Evaluating the management of construction projects

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EVALUATING THE MANAGEMENT OF CONSTRUCTION PROJECTS

by

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A Doctoral Thesis submitted in partial fulfilment of the requirements for the award of Doctor of Philosophy of the Loughborough University of Technology

May 1991

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TO MY WIFE
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ABSTRACT

Current approaches to evaluating the success of construction projects are inadequate in assessing and improving the management of ongoing and future projects. This is concluded from a study of the relevant literature and of construction project management in Sri Lanka and the U.K.

The main criticisms of current practice are the ad-hoc nature of the evaluation itself, the failure to properly relate the evaluation: to the original project objectives; to contextual conditions; and to realistic targets derived from historical databases of similar projects. The absence of any such comprehensive database is a particular shortcoming in Sri Lanka.

This research work develops and tests a framework for a comprehensive construction project evaluation system that would overcome such shortcomings. The system would help an evaluator generate a specific project evaluation framework depending on the category (type) and stage of the project and the particular purpose of the evaluation. Such a framework would contain criteria of project performance (eg: related to cost, time, quality, safety, satisfaction etc. and associated sub-criteria), hierarchies of 'indicators' by which to measure such criteria and typical target values (and ranges) of such indicators in that category. Such target values are weighted by the specific project profile, based on project priorities and contextual conditions.

The sub-systems of the proposed evaluation system are the criteria, the indicators (with typical target values) and an expert system front-end. Supporting 'tools' modules contain techniques for information elicitation, weighting, analysis and presentation.

The three sub-systems of criteria, indicators and the expert system were tested. For example, groups of cost indicators and their average values within specific project categories were derived from data obtained from 138 building, 35 roadworks and 38 bridge projects in Sri Lanka. Their validity was tested by their consistency within project categories, by comparison with projects outside the original database and at a Workshop with experts in Sri Lanka. A pilot expert system was developed to demonstrate the viability of integrating appropriate modules.

It is concluded that the proposed system is viable and would provide comprehensive and realistic evaluations of the management of construction projects.
DECLARATION

No portion of the research referred to in this thesis has been submitted in support of an application for another degree or qualification at this or any other university or other institution of learning.
ACKNOWLEDGEMENTS

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PCWM - Pairwise Comparison Weighting Matrix
PICKMESS - Pilot Construction Management Evaluation Expert System
PMO - Project Management Oversight
PPAR - Project Performance Audit Report
PROBEMESS - Prototype Buildings Construction Management Evaluation System
QA - Quality Assurance
RDA - Road Development Authority (Sri Lanka)
RICS - Royal Institution of Chartered Surveyors (UK)
SD (or sd) - Standard Deviation
SD&CC - State Development & Construction Corporation (Sri Lanka)
sq.ft. - Square Foot
TRRL - Transport and Road Research Laboratory (UK)
UNCHS - United Nations Centre for Human Settlements
UNDP - United Nations Development Programme
USAID - United States Agency for International Development

Notes: - Some other abbreviations as used to designate building, road or bridge project categories in the pilot investigation are as per the classification systems described in Appendices AP5-4, AP5-5 and AP5-6 respectively. Symbols in formulae are described in the relevant section itself.
CHAPTER 1: INTRODUCTION

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(Note: Appendix AP1-1 on page 265 contains the Sri Lanka Rupee conversion rates vis a vis the United Kingdom Pound Sterling and the United States of America Dollar)
CHAPTER 1: INTRODUCTION

'There is a better way. Find it.' Thomas Alva Edison.

1.1 BACKGROUND

1.1.1 Managing Construction

The construction sector usually stands out in national economies, by being at the cutting edge of most development initiatives. This is confirmed by its normally significant share in a country's fixed capital formation. For example, in a developing country with a low per capita income such as Sri Lanka, 'building and other construction' accounted for 53.1%, 54.1% and 56.3% of the Gross Domestic Capital Formation in the private sector and public corporations in 1986, 1987 and 1988 respectively (Central Bank of Sri Lanka, 1988). Furthermore, figures derived from the 1989 Annual Report of the Central Bank of Sri Lanka indicate that construction as a proportion of Gross National Product, at constant (1982) factor cost prices was 7.2%, 7.2%, 7.1% and 7.0% in 1986, 1987, 1988 and 1989 respectively. Such a pattern is consistent with Simkoko's assertion (1989) that construction accounts for about 50% of Gross Fixed Investment in most developing countries and from 3% to 8% of their Gross Domestic Product.

Such a prominent role played by the construction industry in a national economy also confers a particular responsibility for effectiveness and efficiency, so as to maximise the benefits from such significant investments. Secondly, a very visible 'front-end' role in most individual development projects, must necessarily be discharged properly and as planned, in order not to disrupt the development itself or jeopardise the total project viability.

Construction has many other special features that distinguish it from most industries. Compared to manufacturing or most services for example, the degree of complexity is heightened by the diversity of participating organisations and transient teams with multiple goals, interacting within a limited time span to construct a one-off product in an unique location and under other such project specific and dynamic conditions. Unknowns and variables such as ground conditions, weather and human interactions in rapidly changing situations aggravate the risks and uncertainties inherent in the construction industry.

The demands of effectively and efficiently managing such a complex set of multi-dimensional interacting variables in a state of continuous flux, led to the development of special management techniques. Construction management improved with the development of an array of tools for planning, organising, co-ordinating and controlling the monetary, material, equipment and human resources deployed during the different stages of a project. Many techniques and tools were also borrowed from other disciplines such as operations...
research, cost accountancy or general project management (for example, network and critical path analysis)

1.1.2 Sri Lankan Construction Industry

The background of the Sri Lankan construction industry is relevant in that most of the project data was drawn from it. As such, it is reflected in the development of the rest of this thesis. At this point, it is worth recalling:

(a) the historical origins of the industry, dating back to about the fifth century BC with rich traditions in the construction of complex irrigation works and impressive religious edifices, as traced by Weerakkody (1986); and

(b) the apparent boom in the construction industry from 1977 to 1981 as reflected in its average growth rate of 14%, following a 3% negative growth from 1970 to 1976, as illustrated by Weerapana (1984).

But this apparent boom triggered by assigning the construction sector a lead role in 1977, hardly benefited the local industry itself, since it was accompanied by an influx of foreign funds and construction organisations. There are arguments and evidence illustrating that large sections of the established local industry actually suffered during this phase. This was aggravated during the subsequent decline of the sector from 1982 to 1985 as described in a detailed confidential study for the Ministry of Local Government Housing & Construction and the Institute for Construction Training and Development, in association with the World Bank, in 1986.

The local construction industry suffered further setbacks during the last few years, some of which reflected the general problems and budgetary constraints in the country itself. The absence of an integrated strategy for the construction sector was highlighted by the Secretary to the Ministry of Policy Planning and Implementation, Dr. Lloyd Fernando (1989). Such a heightened state of uncertainty superimposed on the traditional risks inherent in the construction sector, invited attention to the main causes of the perceived problems. One positive step was the formulation of guidelines for the development of domestic construction contractors following cabinet recognition of the needs for sufficient volume and continuity of workload, faster payments, adequate financing systems and improved construction management.

A common argument advanced by those advocating foreign involvement in construction projects (apart from justifications arising from the special conditions imposed by foreign funding agencies or the inadequacy of local capacity or specialised technology) was the supposedly enhanced certainty of performance in achieving agreed targets. It was
found that the actual setting of such targets and the measurement of how well they were met, needed closer examination. Collective evidence, other than anecdotal or from individual projects was necessary, in for example assessing cost and time over-runs or other performance shortfalls. A consistent and rationalised system of evaluation would help to assess as well as compare the management of different construction projects, whether in justifying or disputing general or particular claims as to the effectiveness and efficiency of such management.

The efficiencies that can result from remedial action and lessons learned from such evaluation of the management of completed construction projects should also generate much needed savings in resources that could be diverted to other projects or critical needs.

Since the values of construction projects studied in Sri Lanka are quoted in Sri Lankan Rupees, Appendix AP1-1 provides a tabular comparison of how the Sri Lankan Rupee varied with the U.K. Pound Sterling and the U.S. Dollar, in the period under consideration.

1.1.3 This Study

This study was inspired by the apparent lack of systematic approaches to the evaluation of the management of construction, but which were perceived as necessary, for example as in the previous sub-section. Despite the development of improved techniques of design and construction management, there appeared to be a lack of proper means of verifying the success or otherwise of such management. The following were noted as particular shortcomings in most existing approaches to evaluation:

(a) while performance in the construction industry was admittedly affected by the complex contextual conditions of each project, these were often used to excuse failures rather than to weight and adjust target performance levels;

(b) inadequate attention was paid to the original project objectives when evaluating the performance of the project participants. For example if a client wanted a prestigious building with no initial budgetary restrictions, the designers should not later be blamed for not having controlled the cost per m² to within typical levels for buildings of that type;

(c) there was inadequate collection and codification of past project data and experiences especially in the Sri Lankan construction industry. Such a database would not only be generated by project evaluations, but also provide reference data from similar projects against which to evaluate;

(d) the emphasis on the evaluation of most projects for example by many international funding agencies, appeared to be on evaluating the project benefits, rather than the
implementation itself. While the former was necessary for its own purposes, lessons to be learned from evaluating the implementation would themselves improve future performance; and

(e) even the limited implementation evaluation that transpired, appeared to be ad hoc and usually carried out after a crisis. The need for more systematic and regular evaluation to avert crises and improve performance was noted. Furthermore as described in sub-section 1.1.2, evaluation can usefully compare the performance of management of different projects and in different types of construction organisations for particular purposes.

The hypothesis that drove this study was that 'it is possible to develop a viable and comprehensive system to evaluate the management of construction projects against realistic targets as a systematic exercise; incorporating both the special project priorities and contextual conditions as well as relevant historical data from similar projects'.

1.2 EVALUATION

1.2.1 Different terminology

The word 'evaluation' has many connotations even within the construction sector. Two approaches illustrate such divergences:

(A) The Overseas Development Administration of UK, uses the term 'evaluation' (ODA, 1988) to refer to an ex-post study (ie. one carried out after the event), at the end of the project cycle outlined as follows:

- Project Identification
- Project Design
- Project Appraisal
- Implementation
- Project Completion Report
- Evaluation.

In contrast, the word 'appraisal' is used by the ODA to signify ex-ante studies (ie before action is taken) and the term 'monitoring' for reviews of on-going projects. The project description submitted for initial approval is called an 'appraisal' (Bovaird, 1987), although the evaluatory element in an appraisal is acknowledged. 'Monitoring' is defined as the act of checking on project progress in different aspects.

Evaluations are further distinguished from audits (Cracknell et al, 1983) which usually test compliance with management controls and regulations rather than with the overall objectives set for an activity.
The ODA uses evaluations to check if a project has achieved its objectives, whether it was well planned at the outset and also if it was implemented in the way and to the cost, time and other targets intended. It looks at whether the impact on the intended beneficiaries is as originally envisaged. Higginbottom (1990) points out that evaluation identifies successes and failures of past projects, looks for their reasons and applies lessons learned when designing new projects or managing ongoing programmes.

(B) In contrast to the specific ODA definition of evaluation that confines it to ex-post exercises, Corrie (1991) identified three types of evaluation that would be carried out at the following stages:

(i) planning and feasibility studies;
(ii) in-project evaluation during implementation; and
(iii) project performance reviews.

The 'planning and feasibility studies' were considered the first complete evaluation of a project aimed at a consideration of all possible alternatives and the selection of the best. 'In-project evaluation' was considered one of the inherent tasks of project management when approaching points of decision, approval or change. 'Project performance reviews' were those usually conducted for a specific reason by specialists not directly engaged in the project.

1.2.2 Chosen terminology

For the purposes of this study, the broader context of evaluation was chosen in order to include all phases of a construction project. The reasoning justifying this broader coverage originated from:

(i) the potential incentive of an immediate impact through remedial action prescribed for ongoing projects being evaluated; and
(ii) the clear need to link mid-project or post-project evaluation to the setting of the original targets of time, cost, performance levels, specifications and other priorities. However it should be noted that the evaluation of the overall viability of the project itself at feasibility stage is excluded from this study.

1.2.3 Evaluation of what, by whom, for whom, and when

This study set out to evaluate, the management of construction projects or the construction component of mixed projects, at all stages commencing from project
identification through the design, procurement, construction, commissioning, hand-over and maintenance.

Evaluation could be either:

(i) in-house by line management or by a specialist function, similar to but separate from an internal audit unit; or

(ii) by an external agency commissioned for a general or a specific purpose.

Such evaluation, and specific aspects of it would be of use to all participants in a project, for example to:

(a) clients in evaluating the performance of their designers and other consultants, project managers or management contractors and contractors (on previous jobs, the current one or for future jobs);

(b) project managers or management contractors in evaluating the performance of contractors (to prequalify them, or assess current performance in granting extensions, or considering them for other work); and

(c) contractors in evaluating their sub-contractors or vice versa.

This study first focussed on evaluation from the point of view of a large construction industry client, his project manager or financier, who would be assessing the management performance of the designers, constructors and related parties (eg: sub-contractors). Evaluation systems proposed for such purposes would have elements which could be isolated and developed to suit the evaluation priorities of other participants such as the constructors themselves; for example in assessing their own efficiency and effectiveness in meeting their own targets as well as those of the client.

However this study did not venture into the realm of benefit evaluation (that incorporates cost benefit ratios, internal rates of return, or social and environmental impact assessments), but was confined to implementation evaluation, and specifically the evaluation of the management of the design, procurement and construction during a project. This study therefore did not seek means of measuring the overall validity of the clients broad assumptions in commissioning the project (for example as to marketability levels, the financial feasibility and economic viability of his projections or other non-construction phenomena) but was restricted to modelling a realistic design and construction brief, while only pointing out unmanageable inconsistencies of stated requirements (for example a
budgetary limit well below the minimum cost of a building of the envisaged capacity) for necessary revision by the client.

1.3 OBJECTIVES AND REASONS FOR OBJECTIVES

1.3.1 Principal Objectives

Having recognised a general need for evaluating the management of construction projects in a more systematic and reliable manner, the following principal objectives were identified for this study:

(A) to survey the state of science and art of systems (if any), techniques or tools, both in Sri Lanka and abroad, for the evaluation of the management of construction projects; and

(B) to formulate a framework for a suitable general system to evaluate construction management performance (initially from a client's point of view and at different stages of a project but eventually for use by any project participant with a specific evaluation purpose).

1.3.2 Reasoning behind Principal Objectives

It is necessary to identify and codify criteria of success and failure, so as to apply those relevant to a particular construction project before pronouncing judgement on its management; particularly in view of the complexity of the multitudinous factors that could affect or distort such criteria and their measurements in the extremely variable construction environment. It is also necessary to isolate the specific goals of the evaluators and select the appropriate criteria efficiently. For example, it should be ascertained whether the evaluation is to merely assess effectiveness in meeting a client's explicit requirements, or also to measure levels of efficiency in resource utilisation or productivity.

It was felt useful to first examine and extract any suitable evaluation techniques from within the industry itself. The fragmented nature of the construction industry has often obscured developments in diverse directions to meet the current needs of particular groups or sub-groups (such as quantity surveyors, architects, geotechnical engineers, large public sector clients or supermarket chains). Tried and tested techniques from within such methodologies may be chosen and integrated to help meet the second objective of this study.

This second principal objective sought to initially establish a suitable framework for a comprehensive evaluation system. By defining the system requirements at the outset, it would be assembled within a framework of clear objectives, and desirable functions, rather than haphazardly built up from assorted techniques and tools available at the time.
The apparently large gap to be bridged in designing a comprehensive and reliable (foolproof) evaluation system to cover all types of construction projects, coupled with the limited data and other resources available, militated against a more optimistic second principal objective at the outset. However, substantial improvements to both the framework and proposed system components were deemed possible through testing and exposure to the industry.

1.3.3 Sub-Objectives

The following sub-objectives were derived from the two principal objectives listed in 1.3.1:

A-1 to identify the specific goals of evaluating construction management, initially from the point of view of the client and also generally from a broader perspective;

A-2 to isolate the strengths and shortfalls of existing systems (if any), techniques and tools in achieving such evaluation goals;

A-3 to collect information on construction projects in Sri Lanka with a view to identifying useful criteria for evaluating the effectiveness and efficiency of their management and measures of success and failure;

A-4 to investigate any methodologies developed by other disciplines for similar evaluations of management or management systems; and isolate any elements that could be tested in overcoming weaknesses or shortfalls identified in sub-objective A-3;

B-1: to propose a specification, a structure and suitable components for a general construction management evaluation system;

B-2 to identify components that could function as independent modules within the evaluation system; and

B-3 to formulate or propose key modular components for particular project categories (for example within the buildings sub-sector) and for specific purposes of evaluation (for example, for a client to verify how effectively his brief was fulfilled or to select a project management team or management contractor for a new project).

1.3.4 Reasoning behind Sub-Objectives

A focus was needed to ensure an efficient search for the current needs and available techniques of evaluation in the wide field of construction. Initially narrowing down the
detailed survey to specific categories of construction and in a country like Sri Lanka, would facilitate a deeper analysis of the problems and possible solutions in the realm of evaluation.

However an overview of generic problems and available methodologies was also needed and could be achieved by a parallel general (overall) survey. The apparent scarcity of universally accepted systematic and consistent approaches to the evaluation of construction management, suggested the additional sub-objective of surveying other disciplines as well, in order to verify what could be borrowed and adapted for this purpose.

The formulation of a system framework to meet the identified evaluation needs in theory, would by itself be inadequate, unless developed in stages by the testing of it's structure and components with realistic data and by exposure to the industry. Techniques that were proven in other domains needed to be tested as part of a new system with different underlying goals. When more than one technique was apparently available to serve a particular function (for example for cost reconciliation), it was necessary to evaluate them for their own effectiveness and efficiency in achieving such goals.

Modular components capable of functioning independently within the system would have many advantages. For example, once the specific functions of each module were identified, such modules could be developed independently and integrated subsequently, rather than attempting to develop all elements of a comprehensive and probably unwieldy system simultaneously. Once an operational system was available, a particular evaluation could be made more efficient by excluding unnecessary modules from the exercise. Furthermore where information was inadequate to mobilise the output of a particular module, it could be isolated and a partial evaluation undertaken with the rest of the system.

1.4. METHODOLOGY OF STUDY

The methodology adopted is merely summarised herein as descriptions are provided where deemed necessary in relevant chapters (for example in Chapter 2 on the literature search and interviews and in Chapters 5 and 6 on the derivation and development of Indicators). The overall pattern of the study is reflected in the structure of this thesis.

The preliminary interviews of industry experts, the site visits and the literature search led to a formalised systematic pilot project to derive and develop 'Indicators' of success in building, road and bridge construction projects and their management in Sri Lanka. This specific exercise in Indicators for example, generated more focussed interviews, site visits and literature reviews. The threads from contemporary theory and practice together with direct case study findings and propositions were drawn together from time to time; for example in formulating a system specification, in proposing a generalised evaluation system.
structure to suit the specification and a prototype for a specific purpose as described in Chapters 7 and 8.

Relevant modules of the proposed system were tested during the development of construction project Indicators in Sri Lanka. The possibilities of incorporating Expert Systems, decision matrices and other ranking/weighting tools were explored, in order to handle the less quantifiable aspects of an evaluation.

Literature reviews were carried out in Sri Lanka and the UK. Specific publications of relevance were followed up by correspondence with authors and further information obtained where possible. Visits to the UK were in December 1985 to formulate the study, in September 1986 for review, interviews, site visits and an intensive literature search; and a longer visit from December 1990 for further intensive literature searches, interviews and review; the development and consolidation of the proposed system; the exploration of possibilities in Expert Systems, weighting tools and for the integrated documentation. Internal reviews of the study were also facilitated by visits to Sri Lanka of the research Supervisor in June 1988 and May/June 1989; and the Director of Research in April 1988, September 1988 and February 1989.

Interactions with the Sri Lankan construction industry and with specific projects were facilitated through participation in relevant committees, panels, specialist study groups and projects of the Institution of Engineers, the Institute for Construction Training and Development, the Centre for Housing Planning and Building, the Association of Construction Contractors, the Moratuwa University, the Open University and the researcher's own company. Specific relevant exercises were initiated, for example the one year pilot project to define, derive and develop construction Indicators in the three subsectors of buildings, roads and bridges. A team of 6 civil engineers and 1 architect directly assisted the researcher in the data collection and analysis on this project in different but overlapping phases of the project from January to December 1990. A Workshop was organised in early October 1990 inviting industry experts to test interim findings and identify new directions of investigation. A Seminar in late November 1990, presented the further findings and conclusions of the project to the industry.

Specific areas of interest were investigated in detail for example the approaches of international (multilateral and bilateral) funding agencies. Other areas needed to strengthen the proposed system were also examined, for example improved techniques of establishing initial targets realistically, even at early stages; for instance approaches to quick first order estimates of time and cost, based on limited initial information.
A specification for a general evaluation system was formulated. A system structure to meet this specification and a prototype for the building sub-sector was developed from the point of view of the clients. A pilot Expert System was developed to test its value and viability in servicing such a system. It was proposed to weight priorities and subjective judgements using matrices of pairwise comparisons. Samples of data collection and reporting formats, checklists, reconciliation charts, responsibility and information flow matrices etc. were suggested, demonstrating the potential for adaptation and use of the evaluation system by others on the same project, such as financiers, project managers or contractors; as well as for the same client at different times or on different projects.

Figure 1 - A overleaf outlines the main stages of the study and the major interactions, but does not incorporate the many secondary interactions and overlaps encountered at various stages.

1.5 THESIS OUTLINE

Figure 1 - B illustrates the thesis structure, tracing the main connections between chapters. This thesis is structured to reflect the methodology of the study, and the approximate stages of development of the investigation. Although the chapters are not independent, a certain degree of repetition of common principles or findings have been necessary to substantiate the chapter theme, but the detail is developed in one chapter only in such cases, with appropriate cross-referencing in other chapters. There is a necessary interaction in drawing together the threads towards the formulation of a framework for a general evaluation system for the management of construction projects.

Following this introduction in Chapter 1, Chapter 2 contains an overview of the survey of the states of the science and art of general evaluation theory and practice. This includes principal findings from the literature review, interviews and site visits except those specifically dealt with as evaluation 'Criteria' in Chapter 3 or Indicators in Chapters 4, 5 and 6.

Chapter 3 focuses on performance Criteria in use and proposes a new format for assessing performance, including a multi-dimensional 'Project Performance Profile'. The effect of contextual conditions on performance is considered. Approaches to assessing qualitative aspects in contemporary management theory are briefly examined.

Chapter 4 introduces the concept of Indicators as a powerful evaluation tool, assesses the usefulness of construction Indicators and examines how different types could be integrated into a family of Indicators, which itself could be usefully incorporated in an evaluation system for construction projects.
Preliminary Status Survey (of evaluation theory and practice)

Extend Survey of International Funding Agency evaluation practice

Scan Evaluation Theory and Practice in other sectors

Extend Survey of Criteria used in evaluation of construction projects

Formulate useful Indicators and consider their use in evaluation

Select suitable techniques of evaluation

Develop suitable Criteria of evaluation

Derive major Indicators (in specific sub-sectors)

Design system specification and structure for a general construction management evaluation system

Develop major Indicators

Formulate key modules of a prototype evaluation system for a specific type of evaluation

Formulate and Test main Sub-Systems of the proposed evaluation system

Formulate or Propose associated elicitation and presentation Tools

Document current findings, their basis and areas for future development

METHODOLOGY MAP

FIGURE 1 - A
THESIS STRUCTURE

FIGURE 1-B

Chapter Number
Chapter 5 introduces general approaches to the derivation of construction Indicators and documents the pilot study into the buildings, road works and bridges sub-sectors in Sri Lanka. A series of Indicators are proposed and typical values of Indicators such as elemental costs are derived for identified categories of projects.

Chapter 6 demonstrates the development of the Indicators proposed during the pilot study, including the contributions from the Workshop and Seminar specifically designed to supplement this development.

Chapter 7 draws together relevant findings from previous chapters and proposes a general specification, and a model structure for the proposed evaluation system. Formats for 'Project Evaluation Frameworks' and 'Project Performance Frameworks' are proposed. The main modules of a prototype (system) for clients in the buildings sub-sector are also proposed, incorporating suggested Criteria and Indicators.

Chapter 8 develops particular tools to be used in the evaluation system. It introduces Expert Systems in general, verifies their usefulness in the context of this study and demonstrates a pilot Expert System designed as a 'front-end' for the evaluation system. It also examines available tools for weighting subjective assessments and proposes a technique based on pairwise comparisons. This chapter also surveys other tools such as data elicitation and presentation formats needed to supplement the system.

Chapter 9 summarises the main conclusions of the study, and incorporates recommendations for development of the sub-systems, the system tools, the databases and the general evaluation system itself. It also suggests how the system may be adapted and developed for use in other sub-sectors, countries and for other evaluation purposes.

Scope of the study

After a preliminary (overview) survey of about 30 construction projects in Sri Lanka, and the literature in Sri Lanka and the U.K.; the breath of the detailed study was restricted to the buildings, roads and bridges sub-sectors so as to focus on an useful and 'workable' domain. A narrower survey, for example focussing on a single sub-sector, was also precluded by the dangers of being distracted by distortions peculiar to that sub-sector and of excluding general characteristics of the construction industry. A still deeper study of particular sub-sectors could now be launched, with projects tracked from their inception, since the techniques are established and sample modules developed in this study.
CHAPTER 2: STATUS SURVEY OF THEORY AND PRACTICE
IN EVALUATION TECHNIQUES

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FIGURE:
2 - A | Example of a Cumulative Expenditure S curve |
2 - B | Using S curves in computing variances |

(Note: For list of related Appendices at the back please see the General Contents at the beginning of this Thesis).
CHAPTER 2: A STATUS SURVEY OF THEORY AND PRACTICE IN EVALUATION TECHNIQUES.

'Industry observers agree that most construction practitioners do not fully exploit the state of the art. We concur in this general observation.' - John F. Peel Brahtz.

2.1 INTRODUCTION

2.1.1 Objectives of the Survey

Chapter 1 identified the need to evaluate the efficiency of construction management inputs and the effectiveness of its outputs in projects, from the points of view of the client's project manager or representative, or the project financier(s). This survey was designed to elicit the states of both the science and the art of such evaluation techniques. Being conscious of the underlying needs, it was felt useful to focus the search on techniques of construction management evaluation that facilitated:

(a) assessment of how effectively and efficiently the design and construction components of the project were managed;

(b) corrective action on ongoing projects (where the scope of evaluation is extended to include monitoring); and

(c) lessons applicable to the future selection of systems of construction procurement, management and to the choice of specific organisations (whether design, construction and/or management).

2.1.2 Overall Scope and Methodology of Survey

The status survey examined literature and practice in Sri Lanka, in the UK, relevant samples from some other countries (Australia, Hong Kong) and international (both bilateral and multilateral) funding agencies. It commenced in early 1986 and continued into 1991 with the literature search and interviews/field visits overlapping and supplementing each other.

The scarcity of formal structured approaches to a construction management evaluation overview (from the client's/financier's point of view) prompted the decision at the very outset to also draw on approaches from:

(a) overall project evaluation (as in international funding agency methodology) but excluding the 'impact evaluation' aspects while extracting the 'process evaluation' features;
specific tools used in design evaluation and construction evaluation, for example during cost planning and checking in the design phase or during the control of costs, quality and progress in the construction phase; and

parallel techniques of evaluation in other sectors such as general management, manufacturing, education and agriculture; particularly in harnessing useful techniques for measuring/comparing qualitative phenomena.

The multiple probes of the survey reinforced each other with interviews pointing to more literature, and the literature leading to more interviews, visits and correspondence with relevant experts and practitioners.

2.1.3 Chapter Outline

The chapter commences with an examination in Section 2.2 of the specific needs for evaluation of the management of construction projects. It briefly examines in Section 2.3 some sample approaches to identifying factors of success or failure on projects, before scanning the approaches of international funding agencies to the evaluation of their projects, noting their wider objectives of impact assessment as well as of process evaluation. The chapter summarises in Section 2.4 some current approaches to construction project monitoring and evaluation in Sri Lanka and UK; and examines in Section 2.5 the literature on such techniques. Section 2.6 looks at the importance of improving the availability and accuracy of quick estimates of typical cost, quality, time and such performance measures against which projects may be evaluated. The chapter closes with an overview of observations that feed into the subsequent chapters; particularly Chapter 3 which documents more specific surveys.

In such a condensed summary of the observations of this five year survey, there must be a suppression of much of the background literature and observations at interviews or visits. The material presented herein is representative although not comprehensive and highlights the main findings, to be built on in other chapters. For example Chapter 3 examines in more detail the Criteria of evaluation used, while Chapters 7 and 8 describe how a model evaluation system can be developed drawing in threads from contemporary practice as well as from the gaps therein, to meet the identified needs.

2.2 EVALUATION GOALS SURVEYED

2.2.1 Why Evaluate?

The wide range of potential evaluation objectives were narrowed down as in 2.1.1, by specifying for whom (construction clients, project managers, financiers) and for what
purpose (assessing and/or correcting past project performance; and codifying lessons for future construction projects), the evaluation system was being considered.

However, if developed in a modular form, there would be possibilities of wider use, by adapting relevant parts of the evaluation system for use by a contractor to assess the efficiency of his sub-contractors or even his own resource utilisation; or by a financier handling a total project of which the construction is only one activity.

There has been a growing demand from clients and financiers of construction projects (both public and private) for improved performance. For example, this was manifested in positive moves like that of:

(i) the British Property Federation, in the early 1980's to formulate fresh modalities of procurement and operation and aimed at integrating the increasingly fragmented industry specialisations into one cohesive team;

(ii) the ongoing research project 'Clients Requirements in the 1990's for the CIOB, being conducted at the University of Bath, aimed at determining 'what clients want from constructors and to compare that with what constructors believe clients desire' (Fellows, 1991); and

(iii) claims like that in comparing the speed of construction in one country unfavourably with another, for example general claims that construction in UK was slower or less efficient than in the USA, or specific claims (Bennet, 1985) that in the late 1970's the construction cycle per storey for a reinforced concrete building in the USA was 3 days compared with 21 days in the UK. This also triggered studies that tested such generalised claims of low performance, for example investigations by the National Economic Development Office (NEDO, 1983 and NED0,1988). As a specific comparison Swan (1988) indicated that a 3 day floor cycle had been achieved at Chelsea Harbour. More comprehensive Indicators, such as m²/ week of building area constructed (Gale and Fellows, 1989) have been used; as have a range of Indicators for costs and elemental costs. The need for widely accepted measures to evaluate such specific performance was appreciated.

2.2.2 Criteria

It is necessary to first identify the actual needs of the client fraternity in general, while bearing in mind that specific project goals and priorities would have to be extracted with the 'brief' in each case. An obvious starting point would be the classical goals in project management of having the project delivered within budget, to programme, to the required specifications and performance levels. Morris and Hough (1987) while confirming
this trilogy of measures of project success, enumerated two more measures, namely 'Project Functionality' - whether the project itself performed financially and technically as expected by the sponsors and 'Project Participants Commercial Performance' - whether the participants (contractors, consultants etc) themselves benefited commercially in the long or short term. This introduced the broader project objectives of different participants.

Variations of this central theme run through the literature. For example Grindley (1987) felt that the competitive battle would be won on three fronts: shorter design and build cycles, reduced overhead costs and a higher quality product (time, cost and quality performance). He also stressed the importance of getting the right information to the right people at the right time.

Denny (1989) quoted Vituvius' 2000 year old call to the architect to spend at least two weeks living with an important client so that he knew exactly what the client wanted before putting anything on paper. This illustrated the importance of distinguishing client's actual needs from wants (or stated needs) and identifying project specific priorities against which to measure performance. Denny went on to postulate that the client wanted only two things in general: Certainty (of cost, time and delegated risks) and Quality.

The preliminary survey in Sri Lanka also revealed the same concerns with cost, time and quality; heightened by the poor record of substantial cost and time over-runs in construction projects, which had apparently strengthened arguments to introduce more foreign involvement with a view to supposedly infusing certainty. However such over-runs still remained a concern even on contracts with foreign organisations, as there was a need to control high initial estimates and large claims. Risk allocation perhaps with tighter forms of contract was therefore a prime client concern. So was technology transfer, for example whether any new techniques were passed on to sub-contractors. Safety was a less articulated but necessary concern (especially with public sector clients). The importance of scope definition was another way of expressing the criticality of the brief, embodying the right requirements as to quality levels, functional purpose etc.

The foregoing sample of typical evaluation Criteria may be used by a client (or financier) to assess the construction management performance on his project, but only if each such Criterion has directly connected, conveniently computable and reliable means of measurement. In their absence clients may resort to less objective Indicators of success and failure.
2.2.3 Signs of Success and Failure

Studies have been carried out to collect and codify common factors contributing to the success of general project management, (Morris & Hough, 1986) and of project managers themselves (Woodgate, 1979). Morris and Hough tested 22 hypotheses against 8 case studies of major projects. They listed useful lessons learned and codified factors leading to project success in major projects in general. There are many other listings of alleged causes and symptoms of success/ failure in general projects, for example by Gilbreath (1986) as well as in construction. For instance Bastiani (1988) identified 114 problems and 3 basic reasons for construction project failure, as failure in economic policy, failure of project design and lack of institutional capacity. Pinto and Slevin (1988) postulated 10 critical success factors based on 400 completed questionnaires. The diversity and variability of projects and client priorities militate against a realistic codification of all such studies at this stage. However it is worth noting some points that emerged:

(a) the interdependence of factors - for example a time over-run, would imply more overheads and higher costs; and possibly lower quality resulting from attempts to make up for lost time. Similarly a cost over-run or quality failure could adversely affect each other as well as the time factor;

(b) the importance of the original estimates of cost, time etc, and the specification - since performance is measured against such estimates in the belief that they are realistic. One approach would be to have them re-formulated or at least checked independently. Otherwise an apparent over-performance or under-performance may not be as good or as bad as it seems; or on the other hand it could be even better or worse than it appears;

(c) the special dynamics of the construction scenario - that may help construction personnel to justify performance shortfalls by quoting drastically changed conditions; so that for example:

\[
\text{Performance + Excuses (or reasons for deviations) = Original Estimate; and}
\]

(d) the increasing importance of a shift from effective to efficient and cost effective management - after reaching a stage where over-all goals are eventually being achieved in general, as quoted by de Wit (1986) using the North Sea oil projects as an example.

Such efficiency could be eventually passed on to the general client by the market mechanism, and a particular client may reap immediate benefits by setting up an efficient procurement system, identifying (through competition and evaluation) and employing efficient construction organisations. Problems arose however with the perceived lack of a
comprehensive body of techniques in evaluating construction management effectiveness let alone efficiency. While certain techniques are already in use when selecting consultants or pre-qualifying contractors, these have been found to sometimes fail in predicting potential effectiveness in meeting ultimate time or quality targets.

2.3 APPROACHES TO EVALUATION BY INTERNATIONAL FUNDING AGENCIES

2.3.1 Overview

This study aimed initially at examining any available evaluation guidelines, techniques and sample project evaluation reports from different bilateral and multilateral funding agencies with a view to extracting:

(a) standardised approaches to general project evaluation in each agency;

(b) a common language of terminology which could be readily understood by evaluators from different agencies or host client agencies;

(c) particular approaches to evaluating the construction components of total projects;

(d) techniques used in process (or implementation) evaluation as against the more common impact (or cost/benefit) evaluation;

(e) tools used for qualitative evaluation; and

(f) comparisons between agencies in their approaches to total project, process and construction project evaluation.

Of the foregoing aims, the first was achieved in stages with visits to the United States Agency for International Development (USAID) office in Colombo, the Overseas Development Administration (ODA) office in London, the World Bank office in Washington and follow-up correspondence and documents received from both London and Washington. The Asian Development Bank declined to forward any information, the ILO did not have a specific evaluation unit, and information in some other agencies was not easily accessible. However the last aim of cross-agency comparisons was attained easier because of an existing exhaustive ODA study comparing multilateral agencies (Bovaird et al, 1987). It was evident that apart from some conscious efforts at co-ordination, such as through the Organisation for Economic Co-operation and Development (OECD) and a joint conference sponsored by the ODA (Cracknell, 1984), there were still divergent approaches to evaluation by different agencies. While some convergence was noted in the framing of objectives and their measurement, there were still differences in some of the terminology.
used, for example to describe the project cycle. There was no evidence of specific efforts towards special techniques for evaluating building or civil engineering projects or such components of projects.

2.3.2 USAID (United States Agency for International Development)

The evaluation reports of a hospital building project and an irrigation/water management project in Sri Lanka were studied. Apart from the common formats of the 'Executive Summary' at the beginning and the framing of the project objectives and their Indicators at the conclusion, no common structure was discerned. Evidently the body of the evaluation report treated each project on its own merits.

The Executive Summary format was prescribed in guidelines, yielding obvious advantages for quick comparisons at top management level. The usage of the terms 'Findings', 'Conclusions' and 'Recommendations' had also been standardised by a detailed description with examples. (A similar format is followed in Section 9.2 of Chapter 9 of this Thesis).

The central feature noted was the 'Logical Framework Design and Evaluation Matrix', used by USAID from 1971, for developing and evaluating projects. This Logical Framework approach was introduced to rectify shortcomings noted in previous programmes where objectives were not clearly stated to start with. Now objectives are clearly specified and the development hypotheses presented along with the key assumptions and verifiable indicators of project/program performance. It is also used as the basis of subsequent evaluations. The structure of the Logical Framework Matrix is indicated in Appendix AP2 - 1.

This approach to project objectives definition and eventual evaluation has been adopted by many bilateral and multilateral (mostly UN) donors (Cracknell, 1984). No comparisons of construction projects were available for access, but (the Office of Evaluation of) the U.S. Agency for International Development (1982) examined 159 Institution Building projects, focussing on project development and implementation rather than impact measurement and prediction. 34% of the studies dealt with the adequacy of project management and the achievement of initial outputs, while another 32% focussed on the adequacy of project planning. This thrust is similar to that of this study into the construction sector.

2.3.3 (World Bank) International Bank for Reconstruction & Development

The World Bank has a well established Operations Evaluation Department, which supplements the ongoing supervision, monitoring and Project Completion Reports (PCRs)
produced by the operational unit or project staff. The host (recipient/borrower) agency or Government are encouraged to participate in the initial self-evaluation of the PCR. In fact, the researcher was sent sample reports including a PCR prepared by a host agency in Sri Lanka, to which had been added a Project Performance Audit Memorandum by the Operations Evaluation Department and embodied in the final Project Performance Audit Report (PPAR). Borrowers are invited to comment at all stages, even if they are not directly involved in the preparation of the PCR.

The Operations Evaluation Department also prepares an overview of all PCRs and PPARs on an annual basis. This assists in discerning emerging patterns and common causes of success and failure. The patterns are clearer after classification by sectors.

For ongoing monitoring of their projects, the World Bank tried a scheme of 'Built in Project Monitoring and Evaluation'. Overview studies were instituted to learn lessons from different sectors. The third such review related to eight irrigation projects in South and East Asia, but as in the other reviews (of the first five such studies) focussed on benefits such as yield performance (of the crops) rather than the project implementation itself. A positive correlation discerned between the projects overall economic performance and that of the 'Monitoring and Evaluation' components suggested the definitive benefits derived from integrated monitoring and control activities during the implementation. However, neither this scheme of 'Built in Project Monitoring and Evaluation' nor an equivalent is being used for formally monitoring construction projects.

As for external monitoring of ongoing projects, there was a suggested format of a 'back to office report' which included summaries of physical progress, financial progress, compliance with covenants and disbursements. Ratings on scales of 1 to 3 were suggested for items such as availability of funds and progress. Prescribed formats were available, for example a confidential Form designated as Form 590 was used to review problem projects, directing them to a regional Vice President of the Bank, highlighting completion delays, cost over-runs etc. Any project extensions granted were invariably preceded by a more intensive review.

The formats of the confidential Project Completion Reports studied did not show evidence of standardisation, even for example when comparing water supply projects in two neighbouring countries. It was confirmed by the researcher's visit to and correspondence with the Operations Evaluation Department that there was no formally established system for evaluating construction projects.
2.3.4 (ODA) Overseas Development Administration of the UK

Evaluation of the British Aid Programme had become more structured after systematic and formal evaluation studies were introduced from the late 1960's. Browning (1984) pointed out that for the approximately £1000 million per annum aid programme at that time, the evaluation expenditure of around £500,000 or 0.05% was well justified, in that aid efficiency could be increased by a much greater margin. In comparison, Sweden allocated 1% of their aid budget for evaluation activities; while Berg (1984) quoted a case in Australia, where the overall staff of the aid agency was cut from 500 to 350 but the evaluation unit was expanded from 7 to 14 people, illustrating his assertion that evaluation was a 'counter-cyclical' phenomenon, since more of it was needed when one had less to spend.

The ODA treats evaluation as an ex-post study ie carried out after the event or at the end of the project cycle. The 'Project Cycle' in ODA terminology covers Project Identification, Project Design, Project Appraisal, Implementation, Project Completion Report and Evaluation. In fact this terminology does not differ much from that of the World Bank except that Project Design replaces what the World Bank calls Preparation and it lists an additional step of Negotiations/Board presentation before implementation.

The ODA's objectives in evaluation (ODA, 1988) are to assess the effectiveness of past aid activities, and to learn lessons for improving the impact and efficiency of future aid activities. ODA evaluations address questions of whether a project achieved its objectives, whether it was well planned at the outset and whether it was implemented in the way, and within the cost and time intended. ODA aims to learn lessons both about the project itself including such aspects as the design of the project, the accuracy of measures used in the appraisal, the efficiency of implementation, the identification of beneficiaries and so on; and also to learn lessons about ODA's internal procedures and other administrative issues.

ODA claims (ODA, 1990) to be the first donor agency to establish a feedback system operated by its evaluation department, indicating a variety of feedback mechanisms in use, the most significant being the one sheet summaries of evaluation findings on each project called EVSUMS made available to ODA staff, who are expected to refer to all relevant evaluation material before submitting new projects for consideration. The EVSUMS are in prescribed formats enabling easy comparison.

Another step has been taken in grouping and comparing evaluations within a sector in 'Synthesis Studies' to identify common lessons, for example by Barnet et al (1990) on large power generation schemes. Higginbottom (1990) advanced this a step further in
synthesising lessons from EVSUMS between 1980 and 1989, looking at lessons from each stage of the project cycle (and beyond, to sustainability) and examining ratings by sections and regions.

The rating system introduced in 1988 judged performance against objectives and overall benefits relative to cost, to convey a first order impression of the success (or otherwise) of a project. The scale of four ratings prescribed were:

**Highly successful**: Objectives achieved (or exceeded) in terms of outputs, cost and timescales with very significant overall benefits in relation to costs;

**Successful**: Objectives largely achieved in terms of outputs, costs and timescales, with significant overall benefits in relation to costs;

**Partially successful**: Some objectives achieved, but significant costs or timescale overruns or shortcomings with some significant overall benefits in relation to costs; and

**Unsuccessful**: Significant shortcomings in meeting objectives with uncertain or no significant overall benefits in relation to costs.

Inherent shortcomings of such rating schemes can still arise from different perceptions of those who finally do the rating, perhaps based on prevailing and personal value systems and conditions. A more structured 'Project Frame Work' approach to project appraisal, design and management was recommended by Cracknell and Rednall (1986) in order to strengthen the setting of objectives and to use related performance targets as output measures. This followed a study of practices at ODA and other donors. It was a modified version of the Logical Framework approach used by USAID and also adopted/adapted by other funding agencies, such as in Canada, Germany and some agencies of the United Nations. The Project Framework proposal for ODA also has a matrix structure in which to frame and relate the wider (sectoral or national) objectives with immediate objectives, outputs and inputs (listed vertically); in terms of their Indicators of achievement, how such indicators could be assessed and important assumptions (listed horizontally). Appendix AP2-2 incorporates the detailed structure (describing each matrix cell) and Appendix AP2-3 (2 pages) gives one ODA example of its use. Cracknell and Rednall (1986) proceeded to list advantages (for example coherence, discipline, base for monitoring and evaluation) and disadvantages (for example the dangers of mechanical use, of not revising targets when necessary, misuse of quantified targets, neglect of qualitative targets, and of setting low targets).

The ODA has consistently continued its self-evaluation and improvement exercises; for example Scott et al (1987) were commissioned to assess whether agreed project procedures
were carried out and to test the effectiveness, strengths and weaknesses of ODA's monitoring practices, and whether effective use is made of resources available to ODA for monitoring. The Internal Audit Unit of ODA first checked on whether prescribed procedures had been followed on project studies, after which the Evaluation Department assessed whether such procedures were the most effective and efficient means of monitoring. The conclusions were that monitoring procedures were carried out in practice, but their effectiveness was mixed. While financial monitoring objectives were usually achieved, project objectives were not so effectively monitored. Furthermore, problem identification was slow, but response once identified was fast. A positive relationship was noted between project reporting systems and effective monitoring. An indirect but positive link was discerned between effective monitoring and project outcome.

The ODA has played a prominent role in promoting 'cross-fertilisation' of evaluation techniques between funding agencies, for example by arranging the Conference on the Evaluation of Aid Projects and Programmes at the University of Sussex in April 1983, and by the study of Multilateral Agencies Evaluation Systems (Bovaird et al, 1987). The latter study effectively evaluated the evaluators of 24 multilateral agencies, who were at that time (1985/86) disbursing approximately $21 billion per annum and spending about $36 million (about 1.7%) on evaluation. All the agencies had comprehensive formal appraisal and physical monitoring systems; and all but two had in-house evaluation units.

Of these agencies just under 1/3 sought only to learn lessons for their future programmes, but the rest also wanted to account for the performance of their past projects. Four forms of evaluation activities were noted as:

(i) self-assessment by line management;
(ii) in-depth studies organised by line management for their own purposes;
(iii) review by a panel of experts usually reporting to the governing body; and
(iv) in-depth studies organised independently of line management.

Evaluation was recognised as a political activity, involving many stakeholders with different interests even within the same organisation. The effectiveness of joint evaluations therefore depended on the coincidence of interests.

Evaluation systems in different agencies were comprehensively described, compared and documented by Bovaird et al, (1987) in Volumes I and II. One example of the comparative assessment was the study of the degree of centralisation of decision-making as derived from the questionnaires and summarised in a Table and a Scatter Diagram in
Volume I. Volume III of the report incorporated the results of a quick 'litmus test' based questionnaires and checklists, in an agency by agency description and commentary, with postscripts by each agency itself.

Apart from such initiatives towards collective assessments and co-ordination of multilateral agencies, the exchange of evaluation experience is facilitated through the 'Development Assistance Committee' of the Organisation for Economic Co-operation and Development (OECD) in Paris.

Lessons learnt by the ODA are usually incorporated in amendments to the manuals of Office Procedure, new ODA Policy Guidance Notes, a revision of ODA's Project Appraisal Guidelines or even changes in ODA's internal administration and staffing (ODA, March 1987). Feedback is treated as a vital function. 'Cross-cutting' issues such as impact on women, environment and poverty are also incorporated into evaluations.

2.3.5 Other general aspects

Berg (1984) endorsed a view that the responsibility for evaluation of internationally funded projects should move to the host developing country. Shah (1984) described India's system incorporating a national Programme Evaluation Organisation with the central Planning Commission and the additional decentralised State Evaluation Organisations. He stressed the need for host agency interaction with funding agency evaluations.

2.3.6 Findings of Value for Construction Project Evaluation

Structured approaches such as the Logical or Project Framework approach would be useful in defining, designing and evaluating the project. The need for verifiable Indicators in each construction sub-sector reassuringly coincided with conclusions reached by the researcher in parallel studies. Such Indicators would help measure project performance levels more accurately and also derive more benefits from such comparative evaluations.

Standardised formats for summarising evaluations for top management, such as the 'EVSUM's of the ODA or Executive Summary Outline formats of USAID would also be useful for rapid overviews and comparisons.

Some strengths and shortcomings of techniques, for example in implementation monitoring and in qualitative assessments were noted. For example, it was appreciated that at times the evaluators have to ask the right questions to elicit what project participants would have said, had they the opportunity to say it without fear of recrimination or loss. Dangers arose from being misled by biased views of the more articulate and from more
unrepresentative samples distorted for example by non-availability of key participants or by language barriers.

More emphasis on technology transfer would be needed, on each project rather than the random sponsoring of specific appropriate technology projects.

It is possible to draw on relevant techniques for evaluation from the point of view of the construction client or other project participants both for assessing project impact and performance. However this study was concerned only with the effectiveness of construction project performance and related aspects such as efficiency and optimising of resource mixes.

2.4 INTERVIEWS, VISITS & RELEVANT LITERATURE

2.4.1 Summary

The following is a condensed overview of key points extracted from interviews and field visits which were conducted by the researcher in pursuit of patterns, trends and pointers to evaluation techniques in Sri Lanka and UK. All visits were followed up by reviewing any relevant literature available or pursuing pointers to other experts or sources. Research in Sri Lanka progressed (in parallel with the researcher's own work in a project management company) from January 1986 up to December 1990. But the work in Sri Lanka throughout 1990, focussed more on the derivation and development of specific Indicators for evaluation and that particular phase is dealt with in detail in Chapters 5 and 6.

Visits in the UK were for comparative purposes and to elicit the latest techniques with a view to transplanting or adapting suitable elements. These visits were in December 1985, September 1986 and in 1990/1991. Visits, interviews and review in connection with funding agency evaluation techniques are excluded in this Section having been dealt with in Section 2.3.

2.4.2 Sri Lanka

2.4.2.1 Background

Exercises in formal post project evaluation were rare, except where foreign funding agencies were involved. Ongoing monitoring of construction projects made use of methodology linked to contemporary planning and estimating techniques that had been further popularised through the normal learning and interaction process in the Industry, and also through the proliferation of construction management training programmes. The latter
were mainly sponsored by the Institute for Construction Training and Development (ICTAD) and by similar management courses imparting principles of planning and control, as run by a number of other organisations such as the Institution of Engineers Sri Lanka (IESL), the University of Moratuwa, the National Institute of Business Management etc. A further impetus to systematic construction management inputs was imparted following the Cabinet paper embodying guidelines for the development of domestic construction contractors (Institute for Construction Training and Development, 1988). These guidelines were recommended to alleviate four primary problem areas highlighted by a Cabinet appointed committee, namely:

(a) poor construction management (mainly resulting in cost and time over-runs);
(b) insufficient work load and lack of continuity of work;
(c) delays in payments to contractors; and
(d) an inadequate system of financing of contractors.

This attempt to reverse the downturn of the local construction industry, (as described in Section 1.1.2 of Chapter 1), was supplemented by other mechanisms such as intensified development and training activities, and experimentation with different types and forms of contract. However the results have yet to materialise, and more concerted comprehensive efforts appear necessary in the light of earlier reversals and neglect of the local industry that accompanied the foreign funded construction packages in the early 1980's.

Although approximate UK £ equivalents are quoted against the project Rupee values cited in the following sub-section, Appendix AP1-1 better illustrates the value and variation of the Rupee vis a vis the UK £ and U.S.$ over the last 5 years.

2.4.2.2 Projects Studied

The Rs. 3,200 million (at that time about £ 80 m) Katunayake Airport Expansion Project was funded jointly by Japanese and British packages. The Dutch Project Managers (from Netherlands Airport Consultants), the Client's Engineering Manager, Engineers with the local design team and the Contractor, were interviewed. Different approaches to construction monitoring and control by the British and Japanese contractors were noted, for example with the early morning general site meetings arranged by the latter, for daily progress reviews and target setting. Planning, programming and monitoring were dictated by a master programme which unfortunately was not the perceived optimal. The master programming was in turn dictated by the availability of each of the funding components
from different sources depending on the finalisation of the protocols and the terms of funding.

Visits to major dam construction sites at Kotmale, Randenigala and Samanalawewa (and previously to Victoria), were followed up by an assessment of monitoring practice. The ODA evaluation report on Victoria was studied but did not yield significant information relevant to this study on evaluating the construction management. Monthly progress reports on Randenigala (by the German contractor) and Samanalawewa (by the supervising joint venture comprising of Japanese, Swiss and Sri Lankan organisations) were framed in completely different formats. This was not surprising because of the different sources of the information and functions of the authors (contractor and supervisor respectively); but the destination was similar (the Client's representative or the Client itself). For example the contractor's report from Randenigala displayed more detail on critical resource deployment such as equipment, cement and aggregate, and production activities such as concreting. Lists of variations, claims and contingencies were incorporated in both cases, illustrating the client concerns with cost over-runs and other risks. The Samanalawewa Dam & Power-house project, like the Katunayake Airport expansion project was fragmented, in this case (into seven major sub-projects) by virtue of the mix of financing packages. This reflected in an unusual additional contract agreement entered into with one of the contractors to provide a separate service of an 'Interface Liaison Committee' to help co-ordinate the work of all the contractors, for example by preparing and helping monitor a master programme. This Interface Liaison Committee had no authority except through the Supervising Engineer (itself a joint venture), but co-ordination agreements signed by all contractors imparted some operational flexibility.

The Victoria, Kotmale and Randenigala projects came within the purview of the accelerated 'Mahaweli Development Scheme' which was the biggest co-ordinated engineering construction undertaking in Sri Lanka, incorporating a complex of dam headworks and downstream irrigation works and costing about Rs. 60,000 million (about £ 1, 500 million at the time). The client, the Mahaweli Authority had set up a Planning and Monitoring Unit in Colombo reporting directly to the Director General and employing a trained staff of economists, engineers and field data collection officers for regular up-dating of progress. Key officers were interviewed in this unit on three different occasions gaining insights from the macro planning level to the preparation of monthly presentations to the Minister of Mahaweli Development and his top officials. Such preparations incorporated audio-visual aids in summarising the monthly status and enabled corrective action on major shortfalls. The accuracy of the detailed information dispatched regularly from remote sites was subject to periodic checks.
The Financial Co-ordinator of the client Mahaweli Authority kept an independent check on the financial progress of the different projects, himself reporting to the Secretary-General. As regards overall economic evaluation, he demonstrated how by altering the crop mix in an area, the internal rate of return could be dramatically increased to compensate for previous reversals caused by a drop in the price of rice for example.

This drew parallels with how time targets in some projects were revised, based on possibly exaggerated extensions for unforeseen conditions. Progress monitoring then suddenly reported late projects as ahead of schedule.

Many senior engineers and project managers of the Central Engineering Consultancy Bureau as well as the Mahaweli Engineering Construction Agency, participating in the supervision of these projects, were also interviewed.

The completion report on the Minipe (Right Bank) transbasin project (approximately Rs. 800 million or about £ 20 million value) prepared by the Japanese consultants was examined. While comprehensive, it was project specific and did not appear to follow a standardised format which would have facilitated easier comparison with similar studies. The chapters describing the 'Contract Administration' and the 'Contractors', contained some useful elements of the construction management monitoring and evaluation being studied, for example looking at incremental quantities of work performed relating to planned and actual working hours etc.

The Auditor General had employed a civil engineer from about 1986, to evaluate the design and construction aspects of suspect projects which his department was investigating. The researcher was invited to join in some of these evaluations and study reports on others. The formats of the reports on 3 building projects studied were again very project specific. This highlighted the danger of omitting some areas by oversight, perhaps aggravated by the predominance of significant flaws in the first areas to be examined. The usefulness of preparing checklists was realised. The possibility of standardising them for different categories of projects was considered, since no single checklist could realistically cater to all types of construction. The researcher participated in the data collection for the evaluation of the then ongoing Chinese funded Superior Courts Complex project. The total project value was about Rs. 1,000 million or about £ 18 million at the time. There were difficulties in evaluating the Chinese construction management itself due to language barriers as well as a reluctance to divulge their internal systems. However a technical (quality) audit of the building was carried out, to supplement the financial audit by accountants. A more comprehensive evaluation of four design and build contracts awarded for multi-storeyed housing blocks to house families displaced by the project, was launched because of apparent disparities in unit costs. Though the researcher could not participate in
this final exercise, the need for more realistic Indicators of value for money was evident, especially in evaluating design and build outputs.

