weaknesses both in method and application in order to discover ways for improvement.

There is also a need to investigate Wymore's (1976) application of systems engineering to societal issues particularly those associated with world aid programmes. His definitive work highlighted some interesting theories that could find use in the understanding and resolution of famine relief and the supply of humanitarian aid in war-torn areas, particularly in the scoping of these programmes in the early planning days. It would appear that at present only historic data is used for scoping and little or no systematic analysis is undertaken. This research could find little development of Wymore's theories. This last suggestion for additional research would greatly enhance the work undertaken in this thesis and would be complimentary to it.

9.4.3 Project Economic Analysis

There is a need for further work to develop a formal approach to project economic analysis of BOOT infrastructure projects in third-world countries. The research will need to concentrate in two areas: firstly, how does the national economy in question support the operations phase of the BOOT project and what measurements can be used; and secondly, how can the national political system in question be measured, in risk terms, for stability over a long-term senior debt service period. Both of these areas will need to be addressed during a project definition in order for investment decisions to be made on a sound basis. Over the next 50 years many £trillion will need to be invested in third-world or developing economies and much of this money will be provided through BOOT arrangements. Providers of senior and mezzanine finance are searching for a more systematic approach to project assessment during the definition stage. An example being a telecommunications infrastructure required for a Pacific Rim country – the cost of which exceeds that country's GNP for one year. The MM Model will provide a first approach to the scoping of the problem but considerable additional work is required.

9.4.4 Using Soft System Methods for Designing and Managing Projects

A clear area for further research is in the use of specific soft system methodologies for solving project problems; particularly for formal project design when related to the wider system of interest and the subsequent project management organisation design (ie, M'Pherson's first and third systems engineering perspectives), and for supporting objective setting. The research will need to be practical and based on a wide range of real-world case studies. The aim will be to identify a specific and significant difficult project problem areas such as the formulation and specification of the WSOI and then to firstly test a range of soft systems tools to address the problem, and secondly test the tool set in a real-world setting. Designing and conducting the tests will in itself be difficult as the researcher may encounter resistance to change and conflict within the project team, and time constraints as the definition will run against the clock. The output from the research will be valuable in two ways; it will surface any difficulties experienced surrounding the use of such models by staff employed by organisations, and it will demonstrate to organisations that such models, through practical application, can tackle ill-structured systematic problems associated with large projects.

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APPENDIX 1

PROBLEMS ENCOUNTERED ON MAJOR PROJECTS

Source	**Projects Studied**	**Problems Encountered**
Canaday, 1980	35 US Nuclear Power Plan	50 – 400% Cost Overruns • underestimation of technical difficulties • increased safety requirements • contractual arrangements • inflation • interest charges • management and staff difficulties
Edmonds, 1975	Rolls Royce RB211 Aeroengine Study "A Case Study in this Research"	200% Cost Overrun • poor project definition • underestimation of technical difficulties • poor contractual arrangements • reliance on government backing • poor project appraisal
General Accounting Office (USA), 1993	400 Civil And Military Projects	140% cost overrun • inflation • engineering changes • underestimation of cost, schedule and complexity during initial phases • support costs • schedule changes
General Accounting Office (USA), 1988	50 Major Weapons Systems	Up to 200% cost overrun • poor or limited acquisition strategies • lack of high level management commitment • insufficient funding • poor contractor management • premature commitment to design • limited consideration to alternative designs • decision times • limited funding causing limited testing • unproven designs • unproven technology • poor or inexperienced project/programme management

Source	Projects Studied	Problems Encountered
General Accounting Office (USA), 1980	900 Civil And Military Projects	75% cost overrun • inflation • engineering changes • underestimation of cost, schedule and complexity during initial phases • poor contracting
Hatfield, 1992	30 Non-military Projects (Pre-dominantly Software Based)	100% cost overrun, 4 year schedule overrun • specification problems • decision time too long • lack of management commitment • technical problems • underestimation of cost and technical difficulties • concurrency • poor project definition • effects of outside project issues • poor project management
Myers and Devey 1984	55 US Process Plants	Up to 200% cost overrun and up to 30 months schedule overrun • poor project definition • unproven technology • underestimation of cost and schedule during initial phases • concurrency
National Audit Office, 1992	Statement on Major Defence Projects	Up to 30% Cost Overrun, 1-2 year schedule overrun • technical difficulties • software problems • poor performance • inadequate prime contractor management • decision times • inconsistent specifications • concurrency • poor project definition • poor contractual arrangements

Source	**Projects Studied**	**Problems Encountered**
National Audit Office, 1991	8 International Collaborative Defence Projects	Up to 50% Cost Overruns • resolution of configuration difficulties • impact of conflicting national approval processes • weaknesses in international industrial management • international agreement on requirement specifications • work sharing agreements • reconciliation of national procurement practices • changing economic and political conditions
National Audit Office, 1986	12 Large UK Defence Projects	30 to 120% Cost Overrun • underestimation of cost, schedule, technical complexity • poor project definitions • weak design control • optimism of contractors • poor contractual arrangements • effects of concurrency • interrupted funding
Public Accounts Committee, 1986	4 Major Defence Projects	25% Cost Overrun • unrealistic cost and schedule estimates • technical difficulties • poor project definitions
Pugh, 1985	70 UK Aerospace Projects	Cost and Schedule Overruns Normal • poor project definitions • underestimation of technical difficulties • concurrency • risks not identified • introduction of new technologies
World Bank, 1985	1000 World Bank Projects	30 – 50% Cost Overruns • underestimation of technical difficulties • complexity of projects • host country infrastructures unable to support projects • decision times • poor change management

APPENDIX 2

FACTORS THAT AFFECT FAILURE AND SUCCESS

Factors that Affect Failure

1.	Insufficient use of status / progress reports	15.	Job insecurity within the project team
2.	Use of superficial status / progress reports	16.	Lack of team spirit and sense of mission within project team
3.	Inadequate project manager administrative skills	17.	Parent organisation stable, non-dynamic, lacking strategic change
4.	Inadequate project manager human skills	18.	Poor co-ordination with parent organisation
5.	Inadequate project manager technical skills	19.	Lack of rapport with parent organisation
6.	Insufficient project manager influence	20.	New "type" of project
7.	Insufficient project manager authority	21.	Project more complex than the parent has completed previously
8.	Insufficient client influence	22.	Initial under-funding
9.	Poor co-ordination with clients	23.	Inability to freeze design early
10.	Lack of rapport with clients	24.	Inability to close-out the effort
11.	Client disinterest in budget criteria	25.	Unrealistic project schedules
12.	Lack of project ream participation in decision-making	26.	Inadequate change procedures
13.	Lack of project ream participation in major problem solving	27.	Poor relations with public officials
14.	Excessive structuring within the project team	28.	Unfavourable public option.

Factors Associated with Success

1.	Frequent feedback from the parent organisation	13.	Parent desire to build-up internal capabilities
2.	Frequent feedback from the client	14.	Project manager commitment to established schedules
3.	Judicious use of networking techniques	15.	Project manager commitment to establish budgets
4.	Availability of back-up strategies	16.	Project manager commitment to technical performance goals
5.	Organisation structure suited to the project team	17.	Client commitment to established schedules
6.	Adequate control procedures, especially for dealing with changes	18.	Client Commitment to established budget
7.	Project team participation in determining schedules and budgets	19.	Client Commitment to technical performance goals
8.	Flexible parent organisation	20.	Enthusiastic public support
9.	Parent commitment to established schedules	21.	Lack of legal encumbrances
10.	Parent enthusiasm	22.	Lack of excessive government red tape
11.	Parent commitment to established budget	23.	Minimised number of public / government agencies involved
12.	Parent commitment to established performance goals		