The researcher's direct involvement as Project Director of the Project Managers for an University Building Complex (Rs. 19 million or about £ 350,000 in value) had previously afforded an opportunity (from 1988 to 1989) to design, set up and operate such a system for awarding and managing a design and build contract. The information, reporting, approval and monitoring systems were designed in detail to cater for the special relationships between the Clients, Project Managers, and even within the Joint Venture partners for the 'design and build' function. This exercise provided useful insights into evaluating such a 'design & build operation, which were incorporated in the development of the system proposed in this study.

The researcher's project management company provided other opportunities for testing monitoring techniques on ongoing projects, for example:

(i) a number of housing projects where the productivity levels of labour contractors were compared with expected work norms (published by the Buildings Department in Sri Lanka in a 'Building Schedule of Rates' document and revised to suit the project conditions) and labour sub-contract rates adjusted accordingly where possible;

(ii) the construction management in association with Bovis International Ltd. of the 400 room Rs.1, 200 million (about £ 30 million at the time) Ramada Renaissance Hotel project where the work of over thirty contractors was planned, programmed, co-ordinated and controlled on behalf of the client. Special macro (project level) and micro (at room level) monitoring systems were instituted to cope with the complexities of the co-ordination and control of the contract interfaces;

(iii) a consultancy assignment for the UNDP/ UNCHS to prepare an Action Planning Manual for the Engineering Services Division of the National Housing Development Authority (Project Management Services Ltd., 1990) in order to improve their design and construction management of the sanitation infrastructure for low income housing schemes. Comprehensive guidelines were drawn up for planning, implementation and control activities throughout the different stages of the project cycle from preliminary studies to hand-over of the infrastructure services. For example, 'Function/ Responsibility matrices' were provided to summarise the allocation of functions to different officers at different stages of the project. Of particular interest to this research were the planning, monitoring and evaluation systems set up for the design activities of engineers (incorporating size and complexity weightings when distributing and evaluating design 'load'); and the construction project planning and monitoring sub-system. An 'applications utility computer
The package was specially developed using both the Lotus 1-2-3 Spreadsheet package and the Harvard Project Manager package; along with suitable reporting formats. The package (which was named LOCHOSPROMOS an acronym for LOw in Come HOusing Sanitation infrastructure PROject MONitoring System), helped plan and evaluate the design and construction projects of the organisation;

(iv) the preparation of two sets of Construction Management Training Packages including audio-visual and computer applications support material, and the presentation of pilot courses for construction managers using this material, under contract to the ILO and for the Institute for Construction Training and Development (ICTAD). The review panels of experts, ICTAD and ILO officials and the target construction manager groups provided useful feedback on areas relevant to this study such as Progress Control, Quality Control and Technology Management. Questionnaires issued to participants before and after the courses tested attitudes to the importance of different aspects of construction management, including planning and control.

The researcher had similar opportunities to interact with groups of engineers and construction managers during lectures at the University of Moratuwa, the Centre for Housing Planning and Building and at the Institution of Engineers. For example one exercise provided an insight into comparative management styles by assigning scores in a 2-dimensional grid based on responses to questionnaires. Further interactions during students' project studies illustrated approaches to monitoring in other organisations such as the State Plantations Corporation, where a new computer based system was being developed for comparing building estimates from different remote regions and then monitoring progress from a centralised Head Office. Monitoring and evaluation was currently approached through random site visits by the Head Office Engineer and therefore dependent on the regional technical staff to implement a more structured system. One perceived advantage of formalised procedures was the accompanying image of institutionalised checks rather than personalised fault finding on occasional visits.

The project reports of construction managers, engineers and supervisors who had followed short term courses in construction management at ICTAD and the Centre for Housing, Planning and Building, were also perused. They indicated similar approaches towards developing a quick overall assessment of each construction project using techniques taught in the courses. Solutions were suggested for perceived shortcomings. Cost and time over-runs were projected on most projects nearing completion, but sometimes justified by the extent of variations to the original scope. Unfortunately it appeared that poor planning and performance was sometimes concealed behind inflated versions of such variations.
2.4.2.3 Experts interviewed

Apart from the participants interviewed on the foregoing projects, specific semi-structured interviews were conducted with a number of key figures in the construction industry as follows. The interview formats varied with the focus of the information sought from each party in his area of expertise, but with the common theme of evaluating the performance of design and construction management.

For example Mr. C.H. de Tissera; then the Director General of ICTAD, and now Secretary of the State Ministry of Housing provided guidance and many pointers in the initial phase of this study. Dr. Ganesan, a Hong Kong University based consultant was interviewed when in Sri Lanka on 14/8/1986 to obtain a broader overview of factors affecting the local construction industry on which he had just completed a detailed study. Interviews with the President of the Institution of Engineers, Sri Lanka confirmed the importance of Indicators for measuring construction performance and eventually led to the Indicators project (described in Chapter 5 and 6) designed to determine such Indicators.

Another past President of the Institution of Engineers, Sri Lanka, Mr. G.J.P. Gunawardane was interviewed first on 2/4/87 and informally on two more occasions, in his capacity as a Director of the Mahaweli Engineering & Construction Agency. He provided insights into evaluation and monitoring practice on their bigger projects. Mr. M. Chandrasena and Mr. Tilak Wijesinghe, both senior engineers Mr R. P. Nanayakara an experienced roads engineer, Quantity Surveyors Mr. T.P. Miskin and Mr. H.D. Chandrasena were each interviewed on a number of occasions with a view to ascertaining the consultants approach to planning, estimating, monitoring and evaluation. 22 other interviews were undertaken between 1986 and 1989, on specific issues that arose during this study, with engineers such as the late Mr. Siripala Jayasinghe (private sector contractor), Mr. Gamunu Silva (public sector contractor), Mr. Felix Weerakody (private sector contractor), Mr. Vasantha Abeysekera (lecturer and consultant). For example the last two having published relevant documents, were interviewed on measures of productivity. Weerakody had postulated (1986) that labour productivity had dropped with the increase of mechanisation and also that supervision was inadequate with high spans of control etc; while Abeysekera was engaged in research to evaluate productivity (September 1990) looking in detail at factors affecting both productivity and the enhancement of productivity.

Interaction with experts at Seminars relating to construction management also provided a valuable source of information and feedback to propositions under consideration.
Dr. Susantha Gunatillake (an economist who was also an engineer) was interviewed on general evaluation techniques in his capacity as Director, Research of the Peoples Bank. Dr. Ramanujan, a Director at the Ministry of Policy Planning and Implementation was interviewed to determine the latest developments in physical progress monitoring as distinct from financial progress monitoring, following previous work in the Ministry (Ambalavanar, 1987 and Jayawardane, 1987).

2.4.2.4 Overview

The foregoing interviews, visits and connected documentation reviews in Sri Lanka fed in at different stages to:

(i) the researcher's conceptualisation of the root causes of specific shortcomings and the attendant need for improved monitoring and evaluation of construction projects in Sri Lanka;

(ii) the identification of Criteria by which to measure such performance levels as outlined in Chapter 3; and

(iii) the researcher's development of possible approaches to such evaluation and solutions to such shortcomings in a systematised framework as presented in Chapters 7 and 8.

2.4.3 The U.K.

Visits were arranged to offices or sites of a small cross-section of the UK construction industry. Where this was not essential, correspondence elicited relevant documents, for example, as with Professor Horner of the University of Dundee, Mr. Nicholas Hamilton of the Dundee Institute of Technology, Mr. David Langford of the University of Bath and Mr. Francis Graves a Senior Quantity Surveyor/Project Manager famous for his project management role in the Birmingham New Exhibition Centre project.

(A) Dr. Martin Barnes was interviewed in 1985 and 1986 when identifying current practice and further needs for construction project evaluation. His writings on related topics are also referred to later.

(B) Mr. Bernard Jupp of Bernard Jupp & Partners, a Quantity Surveying practice was interviewed in September 1986 and February 1991, discussing broader project management and cost planning issues, while obtaining pointers to design evaluation and those practitioners directly involved with project evaluation.
(C) Mr. David Bucknall of Bucknall Austin Project Management Ltd was interviewed in September 1986, having recently undertaken the project management of the Birmingham Convention Centre. The evaluation of the construction phase and the methods of evaluating prospective management contractors were discussed with Mr. Bucknall and Mr. M. McCarrurh followed up by correspondence with the latter as to the allocation of risks and responsibilities for cost, quality and time performance.

(D) Mr. Peter Miller, Divisional Systems Manager of the Development Division of J. Sainsbury Plc. was interviewed being an innovative manager with a private Client, planning and controlling a major building programme. Since they were dealing with similar types of buildings, a greater degree of systematisation was anticipated than usual. His active participation in operational research and knowledge based systems applications for building planning and control systems, also provided useful inputs into this study. He was interviewed in September 1986 and February 1991.

Issues covered ranged from estimating and cost models, planning, programming cost and time control on projects, related to client priorities. At the 1991 interview an encouraging coincidence of approach (with that of the researcher) emerged. While the researcher was modelling the contextual variables affecting the project and the client's priorities (as illustrated in Chapter 3), Mr Miller and his colleagues were working on a 'trade-off model' for the equilibrium needed between the 'business set of variables' and the 'project set of variables'. He disagreed with the researcher's inclusion of what he called the 'soft' priorities and evaluation Criteria such as client satisfaction; but preferred to confine attention to the 'harder' Criteria of cost, time specification and (functional) performance.

(E) Mr. David Butler, Chief Surveyor, Mr Percy Ward, Assistant Director - Architect and Mr. B.K. Gilbert, Superintending Surveyor, of the Department of Health were interviewed in September 1986 and the former two again in February 1991, from the point of view of a major public sector client.

The benefits achieved from standardising systems in their Department were evident, for example:

(i) design standardisation achieved through the Nucleus system (Department of Health and Social Security, UK, 1988) for hospital buildings using cruciform shaped templates. (But particular buildings could still be developed differently for individuality as 'clusters');
(ii) a mandatory procedural framework called Capricode governing the inception, planning, processing and the control of the National Health Service capital building schemes;

(iii) the 'Certificate of Readiness to Proceed to Design' which imposes a discipline and explicit responsibility, requiring the Designers to be certain of having extracted all aspects of the 'Brief' from the client. Relevant 'Building Notes' and checklists constituted a comprehensive 'Design Briefing System' which facilitated this process;

(iv) the 'Certificate of Readiness to Proceed to Tender', which demands a similar certainty that the design is complete. This discipline was claimed to have reduced cost and time overruns (previously caused by variations and changes) from 25% to 5% on average;

(v) 'Departmental Cost Allowances' (DCAs) worked out for each hospital function such as operating theatres or wards of a certain capacity enabled easier cost planning;

(vi) the 'Concise' suite of seven integrated computer programmes designed around 'Capricode' requirements; for use during planning and control. The vast data bases used by these programmes provided a good basis for monitoring the hospital building projects during design and construction;

(vii) The 'S curves' as in Figure 2 - A in section 2.5.3, developed to project expected client expenditure and monitor progress against same. These had been developed drawing on the large database of projects assimilated from the 1960's. A forecasting formula was developed (Hudson, 1982) to model the expected expenditure as an extremely close approximation to the formula:

\[ y = S \left[ x + Cx^2 - Cx - \frac{6x^3 - 9x^2 + 3x}{K}\right] \]

where \( y \) = Cumulative monthly value of work executed before deduction of retention moneys or addition of fluctuations

\( x = \) month (m) in which expenditure \( y \) occurs/contract period(p)

ie. proportion of contract period completed

\( S = \) contract sum

\( C \) and \( K \) are parameters which were determined for different cost categories of projects from the data base.

The formula was used in two ways:
(1) knowing $C$ and $K$, contract sum and contract period, the cumulative value of work executed after any given number of months could be estimated; and

(2) knowing $C$, $K$ contract sum and cumulative expenditure in any month, the likely works duration could be estimated. During monitoring if the actual expenditure consistently deviates from the standard curve, a different completion period would be expected.

Such S curves were incorporated and used in monitoring through the Concise suite of programs. Parallel approaches using S curves for forecasting and monitoring are examined in Section 2.5.3.

(F) Mr. B. Whitehouse of the Department of Education and Science was interviewed during the researcher's M.Sc project investigations (Kumaraswamy, 1985). Some of the practices of this other large public sector client are worth noting in the context of this study. Standardised guidelines in the form of 'Design Notes' and 'Building Bulletins' take account of user needs and ultimate conditions to be attained, (eg. in energy conservation or minimum spaces) rather than specifying methods to attain them. Such standardisation would provide 'bench marks' against which to evaluate value for the client's money and design efficiency.

(G) Mr. Ken Wright a Project Manager with Bovis, was interviewed briefly in 1986 and in detail in February 1991. The second interview was on the £ 450 million Minster Court Office complex development (construction value £ 180 million) for Prudential Assurance in London. Two of the three building blocks were nearing completion when the researcher visited the site.

Bovis Construction Ltd. as Management Contractor, kept a tight control of 25 main sub-contractors on this job. For example there were procedures and forms for evaluating sub-contractors against Criteria such as 'performance of work force on and off site'; 'quality of finished product on and off site'; 'quality of supervision and co-operation'; 'quality of storage operations'; and 'record keeping and compliance with quality plan'. Scores were assigned on a monthly basis against each such Criterion by the responsible supervisor/superintendent and the project manager. The averages were taken and added up to a total score. Each average Criterion score was also compared across a performance league type table with those of all the other sub-contractors. Coloured bands highlighted the excellent, good, average and below average sub-contractors and those needing review. These sheets were displayed and circulated on site as well as sent to Bovis Headquarters monthly, for reference when evaluating sub-contractors for new contracts.
Broader issues of evaluation under the management contracting vis a vis other procurement systems were discussed with Mr. Wright and Mr. Roy Bentley a planner and senior Bovis executive. Turnover was considered an useful Indicator of the management contractor's performance for it's own purposes, but their American partners on another project preferred the Indicator of payback per person, when evaluating their own success levels.

Networks had been used for planning on this project as the work was not at all repetitive to justify for example, 'Line of Balance' techniques. Monitoring also required the use of networks, but little confidence was placed by those interviewed on the reliability or usefulness of monitoring by revised networks as against more direct approaches.

(H) Dr. Geoff Simms (an Associate Director/ Chief Civil Engineer) and Mr. Everard (a Project Manager) of Balfour Beatty Projects & Engineering Ltd were interviewed at Sidcup in February 1991, eliciting approaches to monitoring on their civil engineering design and construction supervision activities. Much reliance was placed on Quality Assurance systems and Project Manuals to ensure proper procedures were followed and targets met. As regards evaluation, their project manuals had a chapter on the systematic 'closing down' of projects which prescribed procedures for presenting a project summary, the status of all documents, final accounts etc.

Commenting on the researcher's proposed model of performance evaluation Criteria, Dr. Simms queried the feasibility of modelling realistic relationships between them. Mr. Everard agreed that clients satisfaction was important and suggested that the incidence of repeat orders was a good Indicator of such success.

(I) Mr. R. D. Thomas (a Senior Consultant and Mr. Peter Rooney (a Chief Engineer/ Construction Manager) both of W.S. Atkins Project Management were interviewed at Epsom in February 1991. Mr. Thomas gave the researcher a copy of a paper (1989) he had co-authored with Mr. P.J. Duffy, a Director of W.S. Atkins. According to this paper on 'Project Performance Auditing', Atkins had completed about 50 project audits in different types of projects (not all construction), the aim being to provide top management and the investor with an independent review, analysis, appraisal and recommendation on project management activities. This was the closest general approach detected in principle to the researcher's own objectives, but no special techniques of significance were described. Preference was expressed in being commissioned for pre-project audits so as to help set up project management systems; though in-project audits and post-project audits were more frequently undertaken as well. Audits typically took from two weeks to two months.
The technical paper set out the scope of the audit service, in investigating the suitability of the organisation itself for the task at hand; in verifying progress against plan; in evaluating other restraints on project progress and making recommendations. It set out the main factors so reviewed as Organisation and Management; Project definition; Time; Money; Procurement Strategy; Communications; Site; Restraints; Commissioning and Operations.

Duffy & Thomas (1989) also noted that government and public authorities required two types of independent audits - value for money and efficiency of multiproject design and management organisations. Banks generally required Project Performance Audits of a financial nature. Lessons learned were summarised, for example many problems arising from inadequate project definition, weak technical management and poor communications. Factors 'promoting project delay and overspend' were also identified, including for example, inappropriate project organisation; lack of direction and control in the project team etc. Duffy and Thomas recommended the development of a predictive model to help assess project success levels.

The researcher's own model outline, listing and describing performance Criteria was discussed in detail at the interview with Mr. Thomas and Mr. Rooney. No further Criteria were added.

2.4.4. General Overview

While specific isolated conclusions were avoided as far as possible, the foregoing sub-sections of Section 2.4 summarise observations from the foregoing visits, interviews and relevant literature in Sri Lanka and UK. It was gratifying to notice the emerging awareness of the need for standardised systems of performance Criteria (and related means of measurement) for evaluation of design and construction management (as at W.S. Atkins) and other efforts towards developing such Criteria (as with W.S. Atkins and Peter Miller of J.Sainsbury Plc).

The researcher obtained constructive feedback on sets of proposed performance Criteria which enabled their improvement as in Chapter 3 and further refinement as in Chapter 7.

Some generic problems during design and construction management which could be alleviated by systematised evaluation and short or long term corrective action also emerged from this survey.
2.5 LITERATURE REVIEW IN SPECIFIC AREAS

2.5.1 Introduction

This Section focuses on overviews of certain areas that were not already summarised previously in this chapter (in relation to success/failure factors in projects, interviews and visits or funding agency approaches for instance) or that are covered later (for example in Chapter 3, where the development of project profiles and performance criteria is specifically considered). The literature search also looked at parallel approaches (in other disciplines) to evaluation. Material considered particularly useful to this study was selected for feeding into the development of the proposed evaluation system, and is expanded in Chapters 7 and 8. Having commenced in January 1986, the literature search was undertaken using the libraries of the British Council, the Centre for Housing Planning and Building, the Institution of Engineers and other similar sources in Sri Lanka; and the Loughborough University of Technology Library in September 1986 and 1991. In both searches at Loughborough, all available facilities were accessed, for example, including external material through publications databases in Civil Engineering; Management, Applied Sciences & Technology; Social Sciences etc.

2.5.2 Some other general approaches to Evaluation & Monitoring

A generalised but structured approach to the control of capital projects by local authorities had been documented by the Audit Inspectorate of the Department of the Environment, (1982) setting out principles, procedures and guidelines for good practice in all phases of a project, from identifying strategic objectives, responsibilities, roles and the basis of contracts; through design, tender, contractor selection, contract management including monitoring and reporting of progress and costs. Checklists and standard formats supplemented the recommended procedures.

Cavallone (1987) outlined the auditing of large plant engineering projects summarising the main phases of such an audit, the key issues to be examined and suitable reporting formats; while warning of the 'irreducible subjectivity of judgements' and the need for the greatest objectivity possible.

A special summer issue of the Project Management Journal in August 1985 was devoted to project evaluation. Cleland (1985) took the term evaluation to cover pre-project appraisal, ongoing project monitoring as well as post-project evaluation. He was concerned with evaluation as the part of project control appraising the probability of a project attaining its technical performance, schedule and cost objectives; and presented a strategy for ongoing independent project evaluation. Anbari (1985) formulated a systems approach to
evaluation focussing on the system of the project management process transforming inputs to outputs; and concluding with the need to evaluate the sub-systems of scope, time, cost, quality, human resources and communications. Salapatas (1985) postulated that project management performance could be measured in the same way as measuring a project (through success/failure levels). Loo (1985) compared common concerns in broader program evaluation with the more common project evaluation; and also identified potential psychological impediments to project evaluation.

Brown (1985) examined how critical path method network scheduling could be used to analyse and control project schedules while warning of excessive concentration of resources in the perceived critical activities. He also examined the measurement of work accomplished by using an 'earned value' concept of company costs incurred with actual value achieved (for cost performance) and planned vs. earned value (for schedule performance). He derived schedule performance and cost performance indices accordingly. He then used different combinations of these two Indicators along with a third Indicator, namely the network float, to predict the state of the project. Tatum (1985) also promoted the use of suitable Indicators (for example cubic yards of embankment or lineal feet of tunnel) to describe progress on civil engineering projects. He called for major research to develop suitable Indicators for different types of construction while suggesting the failure of network-based control techniques in providing suitable standards or status reports.

Wearne (1989) drew attention to a three term basis for control analogous to mechanical, electrical and biological control systems:

(i) error: difference between measured and required rate of work;
(ii) rate of change: rate of change of the error, whether increasing or decreasing; and
(iii) accumulated error: integration of results to time of measurement. Comparison with the required total would indicate whether remaining work must be re-planned.

He also illustrated how a 'feed-forward' circuit would feed predictions into planning for future work while the feed-back circuit would feed measurements obtained by monitoring to the same work unit.

Richard Neale and David Neale (1989) demonstrated the details of different planning and allied monitoring and control techniques currently popular in the construction industry, such as network methods, line of balance, linear programmes and bar-charts. A formal and systematic monitoring process was said to constitute an integral part of a management information system.
Halpin (1985) focussed on financial and cost control systems in construction management before examining time and cost integration. He demonstrated the use of devices such as a 'completion date trend chart' that would readily indicate deviations from the schedule of crucial milestone points (for example a critical achievement such as completing a building roof or completing a coffer-dam) and the progress trend. Similarly he showed how a 'cost trend chart' if updated regularly can signal deviations before they become unmanageable.

The Project Management Handbook edited by Dennis Lock (1987) examined monitoring by milestones and predicting trends that called for corrective action or otherwise.

Many computer software packages have been developed using similar principles and techniques to facilitate quick monitoring and control on construction projects. Apart from standard planning and programming packages like Harvard Project Manager, Artemis and Pertmaster for example, specific packages have been developed both in-house in organisations such as the Department of Health, UK (Concise system) and commercially, for example Project Cost Model, one of the earlier packages (developed by Project Software Ltd. in 1971) which integrated planning, monitoring and control.

A NEDO booklet (National Economic Development Office, 1989) formulated a detailed productivity measurement system for the engineering construction industry, based on performance norms, and demonstrated it's use in monitoring productivity with defined cost and productivity factors (eg: allowed hours/ spent hours for a task). Productivity rates between one site and another were said to vary by as much as three to one. It was noted that at times only around 30% of the day was utilised for effective work. Activity sampling techniques were described. Formats were also prescribed for other known techniques such as Foreman Delay Reports, aimed at capturing the subjective assessments that may escape standardised quantitative monitoring systems.

2.5.3 Monitoring with S Curves

The extensive incorporation of standard S curves in the planning and monitoring system of the Department of Health UK, has already been noted in Section 2.4.3 with the original equation used as a basis for it's development. The literature demonstrated many examples of similar development and the use of such 'Bell' or 'S' curves.

Other equations have been formulated, for example by Miskawi (1989), relating P, the percentage complete of a project to time (T) with a shape factor (Tp) through an equation as overleaf:
Envelopes of curves from $T_p = 5$ to $T_p = 95$ indicated the possible variations in shape under differing conditions.

Kerridge and Vervalin (1986) described the visual impact of such S curves and how the shape of the curve could be an indicator of comparative performance and efficiency. They showed how they could be front-end loaded or back-end loaded thereby distorting the symmetry. The closer the S curve to a straight line, the greater would be the degree of resource levelling. They also listed some applications of S curves such as checking quantities of work done (by man-hours, by cubic yards of concrete or by feet of pipe line), material requirements or purchase orders to be placed, by money value; drawings by number or by weighted value; expenditure or cash flow.

Brous et al of Ebasco Services, New York described (1979) a version of a now widely quoted performance measurement system using earned value concepts and the following terms that are illustrated by Figure 2 - B overleaf, on the basis of that developed by Harrison (1985).

- Budgeted Cost for Work Scheduled (BCWS)
- Budgeted Cost for Work Performed (BCWP)
- Actual Cost of Work Performed (ACWP)
- Budgeted Cost at Completion (BAC)
- Estimated Cost at Completion (EAC)

Cost Variance Index (CVI) = \((BCWP - ACWP)/ BCWP\)

Schedule Variance Index (SVI) = \((BCWP - BCWS)/ BCWS\)

At Completion Variance (ACV) = \(BAC - EAC\)

A number of applications of the graphs and indices could help monitor progress and trends, for example, in estimating the cost and schedule variances at any point of time, in projecting the expected cost and time differences if present trends continued (and alerting management to take any necessary remedial action) in separately plotting Cost Variance and Schedule Variance indices against time, to assess their trends.
EXAMPLE OF A CUMULATIVE EXPENDITURE S CURVE

(after K.W. Hudson - 'DHSS Expenditure Forecasting Method' in 'Construction Projects - their Financial Policy and Control' edited by R.A. Burgess, Construction Press, 1982 -for schemes of approximately £4 million)

FIGURE 2 - A

USING S CURVES IN COMPUTING VARIANCES

(after F.L. Harrison - 'Advanced Project Management', Gower, 1985)

FIGURE 2 - B
Harrison (1985) confirming how these measures could integrate schedule and cost control, combined them with a project work breakdown structure so that the analysis could be carried out on any part of a large project.

2.5.4 Post Project Auditing for Contractors

Nicholas Hamilton of the Dundee Institute of Technology was corresponded with, as his paper (1990) for the ARCOM annual conference highlighted interesting findings from a study in 'Post project auditing for UK construction contractors'.

He tested the evidence that 'the construction contracting industry in UK does not learn lessons from past experience in a systematic fashion. Individuals learn lessons but it is unusual to find these lessons being fed back into the organisation in a formal manner'.

He surveyed 30 building, civil engineering and general contractors with annual turnovers ranging from £0.5m to more than £1.0 Billion. His findings confirmed that the use of post project auditing is not widespread among UK construction contractors. Over 90% of the sample had no formal systematic approach to the assessment of completed projects. Although most of them saw at least some merit in moving towards a use of systematic project performance auditing techniques, 77% of the sample were of the opinion that the lack of resources represented the greatest obstacle to adopting such a system. 10% felt there was insufficient evidence that such a system would be beneficial, another 10% that the dispersion of personnel after the project would make it difficult to implement and 3% that the varied nature of the project made standardisation difficult. His observations were based on three specific questions he put to them along with some suggested alternatives.

2.5.5 Project Management Oversight

Werderitsh (1990) drew attention to the concept of 'Project Management Oversight' (PMO) for evaluating management effectiveness. PMO being concerned with the quality, time and cost performance of the project shared the management concerns of the owner, designer, contractor, sub-contractor, vendors and suppliers; differences arising only from the isolated view each party had of its own part of the project. PMO called for a total project viewpoint, which could perhaps be manifested by the client or the client's project manager(s). PMO had evolved with increasing requirements for clients to oversee different aspects of their projects as for example in the nuclear power industry from the 1960's through the 1980's. The 1990's saw quality assurance programmes expanding in the power industry, requiring another form of oversight management. PMO is supposed to be supportive of management efforts in identifying potential problem areas and suggesting
solutions. It is being advocated as a means to minimise the impact of disputes before they occur and to facilitate their timely resolution.

Werderitsch compares the delegated construction management role with PMO by stating that Construction Management performs by planning, organising, implementing and controlling, while PMO evaluates the effectiveness of performance.

2.6 ESTIMATING REALISTIC COST, TIME & PERFORMANCE TARGETS

Costs incurred should be evaluated against realistic budgets and cost plans, while time spent must be checked against reasonable time standards. If not, statistics of cost and time over-runs will be meaningless as would be judgement of performance on specific construction projects. Furthermore an assessment of the quality and performance targets must be also incorporated in order to provide a wider perspective of planning and control efficiency.

2.6.1 Cost Planning & Control in the Pre-Construction Phase

The three primary functions of cost control in building design were identified by the Ministry of Public Buildings and Works UK, (1968) as giving the client good value for money; achieving the required balance of expenditure (to achieve a consistency of say, performance/quality between different elements) and keeping expenditure within allowable amounts. As a secondary factor, one may also consider life cycle costs in choosing between design options, and later (or at the tendering phase) also incorporate cash flow differentials and their costs, in comparing alternative methods of procurement.

Different cost models have been tried in projecting approximate estimates during the design phase. For example Asif (1988) listed four types as: parametric models (for instance based on the cost per hospital bed), regression models (based on relationships to critical variables); approximate quantities models (based on applying estimated item costs to approximate quantities estimated during the design) and elemental models (based on the historical unit costs of building elements applied to estimated elemental quantities).

The degree of accuracy of the estimates increases with the progress of the design through the detailing and final costing. Barnes (1982) illustrated the convergence of the differences between estimates and actual costs through the feasibility, design, tender, construction and claims settlements stages.

A series of studies at the University of Dundee have developed the principle of cost significance in identifying the cost significant work packages in particular sub-sectors or categories, (for example bridges or factories). When such packages are priced
approximately they would significantly predict the overall costs. Iterative estimating during the design stage used no more than 30% of the number of items in a standard Bill of Quantities in the sub-sector to predict costs and times reasonably accurately. This has led to integrated cost and time control systems, for use during both design and construction phases of a project (Saket et al, 1986 and Horner et al 1989). Similar approaches to identifying cost significant work packages in civil engineering projects in Hong Kong were conveyed through correspondence and preliminary papers received from Dr. Steve Rowlinson of the University of Hong Kong.

Controlling costs against overall and itemised (for example, elemental) cost targets becomes feasible as more realistic targets can be estimated for each sub-sector and category of project, for example the school building category in the buildings sub-sector. The Building Cost Information Service (BCIS) of the Royal Institute of Chartered Surveyors and similar services in other countries (such as Australia) provide the data on which to base such systems. The quality of the information also depends on the quantity of data ie. the size of the data base as well as how accurate and representative it is in that category.

2.6.2 Estimating Project Time

Despite the less quantifiable factors that affect the time taken for construction activities and total projects, studies of the Building Research Establishment and the National Economic Development Office (1988) have led to guidelines predicting 'average' and 'good' construction times for commercial buildings depending on significant factors. This is described in Chapter 5, Section 5.4.6.2, along with similar studies by Bromilow et al (1988) in Australia. Of importance at this stage is the possibility of predicting project time scales realistically, so as to control actual progress against realistic yardsticks.

2.6.3 Planning & Controlling Quality

Quality assurance has become more important to clients, consultants and contractors recently with the rush to seek accreditation of compliance with BS 5750 (British Standards Institution, 1990). The self-improvement and self-policing disciplines instilled by such systems facilitate the setting of realistic targets to be achieved and the institutionalisation of policies and procedures to achieve them; as well as inspection, remedial and audit procedures to control them.

Quality consciousness in achieving value for money, evident in the UK construction industry was supported by a flood of literature, seminars and conferences in this area, for example, the CIRIA report (Ashford, 1989) and the ICE conference on Quality Assurance in Construction where McCaffer (1989) spoke of quality assurance as the current buzz
word for good management practice, adding that good management practice is in the end the most economic form of management practice.

Indeed, practitioners interviewed by this researcher stated that their efforts in seeking BS 5750 accreditation helped rationalise and systematise procedures and information systems with direct advantages for management control.

2.7 OVERVIEW

The wide coverage of the foregoing survey together with further searches described in Chapter 3 militate against a detailed codification of all the findings at this stage. However, a categorisation of the observations as has been done through Sections 2.2 to 2.6; is supplemented by the extraction of particular findings useful to this study as follows; to feed into the following chapters.

Generalised conclusions are summarised as follows:

(i) there is a need for a construction project evaluation system that can specifically be applied to ongoing and completed construction projects on behalf of a client, to assess the effectiveness of outputs and the efficiency of the transformation of inputs;

(ii) such a system while borrowing from parallel approaches in other sectors and different disciplines should develop its own framework and methodologies that are directed to address issues specific to construction projects;

For example 'Logical' and 'Project' 'Frameworks' such as those adopted by the ODA and USAID for modelling the project objectives and Criteria; would be useful and could be adapted to suit the construction scenario along with standardised reporting formats;

(iii) modified modules developed further from within such a system would be useful to specific professions within the industry (for example contractors, project managers, designers) to evaluate their own effectiveness and efficiency, as well as that of other interacting organisations (for example sub-contractors);

(iv) appropriate performance Criteria must be identified and developed, by which the evaluation system could realistically and conveniently measure the different aspects of the project.

(v) more accurate techniques of realistically estimating costs, time and performance targets are needed, both at the initial stages, when setting approximate targets and
subsequently when refining them along with the development of the project. Such techniques are being developed and may be adapted for the proposed evaluation system;

(vi) targets and sub-targets of costs, time, performance and of other relevant performance Criteria should be framed in a format such that typical approximate values could be readily obtained for each sub-sector (for example buildings) and each category within the sub-sector (for instance schools). Comparisons with the subject project would then be easier after adjusting for project specific conditions;

(vii) project specific priorities, constraints, strengths, weaknesses, opportunities and risks should be carefully ascertained from the client and other relevant parties before determining the required performance levels; and

(viii) there is an available body of techniques (such as S curves and variance analysis) of monitoring and ad hoc approaches to evaluation that can be adapted, tested for their value and viability and integrated into a comprehensive evaluation system.
CHAPTER 3: DEVELOPING PERFORMANCE CRITERIA

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(Note: For lists of Tables herein and related Appendices at the back, please see the General Contents at the beginning of this Thesis).
CHAPTER 3: DEVELOPING PERFORMANCE CRITERIA

'The analysis of construction performance has typically been performed in a shotgun fashion' - William F. Maloney (1990).

3.1 INTRODUCTION

3.1.1 Background

Many measures have been used to compare performance in the management of construction projects. For example:

(i) a survey of engineering construction projects (design and construction of large industrial plant) throughout Australia (Grad, 1989) indicated that 60% of the projects were completed within cost and the same percentage of projects were completed within time. 45 to 50% achieved under-runs on both;

(ii) Bromilow et al (1988) found 10% cost over-runs (on average) in 683 public sector and 4% cost over-runs (on average) in 94 private sector building contracts also in Australia. The survey carried out in 1986/87 related to projects constructed in 1976 -1986. They also verified previously developed formulae for predicting project times based on significant factors as described in Section 5.4.6 of Chapter 5;

(iii) the National Economic Development Office (NEDO, 1988) study on 'Faster Building for Commerce' in the UK found that 'fast' times were 20 - 25% shorter than typical times, illustrating the potential time gains. The study proposed a system for predicting average and 'good' construction times, also described in Section 5.4.6;

(iv) Rowlinson studying industrial buildings (1988) indicated that 40% of such projects over-ran on cost by more than 5% and only 18% of projects were completed within the contract period, specifically noting high pre-construction time over-runs;

(v) Guha Thakurta (1990) citing 106 case studies of large (over Rs 1,000 million) projects in India, noted the overall cost over-run as 75%, with 9 projects over-running by 50%, 15 by 50 - 100%, 17 by 100 - 200% and 6 by over 200%. Time over-runs were similarly high, with 13 over-running by 2 years, 10 by 2 to 3 years, 13 by 3 to 5 years and 8 by more than 5 years; and

(vi) in Sri Lanka there is similar evidence of a high incidence of cost and time over-runs. However detailed studies to quantify and compare such measures over a wide range of projects have not met with much success, mostly because of the many revisions of cost and
time targets with variations to scope or otherwise and the virtual obliteration of the original targets.

However there is evidence of large over-runs on individual projects, for example on a Colombo - Kandy road rehabilitation project, on the new Kalutara Bridge project and many other large projects. During a general survey by an M.Sc student from the University of Moratuwa in 1989 an official of one large public sector housing organisation, estimated (subjectively) that only 10% of their projects were 'successful' while an officer of an organisation handling irrigation projects said they had to terminate 20% of their contracts in remote areas due to 'non-performance'. However such information is untested and some of it patently unreliable. For example an officer in a local authority claimed that only 7 of 97 of their ongoing projects were behind time, which was questionable, since it was known that a large number of their projects were suspended or delayed due to restrictions on client funding. Their interpretation may have been against a moving time target, which underscores the problems faced in collecting reliable data on such aspects.

However the availability of some such measure of success, as well as their perceived shortcomings, encouraged a search for more definitive and detailed measures of construction management performance. During this study it was realised, as summarised by Rowlinson (1988) that 'the conventional construction industry variables have been seen to be of limited use in predicting performance except in the contingency form' and also that 'the fusion of conventional construction wisdom and management theory has led to a more worthwhile model of the project process'.

3.1.2 Chapter Outline

Section 3.2 examines fifteen recent approaches to modelling and using performance Criteria, while Section 3.3 proposes a system of evaluation Criteria to be based on a modelled set of contextual factors that affect each project. Section 3.4 describes how some of these factors affect the performance Criteria. Section 3.5 examines some of the performance Criteria themselves. Inputs from contemporary management theory are briefly appraised in Section 3.6, with a view to reaching more reliable and realistic judgements in evaluating qualitative aspects of construction management performance. Section 3.7 concludes with the need to develop a set of Indicators against which to evaluate each of the proposed Criteria as well as the need to incorporate the selected contextual variables, the performance Criteria and their Indicators in a pilot evaluation system for testing on some sample projects.
3.2 SOME RECENT APPROACHES TO MODELLING PERFORMANCE CRITERIA

Performance Criteria are introduced in Section 2.2 of Chapter 2. This section examines 15 recent approaches to modelling such Criteria. Other examples are introduced in relevant sections of this thesis.

(A) Franks (1991) summarised clients expectations from a survey of 50 clients of buildings projects, ranking their priorities in descending order of importance as follows:

<table>
<thead>
<tr>
<th>Proposed Criterion</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (of essence)</td>
<td>1</td>
</tr>
<tr>
<td>Economy</td>
<td>1</td>
</tr>
<tr>
<td>Price certainty</td>
<td>3</td>
</tr>
<tr>
<td>Aesthetics / prestige</td>
<td>4</td>
</tr>
<tr>
<td>Facility for variations</td>
<td>5</td>
</tr>
<tr>
<td>Technical complexity</td>
<td>6</td>
</tr>
</tbody>
</table>

This illustrated the overall equal importance assigned by the sample to both 'time of essence' and 'economy'. The results were qualified by the remarks of several clients that their priorities varied with the project. 80% of the clients believed that the organisation of their projects could or should be better. In this context it should also be noted that all clients in the sample had used the traditional form of procurement, while 56% had also used project management methods, 40% management contracting, 22% construction management, 56% design and build and 4% the British Property Federation system.

(B) R.L. Chauhan an Associate Professor and Chen Wei Chiang a former Graduate student at the Asian Institute of Technology in Bangkok, developed a 'Quantitative Performance Evaluation Model' which they described in a preliminary paper by that name dated May 20, 1988. They ranked responses to questions from over 100 construction managers in Asia. Noting the absence of quantitative performance evaluation techniques, they identified thirteen main factors which influence management performance as:

(1) Design Defects           (5) Sociological-Cultural Factor
(2) Overall Job Planning     (6) Legal Political Factor
(3) Site Problems            (7) Human Factor
(4) Project Duration         (8) Organisational Factor
They noted management priority allocated to time, cost/profit, quality and overall company strategy in that order, with marginal differences between the first three. Although they proposed three classifications termed 'good', 'fair', and 'poor' in asking questions on job conditions and management conditions, there was an evident reluctance to classify anything as 'poor' since only 5% of job conditions and none of the management conditions were so categorised.

(C) de Wit (1986) distinguished between project success and the success of the project management effort noting that good project management can contribute towards project success but is not always able to prevent failure. He cited the project objectives as the most appropriate Criteria for success, whereas he restricted the Criteria for success of the project management effort to cost, time and quality/performance. He noted the multitude of objectives of all project stakeholders that made the objective measurement of project success more difficult.

However he quoted macro and micro factors affecting project success. He also suggested a 'Project Success Framework' incorporating all project stakeholders and phases of a project.

(D) Morris and Hough (1986) carried out a major literature survey and listed ten major factors important to project success as:

1. Project Definition  
2. Planning and Design  
3. Politics  
4. Schedule Duration  
5. Schedule Urgency  
6. Finance  
7. Legal Agreements  
8. Contracting  
9. Project Management  
10. Human Factors

They also outlined dimensions of project success allied to the above major factors and listed (1987) 3 broader measures of project success: Project Functionality, Project Management and Contractors (participants) commercial performance.

(E) Phoenix (1979) proposed an integrated system for performance measurement quoting the project managers role as one of continuous differentiation, implementation and integration. The system used a performance measurement matrix with the following parameters as overleaf:
(1) System engineering  (5) Cost/schedule control system

(2) Technical performance measurement  (6) Design to cost

(3) Risk  (7) Integrated logistics support

(4) Configuration Management  (8) Life cycle cost.

He listed corresponding measurement tools, techniques and activities.

(B) Barnes (1988) introduced the concept of measuring 'space' in quality control equivalent to float in time control and contingency in cost control.

Perhaps this could be considered similar to tolerance or quality allowance within a permissible range. Together these three measures could indicate the degrees of flexibility in the project objectives.

(G) Baker et al (1983) studied 650 projects using an evaluation instrument containing over 190 questions and concluded that project success is much more complex than simply meeting schedule, budgetary and technical performance goals. They proposed a condensed version (with 97 questions and multiple choice type answering frames) of their proposed evaluation instrument where all the objective and subjective variables selected had high correlations with success/failure.

(H) McCamish (1988) developed a grading scale for rating managers capabilities, to be weighted by factors considered important for a given role. He extended this to team evaluation, so that judgemental ratings could be translated to comparable, though subjective scores to assess the human performance aspect of project management.

(I) Birrell and Paek (1986) proposed a generalised hierarchical model of managing a construction project, drawing on Birrell's previous studies on how general contractors evaluated their sub-contractors and vice versa. They listed the three major requirements for a pragmatic Expert System using their model to forecast the performance of the management of construction, as: (a) participants (historical data about participating organisations and key people) (b) project data and (c) parameters of performance. They proposed the application of value engineering to the process of construction rather than the end products alone. They claimed that if the elements of the generalised hierarchy of managing construction are performed very well, there can be combined savings in costs and durations of 12 1/2% from normal performance by experts and conversely that a very
poor management performance would add about 20% over the combination of normal expenditures of cost and time, when achieving the same end products.

(J) Kocaoglu (1979) presented a hierarchical decision process for program/project evaluation through the measurement and evaluation of subjective decision factors by a panel of experts during a week of intensive discussions, using tools such as structured questions and pairwise comparisons. The subjective factors were measured at three hierarchical decision levels to determine the significance of program outputs, program goals and program benefits. The three levels were then combined to obtain the relative value of each output with respect to the others. The methodology had been successfully used in two agricultural research projects in quantifying and integrating expert judgement with the knowledge of the program management team.

(K) Kettle (1985) prescribed a procedure for measuring the performance of construction management; using a numerical system based on 9 key factors as identified by him. The first 3 factors were numerical ratios such as total project budget/total project cost, and being unambiguously verifiable were each given a weighting of 0.6. The 4th to 6th factors were assessments of the construction manager's efficiency, also based on prescribed numerical ratios, as those relating to savings generated by the construction management. But since there could be differences of opinion on this, a weighting of only 0.2 was applied; as was also applied to the 7th to the 9th factors being the Engineer's, Owner's and Contractor's evaluation of the Construction Managers. The weighted scores were added up to yield a combined project performance rating.

(L) Stretton (1990) recounted the eight functions of project management as encapsulated in the revised (in August 1987) Project Management Body of Knowledge (PMBOK) as classified by the Project Management Institute of North America as follows:

(1) Scope Management  (5) Risk Management
(2) Quality Management  (6) Human Resources Management
(3) Time Management   (7) Contract/Procurement Management
(4) Cost Management    (8) Communications Management

The ninth basic section of the 'PMBOK' was the 'framework' that integrated these functions. Measures for evaluating such functions can be developed on the basis of the Function Chart described by Stretton, as a detailed Work Breakdown Structure into the function's component processes, activities and relevant techniques.
Rowlinson and Newcombe (1986) in a study of design and construct projects and organisations found that although there was a direct link between achieving cost and time targets and client satisfaction a significant number of clients still expressed satisfaction when either or both were exceeded. They found that Criteria of project success included communications, flexibility of design and construction processes.

Rowlinson (1988) concluded that management organisations and contextual variables were more strongly associated with performance (than the impact of the procurement form variable which he was initially studying). He developed a set of both objective and subjective performance measures such as:

<table>
<thead>
<tr>
<th>OBJECTIVE MEASURES</th>
<th>SUBJECTIVE MEASURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) actual pre-construction time</td>
<td>(1) timely completion</td>
</tr>
<tr>
<td>planned pre-construction time</td>
<td></td>
</tr>
<tr>
<td>(2) actual construction time</td>
<td>(2) total cost of construction</td>
</tr>
<tr>
<td>planned construction time</td>
<td></td>
</tr>
<tr>
<td>(3) final account</td>
<td>(3) physical quality (of building)</td>
</tr>
<tr>
<td>tender</td>
<td></td>
</tr>
<tr>
<td>(4) final account + fees</td>
<td>(4) suitability for purpose</td>
</tr>
<tr>
<td>area</td>
<td></td>
</tr>
<tr>
<td>(5) pre-construction speed (compared to other similar projects)</td>
<td></td>
</tr>
<tr>
<td>(6) construction speed (compared to other similar projects)</td>
<td></td>
</tr>
<tr>
<td>(7) area/actual construction time</td>
<td></td>
</tr>
</tbody>
</table>

Rowlinson also identified contextual and intervening variables that affected project performance under the four headings of:

(1) Project variables
   - physical complexity
   - constraints on budget, time and quality levels
   - certainty of project requirements.

(2) Client
   - sophistication
   - complexity
He found that measures of 'predictability' (for example, on over-runs of cost and time) were associated with variables other than absolute measures of performance (for example speed and cost per unit area). Satisfaction measures while closer associated with other variables were also linked to such predictability measures.

Torrance and Lim (1990) proposed a model of project performance based on environmental, socio-psychological and technical components to test the significance of a concept they termed 'Perceived Site Environmental Uncertainty' (PSEU). They introduced this concept of PSEU based on site uncertainty, as a major variable affecting project performance and tested a number of hypotheses relating PSEU, performance and factors such as task specialisation and site work ambiguity.

Naoum and Langford compared the performance of management contracts and the traditional method of building procurement (1990), using a model containing six headings:

(i) client characteristics (type, experience, business requirements);
(ii) designer characteristics (in-house or external designers experience);
(iii) project characteristics (type, cost, area, complexity);
(iv) contract procedure (competition, negotiation);
(v) procurement methods (management or traditional); and
(vi) project performance (pre-construction time, build time, total time, speed, unit cost, time and cost over-runs and client satisfaction).

Client satisfaction was measured on a scale from 1 to 3, while other measurements were quantitative. One of their conclusions was that to achieve project success, the organisational forms should be matched to the type of client, the client's identified Criteria and priorities in respect of cost, time and quality. The characteristics of the project and those of the professionals also needed matching.

3.3. PROPOSED PERFORMANCE CRITERIA AND THEIR USAGE

3.3.1 Background

The researcher was reassured to find some approaches similar to those adopted while in Sri Lanka, to developing an integrated system of viable, reliable and realistic performance Criteria for evaluating the success or otherwise of a construction project. As the first step in this exercise, it was deemed essential to model the project priorities and constraints as well the contextual conditions. This would then highlight the particular project profile in the context of which performance is required. As suggested in the researcher's M.Sc dissertation (Kumaraswamy, 1985) different project profiles should effectively trigger a 'strategy switch' that would select the appropriate approach to the target project; in this case by adjusting the desirable ranges of the identified performance Criteria; (as described later in section 3.3.5) and even by introducing new project specific performance Criteria or discarding others; (for example if cost is of little concern, while prestige is paramount or a time deadline is crucial).

The researcher presented elements of the proposed performance Criteria and their contextual conditions to experts and industry practitioners interviewed in the UK as outlined in Section 2.4.3. Although their reactions were mixed as to the feasibility of deriving realistic relationships between the different Criteria; the conditions and Criteria as listed were considered reasonable in themselves. A similar response was obtained from Experts and industry practitioners in Sri Lanka who were presented with proposed performance Criteria in three specific sub-sectors of buildings, roads and bridges, as described in Chapters 5 and 6.

3.3.2 Contextual Conditions

The contextual conditions would be ascertained during the initial stage, when being briefed by the client as to needs, priorities, constraints, strengths, weaknesses, special conditions, preferences etc. and by cross-checking on similar local, regional and national (and international where relevant) conditions which could affect the construction project.
All such factors feed into the 'Brief', as in Figure 3 - A overleaf. The project contextual conditions could then be described and used to adjust the typical performance Criteria that had been pre-determined for application on construction projects in that particular sub-sector (for example office buildings) and even of that type (for example multi-storeyed steel-framed buildings):

The following conditions were proposed by the researcher as significant in modelling the context in which project performance should be measured:

(A) **Project** - Sub-sector and project category; value; size; complexity; location.

Relative priorities, of cost, time, quality, risk, safety etc; certainty of scope definition; special conditions and preferences.

(B) **Client** - Ownership and main (commercial/service) functions; organisation structure and style; management information systems in use; general experience; experience in construction projects; source of finance; project briefing and planning systems and personnel; project control mechanisms and personnel.

(C) **Designer** - Availability of disciplines in-house or on call; relevant experience; stability and standing; current work load level, of professionals deployed; attitude (eg: to teamwork); commitment (eg: to client priorities, to performance standards).

(D) **Constructor** - Relevant track record, stability and industry reputation; available resources of adequate manpower, equipment, finance; other major jobs in hand; present priorities and attitude to performance.

(E) **Manager** - (Of design/ of construction/ of total project if different from foregoing (B, C, or D). Managerial track-record; current capacities; motivation; communication and information systems.

(F) **Procurement Method**

(i) Traditional; design & build; construction management; management contracting and (degree of differentiation, with many sub-contractors etc).

(ii) Lump sum; admeasurement; cost plus etc.

(iii) Negotiated; selected competitive; open competitive; in-house (direct labour or with sub-contractors) etc.
DEVELOPING THE BRIEF & THE PROJECT PROFILE

FIGURE 3-A
(G) **Construction Environment** - (local, national and international).

- Technology Levels.
- Labour/equipment mix priorities.
- Special advantages/constraints.
- Current market conditions.
- Risk factors/degrees of certainty of meeting different targets.

### 3.3.3 Performance Criteria

The following performance Criteria were proposed for construction projects in general, for measuring performance during both the design and construction phases. These Criteria were proposed from the point of view of a client, the client's project manager or financier. They incorporate Criteria such as project participant satisfaction (of others) in order to include the element of morale. Satisfaction of either the client (or others) in this context, refers to collective or personal satisfaction, not only that arising purely from achieving the cost, time or quality targets but also for example, from good relationships and work environment. The inclusion of a distinct Criterion for client satisfaction was endorsed by one of the findings of Rowlinson as outlined in section 3.2 (M) previously.

The researcher proposed to the experts and industry practitioners interviewed in Sri Lanka and the U.K. that target scores be assigned for each Criterion, according to:

(i) average performance in similar projects; and

(ii) special priority on this particular project.

Achieved scores can then be evaluated accordingly on a similar scale. Qualitative judgemental assessments can be quantified using appropriate techniques borrowed from contemporary management theory and practice. The following general Criteria were proposed with project-specific Criteria to be added as necessary.

(A) **Cost** - Total as well as unit costs (e.g., per unit area or per hospital bed etc).

   (A1) Certainty of not exceeding cost limit on non-construction as well as construction cost components.

   (A2) Economy of capital cost.
(A3) Cost balance (between elements).
(A4) Life cycle cost economy.
(A5) Cash flow rates.

These would be analysed by management, supervision, direct and other cost components (e.g. by materials, labour, equipment proportions, if relevant; or by cost elements).

(B) Quality
   (B1) Technical specification and standards. Utility/Performance Levels.
   (B2) Aesthetics.
   (B3) Buildability.
   (B4) Durability.
   (B5) Maintainability.

(C) Time
   (C1) Total and unit rates (e.g. per m² of building or per km of road)
   (C2) Certainty of not exceeding overall and itemised time targets (analysed by design and construction stages and milestones).
   (C3) Levels of speed.

(D) Health and Safety
   (D1) Health and Safety Policy & Procedures.
   (D2) Support infrastructure.

(E) Client Satisfaction
   (E1) As organisations.
   (E2) As Individuals involved.

(F) Project Participant Satisfaction
   (F1) Designer.
   (F2) Constructor.
   (F3) Manager.
   (F4) Local Authorities.
   (F5) Important neighbours.
   (F6) Construction industry (e.g. as represented by professional institutions, trade associations).
Risk allocation

(G1) Initial allocation to points where best managed.

(G2) How contingencies were handled.

Technology, Environment etc.

(H1) Appropriateness of technology.

(H2) Technology transferred.

(H3) Innovations.

(H4) Labour/equipment mix.

(H5) Environmental impact.

Note: The foregoing Criteria were concerned mainly with effectiveness in achieving construction project objectives. Other Criteria (eg: of General Management efficiency) may be incorporated depending on the purpose of the evaluation. Such additional Criteria are incorporated in the Framework proposed for a prototype in subsection 7.7.4 of Chapter 7.

3.3.4 Indicators of Contextual Conditions and Performance Criteria

Having identified a set of conditions that would affect each construction project differently from others of its type, and a set of Criteria to evaluate the performance of the project and its management; it is necessary to identify appropriate Indicators by which to measure both the contextual conditions and the performance Criteria.

For example, the complexity of a project may be rated on a pre-determined numerical scale, calibrated according to certain features characteristic of that project category or type. The track-record of a designer or constructor may be rated on a scale as is commonly developed for pre-qualification purposes. Some conditions like procurement method may need absolute rather than numerical classifications. Other conditions such as attitude and commitment may require semantic ratings or judgemental observations to be quantified in some form. Section 3.6 of this chapter examines possible approaches to such exercises.

Table 3-1 overleaf illustrates a summary of the availability or otherwise of Indicators needed to target and evaluate the performance Criteria considered.
<table>
<thead>
<tr>
<th>CRITERION</th>
<th>QUANTITATIVE/ OBJECTIVE INDICATORS</th>
<th>QUALITATIVE/ SUBJECTIVE INDICATORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>many available</td>
<td>needed, eg: on cost consciousness and commitment</td>
</tr>
<tr>
<td>Quality</td>
<td>some available eg: specifications, standards, QA.</td>
<td>needed, on aesthetics, comfort, fitness for purpose etc.</td>
</tr>
<tr>
<td>Time</td>
<td>many available</td>
<td>needed, eg: on dead-line consciousness and commitment</td>
</tr>
<tr>
<td>Health &amp; Safety</td>
<td>minimum statutory levels</td>
<td>needed, eg: on safety consciousness; internal checks</td>
</tr>
<tr>
<td>Client satisfaction</td>
<td>some tried</td>
<td>calibrated indicators needed</td>
</tr>
<tr>
<td>Project participant satisfaction</td>
<td>some tried</td>
<td>calibrated indicators needed</td>
</tr>
<tr>
<td>Risk allocation</td>
<td>some available</td>
<td>needed eg: how contingencies were handled; responsibilities allocated etc.</td>
</tr>
<tr>
<td>Technology &amp; Equipment</td>
<td>some being developed</td>
<td>needed eg: on technology transfer; labour/equipment mix; environmental impact.</td>
</tr>
</tbody>
</table>

**NOTE:** At the very outset, at least a subjective assessment of relative priority levels of all Criteria is needed, to be included in the Brief; and if possible converted to a numerical scale of relative importance.