APPENDIX 3

MEGAPROJECTS STUDIED BY MERROW

Project Name	Location	Type
Arkansas 2	Russellville, Arkansas	Nuclear powerplan
Badak LNG Plant	Indonesia	LNG plant
Balikpapan	Kalimantan, Indonesia	Oil refinery
Bougainville Copper Mine	Papau, New Guinea	Copper mine
Carter Creek Plant	Carter Creek, Wyoming	Gas processing plant
Chalmette	Chalmette, Louisiana	Refinery complex
Cilicap Refinery	Central Javs	Refinery
Cooper Basin Liquids Project	NE South Australia	Hydrocarbon development
Copper smelter	Western USA	Copper smelter
Dallas/Ft. Worth Airport	Dallas/Ft. Worth, Airport	Airport
Dumai	Central Sumatra	Oil refinery
Exxon Baytown Refinery	Baytown, Texas	Residual oil
Farley	Columbia, Alabama	Nuclear powerplant
Garyville Refinery	Garyville, Louisiana	Oil refinery
Gas Pipeline	Neuquen Basin, Argentina	Pipeline
Great Canadian Oil Sands	Fort MacMurray, Alberta	Tar sands plant
Great Plains	Beulah, North Dakota	Coal gasification
Hadera Power Station	Hadera, Israel	Coal-fired power
Helms High Sierra	Fresno, California	Storage facility
Itaipu	Brazil/Paraguay	Hydroelectric project
Jari Plantation	Brazil	Pulp mill
Las Truchas	Michoacan, Mexico	Steel complex
Loop	Louisiana	Offshore oil port
Mobil Joliet Refinery	Joliet, Illinois	Oil refinery
North Ana 1	Mineral, Virginia	Nuclear powerplant
Ok Tedi Project	Papua New Guinea	Gold/copper mine
Pascagoula Residum	Pascagoula, Mississippi	Heavy-oil refinery
Pembroke FCC	Wales	Fluid cat cracker
Ponce Project	Ponce, Puerto Rico	Petrochemical plant
Prudhoe Ast Facility	Alaska	Oil processing plant
Red Deer Ethylene Plant	Red Deer, Alberta	Ethylene plant
Riyadh/King Saud University	Saudi Arabia	Petrochemical complex
Saber Refining Co	Corpus Christi, Texas	Alkylation Unit
SASOL II	Union of South Africa	Coal liquefaction
Saudi Petrochemicals	Jubail, Saudi Arabia	Petrochemical complex
Statfjord A	North Sea	Offshore platform
Surry I	Gravel Neck, Virginia	Nuclear powerplant
Syncrude Ltd, Oil Sands	Mildred Lake, Alberta	Tarsands plants
Tarbela Dam	Pakistan	Hydroelectric dam
Tennessee Eastman	Texas	Goal gasification
Texaco CPI Plant Expansion	Convent, Louisiana	Oil refinery
Trans Alaska Pipeline System	Alaska	Oil pipeline
Trailblazer Pipeline	Beatrice, Nebraska	Transportation project
Trunkline LNG	Lake Charles, Louisiana	LNG refinery
Union Oil Shale	Parachute Creek, Colorado	Oil shale plant
Word Scale Olefins	Texas Gulf Coast	Petrochemical plant
Word Scale Olefins II	Gulf Coast	Petrochemical plant
Word Scale Olefins III	Texas Gulf Coast	Petrochemical plant
Yanbu Petrochemical Complex	Yanbu, Saudi Arabia	Petrochemical complex
Yanbu Refinery	Yanbu, Saudi Arabia	Refinery

APPENDIX 4

FACTORS FOR PROJECT SUCCESS

Project Definition.
The limits of a project's viability should be evaluated on an objective basis in the light of the participants' own objectives, strategies and resources.
Unclear objectives increase the likelihood of an unsatisfactory project.
Changes in commercial, technical, cost and schedule specifications may lead to overruns and are often associated with problems of project management of performance.
Technical Factors
The amount of technical uncertainty of innovation required increases the chances of difficulties and overruns.
Problems in co-ordinating project interfaces can create technical difficulties.
Design management difficulties can cause considerable problems later in a project.
Finance and Commercial Considerations
The amount of finance required may cause difficulties in both initiating a project and keeping it on schedule, particularly if there is subsequent cost-growth.
Projects financed wit a mix of public and private sources of funds are liable to suffer from mixed financial objectives, which may cause problems.
The financial risk posed and the difficulty of forecasting final costs, the business base, fiscal changes and exchange rate changes are clear indicators of potential future problems.
Environmental, Social and Political Pressures
Severe geophysical challenges can increase the chances of overruns significantly.
Political, social, community, environmental and other "external" factors can radically impact a project and alter its chances of success.
Schedule Makers
Schedule length should be chosen so as to minimise risks of adverse political, financial and commercial changes, schedules should be phased to allow for strategic review points.
Urgent schedules create increased management pressures and can lead to problems.
Managerial and Organisational Factors
Inadequate planning will greatly increase the likelihood of project failure.
Legal agreements, contract strategy and terms and conditions fundamentally influence project structure and the roles project participants can adopt.
Organisation structure should "fit" the project and the participants and should be dynamic, changing as the needs of the project change.
The absence of effective project controls can seriously increase the chances of overruns and poor project performance.
Leadership has a strong influence on the conduct of a project and hence on its chances of success.
Human relations factors and teamwork are particularly important on projects and strongly influence project management success.
Labour relations problems can seriously disrupt project implementation.
If internal and external communications are poor, the chances of project success are reduced.
Human error or incompetence, incapacity of incapability can jeopardise project success.

APPENDIX 5

SUMMARY OF THE FINDINGS OF THE EIGHT CASE STUDIES

	Hypotheses	Channel Tunnel 1960-75	Thames Barrier	Heysham 2 and the AGR programme	Fulmar	APT	COP	Concorde	Giotto
1.	Evaluation of project viability should be objective and realistic from participants view	Very objective individual evaluation; but no "project champion" to respond to these evaluations	Managerial aspects evaluated neither in detail nor objectively	Evaluations made in depth; objectivity increased by (a) previous record (b) fixed price bidding	Contractors appeared to have problems in assessing viability	No viability study undertaken	Very objective evaluations by all parties, as project scope changed as well at outset	Viability study was really a somewhat optimistic feasibility study	
2.	Unclear objectives can mean an unsatisfactory project	Primary objective clear but inconsis-tencies and conflicts amongst secondary objectives	Conflicting objectives with Port of London led to delays	Very tight specification	Clear objectives although not all uncertainties could be resolved, thereby creating future delays	Clear objectives but their point of origin led to difficulty (lack of top management commitment)	Clearly stated, exhaustively researched but later compromised by the ICL and CODA decisions	Being broadly stated led to unsatisfactory project performance	Carefully examined and defined in detail
3.	Changes in specification can lead to management or performance problems	The introduction of a mandatory high speed rail link (in 1973) triggered the project's collapse		Heysham 2 had minimum changes; the first AGRs suffered badly from changes (concurrency)	Changes trickled down throughout project causing severe problems		Changes rigorously controlled	No changes to the basic requirement though of course thousands of design changes	A few small changes, quickly dealt with
4.	Technical uncertainty/innovation increases chances of difficulty		Technical problems caused setbacks but could have been overcome with greater experience	The first AGRs presented substantial technical uncertainties; with inexperienced consortia. Technical uncertainties in the second phase were minimised	Technical uncertainty created difficulty; innovation was low	High innovation from BR view, perhaps rather unnecessarily and dangerously so	Substantial uncertainties faced. Fallback positions adopted to cover the risks posed	Innovation high; design evolution took more effort than planned	Uncertainty minimised by using established technology and resolving outstanding uncertainties on a priority basis

	Hypotheses	Channel Tunnel 1960-75	Thames Barrier	Heysham 2 and the AGR programme	Fulmar	APT	COP	Concorde	Giotto
5.	Interface co-ordination can create difficulties			Significant during construction; very important	Co-ordination and communication of vendor information a little awkward		Very important and given much attention	Difficult both because of technology and bi-national division of work	A very large task: received considerable attention and very well done
6.	Design management difficulties can cause difficulties			Design managed as rigorously as possible	Design management difficulties did cause problems		Great effort made to create standardised design environment	The complex management structure caused design difficulties	Enormous effort put into creating absolute design control
7.	Amount of finance required may cause difficulties			Uncertainty over commitment affected pace of project in early stages			Assumed financing available for whole duration even though not literally true		
8.	Mixed public/private funding can create	Mixed funding created uncertainty contributing directly to final abandonment							
9.	Financial risk/difficulty of forecasting final costs etc indicative of problems	The perceived risks led to good cancellation terms being negotiated	Senior "owner" management was not interested in determining the financial risks; this cannot have been good for the project	Financial risk and outturn cost estimated and controlled in detail				Early forecasts were guestimates' the science of project cost estimating and control were barely appreciated and so risks went unchallenged	
10.	Geophysical challenge increase chances of overruns		River working created delays	Site conditions created complex logistics; seismic matters importance	Winter working in North Sea added around 3 months delay		Networking between the 11 areas is a challenge		Space encounter and global communications added geophysical risk

	Hypotheses	Channel Tunnel 1960-75	Thames Barrier	Heysham 2 and the AGR programme	Fulmar	APT	COP	Concorde	Giotto
11.	Political, social, community and other "external" factors affect success chances	Change in government single biggest factor affecting abandonment. Community opposition	Influences were many, complex and generally indirect, particularly political ones. Interaction with PLA and community affected design	Decisions on reactor type were very political. Heysham 2 had been relatively free of political interference. Community problems have been minimal	Politics affected Fulmar via PRT, the Varley assurances and the objection to exporting oil via Ekofisk	Support of Minister was crucial to the project's initiation and central to its later problems (and cancellations)	Politics directly influenced the choice of mainframe supplier and consequent system design	Initiated politically, affected dramatically by community reaction, maintained for political reasons – Concorde was intimately affected by all these factors	
12.	Schedule phasing chosen so to minimise risks of political, financial etc changes	Schedule was at its most vulnerable when political changes occurred			Several early reviews. Perhaps more detailed reviews prior to letting fabrication contracts would have been beneficial		Schedule was designed to minimise risk of failure and to allow strategic review		
13.	Urgent schedules can create problems		Urgency slowed progress (labour problems); urgency eased the threat of contractual sanctions		PRT and other factors led to great urgency. This clashed with technical uncertainty (concurrency) and caused problems			Urgency was removed when US SST was cancelled	The finite window (launch date) was very valuable to the mangers of the project
14.	Inadequate planning increases the likelihood of failure	Planning largely adequate, with exception of integrating British Rail	Technically excellent but possibly insufficient for contraction work	Heysham 2 benefited greatly from previous AGRs. CEGB developed a systematic project philosophy and management plan	Detailed plans prepared but uncertainties continued that caused future disruptions		A great quantity of high quality planning entered into COP		Considerable planning work resulted in accurate project estimates