**AVAILABILITY OF PERFORMANCE INDICATORS FOR CONSTRUCTION PROJECTS**

**TABLE 3-1**
3.3.5 Determining desirable Ranges of Performance Criteria for a particular project

Although each project has its own unique priorities these are hardly ever clearly expressed to those directly involved with the planning and implementation. Even if explicit, they may be forgotten or neglected amidst other project pressures, unless translated into definitive targets at the outset, and regularly reviewed. If priorities change during a project, the targets may be adjusted where possible and where the real and consequential costs of disruptions are relatively less than the potential benefits.

Figure 3 - B overleaf illustrates how the operating ranges of performance Criteria could be estimated by first selecting the broad possible ranges from past projects in that category and by next introducing the contextual conditions of this project which restrict the ranges somewhat (by the weightings introduced). Definitive client limits, for example budget, cash flow or quality standards may impose additional absolute restraints at this stage. The general interactions of relative client priorities next narrow down the operating ranges further, for example by the cost range being 'pushed up' by stringent quality and time targets on a particular project, as compared with the typical projects of this type.

3.3.6 Modelling the Project Performance Profile

Having established the desirable operating ranges of each of the performance Criteria, a specific target in each range may be set, during the project planning, to be achieved by the design, construction and management teams. These individual targets may be combined as in Figure 3 - D to visualise a combined project targeted profile, that could also be compared with similar projects. The target 'score' of each Criterion would be marked on the corresponding axis. The relative priorities would be reflected in the shape of the connecting polygonal profile; for example elongated towards the high priority items and vice-versa.

The shape of the polygons can also compare the relative importance of project priorities with those of similar projects. It would be possible for example for a large public or private sector client to compare different projects in its portfolio.

Having targeted the project performance profile accordingly, one can then evaluate the achievements against each Criterion using the same established Indicators for measurement and plotting the scores on the same set of axes, to reflect the 'achieved' profile.

Assigning one score to each such broad Criterion is not easy, when either planning or evaluating performance. Each sub-criterion in Section 3.3.3, would need to have it's own scoring scale. The exploded view of the tip of one (Quality) Criterion in Figure 3 - D
EXAMPLE OF THE NARROWING RANGES OF PERFORMANCE CRITERIA DUE TO CONTEXTUAL CONSTRAINTS AND PRIORITY INTERACTIONS

FIGURE 3 - B
The further a point is from the origin along any Criterion (or sub-criterion) axis: the better is the performance against that criterion (or sub-criterion).
shows how each set of sub-criteria would in turn have their own profile; and the weighted score from these sub-criteria would be combined to a representative score for the parent Criterion itself. Realistic detailed comparisons as discussed in the foregoing paragraphs would therefore need to extend to the sub-criteria profiles themselves.

These proposals are described in detail in sub-section 8.6.7 of Chapter 8.

3.4 RELEVANT APPROACHES TO MODELLING CONTEXTUAL CONDITIONS OF THE PROJECT

3.4.1 Importance of the 'Brief'

A previous survey of literature and practice (Kumaraswamy, 1985) illustrated the criticality of formulating the right 'Brief' before commencing the design of a building. This is equally if not more true of civil engineering construction projects, where the uncertainties may be more significant. That this is still not sufficiently appreciated was the reason Crow (1990) stressed that analyses of time, cost and quality should be brought forward to the project initiation stage and not wait for the design process to begin. It is at the project initiation stage that the design may be optimised and the project itself designed to match the particular priorities. The quantification of such priorities in a calibrated ranking system for example, would be useful to both the client and the designers.

The following sub-sections illustrate some sample approaches to modelling particular contextual conditions with a view to quantifying the variables.

3.4.2 Complexity

The scale and calibration of complexity would depend on the type of project; for example in buildings, the extent and interactions of special services; the number of building user organisational interfaces, the multiplicity of utility functions; or in roads, the terrain and the related number of bridges and culverts; the soil conditions; the proximity, size and number of burrow pits and quarries etc.

Santana (1990) proposed a classification of three categories (normal, complex, singular), with an allied list of characteristics that would aid the classification.

Rowlinson used a scale from 3 (for low) to 18 (for high) to measure the physical complexity of a building project (1988) incorporating the level of mechanical and electrical works in the contract, the type of production layout required and the designer's assessment of complexity. Rowlinson found that the unit cost measure increased with project complexity; but that construction time was not necessarily increased, because of the higher
control introduced by altering the management variable (improving the quality of management to cope with such complexity).

3.4.3 Organisation Structure and Style

Rowlinson (1988) summarised the work of Lansley et al and Burns & Stalker, in examining relationships between organisational structure, management style and effectiveness in construction and printing organisations. These used the 'control' and 'integration' variables to position different companies on a grid reflecting the structure of organic, bureaucratic and mechanistic (and anarchic) organisations. The appropriateness of the structure to the environment was also examined.

Walker (1984) described 41 different project management structures for construction projects and then demonstrated how an analysis of functions to be performed by different project participants (for example using linear responsibility analysis and charts) could help the design of appropriate structures. The Systems Gap Working Party Report of the Association of Project Managers (1984) used 'Work Breakdown Structures' analysing projects into work packages with clear definitions and assigned responsibilities before comparing different organisational forms and gaps to be closed in project management systems. Clark (1989) differentiated the technical management from the site management, and compared in a matrix format the relative extent of discretion, power and co-ordination within groups. He then compared the functions and roles of managers, such as leadership. Rowlinson and Cheung (1990) reviewed theories of leadership and presented a model to investigate the effect of project management leadership styles on Hong Kong construction projects.

The many classifications of project management structure and style as summarised by Kumaraswamy (1989), would distinguish tall/ flat structures with different spans of control, and layers of reporting and decision making; and functional / project / matrix structures with different degrees of control along functional and project lines; and rigid /bureaucratic/ informal structures with varying requirements for written/ formal communications before action; and diverse degrees of decentralisation/ centralisation of decision making. Indicators could be designed to highlight the relative status of an organisation in any of the foregoing ranges; for example the number of layers of an organisation to be traversed by an approval for concreting; or a valuation certificate.

Overall measures for reflecting the combined project organisation may be also developed, for example the number of people (layers) in all organisations who would be involved in certifying a contractors bill for work done; or the number of people who would need to be incorporated in a project responsibility matrix assigning functions across the
project; the number of interactions required from each key person and the spans of control of each person.

3.4.4 Management Information Systems

The vast body of theory and practice in this field could be harnessed to develop suitable measures for evaluating the effectiveness of getting the right information to the right people at the right time; and the efficiency of cost-effective transmission processes and procedures. The volume of unused or duplicated information, the extent of action facilitated, the impact of decisions enabled and the value of information added at each stage of transmission may be estimated even qualitatively. Crow (1990) analysed the perceived significant lag in information management and the utilisation of computers for same by the construction industry vis a vis finance, banking and the manufacturing industry. He concluded that available project management systems fell short of the objectives of information management and the needs of project management.

Fisher (1990) outlined a modified form of 'structured data analysis', a technique originating from the electronic data processing industry, for mapping, recording and comparing data flows in different organisations. Baxendale (1990) having described the output from such a data flow case study proposed a prototype Management Information System (MIS) for production control.

Communication Audits in other Sectors have established a general body of techniques to draw on in analysing the communications within an organisation with a view to increasing organisational efficiency (Booth, 1986). The International Communication Association identified five data gathering tools namely questionnaires, confidential interviews, network analysis, critical incident analysis and a communications diary; in evaluating measures of information underload, overload, the quality of information, the quality of communication relationships, information bottlenecks, operational communications networks and the effectiveness and efficiency of communications.

A recent publication by the National Economic Development Office (1990) examined the needs, the requirements and the methodology of information transfer in the building industry. On construction projects, measures may be developed to evaluate the speed of transmission 'from input to output' of each such activity as drawing approvals, instructions, variations, payments, certifications and claims.

3.4.5 Different Types of Procurement

Most performance measures to be used would be expected to alter with the type of procurement chosen, for example whether a traditional type of contract or design & build or
management contracting; and also change with the forms of contract used and the method of selection of the project participants such as designers, contractors and sub-contractors; for example whether on competitive bids or on a negotiated/selected basis. The type of procurement system chosen would in turn depend on many other contextual conditions such as project type, complexity, client priorities, industry environment etc.

An extensive body of literature has developed to suggest appropriate types of procurement to suit such differing contextual conditions, (for example Franks, 1984 [1990 edition now available]; NEDO, 1985; Rougvie, 1987; Rowlinson, 1988; and Singh, 1990). These provided examples of approaches to using (mostly qualitative) 'Indicators' of project contextual conditions to help select a suitable form of procurement.

The increasing evidence of alternative forms of procurement, particularly in buildings prompted studies to compare relative suitability of different forms. For example Rowlinson and Newcombe (1986) compared design & build with traditional forms, while identifying important contextual variables such as project complexity, client organisation and it's particular Criteria for judging project success. Naoum & Langford (1990) compared management contracting with the traditional system. In early 1991, the Reading University Centre for Strategic Studies in Construction published a report of the Construction Management Forum comparing construction management with management contracting (Chartered Institute of Building, 1991). Relatively new systems have emerged, for example 'BOOT' or 'build, own operate and transfer' as in some private motorways in the UK and as offered by the Japanese and North Americans for some time (Gale and Fellows, 1989). This research was concerned with the diversity of the types of performance measures required to evaluate the varying roles of the *dramatis personae* in such different scenarios.

### 3.4.6 Market Indicators

A series of Indicators are available to convey the state of the construction industry and the tendering climate (for example the lower mark-ups triggered by a reduced work-load). Tender Price Indices, by the BCIS and the Department of Environment (DOE DQSS Index). Output Price Indices and Factor Cost Indices and other such Indices from NEDO and 'Spons' are available (Tysoe, 1981) to assist in cost projections in the UK; and also to adjust price levels in projects carried out at different times, for realistic comparisons.

### 3.4.7 Technology

Technology is listed as both a contextual variable affecting the performance Criteria as well as a Criterion of performance itself. Measures of the existing technology base in a
A sector or sub-sector would seek to profile the typical capital/equipment/labour mix and compare the range of possibilities on the particular project, for example in concrete mixing, transporting and placing systems, road paving or bridge beam launching and in different formwork systems. Similarly measures of foreign/local inputs and advantages of transferred technology may be estimated.

The Technology Atlas Project (Asia & Pacific Centre for Transfer of Technology, 1989) devised a system of 4 main parameters (based on the actual technology, the organisational, the information and human resources systems and capacities) and sub-sector-specific sub-parameters for use in assessing technology in manufacturing industries such as steel. Simkoko (1989) presented a series of case-studies on the technology transfer environment. The risks of using unfamiliar technologies and the costs of back-up systems to cater for consequential contingencies need to be evaluated as well.

3.5 SOME RECENT MEASURES OF PERFORMANCE CRITERIA

Having examined approaches to measuring the contextual variables affecting a project in the previous sections, this section samples some of the Indicators tried out for evaluating the project performance itself.

3.5.1 Technology

The foregoing sub-section 3.4.6 discussed the technological environment contributing to the total context within which project performance should be modelled. Technological dimensions of project performance are also relevant, particularly to large public sector clients, who could be interested in measuring the effects of technology transfer in large scale irrigation, roadworks or housing programs. The lack of universally agreed standard tools or methods of quantifying the output of technology transfer programmes in the construction industry has been cited by Simkoko (1989).

The Asia and Pacific Centre for Transfer of Technology (1989) is developing sets of 'Technology Contribution Coefficients' by which to multiply output (value added) in order to assess the 'Technology Content Added'. The multiplicity of interacting variables, unknowns and changing conditions make realistic unbiased evaluation difficult.

In countries where employment is a crucial issue, there may already be Indicators of the benefits of generating employment. Differences in project costs and time-scales resulting from the use of different techniques and labour/equipment mixes may be computed and compared, based on output rates and work norms which have to be validated in advance. Informed judgements can then be made in reducing the equipment component for example, knowing the associated costs in terms of time and money.
For example, Ganesan (1976) developed an input-output matrix for the construction process in Sri Lanka, listing major inputs such as different types of basic materials, labour, equipment, consultancy and overheads, vertically; and corresponding to each sub-sector output that he listed horizontally. The chosen sub-sector outputs were different types of building and civil engineering 'products' (e.g.: roads, irrigation works). An employment matrix corresponding to the same input-output process was developed in parallel. He designed an optimisation model based on linear programming techniques, to maximise employment or output in any year in the industry. On this basis Ganesan proposed an integrated technology, appropriate for the building sub-sector to promote employment and output maximisation, and the optimal use of available resources.

3.5.2 Time & Cost

Investigations of past projects in both UK (NEDO, 1988) and Australia (Bromilow et al, 1988) developed Indicators to predict reasonable time scales for building projects based on prescribed classifications. The suggested formulae and methodologies are described in Section 5.4.6. Cost Indicators are described and examples derived in Chapters 5 and 6.

Cost time profiles can also be predicted based on typical S Curve type models as discussed in 2.4.3 and 2.5.3 and as illustrated by Christian and Kallouris (1990).

Cost and time performance measures can be accessed using such techniques in the absence of data for more detailed estimates and programmes (for example at the outset of a project); or in the absence of time for an independent re-analysis during an evaluation.

3.5.3 Value Management

The concepts of 'value for money', combined elements of quality/performance with cost. Associated techniques of 'Value Engineering' were developed from its origin in USA in the late 1940's to find applications in many fields as described by Kharbanda, Stallworthy and Williams (1987). Comparative measures of performance/cost trade-offs are quantified in monetary terms in the fast developing professional service of 'Value Management', itself considered an evaluation technique by Silver (1990). Silver considered the design development stage the most appropriate to carry out a value management study, incorporating functional analysis, generation and evaluation of alternatives, functional area analysis, functional cost analysis, life cycle costing etc. A body of base data is thereby built up to evaluate future projects and alternatives therein.
3.5.4 Risk

Perry & Hayes (1985) postulated that many cost and time over-runs were either attributable to unforeseen events or foreseen events for which uncertainty was not properly accommodated. They related risk management to size, complexity, speed and location of a project.

The risk and uncertainty elements in construction projects should first be modelled, along with the contextual conditions, so as to provide appropriate systems, to handle that risk, for example by tighter control structures with more frequent monitoring, in high risk areas of significant priority. Statistical predictions of risk probabilities in construction are constrained by the unique conditions that apply to each project. A technique for eliciting subjective probabilities as inputs to risk analysis in engineering construction was proposed by Ranasinghe and Russell (1990).

Having predicted the risks, and designed the project structures to transfer risks to parties best equipped to handle them, one set of Indicators of project performance should devolve on how well such risks were handled in practice. For instance, when contingencies arose, what was the average time for resolving major and minor problems; at what level of the management hierarchy were they resolved; what percentage resulted in significant time or cost over-runs; how many times was it necessary to resort to special conditions of contract to resolve disputes; how many times did the type of procurement system fail to allocate responsibility for risks fairly or as originally intended when framing the contracts; and what were the costs incurred on this account?

3.6 VALUE JUDGEMENTS AND QUANTIFYING THE QUALITATIVE

3.6.1 Modelling Management's Value Systems

Lifson and Shaifer (1982) examining decision and risk analysis for construction management in general, and modelling management's value system in particular, proposed the following stages in an evaluation model:

(i) develop hierarchy of values (including classes and sub-classes of elements and a set of decision Criteria);

(ii) define Criteria and their scales of measurement;

(iii) develop utility functions (with scaling factors); and

(iv) formulate objective function.
This approach was consistent with that adopted in this study, and as illustrated in the Sections 3.3 to 3.5

Finlay (1991) suggested surrogate measures of success and described multiple success Criteria in measuring the success of management support systems.

3.6.2 Subjective Assessments

The Overseas Development Administration in it's evaluation guidelines (1988) states that 'often the lack of hard data requires efforts by the evaluation team to collect subjective data through interviews and assessments based on judgements on the spot. There is no \textit{prima facie} reason why an evaluation on the basis of such a subjective assessment should be any less valid than one using hard data. It is however vital that the report of the evaluation should state how the information was collected so that the reader can make his own assessment of its reliability'. Cracknell (1986) had also said that quantification was not essential for the success of the 'Project Framework' system of evaluation, but qualitative measures should be objectively verifiable. Higginbottom (1990) described the simple rating systems used by the ODA, ranging from 'highly successful' to 'unsuccessful' in evaluation summaries.

3.6.3 Surveys, Sampling and Questionnaires

More rigorous semantic gradings are needed in detailed evaluations, to eliminate ambiguities and to structure the subjective responses along pre-calibrated scales, for example. Questionnaires designed by Ranasinghe and Russel (1990) in eliciting subjective probabilities had built-in check/verifier questions following up each primary question, so as to validate the latter; for instance by comparing a predicted probability of an event with another familiar situation and asking if the chances were better. Casley and Krishna Kumar (1988) stated that qualitative methods were iterative, with an ongoing opportunity to revise interview protocols and observation formats with the emergence of new facts. They added that both verbal and non-verbal communications or behaviour should be examined and that qualitative interviews can be used to generate hypotheses and propositions which can then be tested on a wider population using a structured questionnaire.

Principles and procedures to be followed in a survey design, and the selecting of representative samples would have a bearing on the results. The design of the questions themselves are critical, for instance choosing between 'open-ended' and 'closed' questions, avoiding 'leading' and 'loaded' questions.

Calibration of the responses should be an useful exercise in standardising the responses, for example by comparing responses to 'test' questions.
3.6.4  Eliciting the intuitive

'Knowledge engineers' engaged in developing Expert Systems are in a situation where they must extract the intuitive knowledge of an expert and represent it in a structure suitable for easy access by the non-expert. This situation is similar to exercises in quantifying or adequately representing the qualitative. Male and Aspinal (1986) proposed an interactive computer based analytical technique which allowed a manager to assess the quality of his assumptions and judgements in a decision making context; by making explicit what is implicit and intuitive in their thinking using developments from 'personal construct psychology'.

The far-reaching extent of the need for adequately extracting and representing qualitative judgements, has resulted in many ranking and rating based decision-making or evaluation systems for example the Kepner-Tregoe technique demonstrated by McCaffer and Harris (1989) in the choice of construction plant.

For the purposes of this study, techniques based on pairwise comparisons were considered the most likely to realistically extract the subjective assessments of construction industry personnel. Benefits of alternative solutions can be assessed using a series of pairwise comparisons. Supplementary tools including a value scale to rate the degree of importance of different attributes (for example appearance or layout) can also be used.

Such a series of pairwise comparisons within a matrix; and with calibrated scales and well defined terminology for ranking, appeared the most viable approach to eliciting the priorities of a client or a construction project, for example during the briefing stage.

Finlay (1989) listed commercially available computer software packages designed to facilitate the use of such matrices. One such package 'PRIORITIES' incorporates the possibility of weighting and using the different responses of a group of participants. It uses pairwise comparisons in allowing each participant to compare options in pairs. By highlighting any inconsistencies in such stated preferences, it also gives each participant an opportunity to rationalise their ranking, before these are weighted and combined. Another package cited 'MAUD' asks a user to specify similarities and differences between triads of options.
3.7 CONCLUSIONS

The areas surveyed by this chapter are both broad and overlap with the status survey (of literature and practice) in Chapter 2. The structures of these two chapters as indicated by their respective contents pages (or in more detail by the chapter outlines in Sections 2.1.3 and 3.1.2 respectively) convey both the survey methodology and the framework of their findings. The overview in Section 2.7 of Chapter 2 also lists interim conclusions therein.

The focus of this chapter on 'Developing Performance Criteria' directly followed from such interim conclusions in Chapter 2. Similarly the focus on Indicators in the next three chapters derives from the needs established in this chapter. For example, it was established that:

(i) the relative significance of different Criteria would depend on the project profile, which is in turn dependent on the contextual conditions and project priorities;

(ii) 'Indicators' can be used to model such a project profile;

(iii) more and better Indicators than those presently available are needed to model such a profile, as well as to measure performance more reliably and realistically; and

(iv) improved techniques and tools are required to evaluate qualitative observations and subjective judgements in such exercises.

At this stage it was proposed to eventually test such developed Criteria and Indicators in a pilot evaluation system, so as to validate and develop them further; and demonstrate their usefulness.
## CHAPTER 4: CONSTRUCTION INDICATORS AND EVALUATION

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CHAPTER 4: CONSTRUCTION INDICATORS & EVALUATION

4.1 INTRODUCTION

Previous chapters have highlighted diverse approaches to evaluating construction projects, all of which demand the distillation of mountains of otherwise meaningless data into useful management information. A tried and tested shorthand system of representative parameters would be central to such a formidable exercise in distilling the vast volumes of paper, opinions and computer captured data, that may often be sourced from the many organisations connected with any project. Such data, to be of any use, would have to be translated to an established set of Indicators, in order to project an instant overview of the construction project.

Such Indicators on each project, would provide the language in which to communicate the project status and that of its management. Furthermore, evaluating such Indicators would itself indicate the directions from which to approach and analyse a formidable collection of project data.

This chapter introduces such Indicators in general as well as in specific fields, particularly construction. It explores the need for construction Indicators before proceeding to examine different types of Indicators and how they could be integrated into a comprehensive family of Indicators. Finally this chapter looks at how Indicators could be incorporated into an evaluation system for construction projects and their management.

4.2 WHAT ARE INDICATORS?

4.2.1 In General:

This study has taken Indicators, to mean the shorthand symbols of communication that could represent an otherwise unmanageable mass of data. Indicators could thus summarise a situation, or capture and project a trend.

They can also provide short-cuts for busy managers or professionals to make relatively rapid first-order assessments (for example, in estimating) or evaluations (for example in monitoring or comparing). In this sense, Indicators could be said to be 'proxies
for measurement, when direct measurements are difficult, or perhaps when they would take too long (and even constitute an 'overkill' for the job at hand). For example, in formulating a cost plan for a feasibility appraisal, in the absence of detailed project data, one may use Indicators to formulate the initial estimates based on similar past projects.

Indicators can take the form of ratios, averages, ranges, variances, weighting coefficients, rankings/ratings, cut-off/threshold values, formulae or thumb-rules. They could for example, indicate measures of average (mean, median, mode), measures of dispersion (standard deviation) and correlation (correlation coefficient).

4.2.2 In Economics:

Indicators are commonly used to summarise the strengths, weaknesses, patterns and trends of national economies: For example financial, economic and monetary Indicators such as per capita Gross National Product; rates of inflation, foreign exchange, unemployment and base interest rates at national level; production and productivity Indicators at sectoral level; financial ratios at organisation level and 'internal rates of return' or 'payback periods' at project level.

4.2.3 In Science and Technology

There was evidence emerging from the 1980’s of an international interest in developing Science and Technology Indicators. For example, the Commonwealth Science Council launched an initiative for a commonwealth-wide study through a Workshop in New Delhi, on "Science and Technology Indicators for Development" in collaboration with the National Institute of Science, Technology and Development Studies of India. Sri Lanka was one of the many countries to follow up on this initiative. In 1987 four Science and Technology Indicators projects were launched by the National Resources, Energy and Science Authority (of Sri Lanka) in collaboration with the Commonwealth Science Council. These focussed on 'Science & Technology know-how in the Agriculture sector'; on 'Organisation Structures in Science & Technology'; on 'Industries and Industrial Technologies'; and on 'Scientific Research in Sri Lanka'.

Meanwhile in the USA, the National Science Board has been publishing Science Indicators biennially since 1972.

The Asia & Pacific Centre for the Transfer of Technology, in India (set up by the Economic & Social Commission for the Asia & Pacific, of the United Nations) sponsored
the Technology Atlas Project for the assessment of technology content in various industries. Different technologies are assessed (Asia and Pacific Centre for Transfer of Technology, 1989) for their technology content, through 'Technology Contribution Coefficients' evaluated by rating identified technology components. These would lead to useful technology Indicators.

4.2.4 In Construction:

Certain countries with well established construction industries, have been gradually evolving their own sets of Indicators, which are useful both:

(i) at a macro level, especially where governments try to use the construction industry as a regulator of the economy, for example by expanding or shrinking public expenditure on new construction, or maintenance/rehabilitation; and

(ii) at a micro level; for instance providing useful cost and price indices and average elemental analyses of typical building projects in a particular sub-sector and location eg: secondary school buildings in Sydney, Australia as published regularly in journals such as the 'Building Economist' of the Australian Institution of Quantity Surveyors, or the Building Cost Information Service (BCIS) of the Royal Institute of Chartered Surveyors, UK. Such data is useful in feasibility studies, cost planning during design, and cost comparison and control mechanisms.

Unfortunately, Sri Lanka is only just beginning to develop Indicators on such lines, through the Institute for Construction Training and Development (ICTAD).

However, engineers and builders in Sri Lanka, as elsewhere, have been both consciously and unconsciously using other types of Indicators for a long time. Some of these are cost per square foot of gross floor area; cost per acre foot of water stored; cost per kilometre of standard width road or per "square" (100 square feet) of road surfacing; cost per kilowatt hour of energy generated or cost of plant per kilowatt of power; cost per hospital bed or school desk or hotel room; output per man day in terms of work done, say for example, cubes of excavation or brickwork (work norms); output per man-month in terms of money value; ratios of material: manpower: equipment in an operation; the number of days to construct a floor (through a cycle of formwork, reinforcement and concrete) on a multi-storeyed building structure.
Such Indicators have usually served some purpose by themselves (in the absence of anything better), but need to be refined, weighted and standardised, after drawing on nation-wide historical data, to be of general use. Furthermore they can not be viewed in isolation of related factors such as quality levels. For example, the cost per hotel room (or cost per square foot of hotel building) would vary widely with it's 'star' rating.

Other Indicators have emerged to complement the picture. For example:

(i) the average speed of construction in UK in multi-storeyed building projects was said to have increased from over 157 m²/week to over 169 m²/week over the 10 years up to 1989; while the Broadgate project in London was said to have achieved the then fastest known construction speed of 627 m²/week, claimed to be faster by 50% than the average North American building project (Gale and Fellows, 1989); or a more bizarre:

(ii) 'the acceptable rate of fatalities on such projects in other parts of the world was three deaths for every mile of tunnel. Today the Authority prides itself on it's record of only one death for every mile of tunnel, but --- ' (from a book by Brad Collis relating to the 1960's, as quoted by the Editor of the Journal of the Institution of Engineers, Australia, 1990).

In addition to such Cost, Time and Safety, Indicators, other Indicators of Quality/ Performance/ Specification; of Technology levels employed; of Client Satisfaction; of other project Participant Satisfaction; and of Risk Apportionment would project the broad profile of the project, at a primary or higher level.

At a more detailed level, secondary Indicators, could facilitate comparison of elemental unit costs or elemental percentage contributions (for example, of windows) with that of a database of similar projects (as in the BCIS). At a tertiary level, material: labour: equipment: overhead ratio may be compared by contractors; or steel/concrete ratios may be compared by designers, for example 1 tonne of reinforcement per 13.5 m³ of concrete on average for office buildings; or 1 tonne per 15 m³ for residential buildings (Institution of Structural Engineers, 1985).

Such broad average indicators should not be used blindly, but allowances made for unusual spans or special foundations. In fact such allowances can be built into the evaluation through weighting indicators or coefficients applied to modify the parent Indicator.
How the passage of time affects Indicators is also of vital importance to their usefulness. Economists use what they term 'leading (or 'forward') Indicators to obtain advance warning of for example a change (or trend) in a phenomenon or another Indicator such as the Gross National Product. In the construction industry at a macro level, leading Indicators like the numbers of advertisements for vacancies or calls for tenders in professional magazines signal changes in the volume of work.

At a micro or project level it is difficult but more useful to develop such leading Indicators that forewarn management of impending dangers or crises; rather than lagging Indicators that would be too late for corrective action on ongoing projects, although still distilling lessons to be learned for future projects. For example Indicators of 'physical progress' provide real-time or 'coincident' Indicators; whereas 'Clients payments to contractors' would constitute a lagging Indicator of work done. Clients requests for changes and most management Indicators such as spans of control or those relating to management styles and communication channels would provide leading Indicators of developments to be anticipated in a project, based on comparisons with Indicators and situations arising in similar projects.

In using Indicators derived from a database of past projects, it is useful to update the database not only by weighted price indices, but also by applying higher overall weightings to more recent projects, as these would take account of recent trends, for example in market conditions or technology and resource mixes.
4.3 WHY USE CONSTRUCTION INDICATORS?

Construction Indicators could provide the vocabulary of a common language of communication transcending geographical and professional boundaries, in order to summarise and compare construction projects and scenarios with the norms.

Such Indicators could be used:

(i) as short-cuts to quick first approximations, for example in estimating, cost planning or programming;

(ii) as executive summaries of a mass of unwieldy data to refine data for rapid management overview;

(iii) to identify the profile of a sector, technology, or sub-sector of a project;

(iv) as a shorthand medium of communication and comparison within similar sub-sectors or projects; and

(v) as an alarm signal to alert management to drastic deviations from the norm (variances) in a given area, thereby triggering corrective action.

4.4 HOW TO USE CONSTRUCTION INDICATORS

The critical role that may be assigned to such Indicators dictates that they should be proposed, developed, tested and validated very carefully. Continuous up-grading and up-dating is needed, drawing on a dynamic databank for feedback.

The wide variety of variables distorting any projected construction scenario and sensitivities to specific situations warrant professional cross-checks, rather than relying solely on such Indicators for crucial decisions. Here they should be recognised merely as broad first approximations.

Conversely, Indicators may be used for cross-checking more rigorously derived conclusions, say, as to the cost effectiveness of a particular construction operation.
In this general context, construction Indicators may be used by planners and estimators, financiers and project sponsors, designers and their cost advisors, construction managers, cost and progress controllers, and evaluators. Approximate Indicators would provide the framework and base-line levels against which such project participants could formulate comparisons.

4.5 TYPES OF INDICATORS

A vast and assorted battery of Indicators, may be developed in the realm of design and construction. It was therefore necessary to identify the thrust of a pilot study into Indicators in Sri Lanka, so that the required Indicators may be isolated from the almost infinite possibilities.

4.5.1 Implementation (and not Benefit) Evaluation

This study focuses on the process of design and construction and the effectiveness and efficiency of the management thereon. Thus one would initially differentiate implementation monitoring/ evaluation from benefit monitoring/ evaluation (Jayawardane, 1987). This presupposes that the benefits have in fact been accurately assessed in advance and realistically built into:

(a) the Project and Design Briefs; and, after value engineering, cost/ benefit analyses or equivalent exercises, into the agreed:

(b) cost estimates, cost plans, budgets, programmes, quality assurance systems; and

(c) even finally encapsulated and described in the project procedures or project manual, if any.

An evaluation of how well the management achieved such targets can be undertaken thereafter. The construction project implementation process cannot be responsible for the end benefits (eg: the internal rate of return) not achieving the original projections, for example due to shifts in the external environment (eg. markets). But a responsibility is retained to accurately design and plan the project and convey to the client, the costs, programmes and envisaged performance levels, during design and planning, as well as to achieve such targets. (Unfortunately, adjustments are often necessary during the project to fine-tune the process to chase moving targets. But the system should be able to manage
such change, with efficient response mechanisms geared to definitive client priority adjustments, for instance due to a sudden truncation of funding sources).

Therefore the search for Indicators in this study first narrowed down to process and implementation Indicators, excluding benefit Indicators such as Cost-Benefit Ratios other impact Indicators such as environmental impact verifiers. But environmental effects during the construction process itself, for instance, depending on the technology used, needed to be included in the evaluation. Furthermore direct benefits expected from the design itself, (like quality, performance or utility levels) had to be measured and matched against the Brief.

The foregoing thrust also directed the study to micro (project level) rather than macro (sectoral) Indicators, except that it was necessary to compare project Indicators with those derived as averages (typical values) from at least a complete sub-sector (for example buildings).

4.5.2 Input, Output and Process/Transformation Indicators

Any economic or industrial process, involves the transformation of inputs (for example, resources such as management, labour, equipment and materials) into outputs (for example, buildings or dams). Indicators may be developed to compare:

(i) the inputs (eg: management structure & style; technology level)

(ii) the outputs (eg: quality & utility levels achieved)

(iii) the efficiency of the transformation process (eg: connecting an input [money] with an output [building area], say, in terms of cost per m²)

4.5.3 Financial and Physical Indicators

In Sri Lanka, it has been argued by many senior engineers and planners that 'financial progress' is not always a realistic measure of 'physical progress' on construction projects (Jayawardane, 1987). This was based on reasoning such as 'the completion of major critical but possibly low value items on many construction projects, not reflecting in the project financial status'. Further distortions were introduced by heavy critical expenditure on plant and advance payments on long order items, as well as by delays in payments. Therefore, expenditure Indicators were not reflecting actual work done
(Ambalavanar, 1987). This led to a hasty search for approximate physical Indicators to monitor public sector projects through suggested project component/activity percentage breakdowns. Unfortunately there is no evidence of the initially proposed physical Indicators being even tried out in general practice, and each organisation continued its often ad-hoc approaches to evaluating progress.

Apart from the need to test and validate such broad physical Indicators (linked to major activities completed in each type of construction), it would be useful to refine such percentage contribution components to physical progress, perhaps as follows: each activity could be assigned a physical progress importance component weighted by contributory factors such as:

(i) ratio of activity duration to project duration;

(ii) special skills and other scarce resources content;

(iii) criticality, as indicated by float parameters; and

(iv) value (or cost)

Physical Indicators cannot be used in isolation however, but would need to be supplemented by the appropriate financial and other Indicators.

4.5.4 Towards a Classification of Indicators

In 4.2.4 previously, the range of Indicators possible in the realm of construction project evaluation was taken to include those measuring cost, time, quality/performance/specification/utility, safety, technology, project participant satisfaction and risk apportionment.

Primary, secondary and tertiary Indicators were also introduced previously in Section 4.2.4.

Linkage Indicators may be developed to model the effect of one Indicator on another (say, the effect of cost priorities on quality aspects). The sensitivities to each other are thereby modelled.
There could be further combination Indicators, for instance, combining time, technology and cost factors, by projecting the efficiency of resource planning say, through resource utilisation/resource idling Indicators.

Qualitative Indicators could distinguish the representation (through rankings, ratings and other comparative techniques) of subjective variables, as opposed to quantitative Indicators.

Weighting Indicators could assign weightings to each of the typical primary, secondary or tertiary Indicators, according to the special conditions affecting the project that distinguish it from the typical project, so that typical (average, prescribed or expected) values may be adjusted to accommodate such differences.

4.6 FAMILIES OF INDICATORS

4.6.1 Spanning the Project Spectrum

To achieve an overview of an ongoing or completed construction project through Indicators, it is essential to first identify a comprehensive and connected family of Indicators that can efficiently capture, condense and communicate the data in that type of project, for example a road rehabilitation exercise. To ensure coverage of all relevant performance Criteria during the initial high level evaluation, one could horizontally cross-link the cost, quality/performance/specification/utility, safety, technology, satisfaction and risk Indicators at the top most primary level as in Figure 4 - A overleaf.

4.6.2 Extending the Hierarchy of Indicators

The next step would vertically connect families of secondary and tertiary Indicators to the parent primary Indicators; for example, descending from the broad Indicators of overall building 'cost per square metre' to a secondary level of 'elemental cost per square metre' and 'elemental unit costs', and to tertiary tiers of 'relative material consumption ratios' or broader 'resource cost breakdown ratios' in an item like reinforced concrete.

A hierarchy of appropriate Indicators (relating to performance Criteria) would thereby emerge as in Figure 4 - A, for each category of construction project. While there may be a large core of Indicators common to most construction categories overlapping across different models, some others may be unique to particular domains, eg: on irrigation headworks or downstream channel works.
The objectives of proposing such a hierarchy of Indicators are:

(a) to structure them in a family of primary (parent) Indicators each with related secondary and tertiary Indicators, in progressive levels of detail; and

(b) to thereby rationalise the evaluation process by testing only a reasonable number of (overview) Indicators at a primary level; and narrowing down the subsequent search domains to secondary (and then tertiary) Indicators related only to deviant primary (and then secondary) Indicators.
A TYPICAL FAMILY OF INDICATORS
(in a specific sub-sector)

FIGURE 4 - A

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4.6.3 Weighting, Linking and Calibrating the Indicators

Ranges and average values could be derived for each such Indicator, based on a database of recent projects of that category. Where possible the categories of projects could be further narrowed down ie. where there is data on a statistically significant number of projects of each sub-category eg: multi-storeyed school building projects (main category), of Rupees 1 to 5 million value (sub-category), in the central region of Sri Lanka (sub-category), using traditional procurement systems (sub-category). While the average values of such Indicators may be considered typical, weighting Indicators may be employed to weight the values in order to cater to project-specific factors. For instance wall/ floor area and circulation/ utility area ratios would weight the typical cost and elemental cost Indicators, before comparison with the equivalent project Indicator itself.

Furthermore, relationships to other (horizontally) cross-linked Indicators may be 'modelled in' through linkage Indicators so as to shift one set of Indicators (say cost) to a different operating range, because of the constraints imposed by a rigid project priority assigned to a second set of Indicators (say time).

Calibration of the Indicator values could be approached by identifying the upper and lower bound values and the type of variation within the range (linear, polynomial or exponential etc) depending also on the weightings and linkages (sensitivities to other variables).

4.6.4 Using a Family of Indicators

Having thus developed the norm Indicators in a particular category or sub-category, and adjusted them to appropriate 'target' Indicators that match the specific project profile; the actual project Indicators themselves may then be derived (computed or estimated) and compared with such target Indicators.

The formidable array of figures and formulae flowing from Figure 4 - A, may discourage an evaluator looking for a quick first-order evaluation. But the process could be simplified by initially comparing only the first-order broad Indicators at the primary level. Deviations from the norm in any of the project primary Indicators could then trigger an alarm prompting deeper investigation of those particular families of secondary Indicators as in figure 4 - B overleaf. The deviant secondary Indicators could identify the problem elements or areas, prompting a search leading through abnormal tertiary Indicators to the
SELECTING FROM A TYPICAL FAMILY OF INDICATORS
(in a specific sub-sector)

FIGURE 4-B

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root causes of the problems; be they poor materials management, shoddy supervision or fraud, for example. There could be other types of reasons, for example, stemming from the pre-construction phase (over-design, poor cost planning or unrealistic estimating). Justification for some variances may emerge from certain project conditions diverging from the norms/standards assumed.

The route through the hierarchy of Indicators is thus narrowed, by only proceeding down paths identified by warning signals at each horizontal level. This precludes for example, analysing and computing Indicators on the time-frame/progress family, when the primary Indicators signal that all is well in that domain.

However a *caveat* is in order when by-passing apparently 'normal' primary Indicators. For example, a cost-saving indicated by a positive (good) materials cost variance Indicator (vide Figure 4 - C overleaf) may mask a high negative price variance (reflecting over-spending on purchases) which is over-compensated by a very high positive usage variance (reflecting large savings on materials used even by cutting corners or cheating!). Here, one may need to investigate both the tertiary Indicators of price and usage variances, instead of being lulled into complacency by a seemingly normal materials cost variance secondary Indicator. Random checks and the intelligent approach of an experienced evaluator can minimise such pitfalls.

Each Indicator may also have connected tool-kits, for example including performance and trouble-seeking checklists, trouble-shooting charts and such standardised formats for further data collection and analysis, as well as reconciliation charts (eg: for materials or labour usage). Such tool-kits could be used to explore the areas summarised by an Indicator in greater depth.

4.7 **HOW INDICATORS COULD BE USED IN EVALUATION**

The previous sub-section (4.6.4) identified the need for a systematic structured approach to evaluating construction projects through Indicators and associated tool-kits.

However, another *caveat* is in order at this point; in order not to disregard the value of the subjective/judgemental assessments, statements, opinions and pointers generated by interviewing project participants at different levels and from the various contributing organisations. Such inputs could give the search firmer direction and take it through narrower paths. Interim results may be either reinforced or even discounted by explanations.
COST VARIANCE INDICATOR(S)

LABOUR COST VARIANCE INDICATOR(S)

MATERIALS COST VARIANCE INDICATOR(S)

MATERIALS USAGE VARIANCE INDICATOR(S)

MATERIALS PRICE VARIANCE INDICATOR(S)

MATERIALS MIX VARIANCE INDICATOR(S)

MATERIALS YIELD VARIANCE INDICATOR(S)

KEY

Deviant Indicators

PART OF A FAMILY OF COST VARIANCE INDICATORS

FIGURE 4 - C
that justify special divergences due to project-specific conditions, which do not reflect in
the regime of Indicators designed for that domain.

Such information gathering through interviews, questionnaires or site 'walk-
abouts', would necessarily follow semi-structured formats themselves; be correlated to
reflect a reasonable cross-section; and minimise the risks of vested interests camouflaging
certain areas, while giving prominence to others.

A complementary approach is thus envisaged in formulating a suitable system, so
that the analyses of project data to yield Indicators of levels of failure/ success is
synergistically supplemented by the views of the dramatis personae themselves.

Such views, may well be conditioned by their background experience, stakes in the
project, and the project dynamics including the memorable (but possibly less significant)
events. To extract the essence the evaluator would therefore need to be supported by up-to-
date techniques from Human Relations, Marketing, Decision Theory and such regimes
that aid sample selection, questionnaire design and ranking/calibration of such subjective
statements. Obtaining opinions in pre-designed semi-structured formats would be the first
step in such a process.

4.8 PILOT MODEL OF AN EVALUATION SYSTEM USING INDICATORS

A basic structured approach to evaluating construction projects, using Indicators and
direct input from project participants is illustrated in the flow charts in Figures 4 - D and 4 -
E. Figure 4 - D indicates the preliminary formulation of the evaluation system with the
development of Indicators and the assembly of the tool-kits in a particular sub-sector or
domain; for example, large span pre-stressed concrete girder bridges on piled foundations,
in the Southern and Western provinces of Sri Lanka. Each and every stage could also draw
on experience, formats and families of Indicators developed in previous exercises in similar
sub-sectors; if only to draw on the methodology of those approaches.

Figure 4 - E illustrates the application of such an evaluation system to a specific
project that is identified for monitoring and corrective action, by top management of the
construction organisation or by the client himself. Each and every stage would draw on the
appropriate sub-systems and use tools from the pre-developed domain specific evaluation
system. For example even the preliminary interviews would draw on suggested domain
specific formats for same.
INVESTIGATE RECENT PROJECTS BY COLLECTING, ANALYSING & CODIFYING DATA AND INTERVIEWING EXPERTS & KEY PARTICIPANTS

DERIVE & DEVELOP PRIMARY INDICATORS OF PROJECT PERFORMANCE (INCLUDING AVERAGES, RANGES ETC.)

FORMULATE, TEST & REFINE SEMI-STRUCTURED QUESTIONNAIRE FORMATS

MODEL RELATIONSHIPS BETWEEN PRIMARY INDICATORS (EG: CORRELATIONS, SENSITIVITIES ETC.).

DERIVE & DEVELOP SECONDARY & TERTIARY INDICATORS

PROPOSE & REFINE TROUBLE-SEEKING & TROUBLE-SHOOTING THUMBNAILS, CHECK-LISTS, FORMATS ETC. (EG: VARIANCE ANALYSIS AND RECONCILIATION CHARTS)

DEVELOP LINKAGE INDICATORS

DEVELOP FURTHER WEIGHTING INDICATORS

FORMULATE: (1) STRUCTURED FAMILIES OF INDICATORS WITH TYPICAL VALUES, WEIGHTING ALLOWANCES, CROSS-RELATIONSHIPS, EXPECTED RANGES AND ASSOCIATED CHECK-LISTS

(2) SEMI-STRUCTURED QUESTIONNAIRE / INTERVIEW AND INVESTIGATION FORMATS

BASIC STEPS IN FORMULATING AN INDICATORS BASED EVALUATION SYSTEM FOR A PARTICULAR CONSTRUCTION SUB-SECTOR

FIGURE 4-D
DETERMINE & ASSIGN WEIGHTING & LINKAGE COEFFICIENTS TO PRIMARY INDICATORS

SELECT SUITABLE SAMPLE OF PROJECT PARTICIPANTS

DEVELOP/ MODIFY BASIC SEMI-STRUCTURED QUESTIONNAIRES & DATA FORMATS

INITIAL INTERVIEWS

INVESTIGATE SUSPECT & RANDOM AREAS WITH TOOL-KIT OF BROAD CHECK-LISTS

APPLY DETAILED CHECK-LISTS & RECONCILIATION FORMATS

INITIAL DATA COLLECTION AND ANALYSIS

FURTHER DATA COLLECTION AND ANALYSIS

FURTHER INTERVIEWS

DETAILED DATA COLLECTION

DETAILED INTERVIEWS

INDICATE MAJOR VARIANCES FROM (a) BRIEF (b) SUB-SECTOR NORMS; IDENTIFY CAUSES AND RECOMMEND REMEDIAL ACTION IN THIS OR FUTURE PROJECTS

APPLYING AN INDICATORS - BASED EVALUATION SYSTEM TO A CONSTRUCTION PROJECT

FIGURE 4 - E

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Figures 4 - A and Figure 4 - B illustrate how the family of Indicators developed for any sub-sector, when applied to a particular project, can be selectively used, by proceeding only down paths highlighted as needing investigation, when alarms are sounded by deviant Indicators at the higher levels.

Thus, taken together, Figures 4 - A, 4 - B, 4 - D and 4 - E, illustrate the basic development and application of an Indicators-based evaluation system.
CHAPTER 5: DERIVING CONSTRUCTION INDICATORS

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(Note: For lists of Tables herein and related Appendices at the back please see the General Contents at the beginning of this Thesis)
CHAPTER 5: DERIVING CONSTRUCTION INDICATORS

"The Wealth of Nations which depended on Land, Labour and Capital during the Agricultural and Industrial phases, will come in future to depend on Information, Knowledge and Intelligence" - Feigenbaum & McCorduck (1985).

5.1 INTRODUCTION

Getting the right information to the right people at the right time, is assuming increasing importance; and a system of representative Indicators has been identified in the previous chapters as an efficient vehicle for capturing, condensing and communicating the essence of such information.

This chapter expands the basic approach to the derivation of useful Indicators illustrated in Figure 4-D. Indicators to evaluate particular Criteria need to be individually defined and derived; and then need to be integrated, so as to assess their collective contribution to conveying the total picture.

This chapter also documents the methodology of, and results from such an exercise in Sri Lanka seeking Indicators in the Buildings, Roads and Bridges sub-sectors. Other sub-sectors are also compared, as are parallel practices and developments in other countries. The Indicators that are defined and derived as described in this chapter are developed further in Chapter 6.

Section 5.2 describes a basic general approach to selecting and describing general Indicators of inputs, outputs and the transformation process itself. Section 5.3 provides an overview of the objectives and methodology of the pilot investigation into Construction Project Indicators in Sri Lanka. Sections 5.4 and 5.5 examine the findings and development of databases and Indicators in the buildings, roads and bridges sub-sectors. Section 5.6 summarises the initial phase of this pilot investigation, the further development of the Indicators being described in Chapter 6.

The UK £ or US $ value equivalent of Rupee values cited may be assessed by referring Appendix AP1-1.
5.2 DERIVING INDICATORS IN GENERAL

5.2.1 Standardising the Approach

The objectivity inherent in defining and deriving a set of standardised Indicators for each sub-sector before evaluating a given project, would in itself counter criticisms of how most data could be manipulated to suggest conclusions that corroborate preconceived subjective assessments or collaborate with vested interests. The large volume of data and the many variables in construction increase the dangers of selecting such biased samples during an unstructured evaluation.

A structured or even a semi-structured evaluation, would reduce such bias. However a flexibility is needed to investigate particular areas of concern further; as well as to incorporate necessary subjective assessments within a framework of guidelines. Such a systematic approach would preclude a focus on only obvious or major project deficiencies. Further weaknesses (and strengths) may be uncovered by comparison with the standardised Indicators in that domain.

5.2.2 Selecting & Defining General Indicators

Since this study focuses on the effectiveness and efficiency of the construction process, attention may be first directed towards process or transformation Indicators that would use output/input ratios, as measures of efficiency. In this context a hierarchy of models of the transformation process are illustrated overleaf, commencing from the national level (as in Figure 5 - A); next the industry/sector level (as in Figure 5 - B); and finally the sub-sector level (for example buildings, as in Figure 5 - C).

While some transformation Indicators at national and sectoral level have been cited in Section 4.2.2 previously, it is worth investigating the sub-sectoral ones in detail. Such an exercise initially requires a comprehensive definition of the inputs and outputs.

The change in the sequence and nomenclature of the inputs in the first two models (in Figures 5 - A and 5 - B respectively) is deliberate, in that, for example, construction being an extremely 'management-intensive' industry, would suggest positioning 'management' as the topmost input. Most construction organisations are 'management-driven' and 'management-responsive', as 'good things don't just happen', given the variety of variables militating against order and progress in the construction scenario.
FIGURE 5 - A

FIGURE 5 - B

FIGURE 5 - C

MODELLING INPUTS AND OUTPUTS
Management must make them happen. Money (finance) may be arranged by such management with a track record and potential, so that the lack of capital should not pose serious problems. In turn, using such finance, technical staff and site operatives may be 'bought-in' as would be the materials and plant. A good management track-record would also qualify for some credit in procuring the resources of materials and plant. But this highlights issues such as: 'what are the measures of good management?' and 'How does one compare different 'management performance levels in construction?' For example, general management Indicators would include:

(i) spans of Control: as indicated by the ratio of senior: middle: junior management workers (say: section engineers: supervisors: trades foremen: workers = 1 : 3 : 10 : 100);

(ii) number of Levels in the site hierarchy: (say, 4 in the previous example, 3 in a 'flatter' management structure or 6 in a 'taller' structure);

(iii) degree of Decentralisation: (vs. degree of head office control), as estimated by a point score rating; extracted from answers to questions on the authority to disburse funds and up to what limits; the authority to hire, fire or take disciplinary action and down to what levels;

(iv) speed of Communications and Information systems: their accuracy, efficiency and effectiveness; (with detailed Indicators of information overload, underload, redundancy, shortfalls and transmission time lags;

(v) Decision Times: Response times to various stimuli, or changes;

(vi) Decision Effectiveness: with ratios of 'successful' to 'unsuccessful' major decisions; and

(vii) measures of Efficiency such as Productivity levels relating to output per man-day or per machine-hour.

5.2.2.1 Indicators of Inputs

Similarly (as for Management) Indicators can be defined for each of the important inputs that would help compare it with the corresponding input from another project, or the average of a set of inputs from similar projects.
Interest rates on borrowed funds for example, indicate the cost of the 'money' input. The qualifications, experience and expertise of manpower can be assessed as in individual interviews or organisation prequalification formats as Indicators of potential performance. Collectively, the track record of a team may be assessed using similar Indicators to project future performance. Materials may be measured by their conformity to standards and specifications either on a pass/fail basis or on a graded scale.

5.2.2.2 Indicators of Outputs

Measures of the desirable outputs would be built into the designs themselves; eg: the overall and component specifications and performance levels of roads or bridges. But a large array of such measures would have to be extracted from drawings, Bills of Quantities, project and standard specifications and standards, in order to convey a complete and representative picture. Alternatively special Indicators may conveniently convey a condensed summary, for example (i) that a road can sustain a specified traffic intensity and loading and need maintenance review after 3 years and resurfacing after 10 years; or (ii) that a Hotel is to achieve a 4 Star rating; to also conform to the aesthetic traditions of a particular Hotel chain; to have a specified minimum utility/circulation area ratio; to have 'low' maintenance demands; 'highly' automated building services systems etc. (Such 'lows' and 'highs' should also be rated on suitable scales).

5.2.2.3 Process/Transformation Indicators

These would connect inputs with outputs, in measures of efficiency, usually based on the format of input per unit output, for example, cost per square metre of building; or time per square metre constructed or per kilometre of road surfaced. Although 'Time' was not a primary input resource in any of the models in Figures 5 - A, B or C, it is an important secondary or associated 'resource' connected to each of the primary inputs utilised in that time.

5.2.2.4 Resource Utilisation Indicators

These could also be classified under input Indicators, since they would:
(i) cut across groups of inputs eg: in typical and optimal materials: plant: labour mix ratios; or management: labour ratios; and
(ii) assess the efficiency of each resource deployed in terms of utilisation levels or idling levels.
However their importance justifies them as measures of efficiency. Construction management efficiency, could be summarised simply as optimising resource utilisation in achieving targets; while considering the full range of resources whether primary or secondary; like money, men, management (including organisation systems) machines, materials, information, time and external systems (such as markets, competitors; and even socio-economic and political factors which may be translated into strengths or resources themselves).

5.3 PILOT INVESTIGATION IN SRI LANKA

5.3.1 Background

A proposal for developing 'Construction Industry Indicators' in Sri Lanka was drafted by the researcher in 1987. This was a pilot project within a wider proposal to develop 'Science & Technology Indicators', by the Institution of Engineers, Sri Lanka (1987) and forwarded to the Commonwealth Science Council (CSC) in London; in pursuance of the CSC initiative in Science & Technology Indicators (described in subsection 4.2.3 of Chapter 4 previously). The proposal was formally endorsed by the CSC in 1988. The President of the Institution of Engineers, Sri Lanka (IESL) in 1987, Mr. D.L.O. Mendis, championed the usefulness of Indicators in many fora, including his Presidential address at the annual sessions of the IESL (Mendis, 1987). There was also a parallel need identified by the IESL to collect and record useful data from past construction projects. The absence of such codified information was considered a handicap to the construction industry and the related professions.

These two threads were drawn together by the researcher, when the Institute for Construction Training and Development (ICTAD) requested a specific proposal from IESL in early 1989. It was agreed to commence a pilot investigation into three sub-sectors namely buildings, roads and bridges.

This project was scheduled for 12 months in 1990, and funded by the International Labour Organisation under an existing general Technical Assistance Programme through the World Bank. Although preliminary work had commenced earlier, this pilot investigation officially commenced in late January 1990, with the signing of the Agreement on the 25th between ILO and IESL; and it was completed in early December 1990.
5.3.2 Objectives

The twin objectives of the pilot investigation flowing from the identified needs were:

(a) To assemble a sample database of important information from construction projects in the buildings, roads and bridges sub-sectors of the Sri Lankan construction industry; and

(b) to analyse the information from such a database, with a view to extracting meaningful Indicators of use to construction industry professionals engaged in planning, designing, estimating, managing, controlling and evaluating construction.

Projects of value exceeding Rs. 1 million (about £ 30,000 at 1985 rates or £15,000 at 1989 rates as indicated in more detail in Appendix AP1-1) were to be selected from those that had been completed, preferably within the past 5 years (1985 to early 1990), but if necessary (if projects samples were inadequate in a given category) going back further by another 5 years, i.e. to 1980. A minimum of 30 projects in each sub-sector were deemed necessary to provide a statistically significant sample.

The main reasons for selecting the buildings, roads and bridges sub-sectors for this pilot investigation were that when narrowing down the brief, it was better to focus on areas where: (a) the most data was available for input; and (b) where any useful output could generate the greatest immediate impact. With the completion of the major irrigation headworks projects, most of the forthcoming capital works investment in Sri Lanka was expected in roads. Rehabilitation aid packages expected to finance construction also focussed on roads, bridges and buildings. The buildings sub-sector was an obvious choice because of it's potential widespread usefulness and familiarity to most industry practitioners.

5.3.3 General Methodology

5.3.3.1 Approach

While a general approach to develop Indicators was outlined in Figure 4 - D, in the previous chapter, this is expanded into more specific activities in Figure 5 - D overleaf. Even this model unfortunately presupposes some ideal conditions that are conspicuously absent in construction (eg: complete and accurate data); and also summarises a complex of sub-activities in each activity 'black box'.
DEFINING & DERIVING INDICATORS IN A PARTICULAR CONSTRUCTION SUB-SECTOR.