	Hypotheses	Channel Tunnel 1960-75	Thames Barrier	Heysham 2 and the AGR programme	Fulmar	APT	COP	Concorde	Giotto
15.	Legal agreements and contract strategy and conditions influence structure and roles	The sponsor's legal agreement that when the project was threatened it was easier to abandon it than continue	CTH's experience demonstrated the limited threat onerous contract conditions can have in certain project situations	Firm price contracts assisted the CEGB and helped ensure realistic planning and budgeting	Owner took an active role. Contract conditions (and type) changed where and when necessary		COP was able to exert considerable leverage over its suppliers to everyone's benefit	Most manufacturers required cost plus contracts because of substantial risks	
16.	Organisation structure should fit project needs and be dynamic	British Rail not sufficiently integrated into project situations		Project orientation found to be useful	Mixture of project and functional arrangements was awkward and possibly led to management difficulties	Railways Board was both client and contractor; this caused difficulties, particularly given the division of opinion	Structure evolved to fit requirements	Organisation structure was governed by the Treaty and was bureaucratic and unwieldy	Organisation structure based on ESA's long experience was tailored to project's various requirements
17.	Absence of effective project controls increase chances of overruns and poor performance				Control difficulties experienced on several parts of the project		COP had a detailed, regular, extensive control system which contributed significantly to the project's success	Considerable difficulties experienced in project control. Government had great difficulty in getting information on the project	Very effective systems with ESA having on-line access to BAeD data
18.	Leadership has a strong influence on chances of success	Lack of champion was a major problem	Very important, at every step. More experienced mgt might have prevented initial problems becoming so serious	Very important, particularly in team work, organisational development, industrial relations and contract negotiations	Personality and qualities of project manager very important, particularly in team building and the joint venture	Leadership changed at the prototype stage. No evident qualities of leadership of the requisite quality	Outstanding top management commitment and a manager with vision and leadership	Technically brilliant, managerially lacking	With its strong leadership early difficulties might have wrecked this project

	Hypotheses	Channel Tunnel 1960-75	Thames Barrier	Heysham 2 and the AGR programme	Fulmar	APT	COP	Concorde	Giotto
19.	Teamwork is important to success	Early cultural tensions between the British and French subsided; lack of teamwork by British Rail was disastrous	Important in keeping joint venture staff working effectively	Important	Important	Had relations between the "new" researchers and the "old" engineers been better, the project might have been more successful	Important and effective. Being based in a new town contributed significantly to the project's success		Team work throughout the project as a whole was important
20.	Labour relations can disrupt project implementation		Labour militancy had a direct and dramatic impact on the project. A site agreement and tougher early management might just have helped	NAECI and the Management Group have been a great benefit	Not major	Union blacking and later strike action contributed substantially to the abandonment of APT	Not a major issue (yet)		Union problems at BAeD could have jeopardised the project had industrial relations not been closely monitored
21.	Poor communications reduce the chances of success		Curiously almost too good: OPS knew of GLC decisions sometimes before management did		Geography, contract arrangements and organisational conflicts impeded communication during engineering and procurement	Over emphasis on "standard practice" created communication problems	The Steering Committee was an important vehicle for communications. Team and union communications were good		Maximum effective communications particularly between the client and contractor. Contract terms reflected the desire for this
22.	Error incompetence, incapacity or incapability can jeopardise the project success				Examples, particularly amongst fabricators and suppliers	"Trivial" design faults and reliability finally killed the project			

APPENDIX 6

OVERVIEW TO THE SOFT SYSTEMS METHODOLOGY

Soft Systems Methodology

Soft Systems Methodology (SSM) was developed by Checkland (1971, 1981), following research into the workings of large corporations and government agencies in the UK. He observed that, although some areas of management dealing with facts that were agreed could be communicated in tangible form using hard systems methodologies (HSM), there were many other areas where problems and goals were poorly defined, participants did not agree on the way forward, and HSM was unable to support problem solving. Checkland identified a need for a methodology to address these "soft" issues.

Gabriel (1981) stated that many project managers consider the setting of and commitment to clear objectives, and enforcement of control and communication mechanisms to be the most important elements of successful project management. However, Yeo (1993) writes that many project management situations outside traditional engineering are potentially "soft, ill structured and ambiguous". A methodology was therefore required to translate the various components within a soft issue into a form that would enable the traditional HSM to be employed in managing projects.

Soft issues usually occur in 2 areas of project management; the definition stage and during periods of organisation change (ie, where the product of the project is being transferred to operational use). The issues are characterised by difficulty in identifying firm, clear objectives and courses of action, differences in perception of the situation and goals of participants. The aim of SSM is to facilitate comparison between an ideal model and the real world in dealing with a soft issue in order to stimulate focused debate regarding the deviation of the real world from the ideal. The SSM approach is a seven stage sequence as described below:

Stage 1 – Identify existence of a problem.

Stage 2 – Express the problem situation in pictorial form, conveying observed reality of the problem, including unresolved issues, conflicts and other features.

Stage 3 – Develop root definitions to describe the intended solution of the problem situation using the following 6 elements; transformation process (change which will result from problem solving activity), customers (potential beneficiaries/victims of the transformation process), actors (problem solvers), owners (problem owners who can stop the activity), environment (constraints), weltanschauung (world view involved).

Stage 4 – Build a conceptual model using the root definitions. The conceptual model is an ideal model, based on pure logic, involving experience and insights from other systems models and relevant concepts; eg, organisational theory, psychology, critical success factors.

Stage 5 – Compare conceptual ideal model with pictorial representation of reality in the light of what is operational and politically feasible in the organisation.

Stage 6 – Conduct meaningful debate among participants focusing on the divergence of the real world model from the conceptual model. Identify changes that would be systematically desirable and culturally feasible.

Stage 7 – Agree a model which represents a crystallisation of collective wisdom from all involved in the problem situation regarding action to improve the situation.

The seven stage sequence transforms a soft, messy, ill-defined problem situation into an agreed hard model representing the action to be taken to solve the problem. The problem can, therefore, be addressed using traditional HSM.

Mintzberg (1987) suggested that "successful planning rarely, if ever, takes place in solitary contemplation; rather, the elements of strategy usually come together in the heat of battle (debate)". The advantage of using the SSM approach is that it facilitates consideration of all of the components of a soft issue and involves all participants in that dealing with the issue.

Disadvantages of SSM

There are seven main criticisms of the SSM:

- unable to deal with radical conflict or change, since change can only be represented in terms of communication processes
- unable to uncover invisible power
- cannot explain unintended consequences
- tends to aggregate wider social issues in to the environment
- not linked to underlying organisational theory
- uncritical of existing power structures due to the managerial bias of those involved in developing the conceptual model
- fails to answer the classic problem of legitimacy and rationality; ie, government policy may be legitimate but not rational (unpopular but good for the country), or rational but not rational (unpopular but good for the country), or rational but not legitimate (popular but bad for the country).

APPENDIX 7

OVERVIEW TO OTHER SOFT METHODOLOGIES

Viable Systems Model & Diagnosis

Developed by Stafford Beer as a means of handling complex organisations the Viable Systems Model (VSM) specifies the minimum functional criteria by which a given organisation can be said to be capable of independent existence Viability results from a structured approach to organising five key management functions; implementation, co-ordination, control, intelligence and policy; and the application of recursion for hierarchical analysis. Recursion in this case explains that a viable system-in-focus is a systemic part of a less focused viable system and contains in itself viable systems.

Implementation is what the system is doing, ie a project management organisation, a manufacturing organisation, or an organisation that will receive the product of the project as an operational system. **Co-ordination** ensures that in the short term no part of the organisation is allowed to fail. The aim of **Control** is to promote the exchange of relevant information that can be used to assess how well things are going. When difficulty is achieving control occurs and the implementation is not going according to plan, intelligence is sought. **Intelligence** information details opportunities and constraints in the external environment and represents a learning function in the organisation. If information is uncovered which is of significant long-term importance it is dealt with as policy. **Policy** is also responsible for setting both the long-term goals and the organisation's identity.

VSM is used (according to Flood, 1993) where there is a consensus view among participants about what should be done. The VSM can be used either to design an organisation for scratch, or to test its design by viable system diagnosis and then redesign if necessary. There are two stages to viable system diagnosis, system identification and system diagnosis. For **System identification** a VSM is drawn up to represent a project or organisation in terms of Implementation, Co-ordination, Control Intelligence and Policy.(see example Espejo, 1989). **System diagnosis** involves asking a series of questions that will help define problems and issues. Findings can be used to formulate ideas for solutions for addressing issues and problems. For example, questions relating to project management organisations may include the following:

- how is the implemented organisation perceived to be working with its environment, what constraints have been imposed by management, and how is accountability is exercised?
- how well is the co-ordination functioning, eg what is the quality and timing of important decisions?
- what control procedures and functions are in place and how well are they functioning?
- what intelligence activities are in place and how far ahead do they consider; ie are issues and problems being identified before they impact policy or the project's go-live date?