FIGURE 5 - D
The basic methodology and programme of the pilot investigation had already been mapped out in the agreed project proposal and was implemented as summarised herein.

5.3.3.2 Constraints

The pilot investigation was severely constrained by the difficulties of drawing data from 'dead' projects; since much of the data was lost and most project participants unavailable. There was also a resistance to divulge some information for reasons of confidentiality or vested interests in either promoting or suppressing a controversial issue. Such problems were anticipated and in fact, a calibration system for the perceived credibility of interviews was incorporated in the project data-sheets. However there were difficulties in calibrating or cross-checking because of the limited exposure to some participants and the non-availability of others.

5.3.3.3 The Investigation Team

This researcher as Team Leader, was given a free hand in recruiting Research Assistants and managing the project. An Architect, served as the Research Assistant in the buildings sector, while 5 Civil Engineers (four of them Chartered) were commissioned to investigate the roads and bridges sub-sectors at different stages; (two of them having to relinquish their assignments when they left the country). Another Civil Engineer assisted with the analysis of the data collected. Each of the Research Assistants devoted at least 3 days a week to this investigation.

There was a six member review panel of local experts, who monitored the project in addition to ILO and ICTAD officials overseeing it.

Periodic advertisements and articles in the IESL Newsletters called for interested Engineers to join in or contribute to the investigations. A reasonable response and feedback was obtained.

5.3.3.4 Initial Stages

Initial interviews to extract sub-sector thumbrules used as Indicators by experts, did not yield specific results. However attention was simultaneously focussed on proposed classifications to suitably group projects into comparable categories. This was especially important in roads and bridges where there was much confusion and conflict as to the best
classification. Experts were consulted in parallel on improving the data-sheets designed for investigating the projects in each sub-sector. These data-sheets were up-graded by the inputs from experts interviewed, as well as from an ILO expert Mrs. Patricia Hillebrandt, ICTAD officials and the Review Panel. The data-sheets for buildings, roads and bridges are appended as Appendices AP5-1, AP5-2 and AP5-3 respectively.

The classification into categories of projects (e.g., schools, hospitals, multi-storeyed housing; or different types of bridges or roads) underwent further changes during the progress of the project as determined, by (a) incoming data and (b) further expert opinion. These classifications were finalised after the intensive inputs from the Workshop on 9th October 1990, and the final formats adopted for buildings, roads and bridges are appended as Appendices AP5-4, AP5-5 and AP5-6 respectively.

A basis for up-dating the monetary (Rupee) values of data to early 1990 values for comparison where necessary, was prepared as detailed in Appendix AP5-7.

5.3.3.5 Defining and Deriving the Indicators

The literature search was limited by the lack of local documentation, that was in fact one of the drivers for the investigation. However, comparative studies and even practices in UK, Australia and Hong Kong were used to identify useful directions for the investigation, for example in the regime of price indices, sub-sectoral and regional cost Indicators. For instance, one such parallel was the possibility of identifying cost significant elements in a sub-sector, that would facilitate better cost predictions based on approximate analyses.

In the field studies, the bottom-up approach went through the difficult process of extracting data from incomplete records and the painstaking search for patterns and representative averages through analysis. This was supplemented by a top-down approach, probing the expectations of experts, whether in the form of consciously or sub-consciously used thumbrules. At this intermediate stage, it was possible to expose emerging patterns from the data, to the experts (for example the elemental percentage breakdowns) and generate constructive reactions. This confirmed that such sub-conscious thumbrules used by experts could be triggered when confronted with a specific situation or a contradictory argument.

Organisations from which significant project data was drawn, are indicated in Table 5-1 overleaf.
<table>
<thead>
<tr>
<th>NAME</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road Development Authority.</td>
<td>Public Sector; Client/Consultant.</td>
</tr>
<tr>
<td>Road Construction &amp; Development Corporation.</td>
<td>Public Sector; Contractor</td>
</tr>
<tr>
<td>Central Engineering Consultancy Bureau.</td>
<td>Public Sector; Consultant.</td>
</tr>
<tr>
<td>Engineering Consultants Ltd.</td>
<td>Private Sector; Consultant.</td>
</tr>
<tr>
<td>Colombo Municipal Council.</td>
<td>Local Authority; Client/Consultant.</td>
</tr>
<tr>
<td>Mahaweli Engineering &amp; Construction Agency.</td>
<td>Public Sector; Consultant.</td>
</tr>
<tr>
<td>Design Consortium Ltd.</td>
<td>Private Sector; Consultant.</td>
</tr>
<tr>
<td>State Engineering Corporation.</td>
<td>Public Sector; Consultant &amp; Contractor.</td>
</tr>
<tr>
<td>Surath Wickramasinghe Associates.</td>
<td>Private Sector; Consultant.</td>
</tr>
<tr>
<td>National Building Research Organisation.</td>
<td>Public Sector; Consultant.</td>
</tr>
<tr>
<td>Link Engineering Ltd.</td>
<td>Private Sector; Contractor.</td>
</tr>
<tr>
<td>Ceylon Electricity Board.</td>
<td>Public Sector; Client.</td>
</tr>
<tr>
<td>Sri Lanka Navy.</td>
<td>Public Sector; Client.</td>
</tr>
<tr>
<td>Buildings Department.</td>
<td>Public Sector; Consultant.</td>
</tr>
<tr>
<td>Project Management Services Ltd.</td>
<td>Private Sector; Project and Construction Managers.</td>
</tr>
</tbody>
</table>

Main Sources of Data for Pilot Investigation

TABLE 5 - 1

5.3.3.6 Developing the Indicators

Interim findings were presented to a Workshop arranged on 9th October 1990, with experts and experienced practitioners in the three sub-sectors. They were also assigned specific exercises and divided into special task forces to generate suggestions and solutions. Valuable comments emerged during the brainstorming. Interest that developed in the usefulness of Indicators crystallised into the form of 4 papers that were developed in consultation with the researcher and presented at a Seminar on the 21st November 1990.

Validation exercises were carried out, by testing the emerging Indicators on fresh (hitherto-unanalysed) projects. Reasonable correlations and confirmations emerged in some data domains. Other areas warranted further investigation. But most domains suffered
from the lack of complete data in each project as well as from an inadequate sample of projects in each category. The classification into categories had 'sliced' the 138 building projects, 35 road projects and 38 bridge projects into smaller samples of 5 to 15 projects each. Even such small samples displayed some major differences between projects. While special project conditions explained such differences in some cases the information was inadequate to investigate reasons for all such divergences.

5.3.4 Overview

The usefulness of the project was confirmed by the sponsors and by the feedback from the Workshop and Seminar on the 9th October 1990 and 21st November 1990 respectively. There was an unanimously positive response to the findings from sub-sector experts, professionals and practitioners. Furthermore IESL, ICTAD and ILO agreed to carry out further investigations into Indicators in other construction sub-sectors, such as water-supply and irrigation.

This investigation also served as a precursor exercise; formulating and testing techniques of investigation, forms for data collection and formats for codification. It also developed and disseminated a language of intelligible construction project and industry Indicators for the Sri Lankan professionals, as described in Chapters 4, 5 and 6 herein.

5.4 INDICATORS IN THE BUILDINGS SUB-SECTOR

5.4.1 Some previously tried Indicators

The buildings sub-sector in Sri Lanka, as in most countries, cuts across most divisions, being common to all parts of the country, being sponsored by both public and private sector; and using various methods of procurement, mostly the traditional, but also design & build, some cost plus and construction management formats.

While 'coarse' comparisons of costs per square foot (or m²) of building gross floor area have been very common, even by both professionals and laymen, their liability to mislead was illustrated in an in-house exercise carried out by a Chartered Quantity Surveyor, Mr. T.P. Miskin, which indicated the wide ranges that this Indicator could traverse in respect of the same building shell, but with different specified levels of contents and finishes. The exercise used data from 3 different years, to provide further comparisons over time.
### Variation of Unit Costs with Design & Specification

**Note:** Costs are in Rupees per square foot of gross floor area.

**TABLE 5 - 2**

The dangers of relying on such a primary cost Indicator in isolation (from other qualifications/Indicators) were emphasised in interviews with experts, particularly the Quantity Surveyors, but unfortunately continue to be the 'first resort' of most prospective clients and even their advisers.

Other Indicators have been used from time to time, but have not proved sufficiently valid or useful, to be popularly accepted by the industry. For example Indicators have been used to investigate special cases, such as a quick survey of whether a structure has been over-designed by checking the steel/concrete ratio Indicators. Unfortunately, the absence of a data bank of projects from which one could select similar structures (say multi-storeyed buildings with 6 to 8 metre main spans and similar load configurations) would confine one to merely refer back to the codes (Institution of Structural Engineers, 1985).

Worker productivity ratios, as indicated by bill value divided by the number of work-months, was tried out to compare different sites at the State Engineering Corporation in 1977. The researcher worked on this exercise briefly as the assistant to the Deputy General Manager (Planning). However this approach appeared to have been abandoned soon after, along with the post of Deputy General Manager (Planning)! Had these comparisons been qualified by the types and stages of the projects (to incorporate weighting allowances for such conditions) they may have been used to better evaluate and also encourage competition between sites. As it was, they were compared in isolation, using only basic figures obtained from apprehensive sites managers and projected merely to top management.

Average percentages of inputs into different types of buildings in Sri Lanka were looked at exhaustively in the early 1970's by Ganesan (1976). Such analyses have been incorporated into the construction of cost indices by the Central Bank, Department of

<table>
<thead>
<tr>
<th>YEAR:</th>
<th>1985</th>
<th>1988</th>
<th>1990</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Cost</td>
<td>140</td>
<td>154</td>
<td>235</td>
</tr>
<tr>
<td>Moderate</td>
<td>272</td>
<td>298</td>
<td>420</td>
</tr>
<tr>
<td>Luxury</td>
<td>544</td>
<td>739</td>
<td>1125</td>
</tr>
</tbody>
</table>

113
Census and Statistics and the Ministry of Housing and Construction (Statistics Unit of the Programming Division, Ministry of Housing & Construction, 1990), so that price variations in such components are proportionally incorporated in the combined cost index. Unfortunately these cost indices are hardly used in the industry, and even when have to be used, allowances and approximations are required (vide Appendix AP5-7). One of the reasons for their perceived distance from reality is the change in the proportion of inputs, both in terms of (i) usage differentials arising from different technologies (eg: PVC pipes replacing GI and earthenware pipes; different design codes altering cement/steel/aggregate ratios) and (ii) disproportionate value changes arising from widely varying price differentials between contributory components (eg: cement increasing 6 times against a steel increase factor of 8). The need for up-dating such proportions was recognised by incorporating this in a comprehensive exercise launched by an ILO Consultant, Mrs. Patricia Hillebrandt. This exercise is progressing with data collection by ICTAD and the Department of Census and Statistics.

Physical progress indicators could be developed as proposed by Jayawardane (1987) or as used by the Planning and Monitoring Unit of the Mahaweli Authority in a more basic format (with less elements) as follows overleaf.
<table>
<thead>
<tr>
<th>ITEM OF WORK</th>
<th>WEIGHTING %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Handing over of site</td>
<td>1</td>
</tr>
<tr>
<td>Foundation Excavation</td>
<td>5</td>
</tr>
<tr>
<td>Foundation Construction</td>
<td>5</td>
</tr>
<tr>
<td>Walls Construction</td>
<td>15</td>
</tr>
<tr>
<td>Plastering</td>
<td>10</td>
</tr>
<tr>
<td>Roof Construction</td>
<td>30</td>
</tr>
<tr>
<td>Doors &amp; Windows</td>
<td>15</td>
</tr>
<tr>
<td>Electrical fittings</td>
<td>5</td>
</tr>
<tr>
<td>Sewerage</td>
<td>5</td>
</tr>
<tr>
<td>Water supply</td>
<td>4</td>
</tr>
<tr>
<td>Finishes</td>
<td>5</td>
</tr>
<tr>
<td>Overall</td>
<td>100</td>
</tr>
</tbody>
</table>

Example of Physical Progress Weightings in the Construction of Buildings
Note: (from Mahaweli Authority Planning & Monitoring Unit)

TABLE 5 - 3

5.4.2 Developing a Classification System

The design of a suitable classification system was important to collect similar projects into the same category, so as to analyse them together and to investigate correlations and elicit averages from relatively uniform samples. Appendix AP5-4 indicates this final 5 character classification system which was evolved in stages during the investigation. For example, the 5th character relating to cost (value) ranges was introduced after the Workshop. This 5th character would further sub-divide the projects by relative value/size - which would affect for example: the technology chosen for their construction, the expertise or time devoted to the design and the discounts available on materials, overhead percentages and mark-ups etc. A 6th character was envisaged for the future to further sub-classify projects by their location.

The first 4 characters relate to building function, number of storeys, foundation type and level/quality of finishes respectively. Taking the first characteristic, it is obvious that only certain types of buildings have been chosen, for example, excluding factory/
industrial buildings and low-cost housing. Such selectivity was necessary both in view of the limited data, and resources available for collecting such data. The goal was to collect more projects in each of fewer categories, rather than to spread them thinly throughout many categories. This would facilitate larger samples for comparison and at least some basic statistical analysis. However, where wide disparities were detected within a category, this was split further, e.g.: Housing was sub-divided into 4 sub-groups relating to individual units, dormitory type accommodation units, apartment blocks and single or two storeyed housing schemes.

An attempt was made to align the classification with the CISfB building classification system, but the latter was felt to be both too detailed at this stage and lacking in some common local categories. However, consistency with an internationally accepted classification is advisable with the development of the database.

5.4.3 Elemental Comparisons

Sri Lanka does not yet have the advantage of developed databanks of building costs, categorised by building elements, locations and other characteristics as in developed countries such as the UK and Australia. For example the Building Cost Information Service (BCIS) of the Royal Institute of Chartered Surveyors provides a valuable system, available even 'on-line' to professionals engaged in cost planning and cost control exercises.

The small number of professional Quantity Surveyors in Sri Lanka have had limited opportunities to examine the elemental breakdowns of typical trade-oriented Bills of Quantities (BoQs). The need for a structured database with formats for elemental comparisons emerged from the early interviews themselves. Indicators of significance were anticipated from such an exercise.

5.4.3.1 Elemental Classification

However opinions conflicted as to the 'best' elemental classification to adopt. The researcher chose a modified classification as per Appendix AP5-8, based on the premise that sub-items (e.g: iron-mongery and finishes/decorating) relating to a particular element (e.g: windows) should be classified along with the parent element, so that they could be combined if necessary. This would enable convenient comparison for example of painted timber windows with aluminium windows. Some professionals disagreed, advocating an adherence to an international system, so as not to confuse the practitioners and students.
The compromise accepted at the Workshop, was that by combining certain groups of sub-elements, one could quickly revert to a different standard format, if deemed necessary at any stage.

5.4.3.2 Comparing Elemental breakdowns

Data had to be re-formatted from the basically trade-type-BoQs, and the many different formats found in the industry. For example some formats categorised work in different floors separately.

Although data had been collected in only 88 building projects, another 40 were available from responses to questionnaires received by ICTAD, in a slightly different format.

Classifying these 138 projects, using all 5 characteristics in the classification system, may have left either very few, one or none in each sub-category. Therefore, the initial categorisation in this study, was only by the main building function, as per the first character of the classification. However major divergences between individual housing units according to the levels of finishes used, prompted sub-division of this category into 3 levels, viz: 'average', 'high' and 'luxury' (having excluded low-cost houses at the outset, because of their wider variability) as defined within the 4th characteristic of the classification in Appendix AP5-4.

(A) Within Categories

Comparisons of the re-formatted elemental value breakdowns were first undertaken within categories, for example within the dormitory type housing (used for armed services camps and bachelors' quarters), as in Table 5-4, and illustrated (in part) visually in a histogram format in Figure 5-E.

Distortions introduced by varying 'Preliminaries' and 'Other' items (including 'External Works') were overcome, by:

(a) determining the category average of each of the items 1 and 14 (as in Table 5-4);

(b) substituting such category average for these items in each project; and
TABLE 5-4  Elemental Analysis within Dormitory category

<table>
<thead>
<tr>
<th>ELEMENT COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>TYPE OF BLDG: DORMITORIES</td>
</tr>
<tr>
<td>PROJECT NO</td>
</tr>
<tr>
<td>COST/S.F.</td>
</tr>
<tr>
<td>MEAN AVERAGE COEFF.</td>
</tr>
</tbody>
</table>

| 1.0 PRELIMINARIES | 0.53 | 0.53 | 0.53 | 0.53 | 0.53 | 0.53 | 0.53 | 0.53 | 0.53 | 0.53 | 0.53 | 0.53 | 0.53 | 0.53 | 0.53 | 0.53 | 0.53 | 0.53 |
| 2.0 SUB-STRUCTURES | 0.87 | 10.10 | 0.29 | 7.29 | 6.17 | 5.98 | 9.85 | 7.54 | 8.04 | 9.84 | 0.10 | 7.54 | 9.85 | 0.29 | 10.10 | 0.87 | 6.17 | 5.98 |
| 2.1 Excavation | 0.72 | 0.77 | 0.84 | 1.11 | 0.60 | 0.04 | 0.00 | 1.18 | 2.47 | 0.46 | 0.71 | 0.66 |
| 2.2 Concrete | 8.16 | 3.18 | 3.34 | 4.45 | 1.19 | 2.97 | 0.00 | 1.73 | 1.49 | 0.87 | 5.04 | 1.33 |
| 3.0 FLOOR SLAB | 2.69 | 3.75 | 6.34 | 2.72 | 2.06 | 3.26 | 4.03 | 2.93 | 3.62 | 1.78 | 5.25 | 3.52 |
| 4.0 SUP.-STD. VALLS | 16.69 | 10.91 | 11.02 | 13.08 | 15.68 | 15.24 | 16.03 | 9.44 | 10.38 | 16.57 | 17.22 | 26.85 |
| 4.1 Columns | 0.00 | 2.27 | 2.37 | 2.07 | 0.00 | 2.01 | 1.90 | 0.00 | 5.02 | 0.00 | 3.22 | 2.54 |
| 4.2 Beams | 0.99 | 1.11 | 1.34 | 1.76 | 0.77 | 2.53 | 2.54 | 1.90 | 9.32 | 2.22 |
| 4.3 U.F.Floor | 0.00 | 0.00 | 0.00 | 9.58 | 0.00 | 6.69 | 10.69 | 0.00 | 0.00 | 0.00 | 7.97 | 9.00 |
| 4.4 Staircase | 5.03 | 1.56 | 1.71 | 1.61 | 5.01 | 0.94 | 0.00 | 1.46 | 1.33 | 2.40 | 1.45 | 1.18 |
| 5.0 WALLS | 14.02 | 22.82 | 23.82 | 27.82 | 31.82 | 35.82 | 39.82 | 43.82 | 47.82 | 51.82 | 55.82 | 59.82 |
| 5.1 Fries | 14.02 | 8.63 | 7.71 | 3.90 | 11.57 | 7.21 | 0.00 | 6.55 | 7.33 | 1.10 | 3.00 | 0.00 |
| 5.2 Covering | 0.00 | 14.19 | 15.53 | 4.17 | 0.00 | 7.02 | 0.00 | 20.58 | 15.63 | 14.62 | 6.26 | 0.00 |
| 6.0 FLOOR FINISHES | 6.22 | 2.65 | 2.23 | 6.60 | 5.35 | 3.22 | 3.01 | 2.77 | 3.54 | 4.06 | 5.15 | 4.63 |
| 6.1 Rendering | 2.58 | 2.45 | 2.23 | 2.56 | 2.44 | 3.12 | 3.22 | 3.01 | 2.77 | 3.23 | 4.30 | 2.54 |
| 6.2 Paving/Tiling | 3.44 | 0.00 | 0.00 | 4.06 | 3.06 | 1.74 | 0.00 | 0.00 | 0.00 | 0.31 | 0.56 | 0.61 |
| 7.0 CEILING | 8.95 | 12.15 | 9.42 | 4.11 | 10.60 | 9.43 | 2.77 | 3.54 | 4.06 | 5.15 | 4.63 | 2.54 |
| 7.1 Frame | 14.02 | 3.93 | 2.56 | 3.56 | 2.64 | 3.42 | 3.22 | 3.01 | 2.77 | 3.23 | 4.30 | 2.54 |
| 7.2 Plastering | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.61 | 0.00 | 2.34 | 0.00 | 0.00 |
| 8.1 Doors | 9.14 | 0.00 | 0.00 | 13.46 | 15.03 | 12.06 | 6.15 | 15.20 | 15.20 | 17.28 | 10.96 | 13.16 |
| 8.2 Windows | 4.25 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 15.03 | 15.03 | 20.60 | 12.06 | 13.16 |
| 8.3 Finishes | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.61 | 0.00 | 2.34 | 0.00 | 0.00 |
| 9.0 PLUMBING | 6.57 | 3.81 | 5.41 | 5.64 | 4.72 | 5.56 | 4.18 | 3.47 | 5.00 | 5.41 | 6.62 | 6.06 |
| 10.0 ELECTRICAL | 6.57 | 3.81 | 5.41 | 5.64 | 4.72 | 5.56 | 4.18 | 3.47 | 5.00 | 5.41 | 6.62 | 6.06 |
| 11.0 SPECIAL FITTINGS | 3.36 | 8.29 | 5.41 | 5.64 | 4.72 | 5.56 | 4.18 | 3.47 | 5.00 | 5.41 | 6.62 | 6.06 |
| 12.0 OTHER ITEMS | 3.97 | 3.97 | 3.97 | 3.97 | 3.97 | 3.97 | 3.97 | 3.97 | 3.97 | 3.97 | 3.97 | 3.97 |
| TOTAL | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

---

Not taken to Elemental average

Cost adjusted to 1990 values as per notes

Element evenly distributed

---

1. Element evenly distributed

2. Cost adjusted to 1990 values as per notes

---

TABLE 5-4 Elemental Analysis within Dormitory category
FIGURE 5-E Elemental analysis within Dormitory category
(c) re-distributing the difference (between the actual item value and the substituted category average) among all other elements in each project.

Such standardisation of the more variable (but not category-significant elements) enabled a more realistic comparison of the principal elements.

Arithmetic Means (AM), Standard Deviations (sd) and Coefficient of Variation (sd/AM) were determined for each element. The Coefficient of Variation was a better Indicator of the relative spread of the data in each element.

Data 'outliers' (eg: a relatively high value roof element), were investigated further and where special conditions were noted (eg: a long span steel framed roof) such an item was excluded from the elemental average to minimise distortions.

Following this procedure, 'secondary' Indicators of average elemental value components within each category were derived, with similar tabulation to Table 5-4 for the other categories. These interim findings themselves would be useful for first-order estimation, cost-planning and evaluation of projects suspected of suffering from an over-emphasis on one element (eg: windows or finishes).

A caveat is in order however, since some distortions would be introduced by the different mark-ups for profit and overheads, for example depending on market conditions and also on whether the priced BoQs have been 'front-end-loaded'. However such effects may be insignificant because:

(a) the relative proportions rather than absolute values are the important outputs in elemental comparisons; and

(b) the differentials may not be significant, especially if the projects are further sub-divided by value ranges.

However, one would unfortunately still deal with absolute rather than relative values when comparing costs per sq. foot. These were therefore up-dated to 1990; and Arithmetic Means, Standard Deviations and Coefficients of Variation were also found for up-dated Costs per sq. foot and determined as approximate 'primary' Indicators, within each category; bearing in mind the distortions of varying mark-ups on the pricing.
The averages (AMs) of the elemental contributions (within categories) were next tabulated across the categories as in Table 5-5 and illustrated as in Figure 5-F.

Such comparisons generated interest as to why certain elements assumed greater significance in particular categories of buildings e.g.: roofs in civic, health or shop type buildings. Explanations were forthcoming, as for example referring to longer spans used. Efforts may then be focussed on controlling the costs of the more cost-significant elements during both design and construction. Indicators of cost significance were obtained in this manner.

Parallels were found towards the end of the Sri Lankan investigation, in already advanced work into cost significant elements done at the University of Dundee (Saket, McKay & Horner, 1986; Asif, 1988; Horner et al, 1989) and at the University of Hong Kong, for example an ongoing study by M. Po-hei Fung, supervised by Dr. S. Rowlinson.

Furthermore, various hypotheses were proposed as to relationships emerging between different elements both between themselves, as well as against special features. Some appear basically self-evident, (Emmanuel and Kumaraswamy, 1990), for example 'Cost of sub-structure varies inversely with the height of the building'; or 'Elemental Costs of each of many elements other than the 'Finishes') varies inversely with the level of finishes of the building'. Other hypotheses following more detailed analyses of the data (Raviskanthan, 1990) are more striking, for example 'The super-structure Indicator was seen to increase from 28% for single-storeyed, 35% for two storeyed, to as high as 50% for four storeys. Above four storeys the contribution of the super-structure remained around 50%'.

Figure 5-G depicts another visual interpretation of the elemental averages derived by directly comparing the significance of each element in turn, in relation to different categories.

5.4.4 Weighting Indicators

When analysing the variations between elemental proportions in different categories or even within the same category, it is possible to find justifications for deviations, such as larger spans or better finishes. If such features were regularly found to have a significant
<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>1.0 PRELIMINARIES</th>
<th>2.0 SUB-STRUCTURES</th>
<th>3.0 GROUND FLOOR SLAB</th>
<th>4.0 SUP.-ST.(INCL. WALLS)</th>
<th>6.0 FLOOR FINISHES</th>
<th>7.0 ROOF</th>
<th>8.0 CEILING</th>
<th>9.0 DOORS &amp; WINDOWS</th>
<th>10.0 PLUMBING</th>
<th>11.0 ELECTRICAL</th>
<th>12.0 METAL WORK</th>
<th>13.0 SPECIAL FITTINGS</th>
<th>14.0 OTHER ITEMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Excavation</td>
<td>14.77</td>
<td>7.31</td>
<td>9.78</td>
<td>13.68</td>
<td>8.88</td>
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<td>9.45</td>
<td>13.40</td>
<td>9.93</td>
<td>2.32</td>
<td>17.64</td>
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<td></td>
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<tr>
<td>2.2 Concrete</td>
<td>3.34</td>
<td>4.21</td>
<td>1.59</td>
<td>4.31</td>
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<td>4.04</td>
<td>1.0</td>
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<td>2.3 Rubble</td>
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<td>4.87</td>
<td>31.79</td>
<td>32.24</td>
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<td>38.17</td>
<td>32.24</td>
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<td>25.14</td>
<td>45.71</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.2 Beams</td>
<td>31.57</td>
<td>32.24</td>
<td>41.27</td>
<td>25.14</td>
<td>45.71</td>
<td>31.57</td>
<td>4.53</td>
<td>9.19</td>
<td>6.72</td>
<td>10.18</td>
<td>2.84</td>
<td>4.52</td>
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</tr>
<tr>
<td>4.3 U.F.Slab</td>
<td>4.87</td>
<td>9.19</td>
<td>6.72</td>
<td>10.18</td>
<td>2.84</td>
<td>4.52</td>
<td>4.05</td>
<td>4.87</td>
<td>2.21</td>
<td>4.61</td>
<td>4.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.4 Staircase</td>
<td>11.31</td>
<td>5.41</td>
<td>4.67</td>
<td>5.54</td>
<td>5.72</td>
<td>4.30</td>
<td>9.22</td>
<td>5.76</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.1 Frame</td>
<td>22.08</td>
<td>15.07</td>
<td>16.07</td>
<td>23.94</td>
<td>12.96</td>
<td>11.33</td>
<td>17.41</td>
<td>17.16</td>
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<td>17.27</td>
<td>21.36</td>
<td>20.11</td>
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<tr>
<td>6.2 Covering</td>
<td>11.31</td>
<td>5.41</td>
<td>4.67</td>
<td>5.54</td>
<td>5.72</td>
<td>4.30</td>
<td>9.22</td>
<td>5.76</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.3 Plumbing</td>
<td>11.31</td>
<td>5.41</td>
<td>4.67</td>
<td>5.54</td>
<td>5.72</td>
<td>4.30</td>
<td>9.22</td>
<td>5.76</td>
<td></td>
<td></td>
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<tr>
<td>8.1 Structure</td>
<td>22.08</td>
<td>15.07</td>
<td>16.07</td>
<td>23.94</td>
<td>12.96</td>
<td>11.33</td>
<td>17.41</td>
<td>17.16</td>
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<td>17.27</td>
<td>21.36</td>
<td>20.11</td>
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<tr>
<td>8.2 Plastering</td>
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<td>5.41</td>
<td>4.67</td>
<td>5.54</td>
<td>5.72</td>
<td>4.30</td>
<td>9.22</td>
<td>5.76</td>
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<tr>
<td>8.3 Painting</td>
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<td>5.41</td>
<td>4.67</td>
<td>5.54</td>
<td>5.72</td>
<td>4.30</td>
<td>9.22</td>
<td>5.76</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>10.1 Plumbing</td>
<td>3.05</td>
<td>4.33</td>
<td>5.09</td>
<td>4.01</td>
<td>10.02</td>
<td>5.17</td>
<td>7.87</td>
<td>6.84</td>
<td>7.27</td>
<td>5.22</td>
<td>4.68</td>
<td>5.11</td>
<td>5.11</td>
</tr>
<tr>
<td>11.4 Electrical</td>
<td>8.26</td>
<td>3.39</td>
<td>5.43</td>
<td>5.76</td>
<td>4.86</td>
<td>5.08</td>
<td>4.84</td>
<td>10.11</td>
<td>5.74</td>
<td>8.44</td>
<td>4.44</td>
<td>5.11</td>
<td>5.11</td>
</tr>
<tr>
<td>12.0 Metal Work</td>
<td>3.25</td>
<td>2.49</td>
<td>0.90</td>
<td>3.25</td>
<td>2.49</td>
<td>0.90</td>
<td>3.25</td>
<td>2.49</td>
<td>0.90</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>

**NOTES**

* This element removed and proportionately distributed

**TABLE 5-5** Elemental Averages for each Building category
FIGURE 5 - F Elemental Averages for each building category (Sample)
ELEMENTAL ANALYSIS
COMPARISON AMONG ELEMENTS

FIGURE 5 - G Building category averages for each element (Sample)
effect on an element, there was a justification to 'model them in' to the scenario, by developing suitable weighting Indicators to adjust the elemental Indicator accordingly. To this end, it was decided to compute and compare ratios of:

(a) window area to gross floor area - in order to test its effect on the window element;

(b) wall area to gross floor area - in order to evaluate its effect on the super-structure element; and
(c) usable area to total area (or circulation area to total area) - in order to compare with the aesthetic and utility satisfaction priorities from the clients/users.

Correlation exercises through linear bivariate regression were carried out to determine weighting relationships. These are described in Chapter 6.

5.4.5 The Gaps

Apart from the previously defined Primary Indicator of cost per sq. foot, the investigation soon focussed on the secondary Indicators of elemental cost contributions and related weighting Indicators. There appeared to be data 'vacuums' in other primary features such as time, quality/performance/utility, safety, satisfaction and risk levels; and this, despite:

(a) the data-sheets being designed to capture such information; and

(b) an in-depth study of whatever drawings, BoQs, Contract Documents and correspondence were made available.

It had to be admitted that the information in these areas was very scarce and even the little available was less than reliable. While there was evidence of start and finish dates on sites, design periods were often forgotten. Furthermore, originally estimated dates of starting or completing were lost under the layers of new programmes that had superseded the originals and a possible reluctance to divulge embarrassing delays; so even time overruns could not be accurately assessed.

Staffing information was also unreliable, except in a few projects that maintained and preserved their site records. Materials consumption data for deriving tertiary Indicators was hardly available, except in the case of special exercises (say, on materials consumption) carried out by the organisation itself.
It was realised that such gaps could not be filled by data on a few isolated projects in different categories, but fresh efforts were needed to monitor a set of similar projects from scratch. Care would also be needed to avoid any bias introduced into performance by virtue of knowing that one is part of a sample under scrutiny. For the present, while proposing basic Indicators for derivation in such future studies, attention was next turned to parallel studies abroad. For example, Section 5.4.6 that follows, demonstrates such a dual approach to deriving time Indicators.

5.4.6 Time Indicators

(A) Proposals

Many Indicators of Time performance were considered, and set aside for future usage, when opportunities arose to survey new projects (from time-zero, i.e., from conceptualisation). Examples were:

(i) Time over-runs - in absolute and percentage terms;
   - first excluding and secondly incorporating time extensions granted;
   - on intermediate milestone targets;

(ii) Time/m² of building constructed;

(iii) Time/unit of time-significant (critical) elements e.g., foundations, super-structure or roof;

(iv) Typical cycle times, e.g., per floor in a multi-storeyed structure;

(v) Work Norms e.g., man-hours/cube of brickwork;

(vi) Value achieved/time relationships e.g., billing value/month at different stages of the project;

(vii) Schedule Variance Index (as in Section 2.5.3 of chapter 2); and

(viii) Average time intervals - between bills for work done
   - between bill and corresponding payment
   - if the latter is high, further analysis into components between bill & certification; and certification & payment.
   - between progress vs. programme reviews
   - between site meetings; and also between client reviews.
   - between critical milestones

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(B) **Parallels**

While earlier investigations and databases (eg: BCIS and that of the Australian Institute of Quantity Surveyors) related to the cost priority (which was easier quantified and analysed; and therefore conveniently comparable), the parallel concerns with the timeliness of projects, led to inquiries into the time element. For example:

(i) the Australian Institute of Quantity Surveyors (AIQS) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) collaborated in 2 surveys of time and cost performance of building contracts across Australia. While the first survey was in 1976, the second survey (Bromilow et al, 1988) included 94 private sector and 683 public sector contracts over $A 0.5m in size constructed in the period 1976 - 1986. They validated the results of their original investigation into Australian contracts between 1964 and 1967, one of which was an equation relating 'average' construction time, T (in working days from the date of possession of site to practical completion), with C, the final project cost in millions of Australian dollars, adjusted to constant labour and material price; K, a constant representing 'the general level of time performance for a $1 million project' (350 working days when C was on the June 1965 price basis or 204 working days on the January 1986 price basis) and B a constant describing how the time performance was affected by project size as measured by cost.

They proposed \( T = KC^B \)

Or \( \ln T = \ln K + B \ln C \)

The recent survey measured K and B in different sub-sectors in government and private sectors, and finally proposed:

\[ T = 222 C^{0.36} \text{ for government contracts and } T = 189 C^{0.28} \]

for private contracts; with average time over-runs of 32% on government contracts and 22% on private contracts;

(ii) the National Economic Development Office (NEDO) in its book on Faster Building for Commerce (1988), went as far as providing a plastic card device to literally 'Dial your Construction Time', whether you want to predict a 'good' time or an 'average' time for your type of project, depending on (a) project cost; (b) end-use (building functions) ie. office, miscellaneous or retail; (c) whether speculative or purpose-built (like a supermarket with standardised design Criteria) and (d) whether new work or not. In essence, it related
a good or average construction time to the project cost, with adjustments superimposed for the other factors; and

(iii) work at the University of Dundee (Saket, McKay & Horner, 1986; Horner et al, 1989) was based on identifying and using cost-significant items to predict not only costs, but also durations of projects. The degree of accuracy increases with the quality of the information, as one proceeds through the different design stages.

The Cost and Time models developed in Dundee were said to drive a system that could be used both at the design stage to ensure that an optimum design is achieved, and during construction to procure the minimum variance between actual and predicted durations and costs.

5.4.7 Tertiary Indicators

Although the data derived from this investigation itself was inadequate, for example to model input ratios of materials, labour and plant items, some comparisons were made of major input items using data collected by ICTAD and some projects from the researcher's own experience. The results were inconclusive, pointing to the need for more accurate data. There was a high probability of errors arising from assumptions and approximations in the data compared.

Ratios of concrete: formwork: steel both in quantity and value terms were obtained in a few projects. These could be compared within a wider data base and after adjustment with weighting factors based on spans, heights etc. after the collection of more data.

5.4.8 Productivity Indicators

Here too the data was inadequate or suspect; except in one project within the researcher's direct experience. This was developed to project the 'value of work done per man-day'; with a suggested weighting Indicator (skilled/ unskilled worker ratio) being developed in parallel.

This data was developed as in Appendix AP5-9 into a case-study documented to base a comparative exercise, at the Workshop on 9th October 1990. It was extrapolated to predict a tertiary Indicator of the labour cost component of average multi-storeyed building construction. This figure of about 18% was considered reasonable in the experience of the experts, when allowing 15% for overheads and profits mark-up.
5.5 INDICATORS IN THE ROADS AND BRIDGES SUB-SECTORS IN SRI LANKA

5.5.1 Background

Except for a few minor estate roads, and housing scheme roads that are privately developed or maintained, almost all the roads and bridges in Sri Lanka come under the purview of the Ministry of Highways. The Road Development (RDA) is responsible for the planning and designs (some of which it contracts out to the private sector, especially on large or foreign aided projects). The RDA, has more autonomy than the Department of Highways which it replaced in the late 1970's.

The actual procurement systems for constructing and maintaining roads and bridges have changed dramatically a number of times over the last 2 decades. The Highways Department had a direct labour system as well as a system of 'Road Overseers' who executed specific private contracts. The government from 1970 - 1977, introduced 'Territorial Civil Engineering Organisations', splitting up the Highways, Building and Irrigation Departments into small territorial units and combining their activities under one 'Territorial Engineer', using mostly direct labour systems. The State Development and Construction Corporation (SD&CC) was developed to handle major bridge construction.

After 1977 there was a boom in general construction. Private foreign and local contractors had more opportunities to build roads and bridges. A short-lived joint venture was formed between the new Road Development Authority and a foreign firm to handle roads on a design and build basis. When that arrangement proved unreliable, the Road Construction Development Corporation was formed to handle most of the major locally financed road and bridge construction projects, on rates negotiated with the RDA. The SD&CC still executed a few bridge contracts, but had to branch into other sub-sectors like buildings to survive.

Foreign funded projects, if not divided into small packages, usually resulted in foreign consultants and contractors getting the work, by sometimes even excluding local contractors at the pre-qualification phase. This initially resulted in wide disparities in rates between jobs handled by foreign and local contractors. However, established western contractors and incoming far eastern contractors soon began to bid at similar or lower rates than those locally prevalent and boost their bills later on the basis of massive claims. Foreign contractors often also had the benefits of using construction plant they had
brought down duty free on special jobs. Local contractors pressed for the balance to be redressed with measures such as the 7 1/2% preference rates theoretically available on World Bank and Asian Development Bank (ADB) jobs; confidence in continuity of work to justify investment in plant; slicing (dividing) of road packages (both vertically, along the road trace and horizontally according to operations eg: earthworks, base course, surfacing).

Terrorism first in the North and East, and then in the rest of the country stemmed the expected flow of funds for new roads. Even the World Bank and ADB programmes now mainly focus on the improvement and rehabilitation of existing roads rather than new roads. Furthermore, apart from a few new roads still needed to open up remote areas (as was done under the Mahaweli irrigation programmes; and as may be politically desirable to connect for example, the South or the East with major arterial highways), most of the roadworks planned are for improving existing networks.

The foregoing background was presented to illustrate the enhanced difficulties (apart from the general constraints and lack of data as encountered in building projects) in extracting comparable data from past roads and bridges projects. For example, the markedly different organisations that have handled such projects in the recent past and the dramatic changes and distortions in methods of procurement militated against consistent pricing patterns. Yet another constraint in these sub-sectors was the much fewer projects available for analysis, as having been built within the last 5 (or even 10) years targeted for this study. Apart from the difficulties of gathering data itself, the analysis was destined to be more onerous than in the buildings sub-sector with (a) smaller samples and (b) the wider variables introduced by the very nature of the civil engineering work involved eg: foundations and with the continuously critical ground and environmental conditions.

5.5.2 Some Indicators in use in Sri Lanka

5.5.2.1 Scarcity

The search for such Indicators in conscious or sub-conscious usage, commenced with the initial interviews and the associated 'top-down' approach.

The basic cost/km Indicator for a standard width new or rehabilitated road, varied so widely from Rs. 5 to Rs 10 million depending on the type of road and the people interviewed, that it was decided to await the finalisation of the classification system in order to at least narrow down one parameter. There were however, some Indicators available to
public sector planners in Rs. per km. for different types and components of rehabilitation, re-surfacing and maintenance, but these were in a supposedly confidential document.

Even for bridges, where the design and construction was more standardised, and the super-structure was usually designed incorporating pre-stressed concrete beams manufactured to standard sizes by two government Corporations the operating cost range in the minds of the practitioners from different organisations varied from Rs. 2,000 to Rs 5,000 per sq. ft. of deck. Even allowing for the variability in the foundation systems, these Indicator values should have presumably 'averaged out' in each organisation, to yield a narrower (more consistent) range.

It was concluded that such Indicators were hardly used at present, let alone relied upon, in the roads and bridges sub-sectors. Instead estimates were usually built up from first principles.

5.5.2.2 Cost Analysis

However restricted information available to some planners, relating to proportional cost breakdowns, was obtained from an internationally sponsored feasibility study. It is reproduced overleaf because it was derived from consultations with local contractors and consultants. However, similar information on absolute rates projected for rehabilitation surfacing, and maintenance components are not reproduced in deference to possible confidentiality.
### Example I of Analysis of Asphalt Road Costs

**TABLE 5 - 6**

<table>
<thead>
<tr>
<th>Item</th>
<th>%</th>
<th>Bitumen</th>
<th>Aggregate</th>
<th>Other Mtls.</th>
<th>Equipment</th>
<th>Fuel</th>
<th>Labour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bill 1 (prelims. etc)</td>
<td>10</td>
<td>55</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Asphaltic Course</td>
<td>40</td>
<td>35</td>
<td>15</td>
<td>38</td>
<td>12</td>
<td></td>
<td></td>
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<tr>
<td>Other</td>
<td>20</td>
<td>2</td>
<td>20</td>
<td>30</td>
<td>12</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>Overheads</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Profit</td>
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</tr>
<tr>
<td>100</td>
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<td></td>
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</tr>
</tbody>
</table>

### Example II of Analysis of Asphalt Road Costs

**TABLE 5 - 7**

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>% Contrbtn. to total cost</th>
<th>% of Foreign element</th>
<th>% of Local element</th>
<th>Final % Contribution to total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(1x2) (1x3)</td>
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<tr>
<td>Plant</td>
<td>30</td>
<td>80</td>
<td>20</td>
<td>24.0 (6.0)</td>
</tr>
<tr>
<td>Fuels</td>
<td>12</td>
<td>60</td>
<td>40</td>
<td>7.2 (4.8)</td>
</tr>
<tr>
<td>Materials</td>
<td>20</td>
<td>62</td>
<td>38</td>
<td>12.4 (7.6)</td>
</tr>
<tr>
<td>Labour</td>
<td>8</td>
<td>-</td>
<td>100</td>
<td>0.0 (8.0)</td>
</tr>
<tr>
<td>Overheads</td>
<td>20</td>
<td>60</td>
<td>40</td>
<td>12.0 (8.0)</td>
</tr>
<tr>
<td>Profit</td>
<td>10</td>
<td>60</td>
<td>40</td>
<td>6.0 (4.0)</td>
</tr>
<tr>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td>61.6 (38.4)</td>
</tr>
</tbody>
</table>
### Example of Analysis of Bridge Costs

**TABLE 5 - 8**

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. FOUNDATIONS</strong></td>
<td></td>
</tr>
<tr>
<td>Excavation</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Piles</td>
<td>7.4</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Footings</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>B. ABUTMENT</strong></td>
<td>12.4</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>C. SUPERSTRUCTURE</strong></td>
<td>34.0</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>D. OTHERS</strong></td>
<td>2.0</td>
</tr>
<tr>
<td><strong>E. BILL 1 (PRELIMS.)</strong></td>
<td>6.0</td>
</tr>
<tr>
<td><strong>F. OVERHEADS</strong></td>
<td>20.0</td>
</tr>
<tr>
<td><strong>G. PROFITS</strong></td>
<td>10.0</td>
</tr>
</tbody>
</table>

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It should be stressed that the foregoing approximate Indicators are not substantiated due to their restricted exposure, but appear to be the only available attempt at some indicative breakdowns of such project costs in general.

5.5.2.3 Roadworks Estimating Indicators

Although no standardised method of rapid first order estimating was encountered in the principal roads and bridges organisations, a system of estimating formulae for roadworks was being used by an Engineer attached to the Colombo Municipal Council. Mr. C. Vadivel had apparently developed these formulae personally to expedite his work in building up 'Engineers' estimates' based on standardised items in roadworks BoQs. He had derived a formula for each work item based on the commonly used materials, plant and labour variables.

It was decided to develop this into a comprehensive system during the investigation.

5.5.3 Roadworks

5.5.3.1 Classification

Two classification systems to suit the local scenario were formulated during this pilot investigation (Senanayake, Indrapalan, Daluwatte, & Kumaraswamy, 1990). A detailed classification for an expanded database was proposed and refined after interaction with many experts both individually and collectively at the Workshop. But a broader (first-order) classification was developed in parallel, in order to accommodate more projects in each category, for analysis in this pilot investigation. Both systems are described in Appendix AP5-5.

The broad classification merely identified a road as of type A1, A2, B1, B2, C, D or E; whereas the detailed classification required 6 characters for complete category identification.

5.5.3.2 Main Parameters

In view of the limited number (35) of projects available, categories A1 & A2 were combined to A; and B1 & B2 to B. The project names were suppressed for confidentiality required and the projects grouped according to their classification. The main parameters are illustrated in Table 5-9. Adjustments to the raw price (unadjusted price
<table>
<thead>
<tr>
<th>REF</th>
<th>ID</th>
<th>CATG.</th>
<th>LENGTH (ft)</th>
<th>WIDTH (ft)</th>
<th>RSTRT. (ft)</th>
<th>CONTRACT. (ft)</th>
<th>FINAL (ft)</th>
<th>% INCREASE</th>
<th>CONSTRUCT. (ft)</th>
<th>AT</th>
<th>ADJACENT ADJ (1990)</th>
<th>ADJACENT ADJ AT (1990)</th>
<th>PRICE</th>
<th>ASSYND</th>
</tr>
</thead>
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<tr>
<td>26</td>
<td>A1</td>
<td>967AD01</td>
<td>12.000</td>
<td>6.500</td>
<td>190.000</td>
<td>190.000</td>
<td>210.000</td>
<td>11</td>
<td>1968 - 1987</td>
<td></td>
<td></td>
<td></td>
<td>2524</td>
<td>V 1986 0.7035 3560</td>
</tr>
<tr>
<td>17</td>
<td>A2</td>
<td>971BAD5</td>
<td>0.650</td>
<td>18.000</td>
<td>15.794</td>
<td>22.300</td>
<td>1988 - 1989</td>
<td>2555</td>
<td>V 1986 0.8714 2359</td>
<td>A 3865 531</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>A2</td>
<td>961AD08</td>
<td>3.000</td>
<td>7.400</td>
<td>121.000</td>
<td>84.000</td>
<td>1958 - 1990</td>
<td>3433</td>
<td>V 1980 1.0000 3343</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>5</td>
<td>B1</td>
<td>966AD00</td>
<td>11.200</td>
<td>5.000</td>
<td>36.864</td>
<td>40.000</td>
<td>1968 - 1980</td>
<td>714</td>
<td>V 1987 0.7541 947</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>B1</td>
<td>968AD00</td>
<td>15.500</td>
<td>4.000</td>
<td>33.999</td>
<td>34.000</td>
<td>1968 - 1980</td>
<td>548</td>
<td>C 1987 0.7541 727</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>B1</td>
<td>969AD00</td>
<td>8.000</td>
<td>5.500</td>
<td>40.000</td>
<td>58.117</td>
<td>1968 - 1980</td>
<td>1334</td>
<td>C 1986 0.7050 1597</td>
<td></td>
<td></td>
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<td>27</td>
<td>B1</td>
<td>967AD06</td>
<td>4.500</td>
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<td>30.400</td>
<td>34.300</td>
<td>1968 - 1980</td>
<td>1177</td>
<td>V 1986 0.7541 1555</td>
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<td>5.500</td>
<td>58.800</td>
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<td>1968 - 1980</td>
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<td>V 1987 0.7541 1517</td>
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<td>35</td>
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<td>30.000</td>
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<td>1968 - 1980</td>
<td>1432</td>
<td>V 1987 0.7541 1959</td>
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<td>2</td>
<td>B2</td>
<td>969AD00</td>
<td>49.000</td>
<td>5.000</td>
<td>144.000</td>
<td>244.000</td>
<td>1968 - 1980</td>
<td>905</td>
<td>V 1986 0.7035 1287</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>3</td>
<td>B2</td>
<td>964AD00</td>
<td>24.000</td>
<td>5.000</td>
<td>44.000</td>
<td>56.100</td>
<td>1968 - 1980</td>
<td>420</td>
<td>V 1995 0.7066 610</td>
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<tr>
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at the time of costing) were done as in the case of buildings, using indices based on Appendix AP5-7, to project this to early 1990 values for comparison.

Indicators (Arithmetic Mean and Standard Deviation) of price per m² were derived, for each category. The high standard deviations indicated the still significant residual variability, which could perhaps be controlled by identifying and sub-classifying projects according to other relevant characteristics.

Cost over-run Indicators were not significant since the initial estimates were not always available in the 'original' form. Time Indicators suffered from similar doubts as to their authenticity.

5.5.3.3 'Elemental' Cost Analysis

Table 5-10 illustrates the construction price analysis into its main roadworks elements. While figures were taken from final bills/accounts where available, as in buildings it was often necessary to resort to the less realistic initial/contract BoQs.

Elemental percentage arithmetic means and standard deviations indicated only a coarse relative measure of the average and spread, in view of the small samples. These were considered secondary Indicators, being at the second level of cost.

Items (i) and (ii) in Figure 5-H illustrate three principal components of the elemental analysis viz. (a) Site Clearing & Earthworks sub-total; (b) Road Pavement Works sub-total and (c) Cross-drainage structures, (culverts etc) both (i) within categories and (ii) across categories.

No definite conclusions were possible, due to the substantial variations even within each category. However, some expected positive relationships were confirmed, for example:

(i) the correlation between items on (a) earthworks and (c) cross-drainage structures; and

(ii) the higher variability of the earthworks and culverts items in the 'new' roads category A, rather than in Category C concerned with rehabilitation and improvements.

It was appreciated that project specific variables such as terrain and existing route conditions, could affect the elemental cost contributions dramatically. More projects in
Two Examples (C and A) within Categories

ROADS COST COMPONENTS

(i) FIGURE 5 - H Basic Road Elemental analysis

(ii) Comparison across broad Categories

ROADS COST COMPONENTS

CATEGORIES A.B.C.D.E
each category, and in fact the use of narrower categories from the detailed classification, were confirmed as necessary.

5.5.3.4 Road Pavement Analysis

Meanwhile the less 'volatile' pavement element was analysed further into its sub-elements, as in Table 5-11. Here, while the cost per m² still displayed a disturbingly high variability, the general Standard Deviations and Coefficients of Variation indicated relatively less variability than in the main elements. Figure 5 - I projects such a graphical overview (i) within a category and (ii) across categories.

5.5.3.5 Estimating Indicators

Based on initial approaches by an Engineer with the Colombo Municipal Council as indicated in 5.5.2.3, the team developed a comprehensive set of 'Roadworks Estimating Indicators' for quick first approximations (Senanayake, Indrapalan, Daluwatte & Kumaraswamy, 1990). For example, variables L1, L2 and L3 were assigned to the cost per day of different categories of labour and the effective cost per day incorporating statutory and idling allowances, was computed as, say: 2.1xL1. Similarly each material input was assigned variables from M1 to M16; and Plant and Equipment all-in hire/effective usage cost rates were allocated variables from P1 to P16.

Project-specific factors were incorporated to weight special conditions eg: e, for labour idling, w for materials wastage and i for plant idling. These were incorporated to give an Estimator more flexibility on each project.

Item unit costs were then derived from first principles for all standard items, for example:

Spread, shape and compact Asphaltic Concrete (item)

= i (2P2 + 9P4 + P6 + P8 + 2P15) + 10eL1 (unit cost)

Next, sample composite operation costs were compared by combining the foregoing items appropriately, eg: composite rates for strengthening of an existing road pavement to a given specification by either:

(i) Premix overlay; or (ii) penetration macadam.

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### TABLE 5-11 Pavement data analysis

<table>
<thead>
<tr>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
<th>VIII</th>
<th>IX</th>
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<td>TOTAL</td>
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<td></td>
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<td>2.000</td>
<td>2.000</td>
<td>2.000</td>
</tr>
</tbody>
</table>

**Note:** The table above shows the pavement data analysis with various parameters such as CR, CAT, SURFACE, WEARING, COST, SUBTOTAL, and TOTAL. Each row represents a different category or segment of the pavement analysis.
(i) Comparisons within Categories

ROAD PAVEMENT COST COMPONENTS

(ii) Comparisons across Categories

ROAD PAVEMENT COST COMPONENTS

FIGURE 5-1 Road pavement cost components
Thus an early cost comparison was facilitated between two alternative systems of strengthening existing road pavements.

A *caveat* was issued with the formulae (i) to incorporate appropriate allowances for project specific conditions; and (ii) only to use them as cross-checks or first approximations.

5.5.3.6 Other Roadworks Indicators

Indicators of time, technology levels and quality/specification levels needed to be juxtaposed with purely cost-oriented Indicators for a proper appreciation of their significance. The limited information and comparative studies on such items are re-examined in Section 5.5.5 along with those pertaining to bridge Indicators.

5.5.4 Bridges

5.5.4.1 Classification

This was proposed and modified in stages as in the other cases, according to feedback from experts and the projects available. The classification as finalised after the Workshop appears in Appendix AP5-6.

5.5.4.2 Main Parameters

Prices were approximately updated to 1990 values as before, based on Appendix AP5-7. Table 5-12 illustrates the primary technical, cost and time Indicators of the projects. While suppressing project names for confidentiality, they were identified by their numbers assigned and grouped according to their classification.

High variability was observed in the average costs per m² as per the standard deviation Indicator. It was noted that the sample sizes were small.

Lack of confidence in the authenticity of original time and cost estimates, precluded much importance being attached to time and cost over-run Indicators.
### TABLE 5.12 Main Parameters of Bridges Projects analysed

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<th>NO.</th>
<th>RCSC</th>
<th>N.0.</th>
<th>M.0.</th>
<th>N. D.</th>
<th>L. M.</th>
<th>S. (m)</th>
<th>L. (m)</th>
<th>FOTE</th>
<th>ROTE</th>
<th>TOE</th>
<th>FOTE</th>
<th>ROTE</th>
<th>TOE</th>
<th>PRICE</th>
<th>F. ASB.</th>
<th>ASB.</th>
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<td>4.80</td>
<td>12100</td>
<td>1957</td>
<td>0.7541</td>
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**Notes:**
- TABLE 5.12: Main Parameters of Bridges Projects analysed.
- RCSC: Revenue Cost Survey.
- N.0.: Net Output.
- M.0.: Main Output.
- N. D.: Net Deliveries.
- L. M.: Local Market.
- S. (m): Standard (meter).
- L. (m): Local (meter).
- FOTE: Future Output at Economics.
- ROTE: Risk-Adjusted Output at Economics.
- TOE: Total Output at Economics.
- PRICE: Project Price.
- ASB.: Adjusted Selling Price.

**Adjustments:**
- **F. ASB.:** Denotes Adjusted price at Rs. value at that time.
- **ASB.:** Indicates the Adjusted Selling price.
5.5.4.3 'Elemental' Cost Analysis

The cost contributions in money value, as well as in percentage terms of principal elements, is illustrated in Table 5-13; and a summary of such Indicators is projected in Table 5-14.

Foundations and sub-structure were initially separated and later combined together as a proportion of the structural cost of the bridge. Similarly, the bridge decking (structural component only), the surfacing, services and miscellaneous items were first taken individually, and later combined together as a proportion of the structural cost.

Land acquisition and related costs were to be included with the 'Approaches' item. 'Preliminary items' and 'Approaches' were taken separately in view of the greater variability and potential distortions. The total structure was next taken as a proportion of the total project cost, in order to assess the extent of such distortions introduced by Preliminaries and Approaches items.

The sub-structure and super-structure components within each category demonstrated a reasonable consistency, when taken as a proportion of the total structure costs, except for certain special cases eg: projects 13, 14, 20 and 28, for which reasons were later given to justify the lower foundations and sub-structure cost vis a vis the super-structure.

5.5.4.4 Weighting Indicators at Secondary Level

Although attempts were made to correlate variations in super-structure cost to variations of span numbers and lengths, this did not yield significant results.

5.5.4.5 Analysis of Major Inputs

Major cost-significant items were next identified; and quantities, money values and proportions projected comparatively, where available, in Table 5-15. The average percentages in each category and the standard deviations, are projected through to Table 5-16, in tabular form; and selectively to Figure 5-J in bar chart from both (i) within and (ii) across the categories.
| TABLE 5-13 Bridges data Elemental analysis |
| CATEGORY | AS % | AIS % | AS % | COST | AIS % | AIS % | | | | | |
|----------|------|-------|------|------|-------|-------| | | | | |
| PILLI. | 65.7 | 11.7 | 77.4 | 1442 | 22.6 | 3347 | 28.5 | 71.4 | | |
| ICOST | | | | | | | | | | |
| SFSC | 12.4 | 46.9 | 21.3 | 16.9 | 15735 | 23.1 | 3266 | 17.0 | 67.5 | | |
| ICOST | | | | | | | | | | |
| RCCS | 29.0 | 43.0 | 15.4 | 54.9 | 4372 | 46.0 | 3884 | 11.6 | 56.1 | | |
| ICOST | | | | | | | | | | |
| RIMS | 8.8 | 21.0 | 32.9 | 53.9 | 41157 | 46.1 | 35224 | 12.3 | 66.8 | | |
| ICOST | | | | | | | | | | |
| NSCL | AVG | 8.1 | 8.1 | 8.1 | 8.1 | 8.1 | | | | | |
| SD | | | | | | | | | | |
| NSCM | AVG | 10.5 | 28.3 | 38.1 | 62.7 | 6896 | 37.8 | 3827 | 15.3 | 78.0 | | |
| SD | | | | | | | | | | |
| NPKS | AVG | 21.0 | 21.0 | 21.0 | 21.0 | 21.0 | | | | | |
| SD | | | | | | | | | | |

TABLE 5-14 Summary of Bridges Elemental analysis
| TABLE 5-16 Summary of Bridges major inputs |

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</table>
(i) Comparisons within Categories

**BRIDGES COST COMPONENTS**

DEEP PILE FOUNDATIONS (N.P.C.S)

![Graph showing cost components for deep pile foundations.]

- **A**- Mean: 6.3
- **Std Devn:** 4.1

(ii) Comparisons across Categories

**BRIDGES COST COMPONENTS**

SHALLOW FOUNDATIONS (N.S.C.S)

![Graph showing cost components for shallow foundations.]

- **A**- Mean: 8.8
- **Std Devn:** 8.7

Bridges cost components

**FIGURE 5-J**
5.5.5 Extending the family of Indicators in Roads and Bridges

The Indicators that hitherto emerged from the pilot study appeared inadequate to complete a comprehensive family of Indicators. This was due to lack of adequate projects and insufficient data within each project, despite the carefully designed data-sheet formats. However as in buildings, it was decided:

(a) to develop them further, refining with weighting Indicators, as well as seeking new dimensions and measures (Indicators) for same eg: in the technology level, time and quality/specification levels; and

(b) to examine parallel approaches abroad, for example work at the University of Dundee on the principles of cost significant items (and work packages) and quantity significant items (and work packages); and on iterative estimating that provided short-cuts to predicting and controlling costs; and also work at the University of Hong Kong on developing similar applications.

Specifically in the Bridges sub-sector (Horner, Murray & McLaughlin, 1990) software packages had been successfully developed on this basis, for estimating costs and times to high accuracy in a short time. For example, models used in preliminary design stage simulation of alternatives may use just 17 or 18 elements (cost significant work packages) to predict costs to within a 10% accuracy; and relationships have been proposed between the area of a bridge deck and cost of repairs. As for time-Indicators and time-control, the development of Time-Models has led to the formulation of integrated cost and time management systems.

The goal should be to extend the family of Indicators to cover not only time and cost but also other Criteria of performance as outlined in Chapter 3. A comprehensive family of Indicators as described in Chapter 4 can then help plan, control and evaluate construction activities.

5.6 DERIVATION OF INDICATORS IN THE PILOT STUDY INVESTIGATION

The pilot investigation in Sri Lanka, while satisfying it's sponsors, participants and the industry, by the vast extent of unchartered ground covered, and while fulfilling the investigation brief also paved the way towards a longer term target of developing a
comprehensive family of Indicators for each of the sub-sectors considered. While this investigation proposed Indicators wherever data was available and justified development & testing; it did not venture to propose theoretical Indicators (that could not be developed during the investigation or of which there was inadequate evidence in practice) to fill the gaps.

The derived Indicators were considered useful in themselves and suggested many applications, (eg: in cost planning) as well as in evaluating Criteria of management performance. A methodology for deriving and developing such Indicators was also tested and established as viable.

Studies inspired into the water supply sub-sector (Karunaratne, 1990) and the specific domain of brickwork (Abeysekera, November 1990) while outside the brief of the pilot investigation were supported within it's framework, so as to provide a basis for initiating further studies both into other sub-sectors and in-depth studies into the target sub-sectors.

The further development of the defined and derived Indicators, through validation and exposure to the industry is described in more detail in the next chapter.
### CHAPTER 6: DEVELOPING CONSTRUCTION INDICATORS

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</tr>
</tbody>
</table>

**FIGURE:**

6 - A Developing Defined and Derived Indicators

(Note: For lists of Tables herein and related Appendices, at the back please see the General Contents at the beginning of this Thesis).
CHAPTER 6: DEVELOPING CONSTRUCTION INDICATORS

6.1 INTRODUCTION

6.1.1 Basis

This chapter illustrates the developments of the construction Indicators proposed during the pilot investigation into three construction sub-sectors in Sri Lanka in 1990. It therefore relies on material drawn from Chapter 5, as to how such Indicators were initially defined and derived.

6.1.2 Constraints of Pilot Investigation

Further development was undertaken, with appropriate assumptions and approximations to allow for omissions in the data or differences in the prevailing conditions. This was necessary due to the small numbers of projects in each sample, and the difficulties of tracking authentic data in each project. The biggest problem arose from non-availability of project records which had either been misplaced, destroyed or not maintained systematically and completely. Further constraints were imposed by confidentiality and vested interests.

Such limitations unfortunately precluded the use of detailed statistical techniques that could have analysed wider samples. In view of the smaller samples and the simple analysis, basic statistics such as arithmetic mean, standard deviation and coefficient of variation were obtained from the LOTUS 1-2-3 spreadsheet package on which the data was originally formatted.

Constraints had been anticipated in assembling sizeable samples, in drawing statistically significant conclusions and in scientifically validating (or discounting) all perceived patterns. One approach to help alleviate this expected shortcoming had been built into the formulation of the pilot investigation at the outset. This involved testing incoming data and interim findings/hypotheses with experts, first individually at interviews and then collectively through a structured Workshop and a Seminar.

Figure 6 - A overleaf indicates an envisaged process flow-chart for such a typical development of previously defined and derived Indicators.
DEVELOPING DEFINED AND DERIVED INDICATORS

FIGURE 6 - A

DEFINED AND DERIVED INDICATORS

TEST ON NEW PROJECTS

GOOD CORRELATIONS

CHECK MORE PROJECTS

NOT ENOUGH

ENOUGH

BAD CORRELATIONS

CHECK IF FURTHER WEIGHTING WOULD IMPROVE OR IF SPECIAL CONDITIONS COULD EXPLAIN DEVIATIONS.

ADJUST INDICATORS IF NEEDED

YES

NO

PRESENT TO EXPERTS INDIVIDUALLY, AS WELL AS COLLECTIVELY AT WORKSHOPS AND SEMINARS ETC.

DISPUTES

EXCLUDE OR TEST SPECIFIC AREAS AND ADJUST

CONFIRMATIONS

INTEGRATE AFTER TESTING

USEFUL SUGGESTIONS

DEVELOPED INDICATORS

DEVELOPING DEFINED AND DERIVED INDICATORS
6.1.3 Outline of Chapter

This chapter traces the final phase of the pilot study, after the initial data collection and analysis, through the stages of further development of the Indicators, including the weighting and validation exercises, the Workshop and Seminar inputs and outputs. It also briefly describes Indicators that were proposed in another construction sub-sector (water supply); as well as a parallel literature search for similar approaches elsewhere, which supplemented the Indicators being developed from first principles in Sri Lanka.

6.2 IMPROVING & VALIDATING INDICATORS IN THE BUILDINGS SUB-SECTOR

6.2.1 Weighting Secondary Elemental Cost Indicators

While some representative averages emerged from certain elemental proportions of cost within categories of buildings, the variation across others was too high to be significant in the 'raw' state. Weighting by other factors impinging on such elements (for example, quality levels of the 'Finishes' element) was therefore examined.

Table 6-1 overleaf illustrates some of the weighting parameters chosen and values derived from first principles. Table 6-2 further illustrates a basic comparison between the averages in different categories of two sets of supposedly related data:

(i) between Door and Window/ Gross Floor Area ratio (D&W/ GFA) and D&W elemental cost %; and

(ii) Wall area/ GFA and Wall elemental cost %.

The first comparison indicated a reasonably consistent ratio of D&W Elemental Cost to the D&W/ GFA. The second comparison indicated a wider variation.
## TABLE 6-1 Exercise with sample weighting Indicators (Buildings)

<table>
<thead>
<tr>
<th>BUILDINGS - SAMPLE WEIGHTAGE INDICATORS (All areas in Sq. Ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROJECT: CATEGORY</td>
</tr>
<tr>
<td>NO.</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>71</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>HOUSING UNIT AVERAGE</td>
</tr>
<tr>
<td>02</td>
</tr>
<tr>
<td>06</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>RECREATIONAL BLDG. AVERAGE</td>
</tr>
<tr>
<td>03</td>
</tr>
<tr>
<td>04</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>MEDICAL INST. AVERAGE</td>
</tr>
<tr>
<td>05</td>
</tr>
<tr>
<td>06</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>OFFICES AVERAGE</td>
</tr>
<tr>
<td>05</td>
</tr>
<tr>
<td>06</td>
</tr>
<tr>
<td>07</td>
</tr>
<tr>
<td>08</td>
</tr>
<tr>
<td>09</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>WAREHOUSES AVERAGE</td>
</tr>
<tr>
<td>05</td>
</tr>
<tr>
<td>06</td>
</tr>
<tr>
<td>07</td>
</tr>
<tr>
<td>08</td>
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<tr>
<td>14</td>
</tr>
<tr>
<td>15</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>DORMITORIES AVERAGE</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>OVERALL AVERAGE</td>
</tr>
</tbody>
</table>

U - Individual housing units  
R - Recreational bldgs.  
W - Warehouses  
M - Medical institutions  
D - Dormitories
Comparison of some Elemental Cost patterns with weighting Indicators

TABLE 6-2

In the pilot investigation Emmanuel & Kumaraswamy (1990) added another data set and a regression analysis was tried. A linear correlation coefficient of 0.925 was found between the D&W elemental percentage of total value and D&W/ GFA. But the wall elemental percentage indicated a correlation coefficient of only 0.615 with the wall area/ GFA. It was appreciated that:

(i) the data sets were inadequate;

(ii) there could be other over-riding variables; such as number of storeys, internal: external wall ratios; levels of finishes etc; and

(iii) a comparison within the categories themselves, (by sub-dividing them further on such secondary characteristics), may yield more consistent relationships.

With the expansion of the data base such inter-relationships could be tested with multi-variable and non-linear regression techniques. Cost Planners could then use a weighted relationship, for example: D&W Cost (%) = a + b x (D&W/ GFA), where a and b are constants; to predict the element cost as weighted by such special conditions on the project. Differences between timber or aluminium windows would impose additional differential weightings; and so would other special characteristics.

Meanwhile, a 'spin-off' benefit from an illustration such as in Table 6 - 1, was the facility to conveniently compare project parameters (Indicators of circulation area; external...
wall or window area proportion) with others in the same or similar categories. For example:

(i) Although the local building regulations required a minimum value of 1/7 or 14.3% of GFA to be provided for lighting and ventilation by means of windows, it was found that some buildings far surpassed this minimum whereas a couple of others strangely did not seem to even meet it; and

(ii) similar observations were made with respect to circulation area proportions although in some cases it was not possible to realistically assess the usable area, for example in open plan offices or multi-purpose stores.

Such Indicators could alert an Architect to the 'design efficiency' of an emerging design, for instance, whether there is avoidable wasted space, window areas, or more economical building shape factors. Such considerations would naturally be judged in parallel with aesthetic and other priorities of the project. The availability of such Indicators would make the process easier.

6.2.2 Validating Secondary Elemental Cost Indicators

Having extracted average elemental costs in each building category from the limited data as in Table 5-5, it is necessary to validate them by:

(i) expanding the data base within each category and weighting by special conditions;

(ii) testing against typical sample projects external to the data base; and

(iii) exposure to experts and practitioners for comment.

In pursuit of (ii), a multi storeyed 'luxury' level office project was analysed. The comparisons indicated in the following table, have excluded the distortion of the 'Preliminaries', 'Special Fittings' and 'Other items', by removing them and re-distributing the difference. A reasonable similarity appeared between the two columns except in the sub-structure item. This was not surprising since the example chosen had a heavy raft foundation, being on poor soil. This also accounted for the extra sub-structure contribution to the total, correspondingly lowering the contribution of most of the elements, as compared with the (average or typical) scenario.
Weighting Indicators had not been developed within this category (of luxury multi-storey office buildings), because of the lack of detailed data and the small number of projects. The validation exercise was therefore limited to the comparison in Table 6-3, and by subsequent presentation to experts.

<table>
<thead>
<tr>
<th>BUILDING ELEMENT</th>
<th>CATEGORY AVERAGE</th>
<th>TEST PROJECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 Preliminaries</td>
<td>Excluded and</td>
<td>distributed</td>
</tr>
<tr>
<td>2.0 Sub- Structure</td>
<td>8.97</td>
<td>16.71</td>
</tr>
<tr>
<td>3.0 Ground Floor Slab</td>
<td>1.68</td>
<td>1.11</td>
</tr>
<tr>
<td>4.0 Super Structure</td>
<td>27.24</td>
<td>24.00</td>
</tr>
<tr>
<td>5.0 (Walls Incldg., Finishes)</td>
<td>8.76</td>
<td>7.55</td>
</tr>
<tr>
<td>6.0 Floor Finishes</td>
<td>6.55</td>
<td>6.01</td>
</tr>
<tr>
<td>7.0 Roof</td>
<td>9.42</td>
<td>7.14</td>
</tr>
<tr>
<td>8.0 Ceiling</td>
<td>6.86</td>
<td>8.65</td>
</tr>
<tr>
<td>9.0 Doors &amp; Windows</td>
<td>17.10</td>
<td>16.42</td>
</tr>
<tr>
<td>10.0 Plumbing</td>
<td>4.65</td>
<td>3.61</td>
</tr>
<tr>
<td>11.0 Electricals</td>
<td>8.76</td>
<td>7.41</td>
</tr>
<tr>
<td>12.0 Metal Work</td>
<td>-</td>
<td>1.39</td>
</tr>
<tr>
<td>13.0 Special Services &amp; Fittings</td>
<td>Excluded and distributed</td>
<td></td>
</tr>
<tr>
<td>14.0 Other Items</td>
<td>Excluded and</td>
<td>distributed</td>
</tr>
</tbody>
</table>

Validation Exercise to Test Elemental Cost percentage
Indicators in (luxury type multi-storeyed) Office blocks

TABLE 6-3

The foregoing exercise established a methodology in testing the typical elemental percentage Indicators, found for other categories as well.
6.2.3 Further Analysis with Elemental Cost Indicators

6.2.3.1 Background

Being the first occasion on which almost 140 building projects from different organisations in Sri Lanka, had been analysed into their elemental costs in an agreed format, it was decided to make further use of this database, estimating the average values and their ranges of variations of each element, when the buildings were grouped according to the other characteristics (other than primary function alone) namely number of stories, type of foundations, level of finishes/ quality level, type of roof and cost range. Appendix AP5-4 details the differentiation within each of such characteristics based on the classification system evolved for the purposes of this pilot investigation.

Despite the previously stated shortcomings of inadequate numbers of projects within each category, analysis within narrower sub-categories was considered useful:

(i) as better than merely analysing the projects within the broad building function categories while overlooking the major known differences between projects in the same category; and

(ii) as a precursor exercise to establish techniques and tools for the future when the database was expanded.

6.2.3.2 Basis

The chosen building classification system as per Appendix AP5-4, was the main basis of identifying the sub-categories by primary function, number of storeys, type of foundation, level of finishes and cost range of project. Type of roof was also chosen as a characteristic in view of the significance of the roof element. Data within each such sub-category was first analysed alone (for example, by classifying only according to the type of foundations); secondly on a combination of two factors (for example, by building function and type of foundations) and finally on a combination of three factors (for example building function, type of foundations and number of storeys).

The parameters examined within such categories were the primary Indicator of cost per square foot (which had been up-dated to early 1990 values) and the secondary Indicators of elemental cost contributions.
The database assembled on Lotus 1-2-3 Spreadsheets during this pilot investigation was re-formatted, for such analysis.

6.2.3.3 Results

The results were presented in a paper (Raviskanthan, 1990) at the Seminar organised to disseminate findings from the pilot investigation and to launch further studies. They were well received by the participants as useful Indicators of:

(i) variations in cost per square foot of gross floor area according to the building function and its other main characteristics. Such primary Indicators, particularly when developed further by widening the database, would be of value in providing more reasonable first order estimates of a typical building cost (average for that type) at feasibility study stage, even before any preliminary sketches; or for a quick comparison/evaluation. Further refinement is possible by adding to the classifying characteristics, for example incorporating location, market conditions, type of contract and such other variables;

(ii) elements of cost significance in particular types of buildings and with special features (such as special foundations, number of stories, specified level of finishes, or type of roof). Identifying the normally cost-significant elements in a building of a given type would direct particular attention to these during design, construction and monitoring/evaluation. Deviations from the norms would alert management to investigate such areas.

Examples of the results are appended in tabular form in Appendix AP6-1 and in graphical form in Appendix AP6-2. These were interpreted by Raviskanthan (1990) as for example:

(i) 'the super-structure indicator was seen to increase from 28% for single storeyed, 35% for 2 storeyed, to as high as 50% for four storeys. Above four storeys the super-structure contribution was seen to remain around 50%;

(ii) 'the classification based on cost of the project did not yield any significant patterns in the elemental proportions';

The latter may have been expected since the lower mark-ups on bigger projects should have been distributed uniformly across all elements. But there was a significant step-wise reduction in the cost per square foot from an average of Rs.882 at the lowest
project value range through 637 and 515, to Rs. 489 at the highest project value range (vide the last part of Table (5) in Appendix AP6-1).

(iii) 'the analysis by types of roofs yielded 11% for asbestos, 14% for tiles on asbestos and 15% for asbestos on steel truss' for the roof elemental contribution. But 'as the coefficient of variation is high the error may be of a higher order'; and

(iv) analyses based on combinations of more than one characteristic suffered from the anticipated lack of sufficient numbers of projects in the sample, but some basic patterns were confirmed, for instance 'the analysis based on primary functions and number of storeys showed the same trend for sub-structures and super-structures; while the sub-structure increased when the costlier types of foundations were used'. While such observations may have been expected, its usefulness lay in quantifying such expectations.

When examining the results in Appendix AP6-1, it should be noted that the tables also suggest the adequacy or otherwise of the data sample in each case, by indicating both the number of projects taken in that sample, (as 'count') and the coefficient of variation, computed by dividing the 'standard deviation' by the average.

Further statistical analysis on this database, as undertaken after the presentation Seminar, is described in sub-section 6.7.3.

6.3 DEVELOPING INDICATORS IN THE ROADS SUB-SECTORS

6.3.1 Primary & Secondary Cost Indicators

No validation exercise was attempted on the primary or secondary cost Indicators since the Indicators themselves had not been derived from a wide enough data sample within each category of roads. Ideally the data base should be expanded to incorporate sufficient projects in each category according to the detailed classification (as per Appendix AP5-5), and not merely according to the quick first-order classification which had been used. This would further narrow the data into similar sub-categories; permitting a detailed cross analysis as done for buildings.

6.3.2 Tertiary & Estimating Indicators

The lack of project data in this sub-sector led to the formulation of first-approximation estimating Indicators as in 5.5.3.5. These were tested by assigning current
money (Rupee) values to the Labour, Materials and Plant variables used in developing the formulae, and cross-checking with prevalent rates. The unit rates obtained (for example Rs. 162 per m² for a 75 mm compacted nominal thickness course of penetration macadam) compared well with current rates. The composite rates (for example Rs. 241 per m² for pavement strengthening with an asphaltic premix overlay or Rs. 229 per m² for pavement strengthening by penetration macadam) presented at the Seminar (Senanayake, Indrapalan, Daluwatte & Kumaraswamy, 1990) were also considered reasonable by other practitioners.

6.3.3 Progress Indicators

Physical progress Indicators were estimated on a less quantitative basis, by interviewing experienced road engineers, and identifying their assessment of the critical elements on 'simpler' road projects such as less equipment intensive operations were required on a surfacing operation in a remote area. Two sample roads projects were chosen with bitumen based 'sand sealing' on an existing metal base, using small aggregate, sand and bitumen. The Engineers who handled the projects identified the three major 'physical' components of the operation as:

(a) arranging and supplying of metal (coarse aggregate) to site;

(b) arranging and supplying of bitumen to site; and

(c) the actual surfacing operation involving labour and plant.

Although sand was also needed its availability and transport to site did not present any problem or risk of delay, whereas experience indicated risks and delays in items (a), (b) and (c).

The financial weighting of components a:b:c in the two projects A and B were:

22: 36: 42 in Project A and 24: 38: 38 in Project B - as derived from an analysis of the BoQs.

However, the respective Engineers on each project assessed the physical importance of these components to the success of the project as 62: 9: 29 and 60: 10: 30 respectively.
The significant physical weighting attached to the supply of the coarse aggregate arose from the difficulties and delays in obtaining the stone used on these projects in a remote area in the south of Sri Lanka. In contrast, bitumen, though costlier, could be obtained with less uncertainty, less effort and much faster. The values of physical weighting assigned were subjective assessments, but guided by the relative times (derived from bar-charts taken for each such critical activity and as weighted by the scarcity of the resources required. What was encouraging was the similarity of response from the 2 completed projects in the same area.

If similar results were obtained from a bigger sample of such projects, such physical Indicators could be proposed to help monitor progress towards completion; in conjunction with the financial Indicators. For example, one could propose that physical progress on such 'sand seal' road surfacing projects in this area was indicated in proportion to the following:

(a) 60% when all required metal (coarse aggregate) is supplied to the respective locations (Note: work commencement is usually not sanctioned pending supply of all or most of the metal);

(b) 10% when all required bitumen is supplied to site; and

(c) 30% when all laying is complete.

Proportions of partial completion could be assessed within this framework. eg:
Overall progress is 80% when all coarse aggregate is supplied (60% contribution to overall progress) 50% of the bitumen supplied (5% contribution to overall physical progress); and 50% of the surfacing is complete (15% contribution to overall physical progress). It is assumed that other activities such as the supply of sand, are executed during the foregoing critical activities.

This example illustrates how critical (time significant) activities could be identified, their relative significance assessed and their progress used as 'time-Indicators' for the whole project.
6.4 DEVELOPING INDICATORS IN THE BRIDGES SUB-SECTORS

6.4.1 Elemental Cost Indicators

An attempt to study the effect on bridge elemental costs (of sub-structure and super-structure) when weighted by the number of spans or span lengths, did not yield significant results. When more data is available it would be worthwhile studying the effect of increasing span lengths and reducing the number of spans, while other factors are kept constant. It was expected that the super-structure element would increase and the sub-structure reduce on multi-span bridges as the number of foundations reduces. Although each foundation would sustain more load and therefore increase somewhat in sizing, the numbers of such foundations would be significantly less. The super-structure beams would also increase in sizing because of the larger spans. Bridge design engineers interviewed did not consider this a critical criterion in span selection, focussing more on water flow, soil and other local conditions.

But a 'threshold' Indicator was noted in the case of the standardised pre-stressed bridge beam elements (manufactured by two state Corporations) in that apart from the price/metre rising faster with the increasing spans, beyond the 16.2 m spans, such longer beams were cast at site rather than in the precasting yards and transported. The technology content requirement was thus dramatically changed. The technology of bridge beam casting and launching had been developed over decades, but some different approaches had been tried out recently, so that a technology Indicator was also needed to summarise such conditions.

6.4.2 Technology Level and Time Indicators.

A future exercise should aim at assessing a technology content Indicator (as estimated by the Technology Atlas Project Studies for other industries (Asia & Pacific Centre for the Transfer of Technology, 1989). This would then be linked to a time Indicator, which would help programme realistic project and activity times according to the technology employed, types and quantities of resources available.

Although the scope and resources of the pilot investigation did not enable such studies, a study of 14 BoQs of reinforced concrete bridges at the University of Dundee (Horner, Mair, Peebles & Zakieh, 1989) had demonstrated that 30% of the items in any trade contribute 80% of the work in that trade and 80% of its value. They called these the
quantity significant items, and defined them as those items whose quantity is greater than the mean. They identified a number of quantity significant work packages (whose value also was a constant proportion of the total bill value). They then hypothesised that the duration of critical path networks drawn using such quantity significant work packages, would be a constant proportion of the duration of networks drawn conventionally, and developed a model for reinforced concrete bridges on that basis.

Similar investigations commenced in Hong Kong were described during an ongoing study by M. Po-hei Fung and supervised by Dr. S. Rowlinson. Cost significant items and work packages were identified in 22 reinforced concrete bridge projects. A cost model was developed so that the modelled cost can be compared with the actual bill value.

Such exercises could expand the investigations in Sri Lanka when a wider data catchment is available. Unfortunately bridge data is necessarily limited in the country, and this is more significant when the bridges are classified into categories yielding still smaller samples.

6.4.3 Validation exercise on Secondary & Tertiary Indicators

A validation exercise was carried out using a fresh data set from 10 bridges designed and estimated in detail by the 'Engineer' for a new road network. Averages (arithmetic mean) and standard deviations (sd) from the category samples from Table 5-14 were compared. Nine of the bridges were in the NSCS category as per the classification in Appendix AP5-6. Table 6-4 overleaf illustrates the results from the new sample after analysis. Here the average foundation + sub-structure contribution of 73.8% was much higher than the category average of 62.7 (sd 14.7) obtained previously (Table 5-14). But the NCCS type bridge foundation + sub-structures element of 55.6 compared favourably with the category average of 54.0 (sd 4.4).

A further comparison of the major inputs of the NSCS projects was carried out (Senanayake, Indrapalan, Daluwatte & KumaraSwamy, 1990). The 29.7% contribution of in-situ concrete to the cost, compared well with the category average of 30.5 (sd 10.7). The non-high tensile steel contribution of 23.3% did not compare with the category average of 8.8 which itself had a high sd. of 8.7 indicating a high variability in the category. The pre-stressed concrete beam contribution of 8.9% compared with the category average of 10.9 (5.8 sd).
<table>
<thead>
<tr>
<th>BRIDGE SPANS NO.</th>
<th>LENGTH in M</th>
<th>CAT.</th>
<th>COST as % of IN struct.</th>
<th>COST as % of Deck struct.</th>
<th>SURFACING as % of COST in struct.</th>
<th>SERVICES as % of cost as % of struct.</th>
<th>SUB. TOTAL Rs.000</th>
<th>TOTAL STRUCT COST Rs.000</th>
</tr>
</thead>
<tbody>
<tr>
<td>VBO1</td>
<td>8.5</td>
<td>NSCS</td>
<td>1412</td>
<td>71.57</td>
<td>541</td>
<td>27.43</td>
<td>13</td>
<td>0.66</td>
</tr>
<tr>
<td>VBO2</td>
<td>8.5</td>
<td>NSCS</td>
<td>2561</td>
<td>81.10</td>
<td>575</td>
<td>18.22</td>
<td>13</td>
<td>0.41</td>
</tr>
<tr>
<td>VBO3</td>
<td>8.5</td>
<td>NSCS</td>
<td>1118</td>
<td>66.50</td>
<td>543</td>
<td>32.32</td>
<td>13</td>
<td>0.78</td>
</tr>
<tr>
<td>VBO4</td>
<td>8.5</td>
<td>NSCS</td>
<td>1366</td>
<td>71.13</td>
<td>534</td>
<td>27.54</td>
<td>13</td>
<td>0.68</td>
</tr>
<tr>
<td>VBO5</td>
<td>8.5</td>
<td>NSCS</td>
<td>2325</td>
<td>79.56</td>
<td>575</td>
<td>19.70</td>
<td>13</td>
<td>0.45</td>
</tr>
<tr>
<td>VBO6</td>
<td>8.5</td>
<td>NSCS</td>
<td>1496</td>
<td>72.74</td>
<td>541</td>
<td>26.30</td>
<td>13</td>
<td>0.64</td>
</tr>
<tr>
<td>VBO7</td>
<td>8.5</td>
<td>NSCS</td>
<td>1439</td>
<td>71.42</td>
<td>556</td>
<td>27.60</td>
<td>13</td>
<td>0.65</td>
</tr>
<tr>
<td>VBO8</td>
<td>8.5</td>
<td>NSCS</td>
<td>1682</td>
<td>75.00</td>
<td>541</td>
<td>24.12</td>
<td>13</td>
<td>0.58</td>
</tr>
<tr>
<td>VBO9</td>
<td>8.5</td>
<td>NSCS</td>
<td>1673</td>
<td>75.24</td>
<td>531</td>
<td>23.89</td>
<td>13</td>
<td>0.59</td>
</tr>
<tr>
<td>VBO10</td>
<td>16.2</td>
<td>NCCS</td>
<td>4488</td>
<td>55.60</td>
<td>3454</td>
<td>42.79</td>
<td>74</td>
<td>0.92</td>
</tr>
</tbody>
</table>

**TABLE 6.4 Validation exercise for Bridges**

<table>
<thead>
<tr>
<th>CAT.</th>
<th>NSCS</th>
<th>AVG</th>
<th>SD</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NSCS</td>
<td>73.81</td>
<td>25.27</td>
<td>0.60</td>
<td>0.32</td>
<td>26.19</td>
<td>4.24</td>
</tr>
</tbody>
</table>

**Note:** The table above provides a validation exercise for bridges with details on the cost distribution across different categories and structures.
More tertiary Indicators were examined in the new sample. In the NSCS category average steel/concrete cost ratios of 0.83 and 0.40 were obtained for the sub-structure and super-structure respectively; and 0.79 as an overall average.

Such Indicators from similar types of bridges would aid the designer the cost/progress planner/controller and the evaluator in quick comparison with typical or norm values, and focus attention on deviations as well as on cost or quantity significant items that would reward special efforts on planning and control.

6.5 WORKSHOP ON CONSTRUCTION INDUSTRY INDICATORS

A Workshop drawing on collective inputs from experts to help further assess and develop emerging Indicators was a milestone event identified as critical to the validation exercises, from the outset of the pilot project. This was held on the 9th of October 1990.

6.5.1 Objectives

The objectives were set out in the invitation letter and at the commencement of the event itself. They were:

(i) To compare preliminary project results with the experience of the participants;

(ii) to suggest alternative approaches to areas studied and better Indicators therein;

(iii) to suggest new areas for investigation within these sub-sectors;

(iv) to interact with other experts in formulating proposals for refining and using such Indicators in the construction industry; and

(v) to catalyse interest in Indicators for other sub-sectors of the construction industry.

6.5.2 Participants & Preliminary Documents

80 selected experts, senior practitioners and others associated with the pilot investigation project were sent letters of invitation, outlining project and Workshop objectives on 12th Sept. 1990. A Newspaper advertisement on 19th Sept. 1990 invited others to apply as well.
To the 62 who confirmed attendance, preliminary documents were sent a few days ahead of the Workshop, summarising preliminary findings of the investigation with back-up tables and charts; and inviting comments. Group Leaders were chosen to head special task forces to investigate specific areas, namely, buildings (2 groups), roads (2 groups) and bridges. The group leaders were issued an additional set of documents comprising:

(A) Guidelines to Group Leaders;
(B) Further explanations as to Indicators envisaged;
(C) Examples and Exercises for the Group sessions; and
(D) Questionnaires.

6.5.3 Proceedings

45 participants attended the Workshop.

The detailed Agenda is appended as Appendix AP6-3. The morning was divided into two sessions, an Introductory session and a Group Work Session. The afternoon session was devoted to Group presentations of their outputs.

The Introductory session informed the participants as to the investigations to date, the preliminary findings, and described the objectives and structure of the Workshop. The examples/exercises were introduced.

Two building Groups were formed, as intended but the bridges and roads group merged into one. The group productivity may have suffered due to this larger than intended and varied group.

Recorders and spokespersons were appointed in each of the three groups. Lively interactions took place. Some photographs are appended in Appendix AP6-4. A few participants had come prepared as requested, thereby accelerating the progress of their group. Investigating Team members joined each group to clarify approaches and assumptions in collecting and analysing the data. Two groups did not have time to complete all the exercises and questionnaires. Questionnaires were then distributed to individuals in these groups.

Each Group presentation was followed by a short discussion. Suggestions were encouraged, rather like a brainstorming session.
Many comments were received and discussed, for example, on classification systems in all sub-sectors and elemental categorisations in buildings. Among comments received were those relating to formats of analysis and presentation; to the distortions introduced by foreign inputs and involvement; and to the impact of external factors such as land acquisition.

6.5.4 Conclusions

The Workshop was successful in presenting and confirming interim findings, and in stimulating interest and interactions in construction industry Indicators. For example, five participants initially responded to the invitation to develop papers of interest for presentation at the forthcoming seminar, and four interesting papers resulted. Thus feedback continued well after the workshop itself.

6.6 SEMINAR ON 'BENEFITS FROM CONSTRUCTION PROJECT AND INDUSTRY INDICATORS'.

6.6.1 Objectives

These were:

(i) to present the results of the pilot investigation into construction industry Indicators;

(ii) to generate a feedback as to the validity of the results and suggest fresh approaches; and

(iii) to open up new areas for similar investigation, as well as to inspire in-depth investigations in the target sub-sectors themselves.

6.6.2 Papers

The first 3 papers encapsulated the main findings of the investigating team. The fourth paper (Raviskanthan, 1990) further analysed the data collected from the buildings sub-sector as described in sub-section 6.2.3.

The fifth (Karunaratne, 1990) studied the water supply sub-sector, formulated a classification system, proposed basic Indicators therein and provided a basis for detailed
investigation. The study had progressed within a month to the point of identifying 9 main elements (such as intake, low lift pump house, elevated tank) to be examined in a water-supply project. It also identified sub-elements (such as aerator, flocculator etc. within the treatment plant element) and a classification system based on such elements. Questionnaires/ data-sheet similar to those developed in other sub-sectors were used to collect data from five water supply projects. Indicators such as cost/ unit capacity of reservoir, tower and intake were highlighted. Another factor that emerged from these studies was the deviation from the indicative parameters used for estimating by the sole public sector Client in this area, the National Water Supply and Drainage Board. Such differences would possibly encourage the Board to re-examine or up-date its parameters, incorporating weighting allowances to accommodate special conditions.

The sixth paper (Abeysekera, November 1990) studied different dimensional, cost and productivity Indicators in brickwork based on detailed examples from field investigations under the auspices of this pilot project. Here price, size, shrinkage, dimensional variability and production capacity Indicators were derived. Construction related Indicators were also derived for price (eg: labour only sub-contract all-in-rates); productivity (rates of laying/ output). The seventh paper (Perera, 1990) introduced concepts and Indicators for life cycle cost evaluation using a case study on window design decisions.

The last four papers, were developed after the Workshop in consultation with the Team Leader (this researcher). The fourth paper drew directly on the pilot project data, whereas the other three used new data collected.

The final Seminar programme is summarised in Appendix AP6-5

6.6.3 Participants

Newspaper Advertisements on 29th October 1990 and 19th November 1990, publicised this Seminar held on 21st November 1990. Notices were distributed to major Engineering organisations. Special guests and workshop participants were sent letters of invitation. While 81 registered for participation, 60 actually participated.

A wide cross-section of the local construction industry was represented, with consultants and contractors from both public and private sectors; members of different professions, namely engineers, some architects, quantity surveyors and even a lawyer and consumer association representative associated with the construction industry.
The Secretary to the State Ministry of Policy Planning and the Director, Construction Management Programme, ILO Geneva, gave brief keynote addresses in addition to a Past President of IESL, and the ICTAD Deputy Director in charge of the pilot project. The Chairman was the Director General of ICTAD.

Photographs as appended in AP6-6 show the two key-note speakers and the pilot project investigating team.

6.6.4 Proceedings

The papers generated much interest, suggestions questions and comments. Areas of applicability and impact of the Indicators evinced particular interest, for example, the comparison of life cycle costs, evaluating the advantages of concrete vs bituminous roads; problems and possibilities in standardising of brick sizes; the need to incorporate tertiary Indicators to weight cost reimbursement formulae; the need to assess rehabilitation levels of roads in more detail; and the need to evaluate foreign and local cost component weightings.

6.6.5 Conclusions

The summing up of the Seminar, by Mr.D.L.O.Mendis, a past president of IESL, commended the results of the investigation project, as a landmark in the development of Construction Project & Industry Indicators for Sri Lanka.

Further areas for investigation were pointed out citing the irrigation and water supply sub-sectors as examples.

6.7 FURTHER DEVELOPMENTS

6.7.1 Financial and Progress Indicators

The costs incurred and the value of work done in a typical construction project have been found to take the shape of S curves; namely, with a slow start, and accelerated rate of spend/value achieved and a tapering off towards the more carefully carried out finishing phase. These were illustrated in Figures 2 - A and 2 - B in Chapter 2, which also described how the Department of Health in U.K. successfully uses standardised S curves to plan and monitor their projects.
At the end of the pilot investigation project in Sri Lanka, the profile of value of work done for at least one project in each category was plotted to discern any trends. There were errors for example due to time lags inherent in the value sets obtained as they were derived from the valuation certificates and related to the date of the certificate rather than that of the billing, which often could not be traced. Nevertheless an indicative S curve pattern was observed in most of the projects tested as in Appendix AP6-7. It is also noted that payments from the client would actually lag behind those valuations and assume a step-wise profile rather than a continuous curve, by virtue of the discrete inputs.

Appendix AP6-8 analysed the value of work done, into it's elements on a selected project so as to convey how each element progressed. A typical profile derived from percentage completion averages on a number of such projects, can give an useful comparative picture to a planner or evaluator on another project:

Another useful set of Indicators would quantify the visual divergences seen between a planned and achieved value curve as also described in Chapter 2 in section 2.5.3, in terms of a 'Cost Variance Index' and a 'Schedule Variance Index'.

Such graphical representation could also quickly indicate the absolute time and value differences (losses or gains) as at the date of review; and a projected date of completion and projected value/ cost, if the trends continue. These interpretations would highlight the need for action to arrest adverse trends.

6.7.2 Productivity

Appendix AP6-9 visually compares the 'value achieved' with the 'workforce strength' on a building project used for a Workshop exercise with data as in Appendix AP5-9. It seemed that worker productivity may be higher towards the latter phase of the project, but this is not conclusive in view of the different types of work elements that predominate at different stages, for example 'high value, low labour content' type items or any other such possible combinations.

General work norms of worker output in different operations have been prepared from time to time in different organisations in Sri Lanka, but are neither standardised nor comprehensively documented.
The vagaries of construction would vary such norms according to the conditions. For example, the NEDO hand-book on Promoting Productivity in the Construction Industry (National Economic Development Office, 1989) stated that productivity rates on engineering construction sites in the United Kingdom varied between one site and another by as much as three to one.

In specific trades and tasks, for example in brickwork (Abeysekera, November 1990) the bands of variation of the work norm (productivity) Indicator could be narrowed by detailed studies.

6.7.3 Statistical analysis of derived Indicators

An approach was tested using the 'Students T-test' to estimate the upper and lower bound limits of ranges of elemental building cost Indicators with a 95% degree of confidence (for a two-tailed test). This exercise used the raw building data from the pilot study contained in Appendix AP6-1. Samples of the results are shown in Appendix AP6-10.

6.7.4 Other areas explored

Attempts to extract management Indicators such as spans of control, degrees of decentralisation, hierarchy levels, decision times etc. (as in sub-section 5.2.2) did not meet with much success, despite a semi-structured approach to data collection, for example using a format, as in Appendix AP6-11. While general responses were obtained from most organisations, it was difficult for them to accurately recount and summarise all aspects in the management of each project. Correlation with performance was also not possible due to the previously discussed problems of securing reliable and accurate data on cost or time over-runs and management shortfalls. This area was thus reluctantly abandoned in the pilot investigation, but should be explored in future evaluations.

6.7.5 Technology Level and Employment Indicators

The need to develop Indicators of the level of Technology adopted in a particular project was noted, for example in roadworks or bridges. The cost, time and quality Indicators for completing operations in such projects should necessarily be linked to such technology content Indicators. With this view, 'method statements' were formulated for basic operations on roadworks and an attempt made to model an Indicator along the lines as previously developed by the Technology Atlas Project of the Asia & Pacific Centre for the
Transfer of Technology (1989) for industries such as steel manufacture and adapted in Sri Lanka to evaluate industries such as tyre and steel manufacture. But such a system was found to require major modifications to be applicable to the construction sector. Even the four basic Criteria of 'technoware' (hard technology), 'orgoware' (organisational systems), humanware and 'infoware' (information) would need re-assessment, with the addition of other Criteria.

Employment level Indicators would get incorporated in the humanware component of technology, since employment is an actual issue in developing countries like Sri Lanka with large unemployment pressures. A previous study (Ganesan, 1976) approached the issue of measuring the generation of employment in the construction industry, and work has been revived on this recently, following an ILO/ICTAD initiative.

The incorporation of an 'appropriate technology' in alternative approaches to some construction projects has also been examined, for example by Bambrah (1989) who used a multi-level matrix method, to appraise/evaluate projects against factors including the technology used. Furthermore, the outstanding need for evaluating technology transfer (or the lack of it) in projects with international inputs have been noted both in Sri Lanka and elsewhere. For example, Simkoko (1989) stated that 'The measurement and evaluation of effects of technology transfer programmes in the course of delivering investment projects is a rather complex undertaking. To our best knowledge, there are at present no universally agreed standard tools or methods of quantifying the output of the technology transfer programmes in the construction industry'.

Simkoko undertook many case-studies including that of the Kotmale dam project under the Mahaweli scheme in Sri Lanka. Here, on labour:equipment ratios he observed in general that 'Much use of local labour facilitated the blending of modern technology with local skills. The integration of mechanical plants and human forces achieving lower machine to human force ratio did not lower the quality of the project works'. It would seem that such ratios need to be quantified in terms of numbers and values, for future reference. On the issue of technology transfer, he found that 'In the course of implementing the Kotmale project, no demand for technology transfer or acquisition was presented by the client. As a result no planned technology acquisition programmes were implemented during the project delivery process'. His following conclusion also contains many elements (highlighted in italics) which could benefit from quantification or grading through some sort of Indicators, for evaluation and comparison with other projects. 'The Kotmale project was characterised by relatively low local firms involvement in the project implementation and medium integration of the local personnel on the project management team. However
foreign management and supervision were relatively high. Employment of the local personnel was also high. ...' (emphasis by the researcher to highlight elements needing quantification by Indicators).

The need for more definitive (semantically graded if not quantified) Indicators of technology transfer are evident from such attempts to compare different levels of local and foreign participation. These could for instance be based on foreign/local managerial, supervisory and staffing ratios. This approach could also extend to Indicators of technology, for example comparing labour/equipment mixes, capital/employment ratios, local/foreign finance and material ratios, and the extent of innovative/foreign/indigenous/adapted/research based technology (in assessing appropriate technologies for a given project and the benefits of their development).

6.8 CONCLUSIONS

The further development of buildings, roads and bridges Indicators derived in the pilot investigation, as well as the derivation of Indicators in the water supply sub-sector and the domain of brickwork, validated the viability and usefulness of carefully formulated and developed Indicators.

Although the statistical significance of the typical values derived was curtailed by the small size of samples in each category and although the exercises in field testing and validation were limited by the fresh data sets available; further refinement and testing was carried out wherever possible. Feedback was tested and incorporated where valid and useful. The Workshop and Seminar proved valuable in this context, as well as in highlighting the need for further development. The rapid development of Indicators in the unexplored sub-sector of water-supply (Karunaratne, 1990), in the short period between the Workshop and the Seminar was a successful test of the basic techniques developed in the pilot study. Similar techniques, formats and approaches elicited the required results within one month. Results achieved in the area of brickwork, also vindicated the usefulness of Indicators, the techniques, classification systems and terminology developed in the pilot investigation.

The following specific dangers of relying on untested Indicators or of using them in isolation from other connected Indicators were noted:

(i) incorrect classification and analysis of historical data or comparisons with wrong project categories or conditions;
(ii) inappropriate assumptions and rankings of unquantifiable factors; and

(iii) inadequate weighting for special conditions.

Some areas were highlighted (eg: in management Indicators) where progress was minimal but needs attention. Attention is also needed to develop physical progress, productivity, technology level, employment and technology transfer Indicators; as well as for a detailed statistical analysis of a wider database of developed Indicators, so as to indicate degrees of confidence with which typical or desirable values are predicted.

Figure 6 - A maps the route followed during the pilot investigation in developing construction Project and Industry Indicators in Sri Lanka.

Such Indicators provide the tools and the language by which to evaluate the performance Criteria of projects as discussed in Chapters 2 and 3. Having established in Chapters 4 to 6 that suitable Indicators could be developed to compare projects with others of the same type, the next two chapters examine how such Criteria and Indicators can be integrated into a comprehensive evaluation system for assessing the performance of the management on construction projects.

Finally, it is useful to recount the definitive contributions of experts and key industry practitioners, both individually at specific interviews in Sri Lanka and the U.K., as well as collectively at the Workshop and the Seminar on Indicators in Sri Lanka.

Their contributions were particularly significant in areas where objective data was scarce or quantitative validation was not immediately feasible. Comments in both Sri Lanka and the U.K. on the Criteria and the Indicators chosen, were useful both in confirming items proposed and suggesting new possibilities which were incorporated where useful. Target values were also commented on favourably based on the experience of the experts in Sri Lanka. The project classification systems and data formats, for example for elemental breakdowns, also benefited substantially from such inputs. Leading practitioners in the U.K., confirmed not only the choice of Criteria and Indicators but also endorsed the approaches being used in the study.
CHAPTER 7: DEVELOPING AN EVALUATION SYSTEM

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FIGURE:

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(Note: For lists of Tables herein & related Appendices at the back please see the General Contents at the beginning of this Thesis.)
CHAPTER 7: DEVELOPING AN EVALUATION SYSTEM

'If we wish to make a new World we have the materials ready - the first one too was made out of chaos' - R Quillen.

7.1 INTRODUCTION

The objectives of this chapter are:

(a) to draw together the most relevant advances and ideas from theory and practice in evaluating performance on construction projects (as surveyed in Chapters 2 and 3), together with the identification, derivation and development of sample construction project Indicators for this purpose in Sri Lanka (as outlined in Chapters 4, 5 and 6); and

(b) to integrate and consolidate these developments in a model of a general evaluation system for construction projects, and a prototype system for a specific type of project.

To achieve these objectives, Section 7.2 highlights some of the confirmations obtained during the investigation that reinforced if not validated, particular findings. Section 7.3 illustrates some areas where changes of direction were deemed necessary with the development of the study. Section 7.4 considers the development of some difficult areas, for example in evaluating qualitative judgements.

Section 7.5 sets out a general system specification for the proposed evaluation system. Section 7.6 develops a model structure, based on the findings of this study. Section 7.7 draws on such findings described in previous chapters of this study, in proposing a prototype evaluation system structure for clients of office building projects, and describes typical modules.

Figures 7 - A illustrates the development of the proposed evaluation system. Figures 7 - B, 7 - C and 7 - D illustrate the system structure and operations.

7.2 CONSOLIDATING THE FINDINGS

The researcher's own investigations in Sri Lanka into the specific needs for evaluating construction projects more systematically, highlighted many parallels with developments in relevant literature and practice in UK and internationally. Since such comparative checks were not continuous, but overlapped with the study at different points of time, such parallels when discovered imparted the confidence to proceed further in definitive directions and with particular emphasis.
While major validations are already highlighted at appropriate points in previous chapters some examples were:

(a) the confirmation of the need for systematic frameworks in which to structure the project objectives and conditions; and to select the Criteria as well as the Indicators by which they are to be measured; for instance as in the 'Logical Frameworks' and 'Project Frameworks' used by some international funding agencies;

(b) the need for the development of specific Indicators in the construction sector itself as called for by Tatum (1985) and Mendis (1987), the latter directly relating to this study; and by Crow (1990) to service the top most level of his proposed six-level information management hierarchy; and their actual development in certain relevant areas as for instance by Rowlinson (1988) and by Chauhan and Chan (1989);

(c) the formulation of specifically similar Indicators and approaches, such as those illustrated by Ferry and Brandon (1984) in building morphology Indicators including wall/floor ratios and plan/shape indices and formulae for predicting the 'optimum' number of storeys of a building based on certain parameters; also such as those reportedly used in India to compare the cost per litre capacity of different types of water tanks ranging from ferrocement, brick and reinforced concrete to steel; and also such as those used by the Overseas Unit of the Transport and Road Research Laboratory (1988) in global approximate estimating of cost per unit lengths of road and cost per unit area of bridge deck area or per unit volume of mass concrete. The latter while relying on historical data also uses inflation indices, judgement of market trends and other contextual conditions as well as detailed productivity Indicators with which to adjust the 'primary' Indicators;

(d) the confirmation of the importance of differentiating physical progress from financial progress and the need to incorporate arrangements for physical monitoring as stressed by Scott et al in their ODA evaluation (1987) and by Ambalavanar (1987);

(e) the emerging emphasis on the effect of the management, organisation and contextual variables on construction performance as found necessary by Rowlinson (1988) and as incorporated in the current work of Peter Miller and his associates in modelling the equilibrium between the Client's business environment variables and the project variables;

(f) evidence of similar success Criteria to those suggested in Section 3.3.3 of Chapter 3, emerging from studies such as that conducted by the University of Texas and reported by de Wit (1988). The six success Criteria identified by the University of Texas study, as most frequently used to measure construction project success were: budget performance, schedule
performance, client satisfaction, functionality, contractor satisfaction and project manager/team satisfaction. These confirmed Criteria already chosen for this study; and

(g) the interactions between the performance Criteria such as scope, schedule, quality and cost in modifying the ideal project goals, to better represent the 'real' goals to be pursued, and that would satisfy the priorities and constraints as described by Al- Sedairy (1985). The difficulties of classical (mathematical) optimisation of designs at an early stage, and alternative approaches to merely 'satisficing' (finding satisfactory and sufficient solutions) were described by Atkin (1986) as a background to his proposals for a multi-stage decision model aimed at the approximate attainment of an 'optimum' in preference to the exact attainment of an 'inferior' solution.

7.3 SOME MILESTONES AND TURNING POINTS

The findings that emerged from this study in both the field work and in comparative studies, led in stages to the development of the model proposed in this chapter. For example:

(a) the initial focus on post project evaluation or ongoing project monitoring proved inadequate by itself, unless related to the initial approximate estimates and the management of the design itself in providing improved (more efficient) solutions;

(b) the need was appreciated to assemble historical databases codified by categories of similar projects; to facilitate quick spot checks of the current projects against comparable data;

(c) the importance was realised, to model a comprehensive project profile from an expanded brief incorporating the contextual conditions and performance priorities; to then set out the actual Criteria to be used and their means of measurement, through Indicators for which typical values and ranges would be already available from the database to be assembled as in item (b) previously; and which would be modified by their sensitivities according to the contextual conditions and linkages with each other as determined by the project priorities;

(d) the need was noted, to borrow from, adapt and expand for the construction sector in particular, systematised 'Logical Frameworks' and 'Project Frameworks' as used by some international funding agencies in structuring their general project objectives and their evaluations; and

(e) the realisation emerged that some of the contextual conditions and performance Criteria, as initially proposed by this researcher and as described in Chapter 3 in Sections 3.3.2 and 3.3.3 respectively, would need re-consideration in the light of the prototype to be developed.
as a typical example in this chapter. For example, the performance Criteria of 'Health and Safety' and 'Project Participant Satisfaction' (other than the satisfaction of the Client which is measured separately) may not concern the private sector client, especially if it is a one-time construction industry client, although it may well concern a public sector client. The latter may also be more concerned about the impact of the technologies used on local employment, on training and technology transfer, as well as on the environment. The private sector client may only be concerned with the effect of the technologies used on the quality of the end product and the statutory requirements as to the environment. In such issues and those of Health and Safety, the performance Criteria may then only incorporate minimum standards, unless social consciousness or far sighted public relations suggest otherwise.

However a contractor or designer may take another view point and assign a different value scale to such Criteria. They would also emphasise efficiency and productivity Criteria. There was therefore a need for a flexibility to choose and adjust parts of the evaluation system according to the purpose, this being one reason for the modular structure proposed.

Management efficiency emerged as a crucial measure of performance apart from effectiveness. It was not only achieving the project objectives that was important, but also whether they were achieved with the optimal mix of resources. The efficient use of resources could on occasions be more indicative of project management success than achieving the project targets themselves, especially when the actual achievements were distorted by external unforeseeable circumstances.

Measures of management efficiency thus needed to be incorporated as a specific performance Criterion apart from Indicators of effectiveness in meeting project goals of scope, cost, quality and time etc.

Unfortunately, even meeting the originally specified project goals does not always signify project success. Apart from the goals changing with time, there usually are other undefined elements in the client's perception of success, such as those based on the relationship with, and confidence in, the main project participants; and

(f) the need was appreciated to incorporate modular components in the proposed evaluation system so as to retain its comprehensive coverage of the industry, while excluding unnecessary modules from a specific evaluation. The large databases envisaged and the multiplicity of variables would otherwise make the system unwieldy.

7.4 RESIDUAL DIFFICULTIES

Some domains did not yield ideal solutions, for example in the search for techniques to quantify essentially judgemental situations. However the most useful, reliable and least
unwieldy solution in meeting the system specification had to be chosen. For instance, the use of Expert Systems as well as a weighting technique based on matrices of pairwise comparisons were proposed.

7.4.1 Semantic Differentials

Taking a basic illustration of the wide range of potential semantic expressions and interpretations, if a project was initially set up by a person specifying goals qualitatively in relatively easily attainable terms (eg: a floor finish to an acceptable level) and later evaluated by another person who describes performance in superlative terms, this would drastically distort the success profile, as opposed to that of another case where the reverse conditions prevail.