- does the policy map out the future in terms of goals and mission, how well does policy reflect requirements for change, and how quickly will a policy change permeate its way through the organisation?

Responses to the diagnosis stage indicate how well an organisation is functioning, and what must be done to improve the situation. VSM provides a framework for diagnosis and for identifying necessary changes.

Strategic Assumption Surfacing and Testing (SAST)

According Flood (1993), SAST is most effectively used when different conceptions and opinions exist about what should be done. SAST has been designed to test competing strategies. For example, SAST helps progress situations where there are competing ideas on approach or solution. In these cases advocates of each idea are formed into groups and asked to defend their idea against the strongest attack the competitors can wage. The attacks guided by SAST focus on the assumptions being made about the correctness and value of the ideas. Differences, strengths and weaknesses are highlighted (learning and understanding). The ground is thus prepared for moving toward synthesis and/or choice of the way forward. SAST is normally regarded as having four main stages; group formation, assumption surfacing, adversarial debate, and synthesis.

Group Formation. The aim of this stage is to structure groups in order that productive operation of the three remaining stages is facilitated. As many individuals as possible who have a bearing on the idea (or design) should be brought together to form groups on the basis of one or more criteria; advocates of particular ideas, vested interests, managers from different functional areas, and managers from different organisational levels.

Assumption Surfacing. Each group should initially ensure that they have a common understanding of their preferred way forward. Assumption surfacing then helps each group to uncover and analyse the key assumptions on which its preferred idea or design rests. Three techniques assist this process. The first, customer analysis, asks each group to identify the key individuals, parties or groups on which the success or failure of their preferred idea (design or solution) would depend were it adopted. These are the people who have a "stake" in the project. The second technique is assumption specification. For the customers identified, each group then lists what assumptions it is making about each of them in believing that the preferred way forward will succeed. Each group should list all the assumptions derived from asking this question of all customers. These are the assumptions upon which the value and success of the group's preferred way forward depends. The third technique is assumption rating. This involves each group in ranking each of the assumptions it is making with respect to two criteria:

- how important is this assumption in terms of its influence on the success or failure of the project?
- how certain is the group that the assumption is justified?

The results are recorded on a chart. Those that are both important and uncertain draw particular attention because they highlight weaknesses in the project.

Adversarial debate. The groups are brought together. Each one explains clearly their preferred way forward and their results from assumption surfacing. The is done in turn. Only points of clarification are allowed at this stage. Adversarial debate between the groups then begins. One group defends their solution whilst the other(s) look for weaknesses. The roles are then reversed.

Synthesis. The aim of synthesis is to achieve a compromise on assumptions from which a way forward can be derived. In some cases synthesis may not occur but choice of solution is achieved. A list of agreed assumptions can be drawn up. If the list is sufficiently long then an implied way forward can be worked out. The assumptions on which it is based can equally usefully be tested during implementation. If no choice or synthesis can be achieved, points of disagreement are noted and the question of what research might be done to resolve those differences is discussed.

Interactive Planning (IP)

Flood (1993) comments that IP is most effectively used when different conceptions and opinions exist about what should be done. The special feature of IP is that is challenges the future that the organisation is currently in. It leads participants to consider ideal futures that in principle the organisation could move toward as perhaps a result of introducing the project.. It can help in mission and objective setting, leading the participants to be creative and diversify their thinking about what is possible. A full-blown IP also tackles things like means planning, resource planning, and implementation and control. IP has five phases; formulating the mess, ends planning, means planning, resource planning, and design of implementation and control:

- **Formulating the mess**. Initially, issues, prospects, threats and opportunities facing the project are highlighted
- **Ends planning** concerns specifying the ends to be pursued in terms of ideals, objectives and goals. The process beings with "ideal design". An idealised design is a design which the participants would implement if they were free to do so, and is achieved considering through three steps; selecting a mission, specifying desired properties of the design, and designing the project
- **Mission setting** is achieved by specifying mandatory and desired properties which all participants agree should be met by any project. Designing the system means setting out how all the specified properties can be obtained. This analysis should be passed through twice; the first pass should assume no change in the "wider system". The second pass should assume there are no constraints except that the system must be technically and operationally viable

- **Means planning** looks to close the gap between the future without change and the future with an idealised design. The project must be set up to close this gap where possible

- **Resource planning**; four types of resource should be taken into account:
  - inputs – materials, supplies, energy and service
  - facilities and equipment – capital investments
  - personnel
  - money.

  For each type of resource, questions have to be asked in relation to the chosen means. For example, it must be determined how much of each resource is required, when it will be required, and how it can be obtained if it is not already held.

- **Design of Implementation and Control**. The final phase of IP concerns itself with seeing that all the decisions made hitherto are carried out. "Who is to do what, when and how?", is decided. Implementation is achieved and continually monitored to ensure that plans are being realised and that desired results of project are being achieved.

Critical Systems Heuristics (CSH)

Flood (1993) claimed that CSH was most effective when agreement about what should be done could not be reached and one party brings its resources to bear to get its own way. CSH aims to reveal whole system judgements, or presuppositions, entering into social systems designs. It is, therefore, highly relevant to project management especially for large capital or infrastructure projects where disagreement is jeopardising the project. What CSH attempts to do is to explore the political dimension of projects to reveal their rationality and whose interests are being served by them. CSH also explores what options and rationalities ought to be considered.

The method of CSH amounts to a checklist of twelve questions. The questions penetrate what assumptions lie behind the project in question, and what assumptions belong to its environment. The assumptions in effect are tested to see whose interests are being served by the project. These can then be challenged by other rationalities with their assumptions that people feel ought to exist. What is being proposed can then be compared to other options. CSH is therefore capable of providing insights as to whether the dominant party is wittingly or unwittingly exerting its strength. Ultimately, those who would have to live with the consequences of the project have a chance to validate its consequences on their lives.

Four groups are chosen for questioning; the clients of the project, the decision takers, the project managers, and those who are affected by the project but not involved in its management or design.

The twelve questions in the "is" and "ought" mode that arise are given respectively in Exhibits A7.1 and A7.2 The findings can be recorded in a format that can be analysed. Eg the "is" and "ought" answers are tabulated for each question and critical observations are then recorded.

1.	Who is the actual client of the project, ie who belongs to the group of those whose purposes (interests and values) are served, in distinction to those who do not benefit but may have to bear the costs other disadvantages?
2.	What is the actual purpose of the project as being measured not in terms of declared intentions of the involved but in terms of the actual consequences?
3.	What, judged by the project's consequences, is its built in measure of success?
4.	Who is actually the decision taker, ie. who can actually change the measure of success?
5.	What conditions of successful planning and implementation of the project are really controlled by the decision taker?
6.	What conditions are not controlled by the decision taker, ie. what represents "environment" to him?
7.	Who is actually involved as planner?
8.	Who is involved as "expert", of what kind is his expertise, what roles does he actually play?
9.	Where do the involved see the guarantee that their planning will be successful? (For example the theoretical competence of experts? In consensus among experts? In the validity of empirical data? In the relevance of mathematical models or computer simulations? In political support on the part of interest-groups? In the experience and intuition of the involved?, etc.) Can these assumed guarantors secure the project's success, or are they false guarantors?
10.	Who among the involved witnesses represents the concerns of the affect" Who is or may be affected without being involved?
11.	Are those affected given an opportunity to emancipate themselves from the experts and to take their fate into their own hands, or do the experts determine what is right for them, what quality of life means to them, etc? That is to say, are the affected used merely as means for the purposes of others, or are they also treated as "ends in themselves", as belonging to the client?
12.	What world view is actually underlying the project? Is it the world view of (some of) the involved or of (some of) the affected?

Exhibit A7.1: The Twelve Boundary Questions from CSH in the "Is" Mode

1.	Who ought to be the client (beneficiary) of the project to be designed or improved?
2.	What ought to be the purpose of the project, ie. what goal states ought the project be able to achieve so as to serve the client?
3.	What ought to be the project's measure of success (or improvement)?
4.	Who ought to be the decision taker, ie. have the power to change the project's measure of improvement?
5.	What components (resources and constraints) of the project ought to be controlled by the decision taker?
6.	What resources and conditions ought to be part of the project's environment, ie. not be controlled by the projects decision taker?
7.	Who ought to be involved as designer of the project?
8.	What kind of expertise ought to flow into the design of the project ie. who ought to be considered an expert and what should be his role?
9.	Who ought to be the guarantor of the project, ie. where ought the designer seek the guarantee that his design will be implemented and will prove successful, judged by the project's measure of success (or improvement)?
10.	Who ought to belong to the witnesses representing the concerns of the citizens that will or might be affected by the project? That is to say, who among the affected ought to get involved?
11.	To what degree and in what way ought the affected be given the chance of emancipation from the premises and promises of the involved?
12.	Upon what world views of either the involved or the affected ought the project's design be based?

Exhibit A7.2 – The Twelve Boundary Questions in the "Ought" Mode

APPENDIX 8

OVERVIEW TO SYSTEM DYNAMICS

Background

System dynamics has evolved from the application of control theory to managerial modelling problems. The approach thus allows for a model to be developed to describe the behaviour of a business or project and so allow for improved prediction of the results of management actions and policies related to the business.

Principles of System Dynamics

Non one can carry a full mental representation of a complex business process in their mind, although it is possible to comprehend the direct relationships between actions and direct reactions in the business environment. However, these mental or intuitive models are seldom complex enough to fully explain the behaviour of complex business systems, and so it is necessary to build more complex and detailed models of businesses and their behaviour. This allows the full consequences of policy and managerial decisions to be fully understood.

System dynamics provides three elements to facilitate effective planning and control; an emphasis on understanding how behaviour results from business structure and policies, a theory of behaviour, and the use of computer modelling to aid planning. Management decision making and control may thus be addressed using system dynamics in the following way:

- Identify a behaviour/business parameter that may be improved
- Identify and describe the nature of and the relationship between the factors that are deemed important to this parameter
- Develop an understanding of the relationships and behaviour:
  - Develop a simulation model
  - Compare simulated to historic business behaviour
  - Revise model structure – and repeat until satisfactory
- Design improved business policies and plans:
  - identify policy/plan to alleviate business problems
  - test proposed plans using simulation under a wide range of scenarios.

Using this technique it is possible to identify cause and effect relationships causing difficulties in projects and plan to avoid/minimise the associated risks.

The Rework Cycle

The Rework Cycle is based upon the system dynamics principles introduced above. It seeks to explain many of the difficulties that projects encounter with reference to a model of the project. It is hoped that it may be possible to develop potentially valuable tools and techniques based upon these principles.

The conventional view of project management assumes that progress depends only on the number of people applied and the productivity at which they work. Tasks are assumed complete once the planned/actual time requirements have been expended and the next task is commenced. Using terminology of Exhibit 8.1, below, tasks are assumed to pass from the group "Work to be Done", via the number and productivity of the staff and become work complete (really done).

The Rework Cycle view of project progress is substantially different and is based upon Exhibit A8.1, below.

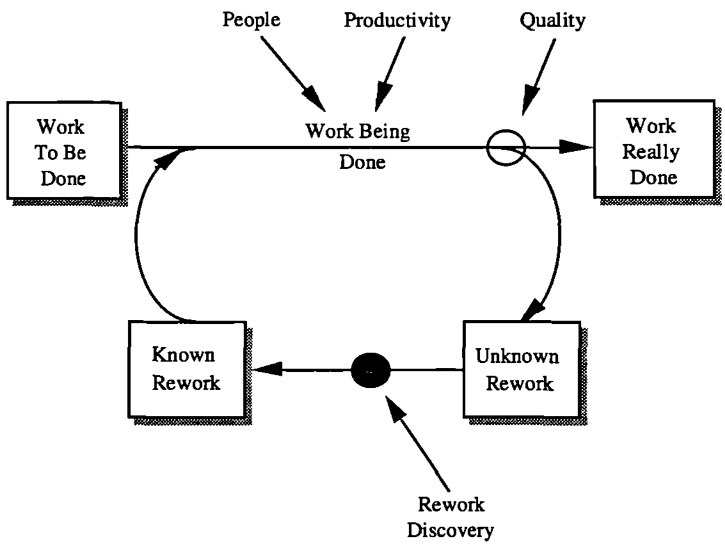


Exhibit A8.1 – The Rework Cycle

The Cycle recognises the presence of rework, that is tasks which must be redone. Quality is thus defined as the fraction of tasks that do not require rework. The element of undiscovered rework is used to describe an alternative view of how project work.

At the start of a project all work elements reside in the pool of "Work To Be Done". As the project begins and progresses, changing levels of people working at varying productivity and thus determine the pace of Work Being Done. Unlike all other programme/project management tools and systems, the Rework Cycle shows the real-world phenomenon that work is executed at varying, but usually less than perfect "Quality". Potentially ranging from 0 to 1, the value of Quality depends on many variables in the project and company. The fractional value of quality determines the proportion of the work being done that will enter the pool of Work Really Done, which will never need redoing. The rest will subsequently need some rework, but for a period of time the rework remains in the pool of Undiscovered Rework. This is work that contains as yet undetected errors, and therefore is perceived as being done. Errors are detected by downstream efforts or testing, this rework discovery may occur months or even years later, during which time dependent work has incorporated these errors. Once discovered, the known rework demands the application of resources, beyond those needed for executing the original work. Executed rework enters the flow of work being done and is subject to similar productivity and quality variations. Some of the reworked items may therefore flow through the rework cycle one or more times.

The Rework Cycle has been used in a number of major projects and has been used to predict/explain many of the difficulties projects generally experience, including:

- projects "stuck" at a perceived 90% complete
- late realisation of major cost and schedule overruns
- discovery of items requiring rework at planned completion
- difficulty is the comparison of projects performance
- uncertainty over which initiatives have lead to "best practice"

A potentially valuable application may be project turnaround, where the techniques could be used to analyse the cause of project difficulties and plan the most appropriate recovery.

APPENDIX 9

PROJECT DEFINITION FOR GOVERNMENT INFRASTRUCTURE PROJECTS

Stage 1 – Scope

Stringer identified seven key stages within the initial project definition stage.

1. General description of the project, with references to documents for details.

2. Notes on status (adopted, under study, undetermined etc) of each aspect.

3. How familiar is the industrial sector to the proponent? What is the general public acceptability of the sector?

4. How does the project relate to its supply markets (for feed stocks etc) and what effect do such relationships have on location, time-scale, finance and organisation? Are supplies secured? Have any obligations to take supplies 'been entered into? What is the range of options on the "input" side? Do they depend on the implementation of other projects or programmes? How much uncertainty is there? To what extent could change on the input side apply pressures to accelerate or delay the project or alter its scale or phasing?

5. How does the project relate to its product markets? What is the evidence of demand? What uncertainties does it contain? Are there options about the markets to be served? Are there any obligations on the proponent to supply? Do they depend on implementation of other projects or programmes? What effect could changes on the demand side have to accelerate or delay the project, or alter its scale or phasing?

6. What associated facilities (access roads; harbours; railway facilities; water supplies; mineral quarries; spoil disposal; effluent treatment; housing; social facilities) will be required permanently? Are they included in the scope of the project for which consent will be sought?

7. What associated facilities (see above list of examples) will be required for the construction period only?

8. What jobs will be created during the construction period? Permanently? What proportions and types of jobs are likely to be fillable locally?

Stage 2 – Objective/Purpose/Need

1. Does the project arise from an obligation (to meet a demand), or entirely as an investment opportunity? How does this motivation differ for the various co-sponsors?

2. What alternative formulations are possible of the "need" for a project having these general characteristics?

3. What alternatives are conceivable for meeting the need, as currently expressed?

4. Is there a stated Government policy setting out the public interest in projects of this class? How has this influenced definition of the project?

5. If there is no stated Government policy, what is the believed position (opposed, neutral, supportive at arms-length, etc)? How diverse would be the views across the political spectrum?

6. What would be the consequences of not proceeding with the project? For the proponents? For other parties? Does the proponent have a reserve project if this one fails?

7. Are there (believed to be) competing projects by other proponents?

Stage 3 – Technologies

1. Have the main technologies been chosen? What alternatives are conceivable?

2. Does the project depend on particular technologies? In what ways?

3. Do authoritative design standards exist for this application?

4. How well-established are the principal technologies to be used? What alternatives are conceivable? How much scale-up is required?

5. How far is the choice of technology influenced by the particular skills or commercial interests of project sponsors? What scope, if any, has been left for competitive design proposals?

6. Does the choice of technology require substantial imports or licence costs? Are there indigenous alternatives? Export stimulation possibilities? Could these become issues?

7. What are the grounds for confidence in innovative features? What is the fall-back position if problems arise with features still requiring development?

8. What are the answers to the above questions in regard to subsidiary technologies (eg, for effluent treatment)?

9. What provisions are necessary for refurbishment and for de-commissioning or demolition at the end of the project's useful life?

Stage 4 – Location/Alignment

1.* What are the constraints on the choice of location (or alignment in the case of a linear facility)?

2.* How closely has the site been surveyed and checked for conservation features?

3.* What methodology has been used (or is proposed) for site selection?

4.* Would specially designated areas be affected, such as:

- Sites of Special Scientific Interest (SSSIs)
- Designated Green Belt

- Areas of Outstanding Natural Beauty (AONBs)
- Environmentally Sensitive Areas (ESAs) (eg, Wetlands)?

5.* Are considerations of archaeological remains, demolition of heritage, etc potentially involved?

6. Is the project confined to areas of reduced planning controls, such as:

- Enterprise Zones
- Urban Development Corporation (UDC) areas
- Simplified Planning Zones ?

7.* Is the land needed already owned or purchasable? Will compulsory purchase be needed? Does the proponent have the necessary powers?

8.* What scope remains for re-location/re-routing? Fundamentally? At the margin? Is there scope for local negotiation on deviations.

9.* What announcements have been made (or public "signals" given) concerning the project's location and land requirements?