7.4.2 Differences of Emphasis

Such discrepancies or distorted evaluations could also arise even with quantified Indicators before the process of quantification, for example where the client's qualitative statements were interpreted differently by different designers; and the range (of performance levels or tolerances) of a designer's specifications were construed differently by contractors; and their instructions in turn were misunderstood by sub-contractors and suppliers; and finally if the evaluators measured performance against yet another interpretation of the client's qualitative statements (which could additionally have also changed with time, unless 'frozen' in an unambiguous brief).

Table 7-1 illustrates a basic example of how the same 'average' performance may be judged differently by different types of evaluators depending also on the type of target setting ie the extent to which the targets compared realistically with typical values or ranges from similar projects in that category. The evaluation 'verdict' also depends on how carefully the performance was evaluated. For example a cursory two day evaluation with an underlying aim of reassuring absent investors, would differ substantially from a systematic and detailed one month audit of all technical and financial data with a commitment to boost performance.
### The same (average) Project Performance viewed under Different Conditions

**TABLE 7-1**

Furthermore this matrix only illustrates discrepancies that may arise between just two different sets of value systems, those of the 'final target setter' and the evaluator. Such differences may be magnified many times by the sets of further discrepancies and misinterpretations that could arise at the interfaces of each of the many layers between the client and such a final 'target setter'.

#### 7.4.3 Differences of Detail

Scarcity of information about similar projects or the subject project itself or a shortage of time to investigate such information in detail would also lead to inconsistent evaluations.

Skitmore et al recounted (1989) Bowman's conclusions in 1963 that evaluation based on incomplete information was generally subject to systematic error (or bias) as well as to an unsystematic error (or variance). The idiosyncracies of human judgement heighten such errors if attempting to compensate for the lack of information by unfounded extrapolations, interpolations or assumptions.

---

<table>
<thead>
<tr>
<th>TARGET SET:</th>
<th>VERY HIGH</th>
<th>HIGH</th>
<th>REALISTIC</th>
<th>LOW</th>
<th>VERY LOW</th>
</tr>
</thead>
<tbody>
<tr>
<td>PERFORMANCE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVALUATION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GRUDGING</td>
<td>exception-ally bad</td>
<td>very bad</td>
<td>bad</td>
<td>poor</td>
<td>ok</td>
</tr>
<tr>
<td>(VERY STRICT)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RESTRAINED</td>
<td>very bad</td>
<td>bad</td>
<td>poor</td>
<td>ok</td>
<td>fair</td>
</tr>
<tr>
<td>(STRICT)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FAIR</td>
<td>bad</td>
<td>poor</td>
<td>ok</td>
<td>fair</td>
<td>good</td>
</tr>
<tr>
<td>GENEROUS</td>
<td>poor</td>
<td>ok</td>
<td>fair</td>
<td>good</td>
<td>very good</td>
</tr>
<tr>
<td>VERY GENEROUS</td>
<td>ok</td>
<td>fair</td>
<td>good</td>
<td>very good</td>
<td>exception-ally good</td>
</tr>
</tbody>
</table>
Not only would the proposed system have to suitably structure and utilise human judgement in evaluating unquantifiable or less quantifiable areas, but it would also have to evaluate the performance of human judgement itself, in examining management performance, for example in evaluating whether optimal decisions were made or the best terms negotiated on a project.

While some elements of a decision making process may be illustrated and quantified to some extent with probabilities, rankings and pairwise comparisons, there are residual elements which are difficult to model. Although there are many models and theories such as utility theory for modelling value systems and decision analysis as described by Lifson and Schaifer (1982), there are also many schools of thought as to their general applicability, like those highlighted by French (1989). Decision trees, probabilities, measures of utility, group decision making, sensitivity and risk analyses are some of the general techniques in use and incorporate specific tools like 'decision conferencing' and 'Delphi group forecasts' (Cooke and Slack, 1984).

Finlay (1989) treated 'problem tackling' as synonymous with decision making. Both these activities being common functions of construction management merit special attention in this study. Finlay followed Ackoff's terminology in that a problem could be tackled either by 'solving' - seeking an optimal solution; or by 'resolving' - seeking only a good enough answer (called satisficing by Simon); or by 'dissolving' - when conditions change to eliminate the problem.

Advances in associated techniques would help optimise design decisions in the conceptual stages; enable more realistic modelling of value systems, contextual conditions and performance targets; and facilitate improved management of the procurement and construction processes and any 'trouble-shooting' thereon. Techniques such as those described by McCartt and Rohrbaugh (1989) developed for evaluating the effectiveness of specific decision support systems may be extended to evaluate the management, systems of decision making and problem solving in construction. Similarly, techniques of evaluating management communication and information systems (Booth, 1986) may be used in assessing the effectiveness and efficiency of information flow within and between organisations.

The ODA in it's most recent edition of general evaluation guidelines (1988) recognised the need for 'subjective' data through interviews and assessments to supplement hard data; and highlighted it's usefulness, provided the context of how the information was collected is
described in detail. Casley and Krishna Kumar (1988) suggested that non-verbal behaviour should be also studied in qualitative assessments in order to evaluate the views, attitudes and perspectives of for example, respondents at individual and group interviews.

However such assessments would introduce extra variables and possibilities of misinterpretations. Consistent ranking and rating systems can reduce such variability and improve the judgements, particularly when incorporating pairwise comparisons, that provide a busy person with familiar items to compare against.

Pairwise Comparison Weighting Matrices (PCWMs) are a particular tool proposed in this study for use in refining subjective judgements. Expert Systems (ESs) are also considered to aid judgement where conditions of uncertainty prevail and expert help is required.

7.4.5 The need for a rationalised system

Apart from the difficulties in quantifying qualitative phenomena and a multiplicity of variables, the major difficulty in evaluating construction management performance was found to be the lack of a systematic approach and a coherent methodology. The need for a construction management oriented evaluation system was confirmed.

7.5 GENERAL SYSTEM SPECIFICATION

The general system specification formulated herein sets out the main objectives, the envisaged functions, the principal components, their scheme of operations and the desirable system characteristics. The specification was framed in a generalised format to accommodate adaptation for the evaluation of any type of construction project and from the point of view of any of the project participants. This general system envisages the totality of policies, procedures and tools to be developed and applied along with the active participation of trained human evaluators.

Figure 7 - A overleaf, traces the development of the proposed evaluation system in this study.

7.5.1 System Objectives

The main objectives are to evaluate (A) the effectiveness and (B) the efficiency of the management of a given construction project, for an identified purpose of one of the project participants and at a given point of time; and to ensure that such evaluation should be reliable, realistic and efficient; with the areas assessed and the level of detail adjustable to suit the purpose of the evaluation.
<table>
<thead>
<tr>
<th>General System Specification</th>
<th>Chapter/Section</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Objectives, Functions, Features &amp; Facilities)</td>
<td>7.5</td>
<td></td>
</tr>
<tr>
<td>Modular Structure of the proposed system</td>
<td>7.6.1</td>
<td>7-B</td>
</tr>
<tr>
<td>System Operations</td>
<td>7.6.1</td>
<td>7-C</td>
</tr>
<tr>
<td></td>
<td>7.6.2</td>
<td></td>
</tr>
<tr>
<td>System Output (principal formats)</td>
<td>7.6.3</td>
<td></td>
</tr>
<tr>
<td>Sub-Systems of the proposed System</td>
<td>7.7.2</td>
<td>7-D</td>
</tr>
<tr>
<td>Framework of Criteria &amp; Indicators for Prototype</td>
<td>7.7.3</td>
<td>7-D</td>
</tr>
<tr>
<td></td>
<td>7.7.4</td>
<td></td>
</tr>
<tr>
<td>Summary of Prototype application</td>
<td>7.7.5</td>
<td>3-B 8-A</td>
</tr>
<tr>
<td>Development of Prototype Modules</td>
<td>7.7.6</td>
<td>5-D 6-A (also Ch.5,6)</td>
</tr>
<tr>
<td>Developing Sub-Systems &amp; associated Tools</td>
<td>Ch.8</td>
<td>8-A 8-B 8-C</td>
</tr>
</tbody>
</table>

**DEVELOPING THE PROPOSED CONSTRUCTION MANAGEMENT EVALUATION SYSTEM**

**FIGURE 7-A**
7.5.2 System Functions

In evaluating the effectiveness of the management of a construction project to:

A1: establish realistic performance Criteria and targets by -

(i) identifying the Criteria used in similar projects (within the same category of that construction sub-sector; say hospitals category of buildings sub-sector) and the typical (average) values, ranges, linkages between relevant performance Indicators, their sensitivities to each other and to special contextual conditions;

(ii) modelling the particular project profile, including the contextual conditions and the project priorities;

(iii) identifying clearly the 'target group' requiring the evaluation, their specific purposes in commissioning it and confirming their agreement with the modelled project profile;

(iv) selecting the relevant project performance Criteria and the related Indicators for measurement, as appropriate for the purposes of the evaluation, from the database derived from similar projects;

(v) adjusting the target values and ranges of the selected performance Indicators by weighting by the contextual conditions (as in Figure 3 - B);

(vi) adding any extra project specific Criteria, Indicators, target values and ranges (eg: budgetary limits, milestone time targets);

(vii) re-adjusting the target values from items (v) and (vi) by accounting for any sensitivities to their interactions through appropriate linkages also as in Figure 3 - B; and

(viii) comparing targets from (vii) with the project performance targets actually set at the outset as well as any revised targets; identifying reasons for any divergences and re-adjusting where necessary; and

A2: assess the performance at the specified point of time by -

(i) evaluating the chosen performance Indicators;

(ii) evaluating any variances from the adjusted targets values and ranges;
(iii) identifying reasons for such variances, incorporating any allowances for same; and re-evaluating the adjusted variances;

(iv) highlighting the achievements and shortfalls of the management; and

In evaluating the efficiency of the management of a construction project, to:

(i) choose suitable Criteria, their related Indicators (based on similar projects and identified project requirements) and level of detail required, according to the purpose of the specific target group and the timing of the evaluation; for example from a range of available Indicators of management systems, resource utilisation levels (productivity and idling factors), optimal resource mixes etc;

(ii) identify the target values and ranges of the relevant performance Indicators from similar projects;

(iii) adjust the values and ranges by suitable weighting Indicators related to the contextual conditions and linkage Indicators relating to the sensitivities of interacting Criteria;

(iv) derive separately, theoretical values and ranges where applicable, for example in resource mixes and productivity norms;

(v) compare any project performance target values and ranges actually set on the project (including any revisions), with items (iii) and (iv) herein;

(vi) identify any special justifications for differences in such targets, adjust where necessary and formulate a finalised project-specific set of targets;

(vii) evaluate project performance values and ranges, and compare with targets in (vi) herein; and

(viii) identify causes of any variances, allow for any justifiable reasons and highlight residual shortcomings and strengths in management efficiency and possible areas of improvement.

7.5.3 Desirable System Features and Facilities

(A) Flexibility, with a central core and a series of independent modules which could be integrated by specific selection into a complete and compatible system for a given evaluation exercise.

(B) As complete a coverage as possible to cater for all reasonably foreseeable eventualities within the available categories; and to highlight areas not covered pending further developments.

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(C) As clear, concise and realistic a representation as possible of project profile, performance targets and actual performance.

(D) Transparency, enabling an user to understand the reasoning in selecting particular modules and other such steps in the evaluation, as well as the justification of any conclusions or suggestions.

(E) Further flexibility, to facilitate intervention by an evaluator dissatisfied with such reasoning or wishing to introduce special project conditions into the evaluation.

(F) Simplicity for efficient use by trained evaluators.

(G) Minimal interference with any on-going projects.

(H) Specific provisions to incorporate tested qualitative judgements, validated opinions etc. to supplement the 'hard' data.

(I) Ability to suggest conclusions with specified degrees of confidence or limited sets of conclusions specifying reservations, warnings and uninvestigated areas; in the absence of all the information required for a full evaluation.

(J) Facility to incorporate current project data in a database of Criteria, Indicators, values, ranges and checklists at the end of an evaluation, subject to confirmation by the evaluator.

7.6. TOWARDS A MODEL EVALUATION SYSTEM

7.6.1 Envisaged system components and their interactions

This sub-section describes a basic system of the type envisaged and as illustrated in Figure 7 - B, overleaf. The intended operations are summarised in Table 7-2 in 7.6.2 and in Figure 7 - C that follows. Figure 7 - D and sub-sections 7.7.2 and 7.7.3 later illustrate the sub-systems and their interactions.

The central component would be a core sub-system consisting of a knowledge based (or Expert System) front-end and incorporating a strategy switch facility to select one setting from among each of the following three groups or selection bands in turn:

(i) different categories of projects (e.g: multi-storeyed office buildings of between Rs. 10 million and Rs. 50 million in value or asphalt concrete roads on rolling terrain and above Rs. 50 million in value);

(ii) different stages of a project (e.g: feasibility, design, procurement, construction) at which the evaluation may be executed; and
MODULAR STRUCTURE OF THE
PROPOSED SYSTEM

FIGURE 7 - B
(iii) different purposes of the evaluation (eg: cutting high costs, regaining programme, identifying sources of specific shortfalls, general assessment of success/failure levels or learning lessons for improving performance in future projects), and from whose point of view it is carried out (eg: client; client's financier, management contractor, contractor's financier, designer).

Figure 7 - B illustrates how the foregoing three selection bands are to be embodied in the core sub-system represented by Circle I. Each of these three bands would have outer circles (Circles II, III and IV) associated with them as in the figure. Each such circle is to contain a series of modules, with each module relating to the corresponding segments of the respective selection band. For example a module would be chosen from Circle II to relate to the category of the project being evaluated, another module from Circle III to suit the stage of the evaluation and the third module from Circle IV to match the particular purpose of the given evaluation. Each such module would contain performance Criteria, families of Indicators (as in Figure 4 - A), questionnaires, data formats of various types (eg: basic reconciliation charts, responsibility and information flow matrices). Where possible each of these questionnaires and data formats would have segments related to particular contextual conditions or project priorities, so as to facilitate replacement or modification according to varying project profiles. Modules in Circle II are to also contain typical values and ranges of the chosen Indicators in the particular project categories.

Circle V is to contain more modules each of which serve as accessories to corresponding parent modules in Circles II, III and IV. Each of such accessory modules in Circle V would contain sets of simple tools such as detailed checklists and reconciliation charts, detailed responsibility and information flow matrices, judgement ranking, rating and integrating systems, as well as more powerful knowledge (rule)-based tools. Such accessory modules would be mobilised along with the respective parent module.

When an evaluator selects a particular type of evaluation, he would effectively choose the three relevant modules from Circles II, III and IV, and the associated 'tool-kits' from Circle V. These selected modules would initially 'overlay' each other combining all their components but the knowledge based front-end in the central core would help modify (add to, delete from, substitute or change) parts of the questionnaires, hierarchy of Criteria, families of Indicators, values, ranges, checklists and other such tools in the combined overlay, so as to provide an evaluation system compatible with the selected items and their inter-relationships. These modifications would be effected both directly by the system, (using the knowledge based front-end, where there are pre-determined inconsistencies to be resolved) and also by prompting the evaluator to verify the relevance or resolve the conflicts between certain Indicators, checklists etc.
In assembling a specific evaluation system to be used in a particular project, the knowledge based front-end in the core sub-system would next assist the evaluator to model the project profile ie the contextual conditions and project priorities. This would refine the performance Criteria along with their Indicators; narrow down the related typical values and ranges as in Figure 3 - B; and also suggest further modifications in the questionnaires, data formats, check-lists and other tools, effectively focussing the evaluation on project specific requirements.

The knowledge based front-end should also allow the evaluators to over-ride any unsuitable system suggestions and to incorporate elements the evaluator deems important, but would continue to guide him in maintaining a consistency with other related areas. For example if he wishes to replace a certain set of questions in a questionnaire or items in a data format or checklist, he would be reminded that these are related to specific performance Criteria or Indicators and asked whether he is certain he wants to exclude the latter and whether he has any alternative means of verifying them.
### 7.6.2 Summary of envisaged system operations

<table>
<thead>
<tr>
<th>INPUT</th>
<th>SOURCES</th>
<th>EVALUATOR'S ACTION</th>
<th>SYSTEM ACTION</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Preliminary information. Other project conditions.</td>
<td>Project client. Evaluation client. Project brief. Local, national, international conditions.</td>
<td>Feeds in findings. Interacts in modelling project profile.</td>
<td>Helps model project profile (priorities &amp; contextual conditions) Narrows indicators values as in Figure 3 - B.</td>
<td>Agreed performance criteria &amp; related indicators Suggested values &amp; ranges. Suggested questionnaires, data formats &amp; tools.</td>
</tr>
<tr>
<td>4. Project indicators &amp; judgements.</td>
<td>Project documents. Project participants. Related documents.</td>
<td>Collects (a) information on prescribed formats (b) supplementary information (c) reasons for deviations.</td>
<td>Compares deviations as in Figure 4 - B.</td>
<td>Hierarchy of variances. Comparison of target/achieved performance profile as in Figure 3-D and Project Performance Framework as in 7.6.3.3. Possible problems to be investigated. Conclusions.</td>
</tr>
</tbody>
</table>

**Summary of envisaged System Operations**

**Note:** Figure 7 - C overleaf illustrates the principal stages of the above operations.

**TABLE 7 - 2**
Select suitable Indicators to measure such Criteria

Select weighting and linkage Indicators to adjust typical values

Adjust typical values of Indicators to suit project by weighting with 'Project Profile'

Compare with original target values and adjust where necessary to set realistic performance targets

Project Evaluation Framework

Collect project information, arrange and analyse in stages

Project Performance Framework

Incorporate new Criteria Indicators & values in relevant databases

FLOWCHART OF ENVISAGED SYSTEM OPERATIONS

FIGURE 7 - C
7.6.3 'Project Evaluation' and 'Project Performance' Frameworks

The 'project evaluation framework' and 'project performance framework' cited in Figure 7 - C could be considered extensions of the 'Logical Framework' and 'Project Framework' approaches to general evaluation initiated by USAID and ODA respectively, with relevant extrapolations into the construction sector, incorporating the particular priorities therein as have emerged from this study.

7.6.3.1 General Category Frameworks

Once data from a sufficient number of projects in a given category (for example 2 to 5 storey hospital buildings on strip foundations of Rs.10 to 50 million value and with an average level of finishes, in major towns) is collected and codified, a general framework of performance Criteria and related Indicators may be assembled for an overview as follows, along with some associated tools that could help in computing the Indicators on a given project.

<table>
<thead>
<tr>
<th>General Performance Criteria</th>
<th>Available Indicators</th>
<th>Typical Values &amp; Ranges</th>
<th>Associated Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Primary Secondary &amp; Tertiary Weighting &amp; Linkage</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Format for a General Category Framework

TABLE 7 - 3

Examples of such performance Criteria are listed in Section 3.3.3, but as outlined in Section 7.3 (e), some Criteria may need to be eliminated or substituted according to the purpose of the evaluation. A hierarchy of Criteria could therefore be developed, for example from a private client's viewpoint with the following at the primary (topmost) level:

Cost; Time; Performance; Scope Management; Risk allocation; general Client Satisfaction; Management Efficiency. A large public client may add Criteria of Health & Safety; Technology transfer and Environmental considerations; Satisfaction of other Participants etc. Each of such primary Criteria would have associated sub-criteria (examples of which were illustrated in Section 3.3.3).
Each of these Criteria and sub-criteria would need to be measured by relevant Indicators, giving rise to a family of Indicators as demonstrated in Figure 4 - A. Typical values and ranges of such Indicators can be derived from an extensive database of projects in that category as demonstrated in Chapters 5 and 6. Techniques and tools to evaluate such Indicators could be developed as described in Chapter 8.

All such Criteria, Indicators, values & ranges and tools may be encapsulated in such a general category framework; but it's application on a particular project would need to be more focussed.

While the first step in such a focus would be to select suitable Criteria and Indicators and refine the values by the project weighting and linkage Indicators as in Figure 3 - D, the next step would be to add on project specific Criteria and Indicators, in consultation with the client and other stakeholders.

### 7.6.3.2 Project Evaluation Frameworks

Having identified the specific purpose of the evaluation and modelled the particular project profile; relevant Criteria and related Indicators would be listed as follows in a 'Project Evaluation Framework', that would also concisely portray the project goals. This should therefore be useful to project participants as well, and could also form the framework for their project management. It may thus be also considered a 'project management framework', in this sense of identifying objectives and performance Criteria; and setting targets towards which the project should be managed. The average target values and ranges should be up-dated and up-graded both with the data from fresh projects and also by adjustments with relevant price inflation indices.

<table>
<thead>
<tr>
<th>Identified Project Objectives</th>
<th>Selected Performance Criteria</th>
<th>Priority Ranking</th>
<th>Selected Indicators</th>
<th>Target Values &amp; Ranges</th>
<th>Associated tools for evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Format for a 'Project Evaluation Framework'**

**TABLE 7 - 4**

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### 7.6.3.3 Project Performance Frameworks

Performance may be evaluated against such target values of Indicators both quantitatively and qualitatively as necessary. A further focus on specific problem areas would be facilitated at this stage, when deviant primary Indicators suggest narrower evaluation paths to be followed, by only examining the related secondary and tertiary Indicators while ignoring those related to the non-deviant primary Indicators, as in Figure 4 - B.

However, a general project performance framework embodying all relevant Indicators may be initially set up as follows:

<table>
<thead>
<tr>
<th>Selected performance criteria</th>
<th>Selected Indicators</th>
<th>Target values &amp; ranges</th>
<th>Revised targets &amp; reasons</th>
<th>Achieved values</th>
<th>Variances</th>
<th>Variances at last review</th>
<th>Reasons for variances</th>
<th>Suggested solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Format for a 'Project Performance Framework'**

**TABLE 7-5**

Variations of this basic performance framework could be applied at different stages of a project, for example during design evaluation or in evaluating resource usage by a contractor on an on-going project; for instance when evaluating the man-hours spent on design or machine-hours on a specific activity.

<table>
<thead>
<tr>
<th>Selected Indicators &amp; Target Values</th>
<th>Related resource usage</th>
<th>Achieved (used) to date</th>
<th>Forecast balance to completion</th>
<th>Forecast Total at completion</th>
<th>Forecast variances</th>
<th>Variances at last review</th>
<th>Causes &amp; trends</th>
<th>Suggested solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Format for a Resource Reconciliation Framework**

**TABLE 7-6**

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7.6.4 Project Performance Profiles

Extensive and detailed information in formats as illustrated in the foregoing sub-sections 7.6.3.2 and 7.6.3.3 may not always facilitate a quick overview of the situation by top management, especially when the Criteria and Indicators are many, complex and inter-related. It was to supplement such formats and provide an overview that performance representations via a summarised Performance Profile are suggested in this study, as in Figure 3-D, to compare achieved values with targets in the case of each Criterion.

Just as the performance against different sub-criteria could be approximately consolidated and represented as a point on the parent Criterion axis and compared with the Criterion target; it should also be possible to represent the overall (combined) performance if such an approximate overview Indicator was needed, and to compare performance against the target. A simple approach to this would be to:

(a) assign scales to the Criteria according to their priorities, so that for example if the relative importance of two Criteria was decided as 3:1, the more important Criterion is assigned a scale from 0 to 15, and the less important one from 0 to 5; and

(b) take the average (arithmetic mean) of all the targeted scores initially, and that of the achieved scores subsequently for comparison.

This is described in detail in sub-section 8.6.7 of the next chapter.

7.7 Prototype Evaluation System for Clients of Office Buildings

This section illustrates a prototype evaluation system in the office buildings category of the buildings sub-sector from the point of view of a client or client's project manager who is interested in evaluating how effectively the project targets were met; and also with an option to examine how efficiently the management achieved such performance levels. While it may be argued that the efficiency of the process management should not be a prime concern of the client, since it may only increase the profit margins of the other participants, it does however become very important if the contract is on a cost reimbursable basis; and still remains important even in other situations for example:

(a) in generating confidence in the contractor's organisational capacities

(b) in foreseeing potential disruptions in time; and
in assessing the capacities available to perform other work connected with this or other projects; and any precautions to be taken if awarding such work.

However the client may be interested in different aspects of construction management efficiency or view the same aspects from different angles. For example, higher than usual spans of control of supervisors may indicate cost effectiveness and efficiency to the contractor, but alarm the client as to how quality could be assured on his project with apparently lower levels of supervision than usual.

This Prototype Construction Management Evaluation System is called 'PROBEMESS' for convenient recognition in this study. The Pilot Construction Management Evaluation Expert System front-end developed in Chapter 8 is similarly called 'PICKMESS'.

7.7.1 Specific features of the Prototype

In addition to the general system specifications formulated in 7.5, and the model evaluation system structure proposed in 7.6, the specific purpose and project type narrow the range of modules required for the prototype. The purpose of a prototype in itself, to test the feasibility of a more comprehensive system, suggested that a representative, rather than complete structure would suffice at this preliminary stage, the emphasis being on simplifying the model to its minimum requirements at the outset, with provision to expand it in steps subsequently.

7.7.2 Sub-Systems and their Interactions

Figure 7-D overleaf illustrates the interactions of the sub-systems in the general model. Each general sub-system of Criteria or Indicators contains many modules pertaining to specific project categories, evaluation stages and purposes as indicated in Figure 7-B. Only those relevant to this prototype are chosen.

The framework in 7.7.4 represent a typical choice for a client evaluating an ongoing or completed office building project, juxtaposing probable performance Criteria with relevant Indicators.

(a) The Expert System front-end in Circle I of Figure 7-B would incorporate or access a pairwise comparison weighting matrix (PCWM) tool to help the client rank project priorities. This Expert System front-end would also assist in assigning default rankings based on similar category data, where the client is indifferent and it does not affect other Criteria. Modelling of the relevant contextual conditions by the evaluators would also be assisted by an Expert System drawing on a knowledge base of relevant factors from that particular
CORE SUB-SYSTEM (using an EXPERT SYSTEM)
for modelling project & evaluation requirements & for selecting modules from other sub-systems

SUB-SYSTEM of INDICATORS

SUB-SYSTEM of CRITERIA

ASSOCIATED TOOLS FOR VERIFICATION & PRESENTATION

ASSOCIATED DATABASES OF TYPICAL VALUES & RANGES

SUB- SYSTEMS AND ACCESSORIES OF THE PROPOSED SYSTEM

FIGURE 7-D
category of project and specific purpose of evaluation. The project profile modelled on such priorities and contextual conditions would be applied by the Expert System in order to weight the expected values and ranges of relevant primary, secondary and tertiary Indicators as in Figure 3 - D; through weighting and linkage Indicators, so as to provide more realistic targets to be evaluated against, during the particular evaluation.

(b) Each module selected from Circles II, III, IV, and V (as in Figure 7 - B) to match the project category and evaluation purpose would contribute segments of a family of relevant Criteria, a related family of Indicators, a set of typical values and ranges from relevant database modules and an array of associated verification tools such as checklists, data formats, judgement ranking matrices etc. Their basic interactions as sub-systems are indicated in Figure 7 - D.

7.7.3 Proposed Criteria and Indicators

As outlined in describing the general system; project specific Criteria, Indicators and special target values may be added to the general framework illustrated in Section 7.7.4. This framework is not intended to be comprehensive, but merely to incorporate core items for purposes of indicating what is common in that category and illustrating the format.

Some of the Criteria and Indicators relate to design efficiency, others to construction and many to both. For example the cost/ m$^2$ of gross floor area would be related to both design and construction. If the evaluation is focussed on the designer or contractor, some items may be omitted or modified appropriately.

Some new Criteria and Indicators have therefore been introduced and others changed from those discussed in Section 3.3.3 of Chapter 3. For example a new Criterion of 'cost balance' in item a.5 seeks to test the consistency of the costs incurred, by comparing the elemental cost Indicators both of percentage breakdowns and costs per unit area of each element with those of similar projects. Discrepancies or distorted patterns would indicate whether certain elements have been overdesigned or attracted an unusually large proportion of cost; as could happen when the types of roof, windows or floor finishes are belatedly changed to be kept within overall cost limits, signifying poor cost planning. Here elemental cost Indicators serve as primary Indicators, rather than the secondary Indicators as envisaged in the pilot investigation project in Sri Lanka.

Each Indicator would have a related target value and a possible range where a flexibility is available. Some would be qualitative Indicators for example the first sub-criterion a.1, being the certainty required of achieving the cost limit, could be ranked on a judgemental scale from 1 to 10. The project-specific time limit Criterion in c.1 while similarly ranked may
be additionally linked to the cost limit Indicator for purposes of cross-checks, by formulae such as those developed by Bromilow in Australia (1988) and NEDO in UK (1988) and described in sub-section 5.4.6 of Chapter 5 herein.

Some weighting factors may be subsequently built into the categorisation itself by increasing the number of categories (sub-classifying for example as intended in the pilot study in Sri Lanka by factors such as number of storeys and location) and decreasing the variability within each such sub-category. However a larger database of projects would be needed in order to have a statistically significant sample in each category. Extensive resources would be required to assemble such a large database categorised as in Appendix 5-4 (i.e., by building function, number of storeys, type of foundations, level of finishes, range of value and location). Even assuming that: only 12 building functional types were taken (adding factories to those chosen for the pilot investigation), that buildings with differing numbers of storeys were divided into 4 groups (single, 2 to 3, 4 - 8 and above 8), that only projects above Rs. 1 million were considered and the country was divided into nine districts, one would theoretically still need $12 \times 4 \times 7 \times 3 \times 4 \times 9 = 36,288$ sub-categories. To obtain statistically significant samples in every sub-category one may ask for 30 projects in each sub-category leading to a staggering 1,088,640 building projects to be analysed in detail, and that too assuming the available projects slot neatly in sets of 30 into the chosen sub-categories. The number of building projects required for consideration would be more likely to be around 3 million to yield even close upon 30 projects in most such sub-categories. The short-term solution as adopted in the pilot investigation in Sri Lanka, was to only classify building projects by the first factor viz., function; and to assign weightings for example to cost Criteria such as elemental proportions, in order to account for the other factors, such as building morphology, location, value, soil condition/foundation type and levels of finishes.

The suggested framework for the prototype in Section 7.7.4 is indicative of what could be obtained by selecting Criteria, and Indicators from the 'general category framework' (as in 7.6.3.1) but before assigning the actual values in a 'project evaluation framework' (as in 7.6.3.2). The associated tools to be incorporated in the last column of a completed 'project evaluation framework' column are those that should be of assistance in evaluating the actual performance values of the chosen Indicators, such as reconciliation charts for variances, checklists and data formats for determining values of ratios and formulae; questionnaires and pairwise comparison weighting matrices for qualitative assessments and flow charts for evaluating information flow procedures, bottlenecks, redundancies and shortfalls etc.
7.7.4 Typical Framework of Criteria and related Indicators of a Prototype (Evaluation System) for an office building Client

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>INDICATORS</th>
<th>TARGET VALUES TO BE:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Weighted by:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>All Contextual Conditions &amp; specially:</td>
</tr>
<tr>
<td>a. COST</td>
<td></td>
<td>a.2 (degree of economy/flexibility incorporated in budget)</td>
</tr>
<tr>
<td>a.1 Certainty of not exceeding cost limit</td>
<td>Over-run: Absolute; and percentage-wise</td>
<td></td>
</tr>
<tr>
<td>a.2 Economy (of capital cost)</td>
<td>Cost per unit gross floor area. Cost per unit usable floor area</td>
<td>Analysed by above functions or cost items. Analysed by building elements (as per Appendix 5-8)</td>
</tr>
<tr>
<td>a.3 Cost balance/consistency</td>
<td>Elemental costs: percentage-wise &amp; per unit gross floor area.</td>
<td></td>
</tr>
<tr>
<td>a.5 Cash Flow advantages.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Suggested Cost Indicators

TABLE 7-7

204
<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>INDICATORS:</th>
<th>TARGET VALUES TO BE:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Primary</td>
<td>Secndry./Tertry.</td>
</tr>
<tr>
<td>[ ]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. QUALITY/SPECIFICATION/PERFORMANCE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b.1 Aesthetics</td>
<td>Form (Shape), Materials mix, Colour blend, Finishes level, Environmental enhancement etc.</td>
<td>Analysed by: Elements; Areas etc.</td>
</tr>
<tr>
<td>b.2 Utility/Performance</td>
<td>Ratios of Usable/Circulation area, Direct use/general use area, Time taken for common movements, Lighting levels, Acoustic levels, Thermal comfort, Structural strength, stiffness &amp; stability Indicators</td>
<td>Analysed by: Areas, Floors, Divisions</td>
</tr>
<tr>
<td>b.3 Build-ability</td>
<td>Skilled/un-skilled manpower &amp; equipment requirements / unit value, Potential speed of specific operations bottlenecks, complexity levels, access problems, formwork problems.</td>
<td>Analysed by: Element, Sub-element Area.</td>
</tr>
<tr>
<td>b.4 Durability</td>
<td>Design life</td>
<td>Analysed by Elements, Areas, Sections, Materials</td>
</tr>
</tbody>
</table>

Suggested 'Quality' Indicators

TABLE 7.8 (continued overleaf)
<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>INDICATORS</th>
<th>TARGET VALUES TO BE:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Primary</td>
<td>Secndry./Tertry</td>
</tr>
<tr>
<td>b.5 Maintain-ability</td>
<td>Maintenance cycle. Maintenance crew type (skills) &amp; size</td>
<td>Analysed by:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b.6 Health &amp; Safety aspects</td>
<td>Standard (statutory &amp; recommended) Indicators. eg: Fire safety</td>
<td>Analysed by Areas</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b.7 Environmental aspects</td>
<td>Standard (statutory &amp; recommended) Indicators.</td>
<td>Analysed by Areas</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

**Suggested 'Quality' Indicators**

**TABLE 7 - 8 (continued from previous page)**

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>INDICATORS</th>
<th>TARGET VALUES TO BE:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Primary</td>
<td>Secndry./Tertry</td>
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<td></td>
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<tr>
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<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. TIME</td>
<td>Over-run: Absolute; and percentage-wise</td>
<td>Over-runs on stages such as: design, approvals, tender, construction &amp; at milestones eg: foundations completion, roof completion.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c.1 Certainty of not exceeding time target.</td>
<td>Time per unit gross floor area</td>
<td><em>Time</em>/ structural floor cycle; &amp; per unit area of roofing or cladding etc</td>
</tr>
</tbody>
</table>

**Suggested Time Indicators**

**TABLE 7 - 9**
<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>INDICATORS</th>
<th>TARGET VALUES TO BE:</th>
</tr>
</thead>
<tbody>
<tr>
<td>d CLIENT SATISFACTION</td>
<td></td>
<td></td>
</tr>
<tr>
<td>d.1 Satisfying explicit Criteria in brief.</td>
<td>Indicators from other main Criteria herein. NOTE: Incorporated so as to estimate relative priority ranking vis a vis other sub-criteria within this Criterion.</td>
<td>All Contextual Conditions &amp; specially:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d.2 Confidence Trust.</td>
<td>No. of repeat orders (on &amp; outside project). Major actions initiated on verbal instructions. Secondary/Tertiary: analysed by different participants.</td>
<td>Changes in emphasis; specially those too late to be incorporated in particular elements or areas. Whether client is to directly or indirectly use building or to assign it to another party.</td>
</tr>
<tr>
<td>d.3 Flexibility</td>
<td>Ratio of nos. of client changes accommodated/ changes requested.</td>
<td>Changes in types of procurement &amp; management eg: towards negotiation; less supervision.</td>
</tr>
<tr>
<td>d.4 Relationships</td>
<td>Degree of formality/ informality of interactions. No. of levels of authority crossed for typical activities. No. of disputes per unit value or time. Time wasted on disputes/ project time. Costs incurred on disputes/ project cost.</td>
<td>Organisational complexities &amp; experience. Styles of management. Types of procurement. No. of participants.</td>
</tr>
</tbody>
</table>

Suggested 'Client Satisfaction' Indicators

TABLE 7-10
<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>INDICATORS</th>
<th>TARGET VALUES TO BE:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Weighted by: All Contextual Conditions &amp; specially:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Linked to: All other Criteria ranking &amp; specially:</td>
</tr>
<tr>
<td>e GENERAL MANAGEMENT</td>
<td>Indicators from other main Criteria herein. NOTE: incorporated so as to estimate relative priority ranking vis a vis other sub-criteria within this Criterion. No. of major crises/unit time. Average time to resolve a crisis. Average time to respond to major changes. No. of major changes due to poor planning. Secondary/Tertiary: in project management, design management &amp; construction management.</td>
<td>Types of procurement, organisation &amp; project complexity</td>
</tr>
<tr>
<td>e.2 Efficiency</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Suggested General Management Indicators

TABLE 7-11
<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>INDICATORS</th>
<th>TARGET VALUES TO BE:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Primary</td>
<td>Secndry./Tertry</td>
</tr>
<tr>
<td>f. RISK ALLOCATION</td>
<td></td>
<td></td>
</tr>
<tr>
<td>f.1 Risk reduction effectiveness.</td>
<td>Percentage of contingencies.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>'Disputes'/year. Value of disputes /project value. Average time to resolve major disputes (absolute &amp; as % of project time).</td>
<td>By type of participant. By stage of project. By type of risk. Repercussions. Consequential costs.</td>
</tr>
<tr>
<td>f.2 Residual risk distribution.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Suggested Risk Indicators**

**TABLE 7-12**

Note: More specific Criteria and Indicators may be designed for evaluating particular functions if deemed useful. For example Table 7-11 could incorporate the number of non-client initiated design variation orders, reflecting poor design management, if the latter is being investigated. It is reiterated that the foregoing framework is flexible and indicative only, and needs to be specifically designed for particular projects.

7.7.5 Applying the Prototype to a specific evaluation

A framework, such as the foregoing could be utilised in this prototype by:

(i) adding the client's own special Criteria and modifying or deleting others where necessary;

(ii) adding, deleting and modifying any Indicators to suit the selected Criteria and any other specific requirements; (eg: for financial reporting co-ordination)
(iii) assigning relative priority rankings to the sub-criteria within each Criterion and then to the Criteria against each other; using Pairwise Comparison Weighting Matrices as aids in making such subjective judgements;

(iv) obtaining and up-dating typical target values and possible ranges for primary, secondary and tertiary Indicators from the database;

(v) modifying such target values and ranges by weighting and linkage Indicators, using the relative rankings and the contextual conditions as modelled manually or with the aid of an Expert System (as in Figure 3 - B), to yield target values of such Indicators;

(vi) assembling relevant tools to aid the measurement of the actual values achieved, as in the Project Evaluation Framework in Table 7-4;

(vii) evaluating the Indicators and their variances using such tools; assessing the causes of problems and suggesting solutions as in Tables 7-5 and 7-6; and

(viii) representing the target and achieved values of sub-criteria and Criteria Indicators in a 'Project Performance Profile' as in Figure 3 - D, by choosing the length of each axis according to the priority rankings assigned as in item (iii) previously and the calibration of each axis according to the range and variation profile of the values (whether linear, logarithmic, polynomial, exponential etc.). This is described in detail in section 8.6.7 of the next chapter.

7.7.6 Developing Prototype modules

The development of the prototype (and the system as a whole) was intended to follow the development of it's modules according to data available. Handicaps were imposed by the absence of structured information collection formats and procedures from the outset of a project. Reliable information was particularly lacking in relation to Criteria other than cost and this unfortunately also affected the value of the cost data in that it could not be weighted by other related priorities and conditions.

To reduce these problems, attention was focussed during the pilot investigation in Sri Lanka, into developing and testing sample modules for Indicators such as unit costs (per gross floor area) related to item 'a.2' in Table 7-7 and elemental (percentage) costs related to item 'a.3' in eleven different functional categories of buildings. Typical values were thus obtained and the effect of weighting by Indicators based on building morphology, was found to improve the consistency of such elemental Indicators.
Such findings are incorporated in the framework proposed in sub-section 7.7.4, but it was considered necessary to collect more reliable data in each category before predicting typical values of proposed Indicators in the relevant modules (in Circle I) of Figure 7 - B.

Meanwhile it was also deemed useful to proceed with the development of the associated system tools and the other sub-system (the Expert System front-end), as in Chapter 8.
# CHAPTER 8: DEVELOPING SUB SYSTEMS AND SUPPORTING TOOLS

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- **8 - A** Basic Knowledge Base Structure of the Pilot Expert System 220
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(Note: For lists of Tables herein & related Appendices at the back, please see the General Contents at the beginning of this Thesis).

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'It is a truth very certain that when it is not in our power to determine what is true, we ought to follow what is most probable' - Descartes.

8.1 INTRODUCTION

A general specification and structure for a construction management evaluation system was formulated in Chapter 7. The 'Criteria' and 'Indicators' sub-systems for a prototype evaluation system in the buildings sub-sector were also proposed therein. It was noted however that these two sub-systems needed further development for typical values to be realistically assigned to the Indicators. Data was needed from wider samples of projects and more information was needed on related Criteria, their relative priorities and project contextual conditions, so as to facilitate weighting.

Chapters 5 and 6 describe the pilot project in Sri Lanka designed to extract such information and develop such a sub-system of Indicators in the buildings, roadworks and bridges sub-sector. Chapter 3 illustrates the development of the 'Criteria' sub-system by formulating sets of Criteria and subjecting to scrutiny by experts and practitioners. Such exercises were also carried out in parallel with the development of the related Indicators as described in Chapters 5 and 6.

This chapter illustrates the development of the third sub-system, an Expert system front-end (the core sub-system as depicted in Figure 7 - D or 7 - B), as well as the development of some key techniques and tools for eliciting and presenting information during an evaluation.

Section 8.2 briefly surveys the developments in Expert Systems, since such knowledge based systems were recognised as useful, to service the evaluation systems proposed in this study. Section 8.3 describes 'PICKMESS' a Pilot Construction Management Evaluation System front end developed for the buildings sub-sector to test the usefulness and viability of the proposals of this study.

Section 8.4 examines how pairwise comparisons of a series of factors by different project stakeholders can be transformed to a more usable set of weightings that would conveniently convert average Indicator values within a category to project-specific targets. Section 8.5 describes how this would be used in modelling the project profile based on project conditions and relative priorities.
Section 8.6 scans other basic tools needed by the system such as specific questionnaire formats, responsibility and information flow matrices and checklists. It also expands on the multi-dimensional project performance profile representation proposed in Chapter 3.

Section 8.7 summarises how such diverse tools could be developed to work together in the system.

Figure 7 - A in Section 7.5 of Chapter 7 maps the development of the general and prototype system, prior to this chapter, for convenience of cross-reference.

8.2 INTRODUCING EXPERT SYSTEMS

8.2.1 Definitions and descriptions

Allwood (1989) described Expert Systems as introducing new ways of capturing and using experience based expertise and considered them to be the blunt end of Artificial Intelligence, whereas the sharp end is concerned with modelling common sense and fundamental knowledge on similar lines. Brandon et al (1988) positioned Expert Systems between well-structured problems requiring 'conventional computing' and highly unstructured problems/information demanding 'human thinking'.

The last publication also quoted the definition of the British Computer Society special interest group in Expert Systems as 'An Expert System is regarded as the embodiment within a computer of a knowledge-based component from an expert skill in such a form that the system can offer an intelligent decision about a processing function. A desirable characteristic, which many would consider fundamental, is the capacity of the system, on demand, to justify its own line of reasoning in a manner directly intelligible to the inquirer. The style adopted to attain these characteristics is rule based programming'. More simply, Forsyth (1984) describes an Expert System as 'a computer system that encapsulates specialist knowledge about a particular domain of expertise and is capable of making intelligent decisions within that domain'. Such specialist knowledge includes not only facts but also heuristics, rules or inference procedures.

8.2.2 Features

Allwood (1989) identified three key features of Expert Systems as:

(a) the central element representing an expert's knowledge in a form comprehensible to man and machine;

(b) that such knowledge is searched to solve a user's problem; and
that the user can be told 'how' the solution was found, by using the same knowledge base.

Lansdown (1982) cited six desirable characteristics of Expert Systems. These were that such programmes should:

(i) know a great deal about a limited but useful area of interest;
(ii) give their advice conversationally in the manner of a consultant;
(iii) embody their knowledge in such a way as to make it easy to correct deficiencies or inaccuracies in their knowledge bases;
(iv) be able to give their advice in probabilistic terms if uncertainty prevails;
(v) ask of their users only sufficient information to arrive at a conclusion; and
(vi) be able to justify their conclusions and explain their reasoning.

8.2.3 Structure

Four essential components of an Expert System were described by Forsyth (1984):
(a) knowledge base;
(b) inference engine;
(c) knowledge acquisition module; and
(d) explanatory interface.

Such a structure illustrated the shift from the traditional computer programming basis of: 'Data + Algorithm = Computer Program' to:

'Knowledge + Inference = Expert System'

Difficulties in developing Expert Systems are usually associated with knowledge acquisition and representation, rather than with manipulation. Knowledge engineering techniques were developed to 'mine' the knowledge from an expert who may find it difficult to explain 'how' he solves problems or express the rules he uses. Approximate knowledge representation is at the core of such difficulties, and many formats have been tried, for example: production rules; frames; semantic networks, predicate logic (Billman & Norman, 1987). Uncertainty is handled with multi-valued, fuzzy sets, bayesian and other probabilistic systems.
Knowledge manipulation varies with the inferencing mechanisms chosen, and could for example be forward chaining, which is data driven or bottom up towards the goals or backward chaining, which is goal directed or top-down.

In the latter approach, the inference engine is given a set of goals and tries to achieve each goal in turn by applying the rules in the knowledge base.

8.2.4 Shells

Commercially available Expert System 'shells' reduce the tedium of building each new Expert System from fundamentals. Such shells are software packages described by Information Builders Inc. (1987) as containing:

(i) an inference engine;
(ii) a language for representing knowledge;
(iii) functions for constructing an user interface; and
(iv) program development aids such as editors as well as tracing and debugging functions.

They are called shells because they are hollow in that they have no inherent knowledge bases.

8.2.5 Advantages and Disadvantages

The principal advantages of Expert Systems flow from their fundamental function, described by Barr & Feigenbaum (1981) as intermediaries between human experts who interact with the system in its 'knowledge acquisition' mode and human users who interact with the system in its consultation mode. The ability to explain their reasoning makes the consultation more useful to detect and correct errors of logic.

Feigenbaum & McCorduck (1985) noted Expert Systems as useful in solving two generic problem types:

(i) combinational problems where unintelligent or straight forward methods of enumeration lead to unmanageable numbers of possibilities; or

(ii) interpreting vast amounts of signal data.
Other advantages are flexibility to cope with absent information by suggesting the most plausible solution under the circumstances; and an ability to accommodate uncertainty in some available information.

Brandon et al (1988) cited some disadvantages of Expert Systems in comparison with traditional computer programmes such as:

(i) being generally slower in operation; and

(ii) requiring more memory.

8.2.6 Uses

From their first known use in a medical diagnosis system, Expert Systems have been developed for a variety of general uses ranging from fault finding in electronic circuits, diagnosis of illnesses or plant diseases, electrocardiogram analysis, classifications of diverse species (Naylor, 1987) to many applications in the construction industry (Allwood, 1989 and Satish Mohan, 1990).

Forsyth (1984) suggested some rules to help decide whether an Expert System would be useful for a given scenario as follows:

<table>
<thead>
<tr>
<th>Suitable for Expert System</th>
<th>Unsuitable for Expert System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diagnostic</td>
<td>Calculative</td>
</tr>
<tr>
<td>No established theory</td>
<td>Magic formula exists</td>
</tr>
<tr>
<td>Human expertise scarce</td>
<td>Human expertise two a penny</td>
</tr>
<tr>
<td>Data is 'noisy'</td>
<td>Facts are known precisely.</td>
</tr>
</tbody>
</table>

8.3 PILOT MODEL OF A KNOWLEDGE BASED FRONT - END FOR THE EVALUATION SYSTEM

8.3.1 The need

The advantages of Expert System or knowledge based tools and front-ends fulfilled certain requirements of the general evaluation system specification in 7.5 and the structure in 7.6. For example, comparing with Forsyth's table at the end of the foregoing section:

(i) evaluation itself was a diagnostic process;
(ii) special evaluation expertise on construction projects was scarce and there was no established theory; and

(iii) data was very 'noisy', as demonstrated for example by the potential requirement considered in 7.7.3 to collect base data from about three million building projects alone to get statistically significant samples in each 'less noisy' sub-category; and each such project could have an equally large number of possible project profiles based on particular permutations of priorities of Criteria, sub-criteria and other conditions related to client, designer, contractor, manager, complexity and technology levels.

Furthermore, the following identified needs matched the previously stated advantages of Expert Systems:

(iv) Flexibility to mobilise selected modules from the vast 'problem-space' and information data-bases; and then integrate them appropriately to generate suitable suggestions from the large 'solution-space';

(v) transparency, for example the capacity to indicate on request the justification for particular choices or suggestions; and the line of reasoning being followed.

(vi) further flexibility inviting intervention by an evaluator dissatisfied with such reasoning or wishing to introduce special project conditions not assimilated by the system; and

(vii) the possibility of introducing probabilities and subjective judgements and to obtain suggestions with a specified degree of confidence.

8.3.2 The choice of a Shell and the development of the Pilot Expert System

Of the two Expert System shells available for immediate use to the researcher, the 'Level 5' shell was found to be the easier to mobilise, apart from having adequate facilities with which to encode the knowledge base and test the system operations.

Brandon et al (1988) distinguished the development of an Expert System from that of the highly structured and controlled approach required for a conventional computer program. They saw Expert Systems, being developed in stages using an ad-hoc approach, and gradually refining the system as new knowledge is gathered in a series of prototypes. The prototypes in their own Alvey/ RICS research project went through six stages from:
Brandon et al cautioned however, that the stages outlined by them were only guidelines and not intended to offer a fixed approach.

The Pilot Construction Management Evaluation Expert System front-end (PICKMESS) for the buildings sub-sector, designed and tested herein is developed to a higher level than that of a 'skeleton system' as envisaged by Brandon et al (1988) in that:

(i) 'it is built after the roles and objectives have been set, to act in approximately the right way but need not give correct answers. It's purpose is to give users some idea of what they can expect of Expert Systems and the knowledge engineers some idea of the domain'; and

(ii) it incorporates some elements of a demonstration system in the 'fleshing out of the skeleton and asking a reasonable set of questions'.

The development of the pilot Expert System to this extent was within the framework of the general evaluation system structure and prototype evaluation system requirements as outlined in Chapter 7.

8.3.3 Structure and contents of the Pilot Expert System

The main system goal was chosen as 'Project Evaluation Framework is formulated' with intermediate sub-goals leading to it in stages. Figure 8 - A overleaf illustrates the knowledge structure. The text of the pilot model is listed in Appendix AP8-1. The output from a sample run in Appendix AP8-2 further illustrates this pilot system.

8.3.4 Provisions

The 'Chain Questionnaires' display will be replaced by a chain command linking the databases of questionnaire segments to help determine project conditions and priorities specific to a chosen building category and evaluation purpose; and also mobilising the knowledge base that would help integrate the selected modules into a compatible and efficient evaluation-specific questionnaire and set of data formats; with provision for the evaluator to alter such suggested combinations subject to system queries to check consistency and redundancy.
BASIC KNOWLEDGE-BASE STRUCTURE
OF THE PILOT EXPERT SYSTEM MODEL

FIGURE 8 - A
Similarly, the 'Chain Circle II', 'Chain Circle III' and 'Chain Circle IV' displays will be replaced by chain commands linking databases of modules related to building category, project stage and evaluation purpose, along with their associated tools modules and also mobilising the knowledge base that would help integrate the selected modules into a compatible and complete set of Criteria, Indicators and target values; with provision for evaluator inputs and system checks as before.

Another knowledge based module would be designed to suggest weightings for the target values depending on the project conditions and the project priorities. This module would function as in Figure 3 - B, narrowing down the target values, or adjusting them with weighting coefficients.

While the basic project conditions are incorporated in the pilot model text, the relative project priorities would be modelled in another module. This is outlined in Section 8.5 while it's basis is described in Section 8.4.

8.3.5 Improvements

All available facilities of the Level 5 Expert System shell were not used in this Pilot Model. The Users Manual (Information Builders Inc., 1987) describes the following additional facilities which can be incorporated during the development of this Expert System:

(i) chaining databases and knowledge bases as per provisions already made in the model and as outlined in 8.3.4;

(ii) 'Confidence' factors to help incorporate subjective judgements and indicate confidence levels of conclusions;

(iii) more 'Expand' statements (one is already incorporated) which will make the model more user-friendly in providing explanations for particular queries or facts if so requested;

(iv) user-friendly query statements, that would be more intelligible to the user and also point out that an unknown status could be registered by pressing the F2 function key;

(v) better presentation formats. For example, apart from the detailed output necessarily available, a concise summary may be needed by top management. Suitable formats for same could be prescribed along with the evaluation specific questionnaire formats after identifying project category, project stage and evaluation purpose. Such formats can be modelled on lines similar to the ODA's EVSUMs and USAID Executive Summary Outlines (vide Chapter 2), but would also incorporate the Project Performance Frameworks
(developed in Chapter 7) and possibly the Project Performance Profiles (described in Chapter 8); and

(vi) a Users Manual.

The databases and knowledge bases themselves would be developed independently of this pilot Expert System. Improvements are also needed within the existing elements incorporated in the pilot model, for example in expanding the project conditions to include factors such as market conditions, speed of information flow and management styles.

8.4 TRANSFORMING SUBJECTIVE COMPARISONS INTO WEIGHTINGS

This study stresses the need to model the 'project profile' in order to appropriately weight typical target values derived from a historical database of similar projects. Such a project profile was defined as based on both the 'project (contextual) conditions', and the 'relative priorities' of the Criteria of success of the client or major stakeholders.

8.4.1 Project Conditions

Most of the important project conditions have been incorporated in the pilot Expert System within the 'decision rule' for 'Project conditions' vide Appendix AP8-1. Some of these conditions such as number of storeys, type of foundations and level of finishes were specific to the buildings sub-sector. These were in fact intended to eventually sub-divide the database into more similar sub-categories to obtain less variable data within each. Other project conditions such as type of contract, types of client, project manager, designer, constructor and level of project complexity are each to be assigned one of a number of possible operating levels for that category of building. These could be on a scale from 1 to 10 as for project complexity, or classified by a type (eg: a categorisation of designers into five types as used in the pilot model, for instance depending on experience, commitment etc).

Elements of subjective comparisons and ranking are therefore evident in the modelling of such project conditions. This would be more significant in comparing conditions such as the level of technologies available with that deployed on the project the management structures and styles. Other factors like spans of control or market conditions would have quantifiable Indicators, but subjective rankings may often be more realistic so as to account for the special impact of connected conditions; for example while a span of control of 6 supervisors may be considered average for a section engineer on a small roadworks project; a particular organisational structure, management style, project complexity and frequent client induced changes may require a smaller span of control. In such cases a subjective ranking, (for example ranging from 'inadequate' through
'satisfactory' to 'excessive'), may be more useful. Similarly overall market conditions could be summarised quicker though less quantitatively by a subjective comparison; enabling a weighting of the cost per unit gross floor area for example, to explain why lower values than expected are obtained when the local industry is in a depression. The national or regional indices and other indicators may take too long to reflect this state, if at all.

8.4.2 Project Priorities

Subjective assessments are called for from the client in ranking project priorities, for example the main Criteria of cost, quality and time, other relevant factors and associated sub-criteria. For example a set of 22 sub-criteria (obtained from the typical framework illustrated in Section 7.7.4) may have to be ranked by the client and assigned weightings. Different combinations of such weightings would affect the target values of the chosen Indicators. This is examined in detail in Section 8.5.

8.4.3 Pairwise Comparison Weighting Matrices

It was postulated in this study that the most realistic comparisons between such a large and inter-dependent array of variables was to compare them in pairs and identify a technique to ultimately integrate such pairwise comparisons to yield a set of relative weights between the factors. The use of pairwise comparison weighting matrices (PCWMs) as a system tool is introduced in Chapter 7.