10.* Which Local Planning Authority Districts are affected?

11.* What are the problems of access, for construction? For Operation?

12.* What are the proposed arrangements for compensation?

13.* What local amenities are included in the proposal?

14.* What opportunities are there for removing existing eyesores, creating new wildlife habitats, and other positive improvements to the site?

Stage 5 – Scale/Size

1. What have determined the size and scale of the project? Could it conceivably be smaller, or composed of smaller units?

2. If the reason is "economies of scale", has consideration been given to the possible "diseconomies" such as:

- problems in scaling-up existing technology
- longer lead-times and hence greater uncertainty in market forecasts
- more serious consequences of disruption (accident; terrorism; breakdown)
- susceptibility to opposition
- costs of "mitigators"
- "learning curve" effects arising from replication of a larger number of smaller units

3. What provision is included for expansion? What are the constraints and limits?

Stage 6 – Time Scale

1.* Within what time bracket is the consent required?

2.* To what extent would earlier consent be useful?

3.* What would be the consequences of delayed consent?

4. What time constraints are imposed by market opportunity?

5. Is political expediency a factor?

6. What other factors apply?

7. What time will be required to develop the technology? How uncertain?

8. What is programme for detailed design and construction? What would be involved in acceleration?

9. What is to be the operational life of the project, and what happens then?

10. How does the time-scale of the project compare with the time horizons within which reasonable forecasts can be made of the key economic and market factors?

Stage 7 – Finance and Organisation

1. How far have the organisation structure and the financing been defined?

2. To what extent does further definition of the project depend on partners yet to join the project? (and vice-versa)?

3. Do joint ventures etc, originally set up to share risks and experience, impose constraints on the project definition? Have they been settled yet? If not, what is the range of options?

4. What separate "actors" make up the "proponent"? What are their individual goals and expectations from the project? To what extent are these goals conflicting? Does the need to reach compromise on these grounds thereby restrict the scope for designing the project so as to minimise consent risks?

5. What is the extent, if any, of Government involvement in the initiation, specification, financing of the project?

6.* Will Government be a partner in seeking consent (eg, in promoting a Hybrid Bill).

7. How sensitive is the return on investment to changes in development and construction cost; to additional operating costs; to delayed completion; to fluctuations in supply and product markets (including exchange rates)? Can these sensitivities be quantified?

8.* How are the consent risks perceived by the providers of finance?

APPENDIX 10

MM MODEL REQUIREMENTS

PROJECT SIZE

	Requirement	Perspectives	The MM Model	Category
1.	The size of the project must be understood from the outset and boundaries defined and maintained (see also complexity)	P1, P2, P3	Integrating system design – WSOI (ISDP) Functional model (ISDP) Project baseline analysis (ISDPM) Balancing (ISDPM)	**S-U**, C-P
2.	Good communication must be established both within the project, and between the project and all interacting organisations	P1	Project communications (ISDPM) Pikes Framework	**C-U**, S-C
3.	Logistics requirements must be fully defined and suitable suppliers identified	P1, P2	Capital cost model (ISDP) Operational cost model (ISDP) Resource planning (ISDPM)	**C-U**, S-U
4.	Financing, contracting with international participation should avoid adding management and control complexity	P1, P3	Financing options (ISDPM) Contracting and procurement (ISDPM) Control and reporting (ISDPM)	**S-U**, C-U
5.	Government support and agreements should be in place before the project commences (where appropriate)	P!	Needs analysis (CF) Project baseline analysis (ISDPM) Pikes framework	**C-U**, S-C, C-P
6.	Long and difficult projects should be implemented in phases in order to avoid political instabilities	P1, P2, P3	Balancing (ISDPM) Economic analysis (ISDPM) Functional model (ISDP)	**S-U**
7.	Minimise the number of public/government agencies involved and where possible establish single point contact and responsibility	P1.	Project organisation and culture (ISDPM)	**C-U**
8.	Establish an appropriate project management structure for the size of the project	P1	• Project organisation and culture (ISDPM) • Control and reporting (ISDPM) • Project interface management (ISDPM)	

COMPLEXITY

	Requirement	Perspectives	The MM Model	Categories
1.	Define the whole picture or system, ie the project and all of the organisations with which the project must interface, and specify the information flows and the control and monitoring needs.	P1, P2	Project baseline analysis (ISDPM) Functional model (ISDP) Control and reporting (ISDPM	**C-U**, S-P
2.	Understand fully both the dynamic and static interfaces.	P1, P2, P3	Functional model (ISDP) Project baseline analysis (ISDPM) Balancing (ISDPM) Project interface management (ISDPM) Project design (ISDPM)	**S-U**, C-U, S-P
3.	Structure the project into parts whose elements have strong relationships.	P1, P2, P3	Project design (ISDPM) Functional Model (ISDP) Balancing (ISDPM) Project economics) (ISDPM)	**S-U**, C-U
4.	Identify the controllable and uncontrollable influence factors.	P1	Project interface management (ISDPM) Control and reporting (ISDPM) Project baseline analysis (ISDPM) Risk analysis (ISDPM)	**S-U**, C-U
5.	Evolve the project through a gradual build up of specifications.	P1, P3	Project design (ISDPM Balancing (ISDPM)	**S-U**
6.	Amplify wherever possible the management, organisational, technical, contractual, legal and political aspects of a project.	P1	Integrated management plan (ISDPM) Various plans (ISDPM)	**S-U**
7.	Reflect project complexity in the risk assessment and establish suitable contingency to both the cost and schedule.	P1, P3	Risk management plan (ISDPM) Balancing (ISDPM)	**S-U**, C-U

TECHNICAL UNCERTAINTY

	Requirement	Perspectives	The MM Model	Categories
1.	Define technical uncertainties during the project's early phases.	P1, P2	State of the art (CF) Technical barriers (CF) Risk analysis (ISDPM)	S-U, C-U
2.	Establish the real need for new technology.	P2	Performance design (ISDP) Reliability design (ISDP) Functional model (ISDP) Capability model (ISDP) Cost effectiveness analysis (ISDP)	S-U
3.	Reduce these uncertainties wherever possible by adopting proven technologies.	P2	Performance design (ISDP) Reliability design (ISDP) Functional model (ISDP) Capability model (ISDP) Cost effectiveness analysis (ISDP)	S-U
4.	Reflect technical uncertainties in the risk assessment and establish suitable contingency to both the cost and schedule.	P1, P2, P3	Risk analysis (ISDPM) Risk measure options (ISDPM) Risk Management plan (ISDPM) Balancing (ISDPM)	S-U, C-U
5.	Ensure that new technologies are demonstrated before the project moves into production or implementation.	P1, P2	Technical barriers (CF) Research and development (CF) Resources and constraints (CF)	S-U
6.	Ensure that the project team has access to suitably qualified staff, or that these staff are part of the project team.	P2, P3	Resources and constraints (CF) Balancing (ISDPM) Project organisation and culture (ISDPM)	S-U, C-U

SCHEDULE DURATION

	Requirement	Perspectives	The MM Model	Categories
1.	Install formal and comprehensive planning for the whole of the project.	P3	Balancing (ISDPM) Control and reporting (ISDPM Project economics (ISDPM)	**S-U, C-U**
2.	Identify clear and substantial milestones in order to judge real progress and provide confidence in a successful outcome.	P3	Balancing (ISDPM) Project economics (ISDPM	**S-U**
3.	Ensure that the human aspects of the project team are being catered for.	P1	Project organisation and culture (ISDPM)	**C-U**
4.	Recognise the major impact that price, inflation, regulation, technical developments, government or corporate changes have on the definition of success.	P1, P2	Project economics (ISDPM) Cost effectiveness analysis (ISDP)	**S-U**
5.	Phase the project wherever possible in order to avoid unnecessary over commitment (phase in this case means a progressive build-up in the implemented project).	P1, P2, P3	Project economics (ISDPM) Balancing (ISDPM) Project design (ISDPM) Functional model (ISDP)	**S-U**

SCHEDULE URGENCY

	Requirement	Perspectives	The MM Model	Categories
1.	Take due note that schedule urgency and technical uncertainty together can be the cause of major problems.	P1, P2, P3	Balancing (ISDPM) Risk analysis ((ISDPM) Risk measure options (ISDPM) Functional model (ISDP)	**S-U**, C-U
2.	Full cognisance should be given to the possible detrimental effects of unnecessary or unplanned urgency.	P2, P3	Balancing (ISDPM) Functional model (ISDP)	**S-U**
3.	Be aware of the project times that emerge from a realistic schedule and systematically consider whether any reductions in time can be accommodated.	P2, P3	Balancing (ISDPM) Functional model (ISDP) Risk analysis (ISDPM)	**S-U**, C-U
4.	Where schedule urgency has to be accepted, then the risk assessment should reflect the possible outcomes and contingency should be identified.	P2, P3	Risk analysis (ISDPM) Risk measure options (ISDPM) Risk management plan (ISDPM) Functional model (ISDP)	**C-U**, S-U
5.	Consider economic phasing in order to get parts of the project in production faster.	P1, P2, P3	Project design (ISDPM) Balancing (ISDPM) Project economics (ISDPM) Functional model (ISDP)	**S-U**
6.	Simplify or cut functionality.	P2, P3	Functional model (ISDP) Balancing (ISDPM) Project economics (ISDPM) Objectives setting (CF)	**S-U**
7.	Ensure that formal and comprehensive planning techniques are used, possibly incorporating the techniques developed for simultaneous engineering if ordered concurrency is needed.	P3	Balancing (ISDPM)	**S-U**

PHYSICAL AND SOCIAL ENVIRONMENT

	Requirement	Perspectives	The MM Model	Categories
1.	Establish the real need for the project.	P1, P2	Needs analysis (CF) Operational requirements (CF) Project baseline analysis (ISDPM)	**S-P**, S-U
2.	Examine the cultural diversity of the area in which the project is to be sited (where appropriate).	P1	Environment study (ISDPM) Systems worth (CF)	**C-U**, S-U
3.	Consider the economic pattern of incentives and taxation.	P1	Project economics (ISDPM	**S-U**, C-U
4.	Judge whether it is appropriate to undertake the project at that time in that place.	P1	Environment study (ISDPM) Systems worth (CF) Project economics (ISDPM))	**C-U**, S-U
5.	Assess the environmental impact of the both the project and the resulting product.	P1, P2	Environment study (ISDPM) Functional model (ISDP) Systems worth (CF)	**C-U**, S-U
6.	Construct environmental and community packages that leave an area no worse off than before the project began.	P1, P2	Environment study (ISDPM) Systems worth (CF)	**C-U**, S-U

GOVERNMENT AND POLITICS

	Requirement	Perspectives	The MM Model	Categories
1.	For public sector projects and those being built under "BOOT" arrangements, ensure that there is effective sponsorship.	P1	Project organisation and culture (ISDPM) Financing options (ISDPM) Contracting and procurement (ISDPM)	C-U, S-U
2.	Recognise the short termism of governments and reflect this in the schedules and financing arrangements.	P1, P2	Functional model (ISDP) Project economics (ISDPM) Risk analysis (ISDPM) Threat analysis (CF)	S-U, C-U
3.	Recognise that both central and local governments pay attention to the fiscal, safety, and employment aspects of projects; particularly the use of labour domiciled in the country or area of origin.	P1	Project organisation and culture (ISDPM) Project economics (ISDPM) Systems worth (CF) Environment study (ISDPM)	C-U
4.	Constrain nationalistic aspirations on international projects.	P1	Needs Analysis (CF) Project baseline analysis (ISDPM) Project organisation and culture (ISDPM) Systems worth (CF) Project interfaces (ISDPM) Contracting and procurement (ISDPM) Financing options (ISDPM)	S-P, C-P
5.	Acknowledge that community factors must be considered.	P1	Project organisation and culture (ISDPM) Environment study (ISDPM)	C-U

MANAGEMENT

	Requirement	Perspectives	The MM Model	Categories
1.	Ensure that the project's goals and objectives have been defined and agreed with the sponsor and all managers responsible for the approval decision.	P1, P2	Objectives setting (CF) Objectives hierarchy (CF) Design objectives (CF) Project baseline analysis (ISDPM) Pikes framework	S-P, C-P
2.	Define an achievable scope of the project in terms of technical options and choice (to include suitable back-up strategies), schedule and cost, taking into account the project's size, complexity, technical uncertainty, schedule duration and urgency, physical and social environment, and government and politics (covering the points outlined above).	P1, P2, P3	Functional model (ISDP) Project Baseline analysis (ISDPM) Balancing (ISDPM) Project organisation and culture (ISDPM) Risk analysis (ISDPM) Environment study (ISDPM) Systems worth (CF)	S-U, S-P, C-P, C-U
3.	Assess the risks that the project may face and identify suitable contingencie	P1, P2, P3	Risk analysis (ISDPM) Risk measure options (ISDPM)) Risk management plan (ISDPM) Systems worth (CF) Functional model (ISDP)	S-U, C-U S-P, C-P
4.	Assess the project's financial requirements, paying attention to budget validity, political support, owner's or sponsor's commitment, inflation, currency fluctuations, etc.	P1	Needs Analysis (CF) Project baseline analysis (ISDPM) Balancing (ISDPM) project economics (ISDPM) Contracting and procurement Financial options (ISDPM)	S-U, C-U, S-P
5.	Define carefully the benefits that the project is expected to deliver and agree these with all beneficiaries.	P1, P2	Objectives setting (CF) Project baseline analysis (ISDPM) Balancing (ISDPM) Operational requirements (CF) Pikes framework Functional model (ISDP)	S-U, S-P, C-U C-P
6.	Assess the financing options for the project and select one that fits best for the business environment of the project.	P1	Financing options (ISDPM)	S-U

MANAGEMENT (Continued)

	Requirement	Perspectives	The MM Model	Categories
7.	Define how the project is to be managed, considering: organisation; authority levels and decision structures; issue management and escalation procedures; communications; control and reporting; change control; project interfaces; interaction with owners, sponsors, governments, pressure groups, local authorities, contractors and subcontractors.	P1, P2	Project baseline analysis (ISDPM) Governance (ISDPM) Project organisation and culture (ISDPM) Control and reporting (ISDPM) Project communication (ISDPM) Quality assurance and control (ISDPM) Transition management (ISDPM) Functional model (ISDP) Project interface management (ISDPM Integrated management plan (ISDPM)	
8.	Identify possible procurement and contracting options, selecting an approach that best fits the project organisation, financing arrangement, and risk assessment.	P1	• Contracting and procurement (ISDPM)	S-U, C-U
9.	Establish how any licensing agreements will be reached.	P1	• Project baseline analysis (ISDPM) • Functional model (ISDP)	S-U
10.	Define the project's influencing factors and establish who is responsible for controlling each one.	P1	• Project baseline analysis (ISDPM) • Project organisation and culture (ISDPM) • Project communications (ISDPM)	S-U
11.	Ensure that the project team is signed up to the achievability of the project and that the sponsor and owner(s) are fully committed to the project's success.	P1	• Project baseline analysis (ISDPM) • Project communications (ISDPM)	C-U, S-C
12.	Avoid any buy-in strategies; ie going in lean and mean to get well later on change.	P1	• Project economics (ISDPM) • Systems worth (CF)	S-U
13.	Make a coherent financially viable business case for the project.	P1, P2	• Systems worth (CF)/ Pikes framework	C-U, S-C

APPENDIX 11

TECHNICAL APPRAISAL OF THE RB211 BY STANLEY HOOKER

Technical Appraisal

The RB211 is a high bypass ratio, high-compression ratio, high temperature fan engine competitive with the Pratt & Whitney JT9D and the General Electric CF6 engines made in the USA.

The take-off thrusts at which the three engines are on offer today are: JT9D, 43,500-45,000 lb; CF6, 40,600 lb for the DC-10 and 49,500 for the A300B Airbus; RB211, 42,000 lb for the Lockheed 1011 TriStar. The specific fuel consumptions and weights of the three engines are competitive. The comparative order of basic size or air consumption is: CF6, 1.0; RB211, 1.10; JT9D, 1.20.

The RB211 is unique in that its fan, intermediate (IP) compressor and HP compressor are each driven independently by its own turbine. This arrangement allows the three components – fan, IP compressor and HP compressor – to be driven each at its own optimum speed, and thereby improves the overall aerodynamic efficiency and flexibility. In particular, the independence of the fan speed, and the ability to raise this speed, the fan being the a major thrust-producing component in the engine, allows further thrust growth as the turbine entry temperature is raised by future development.

As a typical example, the desirable speed relation between the three spools of the RB211 is, in round numbers; Fan, 3,600 rpm; IP, 6,800 rpm; HP, 10,000 rpm.

The situation in regard to the thrust of the RB211 as it existed in January 1971 vis-a-vis Lockheed was:

- A contractual obligation to produce 40,600 lb take-off thrust up to a day temperature of 84 F.
- Because of weight growth during manufacture of the prototype CL1011, and because the RB211 was itself overweight (38,441 lb for a ship set as against the original guarantee of 34,566 lb), Rolls-Royce undertook to produce a thrust of 42,000 lb up to 84 F. This proposal was discussed with Lockheed.
- Notwithstanding the weight growth of the aircraft and the engines (much larger, in fact, on the aircraft) it was the opinion of Rolls-Royce that an acceptable thrust for entry into service of the CL1011 would be 38,500 lb up to 84F. This proposal was not discussed with Lockheed. Summarising: 40,500 lb was the contractual commitment, 42,000 lb was offered, and 38,500 lb was considered acceptable by Rolls-Royce for entry into service.

For the start of the first prototype CL1011 flight programme, Rolls-Royce delivered to Lockheed five Batch 1 engines rated at 34,000 lb at a Turbine Entry Temperature (TET) of 1,167C. For the second prototype, Rolls-Royce delivered six Batch 3 engines rated at 34,200 lb at a TET of 1,202C, with a contingency or emergency rating of 36,200 lb at a TET of 1,232C. These engines flew in the second prototype on 15 February 1971.