The PCWMs envisaged would have the same set of Criteria down the outer (left) column and across the outer (top) row of a square matrix and each of the cells would represent the pairwise comparison weighting of the column Criterion against the corresponding row Criterion. For example, taking four Criteria a, b, c and d; in the following matrix \( w_{ab} \) represents the weighting of how much more important a is than b (say, 3 times). Then \( w_{ba} \), representing the importance of b relative to a, should be \( \frac{1}{3} \). Therefore only one half (triangle) of the matrix need be completed, as the other half would follow from the inverses of the weightings assigned. Furthermore the diagonal values representing weightings of a against a, or b against b would each be unity (1).
Three issues needed to be resolved, the first being considered critical:

(i) how to transform such a matrix of pairwise comparisons into a set of weights such that the relative importance of a: b: c: d = wa: wb: wc: wd and also to normalise them such that for example wa + wb + wc + wd = 1 (or 100); so that such weightings may be easier compared across different projects (or people);

(ii) how to ensure consistency - for example to eliminate the inconsistency if the same person weighted 'a' as 3 times more important than 'b'; and 'b' twice as important as 'c', but 'a' as only 4 times as important as 'c'; and

(iii) how to combine the weightings assigned by a number of stakeholders.

The second issue could be addressed by pointing out such inconsistencies as they arose ie as the weightings were entered, giving an opportunity to revise one or the other of the conflicting weightings. This could be easily done even using spreadsheet formats with a built in threshold variance of say, 20% beyond which consistency queries are raised. The third issue could be accommodated by appropriately combining the derived weights of relative importance of the different stakeholders. Such a combination would be enhanced by weighting these weights in turn by another set of weights derived from the perceived relative importance of the different stakeholders. For example if the opinions of the client's managing director, project director and building end-user (department head), designated as stakeholders 1, 2, 3 respectively are assigned relative importance weights of 45: 35: 20; these would in turn be applied to the weights they had each assigned a: b: c: d. Assuming they had assigned the following three sets of weights:

wa1: wb1: wc1: wd1 for the managing director, wa2: wb2: wc2: wd2 for the project director and wa3: wb3: wc3: wd3 for the end user, then finally:

\[
wa = 0.45wa1 + 0.35wa2 + 0.20wa3
\]
and \( w_b = 0.45w_{b1} + 0.35w_{b2} + 0.20w_{b3} \)

and so on, for \( w_c, w_d \) etc.

### 8.4.4 Relevant Theory

(a) **Inconsistencies in pairwise comparisons**

Returning to the first issue, of transforming a matrix of pairwise comparisons to a set of weights, Dong, Shah & Wong (1988) confirmed the difficulties of obtaining a consistent matrix such as \( R \) that meets the criteria \( r_{jk} = r_{kj}^{-1} \) and \( r_{ij} = r_{jk} \times r_{ki} \) for all \( jkl < m \) where:

\[
R = \begin{bmatrix}
r_{11} & r_{12} & \cdots & r_{1m} \\
r_{21} & r_{22} & \cdots & r_{2m} \\
\vdots & \vdots & \ddots & \vdots \\
r_{m1} & r_{m2} & \cdots & r_{mm}
\end{bmatrix}
\]

(b) **Transforming the pairwise comparisons to weights**

They then quoted a proposition by Saaty, that the eigenvector corresponding to the maximum eigenvalue \( \lambda_{\text{max}} \) provides a good estimate for the weighting factors ie the estimate of the weighting factor \( W \) can be obtained by solving the equation:

\[(R - \lambda_{\text{max}} I) W = 0 \quad (\text{Eqn.1}), \text{ where } I \text{ is an unit diagonal matrix}\]

and \( 0 \) is a zero column vector

The eigenvalue can be obtained by solving the equation

\[
\text{determinant of } (R - \lambda I) = 0 \quad (\text{Eqn.2})
\]

(c) **Verifying consistencies of pairwise comparisons**

The consistency of the pairwise comparisons themselves could be checked, by comparing how close the maximum eigenvalue (obtained from the highest root of the polynomial equation resulting from the foregoing Equation 2) is to \( n \) (the number of variables being considered ie. the size of the \( n \times n \) matrix). Such a check is clearly demonstrated by Novak (1986) who compares the maximum eigenvalues of two \( 3 \times 3 \) matrices, considering the first value 3.27 as too far from 3.00 (the number of variables) but deeming 3.004 as satisfactory. Clearly the tolerance level could be pre-determined.
In this way the pairwise comparisons of different project stakeholders or evaluators may be checked for consistency; an opportunity given for revision where inconsistent; and those that are still inconsistent could be rejected or given a lower significance level when combining the weights.

### 8.4.5 Available Applications

Having traced the theoretical basis for transforming pairwise comparisons to a set of weights, evidence of any such applications was sought. The 'Priorities' decision matrix package marketed by Work Sciences Associates, undertook such a transformation process. The sales literature indicated that:

(i) each manager's judgements across each pair would be transformed by the 'Priorities' program into a table of priority weights totalling 100. The program highlights inconsistencies in judgements and provides opportunities to revise same; and

(ii) the judgements of all relevant managers would be combined using another set of relative weights. At this stage Priorities would even indicate the extent of agreement between the group of managers, for example if there was 'little agreement', 'some agreement' or if it was 'consistent'.

Such available programs therefore satisfied all three issues raised in the third paragraph of sub-section 8.4.3. The proposed construction management evaluation system could therefore access such software packages as tools during the:

(i) modelling of project conditions;

(ii) modelling of relative project priorities (of selected Criteria and sub-criteria); and

(iii) obtaining more realistic subjective assessments of non-quantifiable factors during evaluation; either from the project participants or the evaluators themselves, for example by asking them to compare certain factors with those on other projects.

Although it was not confirmed whether such software was based on the theory discussed in 8.4.4, their availability and known usage validated the viability of such tools, which could therefore be incorporated in or developed especially for the proposed evaluation system.

### 8.5 WEIGHTING TYPICAL TARGET VALUES BY THE PROJECT PROFILE

The envisaged system tool for modelling the project profile, comparing project conditions and relative project priorities would be based on the findings listed in the
foregoing Section 8.4. Pairwise comparisons of sets of factors requiring subjective judgements would be transformed to a set of relative weights. Such weights would be in turn used to weight the typical target values within any project category.

Figure 3 - B in Chapter 3 illustrates how the operating levels or ranges of the target values are narrowed down for a particular project, by the contextual conditions and the project priorities. Not all project conditions would need pairwise comparisons as described in detail in 8.4.1. But the relative priorities of diverse Criteria would need comparisons. If there are n such sub-criteria from a to n considered important in a project, there would be n(n-1)/2 possible pairwise comparisons to be carried out by each stakeholder; eventually yielding (through a system tool such as the 'Priorities' micro-computer package described in 8.4.5) a set of weights such as \( w_a : w_b : w_c : \ldots : w_{n-1} : w_n \). The weights would be standardised (normalised) for comparison so that \( w_a + w_b + w_c + \ldots + w_n = 100 \).

The effect of different combinations of priorities (and also of contextual conditions) on each Indicator such as cost per \( m^2 \) of gross floor area would have to be modelled, so that the typical target value within a category may be adjusted to suit such sensitivities. The large number of such possible combinations of priorities alone would be formidable, hence the need for capturing expertise in such domains, eventually in a knowledge base, but initially even by manual inputs. An example of a format for such a knowledge base is illustrated in Figure 8 - B overleaf, initially taking three main Criteria of cost, quality and time considerations with their normalised weights designated as a, b, c, respectively herein; and corresponding to the Criteria designations in the prototype framework in sub-section 7.7.4. After this stage sub-criteria such as a1, a2, a3, a4, a5, b1, b2, b4, b5, c1 and c2 may be also selected from the framework in 7.7.4 and intelligently incorporated in the system, for example by considering the sub-criteria of a, b or c only if the respective Criterion weight exceeds 15, i.e. if it is 'significant'.

The sizes of the slabs as presently set by varying Criterion 'a' in steps of 15 or criterion 'b' in steps of 5 may be increased, thereby reducing the sensitivity and the number of possible combinations. All possible combinations need not be considered either, but chosen according to their likelihood of occurrence in that category.

Each of the possible combinations of Criteria ranking such as a > 70; b > 15; c < 10 (or a <15, b>70 c <15) would then assign a weight to each Criterion such as \( m^2 \) of gross floor area per cost unit of Rs. 10,000. For example the weight from the first priority profile may be 1.15, to be applied to a typical (in the category) \( 1.2 \ m^2 \) per cost unit of Rs. 10,000, signifying the need for economy; but that from the second priority profile may be 0.9, suggesting the lower significance of cost vis a vis other Criteria. Other weights from project conditions (say, 0.95 and 1.05) would be similarly chosen and applied together to
AN EXAMPLE OF POSSIBLE COMBINATIONS OF RELATIVE PRIORITY WEIGHTS OF CRITERIA

FIGURE 8 - B
the typical category value of 1.2 m² per unit cost of Rs.10,000, to obtain an adjusted target value, say: $0.9 \times 0.95 \times 1.05 \times 1.2 = 1.0773$ (say, 1.08 m² of gross floor area per Rs.10,000) for the project. There will be an opportunity provided to over-ride this value, if the client's specific cost limit is lower or other considerations require such revision.

8.6 OTHER SYSTEM TOOLS

Many other tools would be needed to service the proposed evaluation system and to generate and format the information required. Some such tools are discussed at the relevant points of the study, while a few are discussed at greater length in the following sub-sections.

8.6.1 Questionnaires

Samples of the general core questionnaires to be used for the preliminary investigations in the buildings roads and bridges sub-sectors are illustrated in Appendices AP5-1, AP5-2 and AP5-3 respectively. As described in sub-section 8.3.4 and as in the 'Chain Questionnaires' display of the pilot Expert System, questionnaire segments specific to each category of building would be integrated with such a general core questionnaire to facilitate the modelling of the project profile and the preliminary investigations.

More detailed questionnaires and data formats would be developed based on the responses to the preliminary questionnaire. Such tools may be used as a basis of semi-structured or structured interviews with project stakeholders and key project participants.

8.6.2 Data formats

Data formats to support the evaluation-specific questionnaires that initiate the investigations and summary sheet structures to provide quick executive summaries would be developed.

The 'Project Evaluation Framework' and the Project Performance Frameworks' as described in sub-sections 7.6.3.2 and 7.6.3.3 would be constructed for each project with the aid of the knowledge bases.

'General Category Frameworks' and 'Resource Reconciliation Frameworks' as described in sub-section 7.6.3 would also be useful. For example, specific formats of resource reconciliation charts, for example for labour, critical materials or plant, would be used where efficiency is a Criterion of evaluation.

Formats for analysing critical incidents in the project life cycle would help identify sources of problems, deviations and how they were resolved or affected future processes.
8.6.3 Responsibility Matrices

In analysing the organisation structures and styles of participating organisations, a technique of 'linear responsibility analysis' was described in detail by Walker (1984) and traced from its origins in 'linear responsibility charting'. He outlined how Cleland and King enhanced the linear responsibility chart by using it as an input-output matrix; the type of input being specified by a particular symbol. The source of the input was the person or job position as designated in any given column and the output task was depicted in the corresponding row. Types of inputs listed included 'approves', 'boundary control', 'maintaining', 'monitoring', 'does the work', 'general supervision' and 'consulted'.

Harrison (1985) described a similar responsibility matrix as a graphical form for indicating who is to be responsible for the various job components of a project. A similar structure as in Table 8-1 can be used to portray and compare the distribution of responsibilities on a project. More detail in specific domains under investigation such as design, or in relationships with external statutory and local organisations can also be incorporated as deemed necessary.
`LINEN responsibility analysis' taking a broader systems view as described by Walker, investigates necessary levels of integration, interdependency of tasks, differentiation (in terms of technology, territory and time or sequence) and decision points. It usefully distinguishes transfer functions (of doing the work) from control loop functions (such as approval, recommendation, general and direct oversight, boundary control,
monitoring and maintenance) and from contributions to input (such as consultations with institutions or advice). Such analysis would help evaluators identify the interdependencies of tasks, the expected and actual contributions of different participants and help suggest useful changes.

8.6.4 Information Flow Charts and Matrices

Flow charts are useful to represent the paths of information in common construction information transactions such as:

(i) issue of drawings;

(ii) approval of contractors drawings, including shop drawings;

(iii) issue of site instructions; and other notices;

(iv) requests for information and responses;

(v) issue of variation orders and time extensions;

(vi) submission of interim (and final) bills;

(vii) issue of payment certificates;

(viii) issue of completion and maintenance certificates; and

(ix) compliance with statutory requirements.

Such flow charts would highlight the source, destination, and intermediate processing of the information. They would include the number of copies at each stage together with the type of processing and inputs required. Comparison with standard practice on similar projects would highlight redundancies, bottlenecks, overlaps or gaps.

A NEDO publication on 'Information Transfer in Building' (1990) provides a series of 9 information matrices corresponding to different stages of a building project from inception to completion. The columns correspond to the project participants while the rows relate to the type of information being transferred such as 'Outline Cost Plan' or 'Approx. Construction Times'. Sources and destinations are depicted by symbols.

Specific matrices based on the requirements of an evaluation would be designed to study, compare and suggest improvements to the information flow systems on a project.
Indicators of rate of flow of information and ratios of useful (and used) information to that transmitted would assist such analysis. Such tools have already been tried and tested in other domains (Booth, 1986).

8.6.5 Checklists

Checklists similar to those used for trouble-shooting or as in Table 7-6, would assist in isolating sources of the problems if low performance values have been registered against expected targets, for example on productivity.

Wearne (1989) illustrated by means of a matrix attributed to H.R. Noon, some indicators of over or under planning and over or under control. The format of the matrix is indicated in Table 8-2 with some examples of the indicators cited.

<table>
<thead>
<tr>
<th>UNDERPLANNED</th>
<th>OVERPLANNED</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UNDER-CONTROLLED</strong></td>
<td><strong>OVER-CONTROLLED</strong></td>
</tr>
<tr>
<td>Plans &amp; Budgets unavailable.</td>
<td>Plans out of date etc.</td>
</tr>
<tr>
<td>Few routine reports.</td>
<td></td>
</tr>
<tr>
<td>Meetings only in crises.</td>
<td>Many forms &amp; reports.</td>
</tr>
<tr>
<td>etc.</td>
<td>Frequent formal meetings.</td>
</tr>
<tr>
<td></td>
<td>etc.</td>
</tr>
</tbody>
</table>

Sample Indicators of over or under planning and control
(from S. Wearne and after H.R. Noon)

TABLE 8-2

While detailed checklists would be used for specific areas, broader generic factors should be collected in lists of strategic issues to be examined in particular sub-categories and types (according to form of procurement) of projects. For example at a broader level for general construction projects, de Wit (1988) quoted a University of Texas pilot study on successful projects that indicated the greater likelihood of success when there was more emphasis on the following success factors: planning effort (contractors), planning effort (design), project manager goal commitment, project team motivation, project manager technical capabilities, scope and work definition control systems.

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Morris & Hough (1986) found 80 factors important to project success following a well documented survey. This and similar studies on common causes of project success and failure are also cited in Chapter 2.

Higher level or strategic checklists would collect such common causes as well as symptoms of success and failure in specific types of projects and make them available to an evaluator who could call on them to generally supplement a more systematic investigation. Lower level detailed checklists would be more useful tools to be used during the investigation itself to assist in particular search domains.

8.6.6 Group Sessions, Team approaches and related Tools

Individual interviews and questionnaire responses would be usefully supplemented by group sessions both to gain insights into the organisational group dynamics, strengths and inhibitions, as well as to obtain collective responses via techniques and tools such as 'Pareto analysis' (to identify frequently occurring problems), brainstorming, the 'Delphi method', impact analysis and logic diagrams as described by Pressoir (1989) in the context of team approaches for evaluating and improving contract administration procedures.

8.6.7 Performance Profiles

Sub-section 3.3.6 and Figure 3 - D illustrated the concept of a project performance profile to represent multi-dimensional project targets and achievements against same, by using multiple axes. A simpler case with only six Criteria; and with each having varying numbers of associated sub-criteria is illustrated in Figure 8 - C overleaf.

(i) Constructing and Interpreting the 'Targetted' Performance Profiles

The axes in the main (Criteria) and subsidiary (sub-criteria) 'stars' are drawn according to the number of Criteria and sub-criteria respectively. Each sub-criterion is represented by one chosen Indicator (or an integrated combination of Indicators). The target values (and operating ranges) of such Indicators representing sub-criteria for the particular project are estimated using the project evaluation system through the process illustrated in Figure 3 - B.

The target value on each axis (and on each subsidiary axis) is then positioned at a distance from the origin determined by the relative priority weights as determined by the process of transforming pairwise comparisons as described in 8.4 and 8.5. Thus if the relative priority of Criteria a: b: c: d: e: f: = 30: 25: 15: 15: 5: 10 (note the total of 100) then the target values are positioned 30 (or 3) units, 25 (or 5) units, 15 (or 1.5) units, 15 (or 1.5) units 5 (or .5) units and 10 (or 1) unit from the main Criteria origin respectively.
Targetted Profile — Achieved Profile

The further a point is from the origin along any criterion (or sub-criterion) axis, the better is the performance against that criterion (or sub-criterion).

EXAMPLE OF A PROJECT PERFORMANCE PROFILE

FIGURE 8 - C
Value sets of Criteria would be 'normalised' (standardised to total 100) since this is needed for the system to assign appropriate weightings to Indicators as described in Section 8.5; and also since comparison between projects is eventually required (say of relative values of a, b, c and d).

Similarly if the sub-criteria relative priorities of Criterion 'a' are a1: a2: a3: a4 = 25: 35: 30: 10 then the corresponding target values of their Indicators are positioned 2.5, 3.5, 3 and 1 unit respectively from the sub-criteria origin respectively.

The Indicators should be configured so that an increase indicates better performance than expected and vice versa. Thus in the case of cost and time parameters the inverse of Indicators such as cost per m² or cost per hospital bed would be taken, for example as m² per Rs. 10,000 or hospital beds per Rs. 1 million. Only then would an increase indicate better performance.

The possible operating range of such values in this specific project are also estimated from the project evaluation system. As an example, the target can be to have 1.0 m² of gross floor area per Rs. 10,000, but in the best scenario of this project it may increase to 1.2 m², and the worst achievable may be estimated at 0.75 m² per Rs. 10,000. The scale on the a1 'initial cost economy' sub-criterion axis corresponding to the m² per cost unit Indicator is then calibrated accordingly with 0.75 at the origin and 1.00 at the target value point. The scale is extended to 1.2 to accommodate the better cases. Although the calibration could be uniform assuming a linear variation, this is not necessarily so. Sensitivities to other sub-criteria and Criteria may suggest an exponential, logarithmic or polynomial variation and a corresponding calibration. The other sub-criteria scales are calibrated similarly.

The polygon connecting each set of sub-criteria targets represents the target profile of the respective parent Criterion. The polygon connecting the Criteria targets represents the overall targetted performance profile of the project; and also represents the project priority profile.

(ii) Constructing and interpreting the 'Achieved' Performance Profiles

Since no single Indicator may realistically represent a Criterion unless it is extremely significant, weighted combinations of the sub-criteria Indicators are used to evaluate performance against the parent Criterion target. Taking the previous example of the cost Criterion 'a' with a1: a2: a3: a4 = 25: 35: 30: 10, the target value of the combined Indicator had been determined as being at 30 units from the origin. This was decided in relation to the priorities vis a vis other Criteria considered.
In evaluating performance against each such Criterion the weighted combination of the 'achieved' percentage performance against each sub-criterion would be taken to represent the 'achieved' percentage performance of the parent Criterion.

If \( pa_2, \ pa_3 \) and \( pa_4 \) represent such 'achieved' percentage performance of the respective sub-criteria, then the 'achieved' percentage performance of 'a' is taken as
\[
'pa' = 0.25 \ pa_1 + 0.35 \ pa_2 + 0.30 \ pa_3 + 0.10 \ pa_4.
\]

Having computed 'pa' (for example as 80%) and taking the target of 'a' as before to be 30 units, then the 'achieved' value of 'a' is evaluated as 'pa'\( \times \) 30 (for example, 80% \( \times \) 30 = 24) and marked on the 'a' axis. The 'achieved' performance values of the other Criteria b, c, d, e and f are similarly evaluated from the weighted 'achieved' performance value combinations of their sub-criteria and marked on the respective Criteria axes.

The polygons connecting each set of sub-criteria 'achieved' performance values represent the 'achieved' performance against each Criterion; and similarly the polygon connecting the 'achieved' performance values of each Criterion represents the overall 'achieved' performance profile. These 'achieved' performance profiles can be compared with the respective targetted performance profiles. There could be an over-achievement against some Criteria and an under-achievement against others as in Figure 8 - C. A rapid visualisation of such strengths and weaknesses is facilitated.

A comparison of areas within corresponding polygons can be used as a broad Indicator to compare overall performance against targets on the same project, by taking the ratios of areas of the 'achieved' to that of the 'targetted' polygons in each case (whether sub-criteria or Criteria). However this comparison may not be easily extended across different projects, as not only would the axes and scales vary; but also such areas would be distorted by the relative sequencing (position against each other) of different axes.

8.7 INTEGRATING SUB-SYSTEMS AND SUPPORTING TOOLS

The development of the sub-systems of Criteria and Indicators has been described in detail in Chapters 2, 3, 4, 5 and 6; and was outlined at the beginning of Section 8.1. The formulation and use of modules of Criteria, Indicators and typical target values in particular sub-sectors and project categories, as in the pilot investigation in Sri Lanka, would progressively build up these sub-systems.

The diverse tools surveyed in this chapter are in various stages of development, for example as noted for the pilot Expert System described in 8.3 and the Performance Profile model in 8.6.7. Some other tools and techniques are already available but need to be developed to suit the specific system requirements, for example, techniques for the
transformation of pairwise comparisons described in general in 8.4, would be developed in detail as in 8.5. General tools outlined in 8.6 would be developed to match the system needs.

Questionnaires were developed for three sub-sectors in the pilot study, while sample Criteria, and Indicators were proposed for evaluating buildings for a client in the prototype. Data for roads and bridges though inadequate, was also used to propose Criteria and Indicators in the pilot study; and these were improved with the inputs of industry experts in Sri Lanka.

Common statistical techniques, as well as tools for refining quantitative data and assessments from the social sciences can also be utilised in improving such information collection and codification. Within the realm of suggesting solutions to identified problems in the short or long term, standard reporting formats should be designed to aid both better management of the project and facilitate faster future evaluation.

Once developed, each of such tools would be 'slotted in' to circle V of the proposed system, as in Figure 7 - B, to be accessed by databases in Circles II, III and IV which are also to be developed in parallel.

The pilot Expert System itself would be upgraded in stages as described in 8.3.5 to optimise the benefits when such developed sub-systems of Criteria, Indicators and the supporting tools & techniques are introduced into the system. The sub-systems would function together as indicated in Figure 7 - D.
Summary of work done as against that proposed for the system development

The Expert System front-end was developed to the status of a demonstration system (Brandon et al, 1988); but needs to be developed further into a reliable and comprehensive system, for example chaining other detailed modules of Criteria and Indicators as demonstrated.

Modules of Criteria and Indicators were proposed and tested; but these need to be tested further (where significant results were not obtained) and refined (for example by incorporating further weighting factors to account for common distortions). New data-sets are required in other project categories.

Tools such as Pairwise Comparison Weighting Matrices, specific questionnaires and data formats were identified and developed to fit into the proposed system. Minor additions are needed in developing particular versions to serve special modules; for example listing the project priorities to be weighted in a particular project category (such as schools) and at a given project stage; or in adding optional segments to questionnaire formats that are specific to a project category or an evaluation purpose.

Other tools such as project performance profiles, project evaluation frameworks and project performance frameworks were specially developed in this study and can be used directly in an evaluation after listing the project specific Criteria and Indicators.
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(Note: For list of Tables herein please see the General Contents at the beginning of this Thesis).
CHAPTER 9: FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

'If I have seen further, it is by standing on the shoulders of giants' - Sir Isaac Newton.

9.1 INTRODUCTION

9.1.1 General objectives of the Study

This study originated with the twin general objectives of surveying available systems and techniques for evaluating the management of construction projects; and of fulfilling the perceived need to formulate a framework for a comprehensive and reliable system for better evaluations. Systematised evaluations were expected not only to measure but also to help improve management performance in the short and long term.

The proposed system was to evaluate the effectiveness of managers in achieving desired outputs. It was also to provide the option to evaluate their efficiency in optimising the inputs of resources in both design and construction. An addendum to the research agenda soon emerged: in evaluating effectiveness viz performance against (client) stipulated targets, allowances should be incorporated to ensure that such targets were realistic. This checking and re-alignment of targets was to be accomplished both from first principles (for example by traditional estimating techniques) and also, when needed faster, by recourse to historical data and associated Indicators.

9.1.2 Terminology in this Chapter

The terms 'Findings', 'Conclusions', and 'Recommendations', while self-explanatory, were chosen in an attempt to structure the diverse facts and projections in the foregoing chapters along the definitive guidelines for USAID Executive Summaries by Management Systems International (undated). The analogies in the table reproduced overleaf focussed the analysis, together with the reminders that 'findings without recommendations are useless' and 'recommendations without findings are irresponsible'.

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However the following sections may manifest a residual overlap between findings and conclusions, between conclusions and recommendations and even between recommendations and findings. One reason for this arises from their necessarily strong linkages. Furthermore, the underlying goal of producing useful conclusions for the industry, drove many findings to conclusions and recommendations to be tested in this study itself, thereby generating further findings and conclusions. Cycles were therefore completed in the case of some recommendations, but as was to be expected, many residual recommendations remain for future consideration and action.

### TABLE 9-1

<table>
<thead>
<tr>
<th>Study Terminology</th>
<th>Formal Language</th>
<th>Medical Analogy</th>
<th>Legal Analogy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Findings</td>
<td>Facts</td>
<td>Symptoms</td>
<td>Evidence</td>
</tr>
<tr>
<td>Conclusions</td>
<td>Interpretations</td>
<td>Diagnosis</td>
<td>Verdict</td>
</tr>
<tr>
<td>Recommendations</td>
<td>Proposed Action</td>
<td>Prescription</td>
<td>Sentence</td>
</tr>
</tbody>
</table>

Relationships between Findings, Conclusions & Recommendations
(from USAID Executive Summary Guidelines, Management Systems International)

#### 9.1.3 Chapter Outline

Section 9.2 juxtaposes related findings, conclusions and recommendations. This is intended solely as a representative structured summary and not as a substitute for the many findings, conclusions and recommendations detailed in Chapters 2 to 8. Section 9.3 expands on some of the highlighted findings and conclusions.

It is also useful to view the findings and conclusions of Chapters 2 to 8 in the context of the objectives set out in Chapter 1. This is the principal purpose of Section 9.4 which evaluates this study itself in terms of how effectively it satisfied both the original objectives and other perceived needs that emerged during the study. The perceived shortfalls and major achievements of this study are also highlighted therein.

Section 9.5 summarises some residual recommendations. Section 9.6 contains concluding observations that place the study in a broader context.
### 9.2 SUMMARY OF MAIN FINDINGS, CONCLUSIONS & RECOMMENDATIONS

This condensed and structured summary is merely a device to project the relationships between the perceived highlights of the many facts, figures and other findings; the hypotheses and conclusions; and the tested and untested recommendations that emerged during this study. It is necessarily suggestive, at the best representative and thus in no way substitutes for the material described in detail in the individual chapters. The summary is not sequential either, as there was considerable overlap and interaction between the various findings and conclusions during different stages of the study.

<table>
<thead>
<tr>
<th>FINDINGS</th>
<th>CONCLUSIONS</th>
<th>RECOMMENDATIONS</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evidence of significant cost &amp; time over-runs, quality short falls etc.</td>
<td>Setting realistic targets; and better monitoring &amp; corrective action during projects would help improve performance.</td>
<td>Need for a good brief; accurate estimates; effective planning &amp; control systems; and regular evaluation.</td>
<td></td>
</tr>
<tr>
<td>No satisfactory comprehensive construction management evaluation system available.</td>
<td>Need to design one.</td>
<td>Formulate a framework and sub-systems.</td>
<td>Done. Done.</td>
</tr>
<tr>
<td>Many evaluation techniques are available in construction industry and elsewhere.</td>
<td>Adapt and incorporate in system.</td>
<td>Select, improve &amp; integrate into system.</td>
<td>Demonstrated.</td>
</tr>
<tr>
<td>Shortage of required data on particular project &amp; similar projects.</td>
<td>Study a representative sample of similar projects from their beginning.</td>
<td>Prescribe reporting formats from the outset which would also collect most of the required evaluation information.</td>
<td>Commenced.</td>
</tr>
<tr>
<td>Problems from ill-defined project targets.</td>
<td>Importance of a proper Brief.</td>
<td>Model project priorities and conditions.</td>
<td>Tools proposed.</td>
</tr>
<tr>
<td>Problems arising from unrealistic project targets.</td>
<td>Improve quick (first order) estimates of time, cost etc. in relation to expected standards.</td>
<td>Select from best techniques available. Improved cost planning &amp; pre-construction management.</td>
<td>Examples proposed.</td>
</tr>
<tr>
<td>FINDINGS</td>
<td>CONCLUSIONS</td>
<td>RECOMMENDATIONS</td>
<td>COMMENTS</td>
</tr>
<tr>
<td>----------</td>
<td>-------------</td>
<td>-----------------</td>
<td>---------</td>
</tr>
<tr>
<td>Ill-defined Criteria of success.</td>
<td>Identify project specific Criteria of success (and priorities).</td>
<td>Collect databanks of such Criteria for different purposes, categories &amp; stages of projects.</td>
<td>Sample sets formulated.</td>
</tr>
<tr>
<td>Inadequate means of measuring success levels.</td>
<td>Develop appropriate Indicators.</td>
<td>Formulate &amp; test primary, secondary &amp; tertiary Indicators. Estimate typical values and ranges.</td>
<td>Commenced.</td>
</tr>
<tr>
<td>Wide variability in Indicators, even within specific categories.</td>
<td>Weight by project conditions and priorities.</td>
<td>Develop weighting and linkage Indicators.</td>
<td>Commenced.</td>
</tr>
<tr>
<td>Significant contribution of qualitative value systems and assessments.</td>
<td>Model such value systems &amp; assessments using appropriate techniques from other disciplines.</td>
<td>Incorporate tools based on pair-wise comparisons and weightings.</td>
<td>Identified. Proven possible.</td>
</tr>
<tr>
<td>Sub-systems of the proposed evaluation system work.</td>
<td>Need to refine, test &amp; develop modules further &amp; integrate into a viable system.</td>
<td>Develop system for pilot sub-sector/category. Add modules as required.</td>
<td>Commenced.</td>
</tr>
</tbody>
</table>

**Summary of main findings, conclusions & recommendations**

**TABLE 9-2**

9.3 **HIGHLIGHTS FROM THE FINDINGS AND CONCLUSIONS**

The following are some highlights from items listed in the foregoing summary:

The evidence of dramatic cost and time over-runs appeared more significant in countries like Sri Lanka, where there was less systematised access to past industry data. Where there were industry organised databases like the BCIS in the UK, the availability of at least some Indicators evidently assisted in better cost planning and more realistic
estimates. The usefulness of comparing project elemental breakdowns with averages from that category were established in the pilot study in Sri Lanka.

There was still a perceived need for improved monitoring and standardised approaches to evaluating construction projects both before and during construction. For example large water authorities in U.K. such as the Severn-Trent had been ‘auditing’ their construction projects for many years. Inquiries from the Contract Audit section of Severn-Trent Water revealed that this was mostly on 'problem projects' and usually on an 'exception reporting' basis at present. However there was a perceived need to formulate checklists for the general review of the contractual systems as was usually carried out in parallel with the investigation of such special problems.

While recognising the need for a flexible system to accommodate the unpredictable variables in construction that could escape the attention of a rigid approach; some standardisation appeared essential, as used by major international funding agencies, such as the ODA, USAID and the World Bank for general project evaluations. Standardised formats for framing the Objectives, Criteria and verifiable Indicators, and also for summarising the evaluation findings for quick review and comparison, had been proved both necessary and valuable. This was adapted for the specific field of construction projects. A significant shortfall was noted in techniques of 'implementation evaluation', as opposed to the 'benefit evaluation' with which such international fundings agencies appeared primarily concerned at present.

Many specific techniques and tools (such as S curves, and variance analysis) were found in the current literature and practice. These needed adaptation and integration into a viable system.

The focus on modelling success Criteria and their means of measurement led to the concept of construction project Indicators. Quick comparisons were facilitated with realistic performance expectations in a particular project category. Indicators developed in a pilot study in Sri Lanka were well received by the construction industry at a Workshop and a subsequent Seminar. It was a significant advance in the tools available for quick estimates and comparisons mainly pertaining to cost Indicators. However the limited information available on past projects precluded the development of related Indicators such as those pertaining to time, performance/quality and technology levels. Systematised data collection in standardised reporting formats from the start of a project was recommended so as to obtain enough information to weight the Indicators appropriately to suit the project profile (the special priorities and conditions).
A methodology for defining, deriving and developing Indicators was established. This was tested further in the water supply sub-sector, (Karunaratne, 1990) and the general construction activity of brickwork (Abeysekera, November 1990). More detailed building Indicators with upper and lower bound values linked to specific confidence levels (Raviskanthan, 1990) and life cycle costing Indicators (Perera, 1990) were also developed.

A general construction management evaluation system was formulated drawing on the foregoing threads. The structure incorporated modules controlled by a knowledge based or Expert System front-end. Formats were proposed for a Project Evaluation Framework and a Project Performance Framework. Databases and knowledge bases are to be accessed by tools and with aids such as Pairwise Comparison Weighting Matrices to help model qualitative judgements. A prototype system for clients of office buildings focussed attention on specific Criteria and Indicators. A pilot Expert System (PICKMESS) was developed in stages to test the capability of integrating and accessing as needed, the various modules of the proposed system. Such a system would be a principal aid in supplementing (rather than supplanting) the evaluator from the beginning ie. in modelling the project priorities and conditions and applying such a project profile to weight the typical target values (and ranges) of Indicators selected to measure chosen Criteria.

A device was developed to construct a multi-dimensional project target profile using an axis for each chosen Criterion and separately for each sub-criterion; and to plot a performance profile after the evaluation, for the combination of Criteria as well as separately for each Criterion (as a combination of sub-criteria).

Many confirmations of the researcher's own findings emerged from the literature and current practice during this study (for example on the type of performance Criteria chosen, on the need for Indicators to measure them, on the advantages of evaluation both during and after a project and the usefulness of particular techniques of evaluation).

9.4 EVALUATING THIS STUDY

9.4.1 Fulfilling the Objectives

The study fulfilled both the general objectives and the specific objectives (listed in Section 1.3 of Chapter 1). The (not unexpected) limitations on well documented project data precluded further progress at this stage, but it was concluded that a significant milestone had been reached as intended.

Specifically, the principal objectives were met in:
(A) surveying the availability of systems, techniques and tools for the evaluation of the management of construction projects, both in Sri Lanka and abroad; and

(B) formulating a framework for a suitable general system to evaluate construction management performance (initially from a client’s point of view and at different stages of a project, but eventually for use by any project participant with a specific evaluation purpose).

Related sub-objectives were pursued, for example of examining such techniques in other sectors. Some useful tools were identified, for instance in evaluating information flow efficiency. In this context another parallel was also noted: managers often received a larger volume of information than they required, but still lacked the particular information needed for a good decision. To avoid similar pitfalls evaluations should be structured to efficiently extract only the relevant facts and figures, needed for the particular evaluation exercise being conducted.

As intended, the emphasis was on evaluating from a client’s point of view, primarily to assess effectiveness, but with a provision to evaluate efficiency of resource utilisation as this may be needed on particular types of contracts or for a more generalised overview. Furthermore such provisions can be later developed into modules that would assist a designer or a contractor in evaluating the efficiency of his own personnel or sub-contractors.

The strengths and weaknesses of available techniques were noted. A general survey of construction projects in Sri Lanka was followed by a focus on the buildings, roads and bridges sub-sectors. The usefulness of historical data from a given project category was tested in evaluating how realistically targets set for similar projects could be expected to be achieved. The development of Indicators proved useful in this respect, as well as in alerting evaluators to significant deviations from the norms.

The framework formulated for a proposed comprehensive general evaluation system was followed by the demonstration of it’s viability in a prototype. The flexibility imparted by the modular structure proved both necessary and workable. The pilot Expert System established it’s viability in integrating and controlling the different modules of the proposed evaluation system. The other two sub-systems of Criteria and Indicators were tested by constructing and presenting typical modules to the industry. The tools for evaluating Indicators and the associated database modules were tested along with the Indicators.
9.4.2 Shortfalls of the Study

Possible further expectations from this study could have related to more specific information on time and performance/quality Indicators. However, these were circumscribed by the lack of reliable information both on these particular aspects and also on related aspects such as technology levels and originally stipulated priorities, without which evaluating the former would have been 'unfair' and meaningless.

An actual slotting in of 'real' cost (or other) Indicator values into the prototype evaluation system or the pilot Expert System was precluded for the same reasons - lack of data in each specific category, but more important (especially in the buildings sub-sector where substantial data was collected) the futility of using such isolated Indicators in the absence of the project profile and other Indicators by which they should be weighted in order to ensure meaningful comparisons.

This also prevented testing of the integrated system. But such testing was beyond the scope of the original objectives, which intended the system framework to be proposed and key modules to be developed.

9.4.3 Summary of Special Achievements of the Study

The following list of the special achievements of this study represents the researcher's overview of its impact. It does not therefore include all the findings and conclusions. This study:

(a) surveyed relevant literature and current practice in evaluating the management of construction projects;

(b) identified useful monitoring and evaluation techniques; and noted the absence of comprehensive and reliable systems of evaluation;

(c) established that performance evaluation must be based on identified sets of Criteria and sub-criteria, which may be suggested from sample sets assembled for similar projects but which need to be clearly established in the initial Project Brief;

(d) developed a language of Indicators to measure and convey performance levels against such Criteria. Proposed families of such Indicators to be chosen from as appropriate;
(e) showed that target values (and ranges) of such Indicators should be based on historical databases pertaining to that project category and weighted to suit the particular project profile; which in turn must be modelled from project priorities and contextual conditions;

(f) identified methodologies for such modelling of priorities and also for subjective judgements, eg: by transforming a series of pairwise comparisons into a set of weights using matrices;

(g) formulated a framework for a comprehensive evaluation system to achieve such objectives;

(h) proposed sub-systems of Criteria, Indicators and an Expert System front-end to select appropriate modules from the system along with relevant information elicitation and presentation tools related to project category, project stage and evaluation purpose;

(i) proposed techniques and tools for the system such as: Data Collection Formats, Project Evaluation Frameworks, Project Performance Frameworks, Project Performance Profiles and Pairwise Comparison Weighting Matrices;

(j) proposed a prototype system for office building clients with lists of Criteria and Indicators;

(k) tested proposed performance Criteria by exposure to the industry experts and practitioners in Sri Lanka and U.K.;

(l) extracted average values of cost-related Indicators from the buildings sub-sector and less reliably (with higher variability) from the roadworks and bridges sub-sectors of Sri Lanka;

(m) established a methodology for deriving and developing such Indicators in these and other (eg: water supply) sub-sectors;

(n) developed a pilot Expert System and tested the viability of the evaluation system structure itself by establishing it's ability to integrate appropriate modules selected from the sub-systems; and

(o) thereby established the viability of the three sub-systems of the proposed evaluation system; and of the supporting techniques & tools of information elicitation & presentation.
9.5 RESIDUAL RECOMMENDATIONS

This section briefly reviews some of the recommendations which were both beyond the scope of this study, and which could not have been tested herein, for reasons outlined in sub-section 9.4.2. The following summarises such recommendations for future consideration:

9.5.1 On the Criteria and Indicators

(A) Identify and separately codify the Criteria of effectiveness and efficiency relating to each important category of every construction sub-sector of interest in a particular country; (for example the category of 'long span bridges with piled foundations and pre-stressed concrete super-structures' within the bridges sub-sector).

(B) Select or formulate primary Indicators that would best represent each such principal Criterion. If more than one primary Indicator is required per principal Criterion, a weighted combination may be proposed.

Formulate a family of Indicators - including secondary, tertiary, weighting and linkage Indicators that would relate to both the chosen primary Indicators and to the sub-criteria for each such construction project category.

(C) Design and introduce reporting formats for new projects in the identified categories that would help collect the required information to evaluate these Indicators.

Propose appropriate tools which could be used to analyse the data and evaluate such Indicators efficiently.

(D) Analyse such information from a sample of similar projects and test the validity and usefulness of the proposed Criteria and Indicators.

Obtain typical average values for validated Indicators weighted by any special project conditions and priorities and also time-adjusted with price inflation indices. Estimate operating ranges (upper and lower bound values, assuming given levels of confidence).

Test such Indicators on new projects (manually) pending the development of the Evaluation System.
9.5.2 On the Evaluation System

(E) Develop the proposed knowledge-bases with families of Criteria, Indicators and associated target values and ranges; with rules for weighting the values and ranges according to the project profile; and with further rules for modelling such a project profile by evaluating project conditions and priorities.

(F) Develop the proposed formats for eliciting such project profiles, and for efficiently collecting information pertaining to the different Indicators and for associated tools such as Project Evaluation Frameworks and Pairwise Comparison Weighting Matrices (as proposed in this study), responsibility matrices, resources reconciliation charts, S curve profiles, information flow diagrams etc. Design special tools such as checklists and critical incident analysis strategies to locate and incorporate special project phenomena in the evaluation.

Develop the proposed reporting formats including Project Performance Frameworks, and Project Performance Profiles.

(G) Develop the pilot Expert System to help efficiently integrate appropriate modules of the developed knowledge-bases for any particular evaluation.

9.5.3 In General

(H) Extend the Evaluation System to other project participants and for other purposes (as intended in the proposed structure) by developing the appropriate modules.

Note: Other general benefits could also materialise, for example from the client, designer and contractors using the same core evaluation system on a project and identifying a common set of project conditions and priorities to start with; (even though each could build in his own priorities thereafter and his own Criteria and Indicators of efficiency). They would also be accessing a common knowledge base derived from past projects in that category; (while the designer and contractor would have additional information available from their own historical databanks). The initial identification and alignment of core project Criteria would be a worthwhile exercise in itself.

(I) Test the developed Evaluation System (even if developed only in one or a few categories) in a country like Sri Lanka (with under-developed sources of construction information and Indicators) as well as in a country like UK (with more accessible general construction databases and Indicators at least in sub-sectors like buildings). Extend the
evaluation system to other countries, and to international organisations dealing with different countries. Test and develop such extended applications.

Note: The potential usefulness of such systems in a wider context has been already appreciated. For example the Commonwealth Science Council endorsed in 1988 the project proposal of the Institution of Engineers Sri Lanka, prepared by this researcher for developing Construction Industry Indicators. In April 1989, the Minister for Technology Transfer in the Sri Lanka Embassy in U.S.A., confirmed to the Institution of Engineers Sri Lanka, the interest of an important USAID Division Chief in the Institution's specific proposal 'to develop packages of Indicators and to incorporate them in project appraisal/audit tool kits'. USAID was interested in this development as it would 'reflect a methodology for region-wide study'.

9.6 CONCLUDING OBSERVATIONS

The observations that follow were generated during the pursuit of this study and can therefore broaden the context of the findings, conclusions and recommendations.

The difference was noted between successful projects and the success of it's project management. For example the project targets could be met, but one or the other of the participants may have been inefficient in meeting them and have suffered the consequences (even bankruptcy). In evaluating such efficiency from a participant's viewpoint, a broader perspective would suggest incorporating long term (or organisational) as well as short term (or project specific) Criteria or performance measures. For example, consciously targeting client satisfaction can well result in extended benefits like repeat orders and less stringent conditions of engagement.

'Spin offs' or subsidiary benefits of this study were generated from, for example:

(i) frameworks and examples of an universal shorthand language of Indicators in the construction industry, that can be used to formulate, evaluate and compare construction projects within and across national boundaries;

(ii) structured approaches to modelling the project brief, including the project profile (conditions and priorities);

(iii) alternative approaches to quick first order estimates based on Indicators derived from historical knowledge-bases and weighted by the project profile;
(iv) techniques for 'real-time' monitoring of projects, replacing the time lags and resistance (or reluctant compliance) associated with many reporting systems and the consequently delayed remedial measures, if any;

(v) useful structures and developed modules for databases of projects in the buildings, roadworks and bridges sub-sectors of Sri Lanka; together with an overview of lessons learned from different types of construction projects, with a potential to improve future performance. Indications of strengths, weaknesses trends and emerging patterns in construction sub-sectors and project categories;

(vi) tools for contractors to evaluate their sub-contractors (and vice versa); and for clients or project managers to compare results from different forms of procurement on similar projects;

(Note: the latter comparison is merely made more realistic by weighting allowances for identified conditions; but could hardly be expected to hypothetically reproduce identical scenarios in two different projects. There will thus always be a residual difficulty in unequivocally proclaiming one form of contract as the best to have managed a completed project, although an informed judgement could help a better choice of a form appropriate to the project profile at the beginning of the project); and

(vii) techniques suitable for adaptation by construction clients, financiers, project formulators, strategic planners and estimators (for example in assessing the feasibility of intended projects); for designers and cost planners (for example in design evaluation); as well as for managers of ongoing projects and for evaluators of completed projects (for example in learning lessons from what went wrong and why; and what went well and how).

The apparently ambitious requirements of large databanks of historical information to perfect an evaluation system of the type proposed, coupled with difficulties of collecting enough data encountered even in the pilot project, at one stage suggested a search for simpler solutions; perhaps not too dependent on historical data. However such difficulties were overcome by the incorporation of an Expert System to eventually help handle the data and also to substitute expert opinion for the databank pending its assimilation. Furthermore, it was felt that information collection and reporting would be easier with the specially linked formats developed for same and also with a greater willingness (even commitment) from the project participants to help generate the required information; once they appreciated both the short and long term benefits from project monitoring and improved performance.
It was therefore established that 'it is possible to develop a viable and comprehensive system to evaluate the management of construction projects against realistic targets as a systematic exercise; incorporating both the special project priorities and contextual conditions as well as relevant historical data from similar projects' as per the hypothesis postulated in Section 1.1.3 of Chapter 1.

In the light of laments (Gerwick, 1990) that there is inadequate emphasis on the 'D' (Development aspects) of the 'R & D' (Research and Development) in construction in USA, the situation in Sri Lanka is seen as very much worse, in that there is hardly any 'R' either, despite the significant role of construction in the economy. There was therefore a conscious effort to relate the research and it's recommendations to the real needs of the construction industry, both in Sri Lanka and internationally.


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## APPENDICES

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APPENDIX AP1-1

VALUE OF SRI LANKA RUPEE VIS A VIS UK STERLING (£) AND U.S DOLLAR ($) IN PERIOD UNDER REVIEW

The following table was extracted from the Sri Lanka Central Bank rates for the purchase of foreign currency notes from commercial banks. This indicates the value of the Sri Lanka Rupee and its variation through the period under consideration. Rupee values of projects quoted in the text of this thesis, should be considered in this context.

<table>
<thead>
<tr>
<th>DATE</th>
<th>SRI LANKA RUPEES PER U.K POUND (£)</th>
<th>SRI LANKA RUPEES PER U.S. DOLLAR ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>03-01-85</td>
<td>29.45</td>
<td>25.50</td>
</tr>
<tr>
<td>05-06-85</td>
<td>34.10</td>
<td>26.65</td>
</tr>
<tr>
<td>04-12-85</td>
<td>39.55</td>
<td>26.70</td>
</tr>
<tr>
<td>04-06-86</td>
<td>40.00</td>
<td>27.25</td>
</tr>
<tr>
<td>03-12-86</td>
<td>39.70</td>
<td>27.80</td>
</tr>
<tr>
<td>03-06-87</td>
<td>45.80</td>
<td>28.30</td>
</tr>
<tr>
<td>02-12-87</td>
<td>54.05</td>
<td>29.75</td>
</tr>
<tr>
<td>02-06-88</td>
<td>55.10</td>
<td>30.25</td>
</tr>
<tr>
<td>06-12-88</td>
<td>59.80</td>
<td>32.15</td>
</tr>
<tr>
<td>08-03-89</td>
<td>55.45</td>
<td>32.35</td>
</tr>
<tr>
<td>04-01-89</td>
<td>58.10</td>
<td>32.20</td>
</tr>
<tr>
<td>06-06-89</td>
<td>52.85</td>
<td>33.25</td>
</tr>
<tr>
<td>05-09-89</td>
<td>57.45</td>
<td>37.15</td>
</tr>
<tr>
<td>05-12-89</td>
<td>60.80</td>
<td>39.00</td>
</tr>
</tbody>
</table>

NOTE: During most of 1990 the U.S. Dollar fluctuated around Rs.40 and Rs. 41 and the U.K. £ varied correspondingly.
### LOGICAL FRAMEWORK MATRIX

(based on Project Assistance Handbook 3, USAID, 1975)

<table>
<thead>
<tr>
<th>Narrative Summary</th>
<th>Objectively verifiable indicators</th>
<th>Targets</th>
<th>Means of verification</th>
<th>Major assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Objective</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Target</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Project Framework as used by ODA

**Project Title:**

**Brief Description of Projects**

**MIS Code No.:**

**File Reference:**

#### Project Structure

<table>
<thead>
<tr>
<th>WIDER (i.e. Sector or National) Objectives</th>
<th>Immediate Objectives</th>
<th>Outputs</th>
<th>Inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>What are the intended immediate effects on the project area or target group?</td>
<td>What are the quantitative measures (including the realised internal rate of return), or qualitative evidence, by which achievement and distribution of effects and benefits can be judged?</td>
<td>What are sources of information?</td>
<td>What are sources of information?</td>
</tr>
<tr>
<td>What are the expected benefits (or disbenefits) and to whom will they go?</td>
<td>What are the quantitative ways of measuring, or qualitative ways of judging, whether these broad objectives have been achieved?</td>
<td>What external factors must be realised to obtain planned Outputs on schedule?</td>
<td>What decisions or actions outside control of ODA are necessary for inception of project?</td>
</tr>
<tr>
<td>What improvements or changes will the project bring about?</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Indicators of Achievement

- What are the quantitative ways of measuring, or qualitative ways of judging, whether these broad objectives have been achieved?

#### How Indicators Can Be Quantified or Assessed

- What sources of information exist or can be provided cost-effectively?

#### Important Assumptions

- What conditions external to the project are necessary if the project's Immediate Objectives are to contribute to the Wider Objectives?

- What are the factors not within the control of the project which, if not present, are liable to restrict progress from Outputs to achievement of Immediate Objectives?
**WIDER (SECTOR OR NATIONAL) OBJECTIVES**

Development of adequate supply of well-trained technical manpower to meet needs of public and private sector industrial development and of power, water, construction, transport and communications sectors

By 1990 -
1. Total supply of trained engineers and technicians will be brought roughly into line with demand (current estimates of supply at end of 1990 are 20,000 and 59,000 respectively). (Annex 2)

2. Annual output of:
   a) graduates from polytechnics
   b) graduates from engineering colleges

**IMMEDIATE OBJECTIVES OF PROJECT**

Provision of well-trained technical teachers for engineering colleges and polytechnics from re-organised and re-vitalised Technical Teacher Training College

1. Annual output for 7.4 years of up to 170 polytechnic teachers with Diploma in Technical Education. [5.4.1]

2. Annual output for 7.4 years of up to 40 retrained engineering college staff. [5.4.1]

3. Annual output of (c) from short courses on special teaching methods. [5.4.1]

4. By end 1990 (d) trained teachers graduated from TTTC and in post at polytechnics and (e) at engineering colleges

**INDICATORS OF ACHIEVEMENT**

1. Reports from Planning Commission
2. Polytechnic and engineering college records
3. Tracer studies as guide to supply/demand situation
4. Value judgment of employers as to whether quality of technicians and engineers has improved

**HOW INDICATORS CAN BE QUANTIFIED OR ASSESSED**

1. No shortage of qualified applicants for places at polytechnics and engineering colleges
2. Demand and supply forecasts realistic
3. Improved quality, particularly increased degree of practical training, will make graduates more acceptable to industry
4. Rate of transfer of teachers into the private sector will not differ markedly from current level

**IMPORTANT ASSUMPTIONS**

1. After 31 July 1988 all new teachers appointed at polytechnic will be required to have Diploma in Technical Education
2. After 1 January 1986, GMB to ensure that under-qualified teachers in polytechnics enrol in TTTC programmes
3. Practical attachments to be made by 31 July 1987 requirement for award of Diploma in Engineering and Diploma in Technical Education
<table>
<thead>
<tr>
<th>PROJECT STRUCTURE</th>
<th>INDICATORS OF ACHIEVEMENT</th>
<th>HOW INDICATORS CAN BE QUANTIFIED OR ASSESSED</th>
<th>IMPORTANT ASSUMPTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>colleges out of total staffs of (b) and (g) respectively</td>
<td>5. To assess quality, use pass rates eg % of trainees achieving x 3 or more</td>
<td>4. Binding arrangements will be made for graduates from TTC to return to original posts</td>
<td></td>
</tr>
<tr>
<td>[6. Rate of return not calculated]</td>
<td></td>
<td>5. Contributions from IDA, UNDP and GSB for equipment modernisation, physical rehabilitation, curriculum development and industrial attachments, administrative reform and reform of system examination for polytechnics and engineering colleges are successfully carried through</td>
<td></td>
</tr>
</tbody>
</table>

**OUTPUTS:**

Revitalised Technical Teacher Training College

1. Provision and installation of Training College [Annex 4 and 8]

11. 5 senior staff trained in 1985 (15 man months) [Annex 7]

111. 15 teaching staff trained by 7/87 (273 man months) [Annex 7]

1v. DTE courses commenced in 7/86 [Annex 8]

v. Other courses commenced in ?

vi. Teaching guides prepared

**INPUTS:**

<table>
<thead>
<tr>
<th>GDA -</th>
<th>£'000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital - Equipment</td>
<td>1080 1080</td>
</tr>
<tr>
<td>Books</td>
<td>150 150</td>
</tr>
<tr>
<td>Share of local staff salaries and cost of consumables</td>
<td>40 30 30 30 30 1400</td>
</tr>
<tr>
<td>TC - Senior Adviser</td>
<td>13 34 67 67 21 206</td>
</tr>
<tr>
<td>5 subject Advisers</td>
<td>90 402 360 4 10 852</td>
</tr>
<tr>
<td>Consultants</td>
<td></td>
</tr>
<tr>
<td>288 man/months Training</td>
<td>135 170 50 14</td>
</tr>
<tr>
<td></td>
<td>13 1379 833 517 51 51 1430</td>
</tr>
</tbody>
</table>

(from Cracknell & Rednall, 1986)
QUESTIONNAIRE/PROJECT DATA SHEET BDI FOR IESL/ICTAD/ILO

CONSTRUCTION INDUSTRY INDICATORS PROJECT

SHEET ...... OF ........ FILLED ON ............... WITH................. BY................
(PLEASE USE SEPARATE SHEETS WHERE SPACES ARE INADEQUATE)

0. CONFIDENTIALITY REQUIRED, IF ANY: Should any particular information/
      project name/project personnel remain confidential? ie. not be published
      elsewhere?