At this stage, it was clear that the engine performance was sub-standard, in that the TET was too high for a given thrust. Modifications were, therefore, made to engine No. 100011, and on test at Derby in early February 1971 the following figures were demonstrated: 37,000 lb at 1,167C TET; 39,430 lb at 1,227C.

On another engine, a new design of HP turbine blade discharging its cooling air from the trailing edge was tested, and this improved design reduced the TET at a given thrust by 28C, or increased thrust at a given TET by 2,000 lb. It is intended to cast this type of blade by the lost-wax process, and to conduct further testing on the bench in October 1971, with a view to incorporating into production engines in mid-1972.

Following the successful improvements demonstrated on Engine No. 100011, a further change was being made to the LP nozzle guide van areas, and this is predicted to give 41,5000 lb at 1,227C. This engine will be on test on 17 February 1971. Summarising the performance results (all quoted for the test bench on a Standard Day):

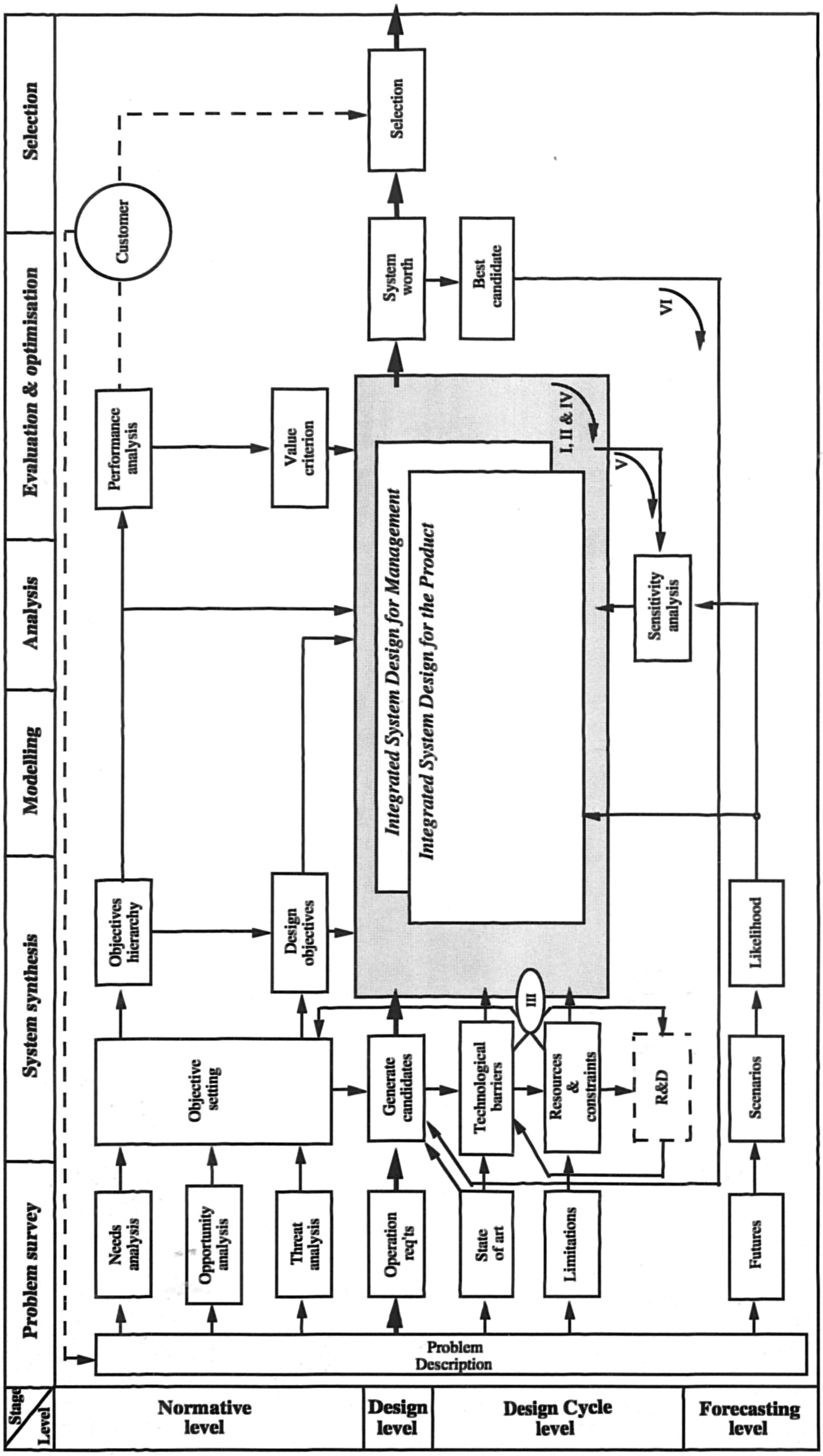
• Batch 1 Engine	34,000 lb at 1,167C
• Batch 3 Engine	34,200 lb at 1,202C
• Engine 100011	37,000 lb at 1,167C
• Engine 100011 (February 1971)	39,340 lb at 1,227C
• Engine 100011 with modified LP NVG	41,500 lb at 1,227C
• Engine 100011 with cast blades (predicted)	43,500 lb at 1,227C.

Actual thrust developed depends upon TET. It is anticipated that a TET of 1,227 $\pm$ 20C can be adequately cleared by bench running. In the future, the new cast turbine blade will not only be better aerodynamically but will be cast in a material (MARM 202) which has better high-temperature properties and will allow at least 50C increase in TET. This will increase the thrust at 1,277C to 47,000 lb on a standard day, and this figure must be regarded as the potential growth in thrust of the RB211 without major redesign.

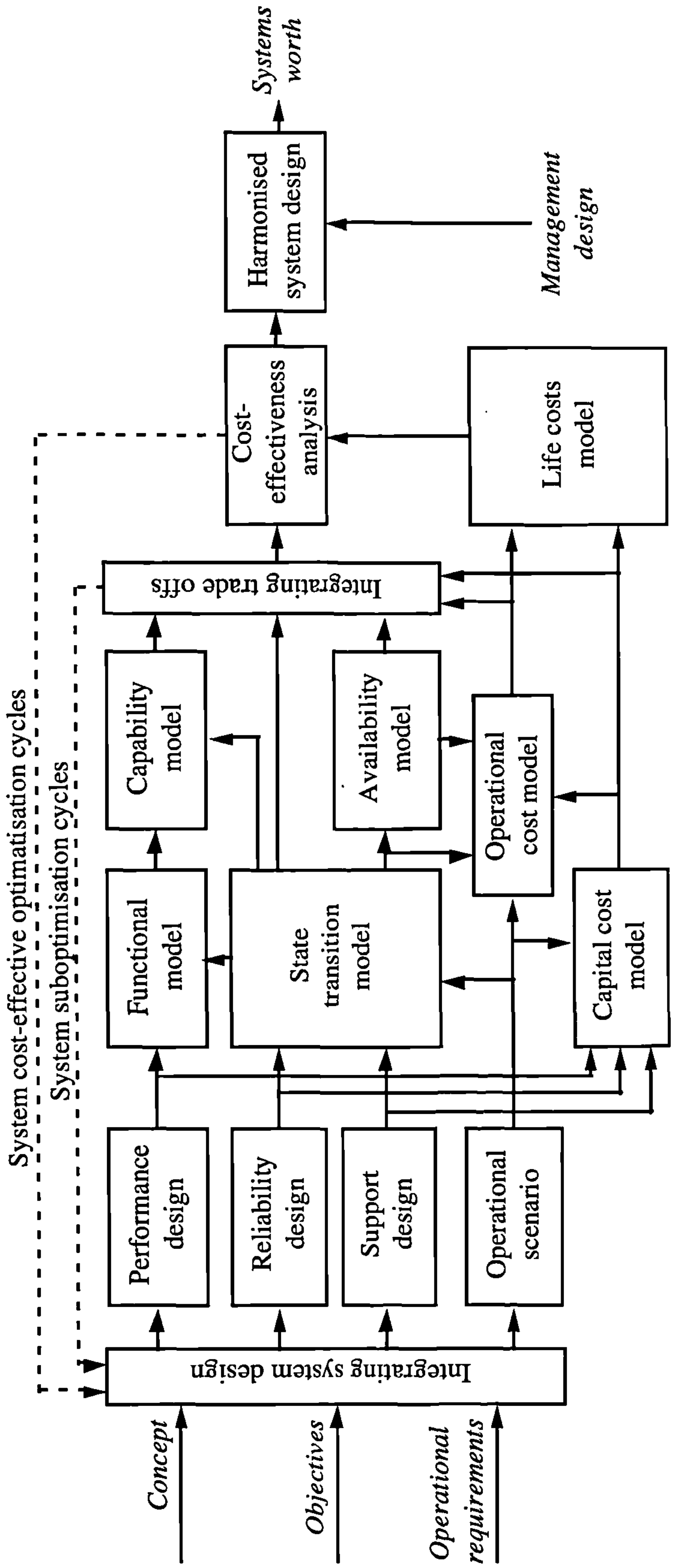
Thus the RB211 in a matter of weeks was transformed, and could promise not only to restore the missing performance but to go way beyond it.

APPENDIX 12

THE OVERALL MM MODEL



The MM Model Framwork



Integrated System Design for the Product