1. PROJECT TITLE:

2. LOCATION:

3. BASIC PROJECT PARAMETERS:

   3.1 Building Type (Categorisation for roof, frame, and walls):
   3.2 Building Function and Capacity:
   3.3 Plinth Area:
   3.4 No. of Storeys:
   3.5 Other (eg: special foundations):
   3.6 Total (Contract) Value:

4. CLIENT/OWNER/USER:

5. FINANCED BY:

6. CONSULTANTS:

   6.1 Consultant's Key Project Personnel, and their deployment schedule, if available
       and a (subjective) performance assessment (on a scale from 0 to 10)
   6.2 Categories and numbers of other project personnel

7. CONTRACTORS:

   7.1 Contractor's Key Project Personnel, their deployment schedules, if available;
       and a (subjective) performance assessment (on a scale from 0 to 10)
   7.2 Categories and numbers of other project personnel

8. MAIN SUB-CONTRACTORS:

   8.1 Main Sub-Contractor's Key Project Personnel, their deployment schedule, if available
       and a (subjective) performance assessment (on a scale from 0 to 10)
   8.2 Categories and numbers of other project personnel

9. MAIN DIRECT SUPPLIERS, if any:

10. ANY OTHER PARTICIPANT eg. PROJECT MANAGERS:

10.1 Key Project Personnel of any such other participants, their deployment schedule,
    if available ; and a (subjective) performance assessment (on a scale from 0 - 10)

Data Sheet Format used for collecting Building Project Data

270
10.2 Categories and numbers of other project personnel

11 FOREIGN INPUTS, PARTICIPATION AND OUTPUTS, IF ANY:
Areas / Disciplines in which participated:
Assessed Percentage share and nature of work load in such areas:
Percentage share of expenditure and payments in such areas
Assessment of having fulfilled a need not available locally (on a scale from 0 to 10)

12 CONTRACTUAL AND WORKING RELATIONSHIPS:
12.1 Type of Contract (eg: standard; design and build; fixed price, cost +)
12.2 Form of Contract signed (eg: ICTAD, FIDIC, Project Consultants Standard Form ie. organisation specific; project specific)
12.3 Special Contractual Conditions
12.4 Organisation Structure (including responsibilities - overall)
12.5 Communication Systems (overall)
12.6 Organisation Structure and Communication System of each major participant, where relevant
12.7 Assessment of (a) effectiveness and (b) efficiency (on a scale from 0 to 10)

13 BRIEF TECHNICAL DESCRIPTION INCLUDING:
13.1 Sub - Structure, Superstructure (frame, walls, windows, partitions, ceilings and roof)
13.2 Circulation areas % (corridors, staircases etc as a % of total plinth area)
13.3 Internal Finishes (walls, ceilings, floors)
13.4 Quality Levels - on a scale from level 0 to 10 for particular finishes, structures etc.
   (a) as planned (eg: 5 star Hotel quality could correspond to level 10 but this is not always needed nor affordable. Perhaps 2 star or level 5 would suffice).
   (b) as achieved : (maybe only a level 3 was actually achieved)
13.5 Method Statement (including Technology and Equipment used)
13.6 Special Conditions

14 COSTS OF TOTAL /SM
14.1 DESIGN -
14.2 CONSTRUCTION (TOTAL) -

Breakdown of Construction Costs

<table>
<thead>
<tr>
<th></th>
<th>CONTRACT BOQ</th>
<th>FINAL BILL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preliminaries</td>
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<tr>
<td>Sub- structure/ Foundations</td>
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<td>Ground Floor Slab</td>
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271
Beams -
Upper Floor Slabs -
Walls -
Roof -
Windows -
Doors -
Door & window Finishes -
Internal Finishes -
External Finishes -
Electrical (excluding fittings) -
Electrical fittings -
Electrical Switchgear -
Plumbing (excluding fittings) -
Sanitary Fittings -
Other Services -
(eg: telephone, fire and sound systems) -
Special Fittings -
External Works -
Other items (in main Construction Contracts) -

14.3 OTHER PROJECT COSTS
Land -
Services Connections -
Miscellaneous -

15. TIME FRAME
15.1 DESIGN:

Estimated Actual Remarks & Reasons

Start Date
Finish Date

15.2 TENDER EVALUATION:
& AWARD:

Start Date
Finish Date

15.3 CONSTRUCTION:

Start Date
Finish Date

Any time extensions granted

16. VARIANCE
16.1 Variations to Design Fees:

Reasons:
16.2 Variations to Original Contract Sum:

16.2.1 Changed scope of work:
   Reasons:

16.2.2 Changed Quantities (where significant)
   Reasons:

16.2.3 Fluctuations allowed in prices

16.2.4 Total variation to original contract sum (add 16.2.1 + 16.2.2 + 16.2.3)
   Main Reasons for changes:
   How could they have been avoided/minimised?

16.2.5 Contractual & extra - contractual claims

17. SCHEDULE OF VALUATION AND OTHER (COMPLETION) CERTIFICATES AND PAYMENTS.

<table>
<thead>
<tr>
<th>Bill No.</th>
<th>Value</th>
<th>Date</th>
<th>Certificate</th>
<th>Value</th>
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</tbody>
</table>

18 GENERAL COMMENTS BY KEY PARTICIPANTS (on special project features, successes, failures, problems, possible, solutions and other lessons learned)

19. In the opinion of key project participants were any indicators (indices/thumbnails/guidelines) used to help (a) plan, (b) monitor, (c) control, (d) evaluate the project. If not what indicators could have been used to draw on experience from similar projects.

   TO BE FILLED BY INTERVIEWER

20 RATE YOUR ASSESSMENT OF THE INTERVIEWEE ON A SCALE FROM 0 TO 10 ON:

20.1 RELIABILITY

20.2 PROBABILITY OF ACCURACY (take time lag, access to all information, vested interests and such factors into account. Perhaps some areas may be more accurate/reliable than others. If so specify).

21. PRELIMINARY CONCLUSIONS AND AREAS FOR FURTHER INVESTIGATION.
QUESTIONNAIRE/ PROJECT DATA SHEET FOR IESL/ICTAD/ILD:
CONSTRUCTION INDUSTRY INDICATORS PROJECT - ROADS DATA

Sheet ....of...... filled on ........ with ............by...........
(Please use separate sheets where spaces are inadequate)

0. Confidentiality required, if any: should any particular
information/ project name/ project personnel remain confidential?
ie. not be published elsewhere?

1. Project/ Title/ Location:

2. BASIC PROJECT PARAMETERS:
   2.1. Road Type and average depth:
       Base:
       Surface:
   2.2 Overall Platform width:
       No. of lanes:
       Carriage width -
       Shoulders width:
       Kerb/Pavement width (s)-
   2.3 Length -
   2.4 Completely New Road or rehabilitation of an existing road:
       if rehabilitation, extent of rehabilitation ( on a scale from
       1 to 10 :)
   2.5 Total ( contract) value :

3. (a)Client      (b)Consultant(s)      (c)Contractor

4. Financed by

5. Design Stage
   5.1 Consultant's key Project personnel
       Investigations:
       Design :
   5.2 Extent of site investigations ( Rate on a scale from 0 to 10 as
       to how detailed the investigations were)
   5.3 Reliability of available data
   5.4 Was the information available adequate for an optimum design:-
   5.5 Extent of clients involvement:-
   5.6 Organisation structure: -
   5.7 Type of Consultancy Agreement with Client ( including for
       Construction stage)

Data sheet Format used for collecting Road project data
6 CONSTRUCTION STAGE
6.1 Consultants / Engineers key project personnel.
   - Head Office Project staff
   - Site staff
6.2 Contractors key project personnel.
6.3 Any specialist Construction Management inputs/personnel
6.4 Main sub contractor's key project personnel.
6.5 Total Labour strength and deployment schedule.
6.6 Main Equipment used and deployment schedule
6.7 Availability of required materials close to site
6.8 Extent of supervision / control that Engineer had over the contractor (on a scale from 0 to 10)
6.9 Extent of control client had over the consultant/ Engineer and/or the contractor (on a scale from 0 to 10)
6.10 Organisation structure (overall)
6.11 Communication systems (overall)

7 TENDERING AND EVALUATION STAGES
7.1 What was the tendering procedure?
   (e.g. negotiated, competitive tendering; and whether tenderers were prequalified / shortlisted)
7.2 Consultants involvement in Evaluation/ Selection of the contractor
7.3 Clients involvement in Evaluation/ selection of the Contractor
7.4 Type of contract (e.g. B.O.Q; Schedule of rates; design & build; fixed price; cost +)
7.5 Form of contract (e.g. World Bank, FIDIC, ICTAD Project Consultants standard form ie: organisation specific; or project specific)
7.6 Special contractual conditions (e.g. no price variations, special risks, limit on variations etc)
7.7 Completeness of the documents at tender stage; at construction commencement:

8 FOREIGN Inputs. Participation and Outputs if any:
8.1 Areas/ Disciplines in which participated:
8.2 Assessed percentage share and nature of work load in such areas.

8.3 Percentage share of expenditure and payments in such areas:

8.4 Assessment of having fulfilled a need which could not be met locally (on a scale of 0 to 10).

9 BRIEF TECHNICAL DESCRIPTION

9.1 Extent of Earthworks/Type of Terrain

9.2 Pavement type, composition and layer thickness

9.3 Design life

9.4 Projected Vehicular traffic considerations
   Design Traffic Flow (passenger car units etc)
   Design Loads (axle loads etc)
   Design Speed

9.5 Drainage Considerations:

9.6 Culverts and other structure with basic parameters:

9.7 Special features

9.8 Method statement including technology and equipment used.

9.9 Provision for services (infrastructure)

10 COSTS

10.1 Budgetary Allocation.

10.2 Design costs:

10.3 Investigation costs

10.4 Supervision costs

10.5 Construction Cost (Total) =
   Engineer's estimate =
   Contract sum =
   Actual (final) cost =

BREAKDOWN OF CONSTRUCTION COSTS

Preliminaries
Site Clearance
Earthworks
Pavement: Sub Base
   Base
   Surface Correction (Regulator)
   Surfacing
Structures.

276
10.6 OTHER PROJECT COSTS
Land acquisition -
Consultants' Contract Administration and Supervision
Miscellaneous

10.7 Major Item Costs (quantities and values)
Excavation
Filling
Bitumen - Type 1
- Type 2
Aggregate - Size 1
- Size 2
Culverts
Side Dips - Size 1
- Size 2

Construction site staff

11. TIME FRAME

<table>
<thead>
<tr>
<th>Estimated</th>
<th>Actual</th>
<th>Reasons for delays</th>
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<td>and Remarks</td>
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</table>

11.1 Design
Start date:
Finish date:

11.2 Prequalification
Invitation date
Receipt date
Evaluation date

11.3 Tender
Invitations date
Receipts date

11.4 Tender Evaluation and Award
Start date -
Finish date -

11.5 Construction
Start date -
Finish date -

12 VARIATIONS
12.1 Variations to Design Fees:
Reasons:

12.2 Variations to Engineers Estimate
Reasons:

12.3 Variations to Original contract sum:

12.3.1 Changed scope of work:
Reasons:

12.3.2 Changed Quantities (where significant)
Reasons:

12.3.3 Fluctuations allowed in prices

12.3.4 Claims

12.3.5 Total variation to original contract sum (add 12.3.1 + 12.3.2 + 12.3.3 + 12.3.4)

Main reasons for changes:

How could they have been avoided/minimised?

13 SCHEDULE OF BILLS CERTIFICATES AND PAYMENTS

<table>
<thead>
<tr>
<th>Bill No</th>
<th>Value Date</th>
<th>Certificate Value Date</th>
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<td>Retention</td>
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</tbody>
</table>

14 GENERAL COMMENTS BY KEY PARTICIPANTS
(Client, Design Consultant, Engineer, Main Contractor)

14.1 Brief Description of each others roles, organisation structure, delays in decision making, availability of information, criticisms, comments and recommendations for improvement.

14.2 Special project features, successes, failures, problems, solutions and other lessons learnt)

15 In the opinion of key project participants were any INDICATORS (thumbrules/guidelines) used to help (a) plan (b) monitor (c) control (d) evaluate the project. If not what indicators could have been used to draw on experience from similar projects.
APPENDIX AP5-3

QUESTIONNAIRE / PROJECT DATA SHEET BR1 FOR IESL/ICIAN/ILD CONSTRUCTION INDUSTRY INDICATORS PROJECT - BRIDGES DATA

Sheet ..... of ..... filled on .......... with ............ by ............
(Please use separate sheets where spaces are inadequate)

0. Confidentiality required, if any: should any particular information/ project name/ project personnel remain confidential? ie. not be published elsewhere?

1. Project/ Title/ Location:

2. BASIC PROJECT PARAMETERS:
   2.1. Bridge Type:
       Superstructure : 
       Substructure:
       Foundation:

   2.2 Overall width:
       No. of lanes:
       Carriage width -
       Footwalk width (s) -

   2.3 Length -

   2.4 Number of spans:
       Span lengths:

   2.5 Average Depth/Range of Depths of Foundations
       ( up to cap level) wing walls -
       Piers -

   2.6 Approaches
       Lengths:
       Widths :
       Type:

   2.7 Total ( contract) value :

   2.8 Completely New Bridge or replacement of an existing bridge.

3. Client

4. Financed by

5. Design Stage
   5.1 Consultant's key Project personnel
       Investigations:
       Design :

   5.2 Extent of site investigations ( Rate on a scale from 0 to 10 as to how detailed the investigations were)

Data sheet Format used for collecting Bridge project data
5.3 Reliability of available data

5.4 Was the information available adequate for an optimum design:

5.5 Extent of clients involvement:

5.6 Organisation structure:

5.7 Type of Consultancy Agreement with Client (including for Construction stage)

6 CONSTRUCTION STAGE

6.1 Consultants'/Engineers key project personnel.
   Head Office Project staff -
   Site staff -

6.2 Contractors key project personnel.

6.3 Any specialist Construction Management inputs/personnel

6.4 Main sub contractor's key project personnel.

6.5 Total Labour strength and deployment schedule.

6.6 Main Equipment used and deployment schedule

6.7 Extent of supervision / control that Engineer had over the contractor (on a scale from 0 to 10)

6.8 Extent of control client had over the consultant/Engineer and/or the contractor (on a scale from 0 to 10)

6.9 Organisation structure (overall)

6.10 Communication systems (overall)

7 TENDERING AND EVALUATION STAGES

7.1 What was the tendering procedure?
   (e.g.: negotiated, competitive tendering; and whether tenderers were prequalified/shortlisted)

7.2 Consultants involvement in Evaluation/Selection of the contractor.

7.3 Clients involvement in Evaluation/selection of the Contractor

280
7.4 Type of contract (eg: B.O.Q; Schedule of rates; design & build; fixed price; cost +)

7.5 Form of contract (eg: World Bank, FIDIC, ICTAD Project Consultants standard form ie: organisation specific; or project specific)

7.6 Special contractual conditions (eg: no price variations, special risks, limit on variations etc)

7.7 Completeness of the documents at tender stage: at construction commencement: 

8 Foreign Inputs, Participation and Outputs if any:
8.1 Areas/ Disciplines in which participated:

8.2 Assessed percentage share and nature of work load in such areas.

8.3 Percentage share of expenditure and payments in such areas:

8.4 Assessment of having fulfilled a need which could not be met locally (on a scale of 0 to 10)

9 BRIEF TECHNICAL DESCRIPTION
9.1 Foundations, sub structure, superstructure.

9.2 Design life

9.3 Vehicular and foot traffic considerations
Design Traffic Flow (passenger car units etc)
Design Loads (axle loads etc)

9.4 Headroom provided for river traffic

9.5 Bridge Deck level
Foundation top level
High flood level
Annual flood level
Normal water level
Design Flood level

9.6 Special features

9.7 Method statement including technology and equipment used.

9.8 Provision for services (infrastructure)
10. **COSTS**

10.1 Budgetary Allocation.

10.2 Design costs:

10.3 Investigation costs

10.4 Supervision costs

10.5 Construction Cost (Total) -
   - Engineer's estimate -
   - Contract sum -
   - Actual (final) cost -

### BREAKDOWN OF CONSTRUCTION COSTS

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<tr>
<th>Category</th>
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<tbody>
<tr>
<td><strong>Preliminaries</strong></td>
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<td>Construction Management provision, if any:</td>
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<tr>
<td>Offices for the Engineer and Contractor:</td>
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<td>Services connections and consumption:</td>
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<td>Traffic Diversion and Temporary bridge erection:</td>
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<td>Traffic control:</td>
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<td>Demolition and Removal of existing bridge:</td>
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<td>Other preliminaries (specify)</td>
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<td><strong>Foundations</strong></td>
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<td>River diversion -</td>
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<td>Abutments, wing walls -</td>
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<tr>
<td>Piers -</td>
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<td><strong>Substructure</strong></td>
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<td>Abutments &amp; wing walls -</td>
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<td>Piers -</td>
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<tr>
<td><strong>Superstructure</strong></td>
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<tr>
<td>Structural works -</td>
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<td>Surfacing -</td>
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<td>Hand rails &amp; other miscellaneous items-</td>
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<td>Provision for service lines</td>
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<td><strong>Approaches</strong></td>
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10.6 **OTHER PROJECT COSTS**

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<td>Miscellaneous</td>
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10.7 **Major Item Costs** (with quantities and values)

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<td>Filling</td>
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<td>Steel</td>
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<tr>
<td>Bitumen</td>
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<tr>
<td>In-situ concrete</td>
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</table>

282
Steel in in-situ concrete
Pre-stressed concrete
   (a) Pre-tensioned units
   (b) Post-tensioned units
      High tensile steel
Concrete in pre-cast units

Construction site staff

11. TIME FRAME

<table>
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<th>Estimated</th>
<th>Actual</th>
<th>Reasons for delays and Remarks</th>
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11.1 Design
   Start date: 
   Finish date: 

11.2 Prequalification
   Invitation date
   Receipt date
   Evaluation date

11.3 Tender
   Invitations date
   Receipts date

11.4 Tender Evaluation and Award
   Start date - 
   Finish date - 

11.5 Construction
   Start date - 
   Finish date - 

12 VARIATIONS
12.1 Variations to Design Fees:
   Reasons:

12.2 Variations to Engineers Estimate
   Reasons:

12.3 Variations to Original contract sum:
12.3.1 Changed scope of work:
   Reasons:

12.3.2 Changed Quantities (where significant)
   Reasons:

283
12.3.3 Fluctuations allowed in prices

12.3.4 Claims

12.3.5 Total variation to original contract sum (add 12.3.1 + 12.3.2 + 12.3.3 + 12.3.4)

Main reasons for changes:

How could they have been avoided / minimised?

13 SCHEDULE OF BILLS CERTIFICATES AND PAYMENTS

<table>
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<th>Value Date</th>
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14 GENERAL COMMENTS BY KEY PARTICIPANTS

(Client, Design, Consultant, Engineer, Main Contractor)

14.1 Brief description of each other's roles, organisation structure, delays in decision making, availability of information, criticisms, comments and recommendations for improvement.

14.2 Special project features, successes, failures, problems, solutions and other lessons learnt)

15 In the opinion of key project participants were any INDICATORS (thumbrules/ guidelines) used to help (a) plan (b) monitor (c) control (d) evaluate the project. If not what indicators could have been used to draw on experience from similar projects.
### Table (1) Classification of Buildings

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<td>Dormitory type housing</td>
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<td>Recreational Bldgs (Community Centres)</td>
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<td>Tertiary Educational Bldgs. (Universities, Technical Colleges)</td>
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<td>Piles</td>
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<tr>
<td></td>
<td>R</td>
<td>Raft</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>Strip</td>
</tr>
<tr>
<td></td>
<td>V</td>
<td>Vierendhal</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level/Quality of Finishes</th>
<th>1 - Average</th>
<th>2 - High</th>
<th>3 - Luxury</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Brick paved cement rendered floor; plastered and painted walls; asbestos ceiling; timber doors and windows; tiles or asbestos; local sanitary fittings.</td>
<td>Concrete floor with terrazzo, tiles, or parquet; plastered and painted, tyrolean or textured walls; basic timber ceiling; tiles on asbestos or equivalent.</td>
<td>Concrete floor with terrazzo, tiles, parquet, granite or marble plastered plus special (textured) paints or timber panelled acoustic suspended ceiling or high grade timber ceiling, tiles on asbestos or profiled roof sheeting; imported sanitary fittings.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Slab of Cost</th>
<th>1</th>
<th>&gt; 50 million</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>15 – 50 million</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>5 – 15 million</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1 – 5 million</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>250,000 – 1 million</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Below 250,000</td>
<td></td>
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</tbody>
</table>

---

Classification of Buildings projects
### Categorisation of Road Projects for Analysis

1. **Broad (First Order) Classification**

<table>
<thead>
<tr>
<th>New/Rehab</th>
<th>Terrain</th>
<th>Base</th>
<th>Surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>New</td>
<td>Hilly</td>
<td>Metal</td>
</tr>
<tr>
<td>A2</td>
<td>New</td>
<td>Flat</td>
<td>&quot;</td>
</tr>
<tr>
<td>B1</td>
<td>New</td>
<td>Hilly</td>
<td>&quot;</td>
</tr>
<tr>
<td>B2</td>
<td>New</td>
<td>Flat</td>
<td>&quot;</td>
</tr>
<tr>
<td>C</td>
<td>Rehabilitation Either</td>
<td>PM,AC or BBB</td>
<td>AC</td>
</tr>
<tr>
<td>D</td>
<td>&quot;</td>
<td>Either</td>
<td>PM+DBM/WBM</td>
</tr>
<tr>
<td>E</td>
<td>&quot;</td>
<td>Either</td>
<td>Existing Sand/Slurry Seal</td>
</tr>
</tbody>
</table>

- **AC** - Asphalt Concrete
- **BBB** - Bitumen Bound Base
- **DBM** - Dry Bound Macadam
- **DBST** - Double Bituminous Surface Treatment
- **PM** - Penetration Macadam
- **SBST** - Single Bituminous Surface Treatment
- **WBM** - Water Bound Macadam

2. **Detailed (Rigorous) Classification**

Using 6 Character identification tags as follows:

#### 2.1 First Character - Number

To denote: degree of rehabilitation or whether new road ranging from: 1 to 9; for example:

- 1 represents minimal rehabilitation
- 5 represents average rehabilitation,
- 9 represents brand new road (on a new trace)
2.2 Second Character: Letter

To denote: Type of Road (from standard RDA classification i.e: A, B, C, D & E)

add: T - Township (internal) roads

2.3 Third Character: Number

to denote: nature of terrain

ranging from: 1 denoting flat

5 average i.e: undulating/rolling
to 9 denoting very mountainous/hilly

2.4 Fourth Character: Letter

to denote: type of base

A - Asphalt Concrete binder/base course
B - Bitumen Bound Base
D - Dry Bound Macadam
G - Gravel Base
P - Penetration Macadam
M - Metal/Existing
W - Water Bound Macadam

2.5 Fifth Character: Letter

to denote: type of surface

A - Asphalt concrete wearing course
B - Slurry Seal
C - Sand Seal (Coat)
D - Double Bituminous Surface Treatment
S - Single Bituminous Surface Treatment

2.6 Sixth Character

Number (0 to 9) to denote extent and intensity of work needed on services lines, (cables, pipe runs etc.) whether new or relocation.

EXAMPLE 589AAA would represent an average level rehabilitation on a B class trunk road on mountainous terrain using an asphalt concrete correction/regulating base course and an asphalt concrete surface; where no change is envisaged to existing services lines.
CLASSIFICATION SYSTEM USED FOR BRIDGES

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>1st Letter</th>
<th>2nd Letter</th>
<th>3rd Letter</th>
<th>4th Letter</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRITERION: WORK</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FOUNDATIONS</td>
<td>Super-structure</td>
<td>Span</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

N - New  C - Cylinder  C - Concrete  L - Long (>16.2m)
R - Rehab - E - Existing  G - Girder (Steel)  S - Short (≤16.2m)

P - Piles
S - Shallow  M - Mixed

Example: RECL indicates a Bridge Rehabilitation project using existing foundations and prestressed concrete beams of long span (above 16.2m)

Note: The 16.2m cut off for short/long spans was chosen because of the distinctive change of section in the standard prestressed concrete beams and the associated leap in cost/metre.

Furthermore, the beams of 16.2 m span and below are usually cast at yards and brought to site; whereas beams above 16.2 m span are usually cast at site.

Classification of Bridges projects
COST/PRICE INDEX FACTORS USED TO REDUCE COSTS/SQM (OR SF) FROM CURRENT YEAR TO CONSTANT (1990) PRICE LEVELS

1 Basis:

(i) Jan-Jun 1990 was taken as 100 for ease of familiarity.

(ii) The basis was the 'All-Construction Outputs' Cost Index from the Statistical Bulletins of the 'Statistics Unit of the Programming Division, Ministry of Housing and Construction - e.g: Vol 18 No.1

(iii) This was compared with the Central Bank 'Review of Economy 1988'. Page 99 confirmed these figures, except for the 1987 index number, which was 865 instead of 765. Since 765 appeared unrealistically low in any case, and led to an inexplicable leap to 943 in 1988, an average of 815 was assumed for 1987.

(iv) Though there was no change shown in the cost index from 1988 (942.39) to 1989 (943.25), this was not consistent with experience. Therefore the unweighted average for the 4 quarters of 1989 was taken; this being 975.87. This also moderated the sudden leap to 1081.42 in 1990.

(v) This led to a range, as follows from 54.77 in 1982 to 100.00 in the first half of 1990.

<table>
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<tr>
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<th></th>
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<th></th>
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<tbody>
<tr>
<td>Index</td>
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<td>58.90</td>
<td>66.04</td>
<td>70.06</td>
<td>70.35</td>
<td>75.41</td>
<td>87.14</td>
<td>90.24</td>
<td>100.00</td>
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</table>

(vi) Industry experience may indicate a higher escalation level in certain areas; and even overall.

In fact, taking 1984 as 100, while the All Construction Outputs Cost Index only proceeds to 151.42 in the first half of 1990. Some parallel indices progress over the same 6 years as follows:

(a) All-Housing output index to 177.39

(b) Other Construction work Index to only 138.81

(vii) The All-Construction Output index was recommended as the best presently available by the ILO Construction Economics expert Mrs. Hillebrandt after a comparison. It is used here for want of anything better, but would be replaced by the ICTAD Index in due course.

2. Comparisons & Comments

Comparisons, with real experience pertaining to price level escalations, were invited.
## PROPOSED REVISED FORMAT OF ELEMENTAL COST ANALYSIS
(Based on Elements whose cost variations are significant)

<table>
<thead>
<tr>
<th>TABLE II</th>
</tr>
</thead>
</table>

### 1.0 PRELIMINARIES

### 2.0 SUB-STRUCTURE
- 2.1 Excavation
- 2.2 Concrete
- 2.3 Rubble

### 3.0 GROUND FLOOR SLAB

### 4.0 SUPER-STRUCTURE
- 4.1 Columns
- 4.2 Beams
- 4.3 Upper Floor Slabs
- 4.4 Staircases
- 4.5 Other Concrete Items

### 5.0 WALLS
- 5.1 Structure (External)
- 5.2 Structure (internal)
- 5.3 Plastering
- 5.4 Painting

### 6.0 FLOOR FINISHES
- 6.1 Rendering
- 6.2 Paving/Tiling
- 6.3 Carpet/Other

### 7.0 ROOF
- 7.1 Frame
- 7.2 Covering
- 7.3 Plumbing

### 8.0 CEILING
- 8.1 Structure
- 8.2 Plastering
- 8.3 Painting

---

[Building Element analysis format used]

290
9.0 DOORS & WINDOWS
   9.1 Internal Door Frames
   9.2 Internal Door Sashes
   9.3 Window & External Frames
   9.4 Window & External Sashes
   9.5 Iron Mongery
   9.6 Finishes

10.0 PLUMBING
   10.1 Storage System (Sump, Pump & Tank)
   10.2 Water Distribution System
   10.3 Waste Disposal Systems
   10.4 Sanitary Fittings

11.0 ELECTRICAL
   11.1 Electrical Switch Gear
   11.2 Electrical Distribution System & Accessories
   11.3 Electrical Fittings

12.0 METAL WORK
   12.1 Grilles
   12.2 Metal hand-rails

13.0 SPECIAL SERVICES & FITTINGS
   13.1 Air Conditioning System
   13.2 Lifts
   13.3 Fire Protection System
   13.4 Others

14.0 OTHER ITEMS
   14.1 External Works
   14.2 Landscaping

NOTES
   I - The above elemental break-down could be related to a standard format (Eg. RICS) by combining appropriate sub-elements
      eg(a) 5.3 + 5.4 = Wall Finishes
      
      eg(b) Ground Floor Slab could be included in Sub-Structure by taking 3.0 as 2.4
## PRODUCTIVITY INDICATORS EXERCISE ON A TYPICAL BUILDING PROJECT

<table>
<thead>
<tr>
<th>VLN. NO.</th>
<th>VALUE OF WORK INCREMENT (Rs.)</th>
<th>PERIOD (DAYS)</th>
<th>SKLD. MAN-DAYS</th>
<th>UNSKLD. MAN-DAYS</th>
<th>TOTAL MAN-DAYS</th>
<th>VALUE/ MAN-DAY (Rs.)</th>
<th>SKLD./ UNSKLD. RATIO</th>
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<tbody>
<tr>
<td>1</td>
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<td>128</td>
<td>321</td>
<td>449</td>
<td>1,667</td>
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<td>295</td>
<td>532</td>
<td>827</td>
<td>650</td>
<td>0.55</td>
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<td>3</td>
<td>2,599,763</td>
<td>96</td>
<td>1700</td>
<td>1480</td>
<td>3180</td>
<td>818</td>
<td>1.15</td>
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<td>4</td>
<td>2,997,277</td>
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<td>1415</td>
<td>1112</td>
<td>2527</td>
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<tr>
<td>5</td>
<td>2,767,756</td>
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<td>1639</td>
<td>1400</td>
<td>3039</td>
<td>911</td>
<td>1.17</td>
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<tr>
<td>6</td>
<td>1,648,423</td>
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<td>1221</td>
<td>1078</td>
<td>2299</td>
<td>717</td>
<td>1.13</td>
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<tr>
<td>7</td>
<td>2,483,753</td>
<td>68</td>
<td>1608</td>
<td>1626</td>
<td>3234</td>
<td>768</td>
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<td>8</td>
<td>1,847,210</td>
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<td>1296</td>
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<td>9</td>
<td>2,801,434</td>
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<td>795</td>
<td>1011</td>
<td>1806</td>
<td>1,551</td>
<td>0.79</td>
</tr>
</tbody>
</table>

Average up to valuation 7 = 960
Average up to valuation 9 = 0.92

**NOTE:** VALUATION 9 SHOULD IN FACT BE LESS & VALUATION 8 MORE THEN INDICATED AS EXTRA WORKS GET LOADED IN LAST VALUATION.

**Notes:**

(a) The value of Work Increment in the given period was obtained by deducting the previously cumulative actual Work Done component excluding materials at site, retention and advance recovery deductions) from the present cumulative Actual Work Done component.

(b) The Rupee values are as at mid - 88

(c) The following additional comparative exercise was attempted to assess the labour component value achieved.

**Assumed:**

(a) Basic labour wages as Rs. 55 for unskilled and Rs. 105 for skilled workers in 1988/89.

(b) Skilled / unskilled ratio of 0.92

(c) 10% of work is on Saturday afternoon or Sundays, yielding 1 1/2 times rate.

(d) 2 Additional hours of work are done each day at 1 1/2 times (overtime rate)

(e) Employees' Provident & Trust Fund contributions total 15%
A labour sub-contractor's mark-up of 10% is superimposed

Then Average Cost of Man-day

\[ = (105 \times 0.48 + 55 \times 0.52) \times (0.9 + 0.1 \times 1.5) \times (1 + 0.25 \times 1.5) \times 1.15 \times 1.1 \]

ref: \( a \) \( b \) \( a \) \( b \) \( c \) \( d \) \( e \) \( f \)

\[ = \text{Rs. 144.28 (say Rs. 145/=)} \]

(i) Then average contribution of labour to total output value

\[ \frac{145}{960} = \frac{145}{960} = 15\% \]

(ii) If Head Office overheads and profits are assumed at 15% of total price:

Then average proportion of labour to total cost

\[ \frac{145}{85\% \text{ of 960}} = 17.8 \text{ or } 18\% \]

Note: This is only an example; and a more representative study is needed. Furthermore direct comparisons could be done of total materials, labour and plant costs.
Table (2) Indicators based on number of storeys and all projects

<table>
<thead>
<tr>
<th></th>
<th>Cost</th>
<th>Sub</th>
<th>Super</th>
<th>Finishes</th>
<th>Roof</th>
<th>D&amp;W</th>
<th>Plmbng.</th>
<th>Elect.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALL PROJECTS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>COUNT</td>
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<td>107</td>
<td>110</td>
<td>110</td>
<td>106</td>
<td>105</td>
<td>107</td>
<td>105</td>
</tr>
<tr>
<td>AVG</td>
<td>509.65</td>
<td>9.68</td>
<td>38.05</td>
<td>11.41</td>
<td>13.36</td>
<td>12.60</td>
<td>5.38</td>
<td>5.13</td>
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<tr>
<td>STD DEV</td>
<td>226.99</td>
<td>6.01</td>
<td>13.84</td>
<td>4.79</td>
<td>7.31</td>
<td>5.59</td>
<td>3.98</td>
<td>3.41</td>
</tr>
<tr>
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<td>0.45</td>
<td>0.62</td>
<td>0.36</td>
<td>0.42</td>
<td>0.55</td>
<td>0.44</td>
<td>0.74</td>
<td>0.66</td>
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<td>SINGLE STOREY</td>
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<td></td>
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</tr>
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<td>COUNT</td>
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<td>34</td>
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<tr>
<td>AVG</td>
<td>461.55</td>
<td>10.92</td>
<td>28.49</td>
<td>11.17</td>
<td>18.34</td>
<td>14.19</td>
<td>4.36</td>
<td>5.44</td>
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<td>231.15</td>
<td>5.12</td>
<td>9.81</td>
<td>4.68</td>
<td>8.15</td>
<td>7.11</td>
<td>3.62</td>
<td>4.17</td>
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<tr>
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<td>47.17</td>
<td>6.68</td>
<td>3.55</td>
<td>7.10</td>
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<td>1.58</td>
<td>64.81</td>
<td>12.70</td>
<td>3.09</td>
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Sample Tables of Indicators from further analysis of Building data

294
### Table (3) Indicators based on primary functions

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| **DORMITORY** |      |     |       |        |      |            |        |
| Count    | 16   | 16  | 16    | 16     | 16   | 16         | 16     |
| Std Dev  | 85.91 | 5.11 | 9.37  | 3.29   | 6.07 | 2.54       | 4.41   | 1.27  |
| Co. Of Var | 0.19 | 0.15 | 0.30  | 0.27   | 0.37 | 0.19       | 0.72   | 0.23  |

| **MEDICAL** |      |     |       |        |      |            |        |
| Count    | 6    | 7   | 13    | 13     | 7    | 7          | 8      |
| Avg      | 564.83 | 11.58 | 26.16 | 10.49  | 17.65 | 13.56      | 4.61   | 4.25  |
| Std Dev  | 303.29 | 5.11 | 13.01 | 6.56   | 5.72 | 9.21       | 2.78   | 1.60  |
| Co. Of Var | 0.54 | 0.44 | 0.50  | 0.63   | 0.32 | 0.68       | 0.60   | 0.38  |

| **OFFICES** |      |     |       |        |      |            |        |
| Count    | 26   | 27  | 16    | 16     | 27   | 26         | 23     |
| Avg      | 568.54 | 11.00 | 41.07 | 9.02   | 11.73 | 10.64      | 3.81   | 4.81  |
| Std Dev  | 203.59 | 8.27 | 11.87 | 3.66   | 6.94 | 5.23       | 2.29   | 1.57  |
| Co. Of Var | 0.36 | 0.75 | 0.29  | 0.41   | 0.59 | 0.49       | 0.60   | 0.33  |

| **SCHOOLS** |      |     |       |        |      |            |        |
| Count    | 7    | 8   | 14    | 14     | 8    | 8          | 7      |
| Avg      | 389.43 | 7.35 | 43.28 | 8.34   | 11.88 | 9.45       | 2.18   | 1.61  |
| Std Dev  | 148.14 | 4.83 | 21.91 | 4.25   | 5.27 | 3.67       | 1.26   | 1.82  |
| Co. Of Var | 0.38 | 0.66 | 0.51  | 0.51   | 0.44 | 0.39       | 0.58   | 1.13  |

| **TERTIARY** |      |     |       |        |      |            |        |
| Count    | 9    | 11  | 15    | 15     | 11   | 11         | 12     |
| Avg      | 678.33 | 6.46 | 39.68 | 10.11  | 14.08 | 12.19      | 5.12   | 8.48  |
| Std Dev  | 351.90 | 5.03 | 18.17 | 5.54   | 6.21 | 5.96       | 2.94   | 7.40  |
| Co. Of Var | 0.52 | 0.78 | 0.46  | 0.55   | 0.44 | 0.49       | 0.58   | 0.87  |

| **IND. HOUSES** |      |     |       |        |      |            |        |
| Count    | 13   | 14  | 15    | 15     | 14   | 14         | 14     |
| Std Dev  | 246.01 | 4.36 | 13.70 | 6.45   | 4.73 | 6.34       | 5.79   | 2.20  |
| Co. Of Var | 0.45 | 0.55 | 0.48  | 0.45   | 0.40 | 0.43       | 0.62   | 0.45  |

| **WARE HOUSES** |      |     |       |        |      |            |        |
| Count    | 6    | 8   | 14    | 14     | 8    | 8          | 8      |
| Avg      | 341.33 | 14.00 | 23.47 | 10.18  | 22.85 | 10.03      | 3.84   | 4.16  |
| Std Dev  | 138.14 | 6.20 | 14.10 | 5.81   | 10.16 | 4.58       | 3.44   | 2.37  |
| Co. Of Var | 0.40 | 0.44 | 0.60  | 0.57   | 0.44 | 0.46       | 0.90   | 0.57  |
Table (4) Indicators based on types of foundations

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Sample bar charts illustrating further analysis of building data
Graph – 3 Variation of Indicators with Storeyes

Graph – 4 Variation of components with Storeyes
Graph – 7 Variation of Indicators with Finishes

Graph – 8 Variation of components with Finishes
WORKSHOP ON CONSTRUCTION INDUSTRY INDICATORS

IESL/ICTAD/ILO = 9th October 90 at
IESL, Colombo

AGENDA
************

1. INTRODUCTORY SESSION
(8.15 a.m. to 9.45 a.m.)

Chairman - Mr. E.I. Munaasinha - Director General, ICTAD

08.15 a.m. - Registration & Inauguration

08.30 a.m. - Opening Address - President, IESL

08.35 a.m. - Welcome Address - Mr. A. Majszyk, Chief Technical Advisor, ILO.

08.40 a.m. - Science and Technology Indicators - Mr. M.A.T. de Silva, Deputy Director General, NARESA

08.50 a.m. - 'The current Construction Industry Indicators Investigation Project' - Mr. Clement Liyanarachchy - D.D (Technology Development) ICTAD

08.55 a.m. - Status Summary of the Construction Industry Indicators Investigation Project
Objectives of the Workshop
Outline of proposed Workshop activities

- Mohan M. Kumaraswamy - Team Leader
  Construction Industry Indicators Project, IESL

09.25 a.m. - Discussion

2. GROUP SESSION
(9.45 a.m. to 12.30 p.m.)

conducted within sectoral groups; say in Buildings (2), Roads (2) and Bridges (1)

09.45 a.m. Appraisal of data collection and analysis summary to date

Agenda at Workshop on 9th October 1990

303
10.15 a.m - Tea

10.30 a.m - Comparisons with Group experiences and alternatives

11.15 a.m - Proposals for new approaches
- Suggestions for other useful Indicators

12.00 p.m - Preparation for Presentation

12.30 p.m - LUNCH at IESL

GROUP PRESENTATIONS
(1.30 p.m. to 4.15 p.m.)

Chairman - Mr. Mohan M. KumaraSamy - Project Team Leader

Panel - Project Review Panel Members and Special Invitees

01.30 p.m - Group Presentations (15 minutes each)

02.15 p.m - Discussion

02.45 p.m - Tea

03.00 p.m - Group Presentations

03.30 p.m - Discussion

04.00 p.m - Vote of Thanks - Mr. D.L.O. Mendis, Chairman, SSG on S & T Indicators, IESL and Past President, IESL
Photographs taken at Workshop on 9th October 1990
Photographs taken at Workshop on 9th October 1990
# Programme

**Seminar on 'Benefits from Construction Project & Industry Indicators'**

21st November 1990 - Sawsiripaya Auditorium, Colombo 7.

**Chairman:** Mr E I Munasingha - Director General ICTAD

## Introductory Session on Indicators

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Programme at Seminar on 21st November 1990
2 CONSTRUCTION INDUSTRY INDICATORS PROJECT PRESENTATION SESSION

09.00 - INDICATORS AND THE 1990 IESL/ICTAD/ILo INVESTIGATION PROJECT - Project Team Leader - Mr Mohan M Kumaraswamy

09.20 - ELEMENTAL COST INDICATORS IN BUILDING DESIGN EVALUATION - Project Team Member, Mr M P R Emmanuel

09.40 - HIGHLIGHTS FROM INVESTIGATIONS INTO ROADS & BRIDGES INDICATORS - Project Team Member Mr V R Daluwatte

10.00 - TEA

3 SPECIAL SESSION ON PARTICULAR BENEFITS

10.15 - DISCUSSION - On Output from the Construction Industry Indicators Investigation Project

10.30 - AN IN DEPTH ANALYSIS OF BUILDING ELEMENT INDICATORS - Mr A Raviskanthan

10.55 - DEVELOPING SUITABLE CONSTRUCTION INDICATORS FOR WATER SUPPLY PROJECTS - Mrs G Karunaratne

11.20 - COST, PRODUCTIVITY & OTHER INDICATORS IN BRICKWORK - Mr W V K M Abeysekera

11.45 - DESIGN DECISIONS AND LIFE CYCLE COST INDICATORS - Dr A A D A J Perera

12.25 - FURTHER INVESTIGATIONS INTO INDICATORS - Chairman Specialist Study Group on Science and Technology Indicators and Past President IESL - Mr D L O Mendis

12.30 - DISCUSSION

13.00 - GENERAL CONCLUSIONS - Project Team Leader, Mr Mohan M Kumaraswamy

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Photographs taken at Seminar on 21st November 1990
APPENDIX AP6-7

Typical financial Progress S curve
Financial progress analysed by building elements

APPENDIX AP6-8
Comparing financial progress with work force as a productivity Indicator
### Table A-2 Building Element Indicators for all Projects and Number of Storeys

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QUESTIONNAIRE/GENERAL DATA SHEET GDI (FOR ORGANISATIONS)
FOR TESL/ICTAD/ ILO CONSTRUCTION INDUSTRY INDICATORS PROJECT

SHEET...... OF ......... FILLED ON...... WITH.................... BY ......................
ORGANISATION: .................................................................

1. GENERAL ORGANISATION STRUCTURE (Use annexes)
   1.1 AT HEAD OFFICE
   1.2 AT SITES

2. GENERAL COMMUNICATION CHANNELS
   (eg: Formal/ informal)

3. GENERAL CHARACTER OF ORGANISATION:
   (eg. Centralised/ Decentralised: Authoritarian/ Teamwork Oriented)

4. SPECIAL ORGANISATION STRUCTURES & COMMUNICATION CHANNELS
   FOR SPECIFIC PROJECTS (past, present & recommended)

5. PLANNING TECHNIQUES USED, ( & THAT SHOULD BE USED)
   (eg. Barcharts, Networks, Method Statements).

6. PROGRESS MONITORING TECHNIQUES USED ( & THAT SHOULD USED)

7. QUALITY CONTROL TECHNIQUES USED (& THAT SHOULD BE USED)

8. POST - PROJECT EVALUATION IF ANY.
   IF NOT WHAT WOULD BE USEFUL?

9. WHAT ARE THE MAIN PROBLEMS ENCOUNTERED ON TYPICAL
   PROJECTS?
   WHAT POSSIBLE SOLUTIONS HAVE NOT YET BEEN TRIED OUT?

10 WHAT HAVE BEEN THE MAIN REASONS FOR SUCCESS ON TYPICAL
    PROJECTS?
    HOW CAN THESE BE REPRODUCED AND ENHANCED?
11 ANY PARTICULAR INDICATORS, (INDICES, GUIDELINES / THUMBRULES) BY WHICH PROJECT SUCCESS OR FAILURE IS (OR COULD BE) ESTIMATED?

11.1 QUANTITATIVE MEASURES

11.2 QUALITATIVE MEASURES

12 ANY SUCH INDICATORS USED (OR THAT SHOULD BE USED) FOR PROJECT FEASIBILITY STUDIES, PLANNING, MONITORING AND/OR CONTROL

13 IS THERE ANY FEEDBACK FROM LESSONS LEARNT FROM PAST PROJECTS WHEN UNDERTAKING PLANNING OR FEASIBILITY STUDIES FOR NEW PROJECTS?

13.1 IF SO, HOW IS THIS CONVEYED?

13.2 IF NOT, HOW COULD THIS BE BEST DONE?

This pilot model is designed for use in the buildings sub-sector, to help develop:

(a) a set of project specific questionnaires to assist in modelling a project profile;
(b) a Basic Project Framework of category specific performance criteria and related indicators; and
(c) a Project Evaluation Framework of selected criteria and indicators with project specific target values.

Please press F3 when you are ready to commence the session

ATTRIBUTE The building
AND The project stage
AND The evaluation purpose

1. Project Evaluation Framework is formulated

RULE for Project Evaluation Framework
IF Basic Project Framework is formulated
AND Project conditions are identified
AND Project priorities are identified
AND Evaluator has adjusted all
THEN Project Evaluation Framework is formulated
AND DISPLAY Conclusion
AND PRINT Conclusion
ELSE DISPLAY Alternative 2
AND PRINT Alternative 2

RULE for Basic Project Framework
IF Building category is identified
AND Project stage is identified
AND Evaluation purpose is identified
THEN Basic Project Framework is formulated
AND DISPLAY Integrate Circles
AND PRINT Integrate Circles
ELSE DISPLAY Alternative 1
AND PRINT Alternative 1

RULE for Apartment block
IF The building: IS an Apartment block
THEN Building category is identified
AND DISPLAY Chain Questionnaires
AND DISPLAY Chain Circle II

RULE for Shopping complex
IF The building: IS a Shopping complex
THEN Building category is identified
AND DISPLAY Chain Questionnaires
AND DISPLAY Chain Circle II

Pilot Expert System Programme text
RULE for Dormitory type housing
IF The building: IS Dormitory type housing
THEN Building category is identified
AND DISPLAY Chain Questionnaires
AND DISPLAY Chain Circle II

RULE for Housing complex
IF The building: IS a Housing complex
THEN Building category is identified
AND DISPLAY Chain Questionnaires
AND DISPLAY Chain Circle II

RULE for Medical buildings
IF The building: IS a Medical building
THEN Building category is identified
AND DISPLAY Chain Questionnaires
AND DISPLAY Chain Circle II

RULE for Office buildings
IF The building: IS a Office building
THEN Building category is identified
AND DISPLAY Chain Questionnaires
AND DISPLAY Chain Circle II

RULE for Recreational buildings
IF The building: IS a Recreational building
THEN Building category is identified
AND DISPLAY Chain Questionnaires
AND DISPLAY Chain Circle II

RULE for Tertiary educational buildings
IF The building: IS a Tertiary educational building
THEN Building category is identified
AND DISPLAY Chain Questionnaires
AND DISPLAY Chain Circle II

RULE for Housing units
IF The building: IS a Housing unit
THEN Building category is identified
AND DISPLAY Chain Questionnaires
AND DISPLAY Chain Circle II

RULE for Warehouses or Stores
IF The building: IS a Warehouse or Store
THEN Building category is identified
AND DISPLAY Chain Questionnaires
AND DISPLAY Chain Circle II

RULE for project complete
IF The project stage: IS complete
THEN Project stage is identified
AND DISPLAY Chain Circle III

RULE for construction ongoing; design complete
IF The project stage: IS construction ongoing; design complete
THEN Project stage is identified
AND DISPLAY Chain Circle III
RULE for construction ongoing; design ongoing
IF The project stage: IS construction ongoing;:
    design ongoing
THEN Project stage is identified
AND DISPLAY Chain Circle III

RULE for construction not started; design complete
IF The project stage: IS construction not started;:
    design complete
THEN Project stage is identified
AND DISPLAY Chain Circle III

RULE for construction not started; design ongoing
IF The project stage: IS construction not started;:
    design ongoing
THEN Project stage is identified
AND DISPLAY Chain Circle III

RULE for neither design nor construction commissioned
IF The project stage: IS neither design nor construction:
    commissioned
THEN Project stage is identified
AND DISPLAY Chain Circle III

RULE for client evaluating effectiveness
IF the evaluation purpose: IS for client to assess:
    management effectiveness
THEN Evaluation purpose is identified
AND DISPLAY Chain Circle IV

RULE for client evaluating effectiveness & efficiency
IF the evaluation purpose: IS for client to assess:
    management effectiveness & efficiency
THEN Evaluation purpose is identified
AND DISPLAY Chain Circle IV

RULE for contractor evaluating effectiveness
IF the evaluation purpose: IS for contractor to assess:
    effectiveness
THEN Evaluation purpose is identified
AND DISPLAY Chain Circle IV

RULE for contractor evaluating effectiveness & efficiency
IF the evaluation purpose: IS for contractor to assess:
    effectiveness & efficiency
THEN Evaluation purpose is identified
AND DISPLAY Chain Circle IV
RULE for Project conditions
IF Type of contract is identified
AND Type of client is identified
AND Type of project manager is identified
AND Type of designer is identified
AND Type of constructor is identified
AND Project complexity is identified
AND Type of technology is identified
AND Number of storeys is identified
AND Foundation type is identified
AND Standard of finishes is identified
AND Value range is identified
AND Location is identified
THEN Project conditions are identified
AND DISPLAY Project conditions
AND PRINT Project conditions

RULE for single storey
IF The number of storeys: IS 1 ie single
THEN Number of storeys is identified

RULE for 2 to 3 storeys
IF The number of storeys: IS 2 to 3
THEN Number of storeys is identified

RULE for 4 to 8 storeys
IF The number of storeys: IS 4 to 8
THEN Number of storeys is identified

RULE for above 8 storeys
IF The number of storeys: IS above 8
THEN Number of storeys is identified

RULE for column bases
IF The foundations: ARE column bases or pads
THEN Foundation type is identified

RULE for inverted tee beam
IF The foundations: ARE inverted tee beams
THEN Foundation type is identified

RULE for masonry
IF The foundations: ARE rubble masonry
THEN Foundation type is identified

RULE for piles
IF The foundations: ARE piles
THEN Foundation type is identified

RULE for raft foundation
IF The foundations: ARE a raft
THEN Foundation type is identified

RULE for strip foundations
IF The foundations: ARE strip footings
THEN Foundation type is identified

RULE for vierendhal type foundations
IF The foundations: ARE vierendhal type
THEN Foundation type is identified
RULE for finishes level 1
IF The finishes: ARE level 1 ie average as in AP5_4 of Thesis
THEN Standard of finishes is identified

RULE for finishes level 2
IF The finishes: ARE level 2 ie high as in AP5_4 of Thesis
THEN Standard of finishes is identified

RULE for finishes level 3
IF The finishes: ARE level 3 ie luxury as in AP5_4 of Thesis
THEN Standard of finishes is identified

RULE for values above Rs. 50 m.
IF The project value: IS above Rs. 50 m.
THEN Value range is identified

RULE for values between Rs. 15 to 50 m.
IF The project value: IS between Rs. 15 to 50 m.
THEN Value range is identified

RULE for values between Rs. 5 to 15 m.
IF The project value: IS between Rs. 5 to 15 m.
THEN Value range is identified

RULE for values between Rs 1 to 5 m.
IF The project value: IS between Rs. 1 to 5 m.
THEN Value range is identified

DISPLAY Chain Questionnaires
This statement will be replaced by a chain command which would connect another database of questionnaire segments & integrate the specific segment designed for this particular building category, with the core general questionnaire.

When you are ready to continue, please press F2

DISPLAY Chain Circle II
This statement will be replaced by a chain command linking the database containing Circle II modules as in Figure 7-B, & selecting the appropriate module of criteria, indicators and general target values designed for this particular building category; & also linking the related tools module from Circle V.

When you are ready to continue, please press F2

DISPLAY Chain Circle III
This statement will be replaced by a chain command linking the database containing Circle III modules as in Figure 7-B, & selecting the appropriate module of criteria and indicators designed for this particular building category; & also linking the related tools module from Circle V.

When you are ready to continue, please press F2
DISPLAY Chain Circle IV
This statement will be replaced by a chain command linking
the database containing Circle IV modules as in Figure 7-B,
& selecting the appropriate module of criteria and indicators
designed for this particular building category; & also linking
the related tools module from Circle V.

When you are ready to continue, please press F2

DISPLAY Integrate Circles
This statement will be replaced by a chain command linking
a knowledge base that helps the evaluator to appropriately
integrate the three database modules of criteria, indicators
& target values as selected from the Circles II,III and IV,
and also the three corresponding database modules of related
tools from Circle V in Figure 7-B. The knowledge base will
suggest deletions, additions and adjustments, as well as
test the evaluator's own inputs for compatibility, consist-
tency and redundancies.

When you are ready to continue, please press F2

DISPLAY Conclusion
The suggested Project Evaluation Framework incorporates
relevant criteria, indicators & target values as adjusted
to suit this particular project

If you wish to see a summary of the stages of this
evaluation please press F2

TEXT Type of contract is identified
At this point the system will be developed,
to ask you to categorise
THE TYPE OF CONTRACT as one of the seven types des-
cribed in the database.
Please enter "TRUE" to signify your choice has been
made in this instance.

TEXT Type of client is identified
At this point the system will be developed,
to ask you to categorise
THE TYPE OF CLIENT as one of the four types
described in the database.
Please enter "TRUE" to signify your choice has been
made in this instance.

TEXT Type of project manager is identified
At this point the system will be developed,
to ask you to categorise
THE TYPE OF PROJECT MANAGER as one of the six types
described in the database.
Please enter "TRUE" to signify your choice has been
made in this instance.
TEXT Type of designer is identified
At this point the system will be developed,
to ask you to categorise
THE TYPE OF DESIGNER as one of the five types des-
cribed in the database.
Please enter "TRUE" to signify your choice has been
made in this instance.

TEXT Type of constructor is identified
At this point the system will be developed,
to ask you to categorise
THE TYPE OF CONSTRUCTOR as one of the five types
described in the database.
Please enter "TRUE" to signify your choice has been
made in this instance.

TEXT Project complexity is identified
At this point the system will be developed,
to ask you to categorise
THE PROJECT COMPLEXITY on a scale from 1 to 10
for this type of project.
Please enter "TRUE" to signify your choice has been
made in this instance.

TEXT Type of technology is identified
At this point the system will be developed,
to ask you to categorise
THE TYPE OF TECHNOLOGY as one of the five types des-
cribed in the database for these circumstances.
Please enter "TRUE" to signify your choice has been
made in this instance.

TEXT Location is identified
At this point the system will be developed,
to ask you to categorise
THE BUILDING LOCATION as one of the nine regions
described in the database.
Please enter 'TRUE" to signify your choice has been
made in this instance.

TEXT Project priorities are identified
Please enter "TRUE" if the project priorities have
been weighted.

If you need clarification of this stage press F5.

EXPAND Project priorities are identified
The relative priorities of all identified criteria
and sub-criteria are assessed at this stage of the
evaluation by chaining the Priority Weighting sub-
��统 which transforms and integrates the pairwise
comparisons of criteria by relevant participants,
into a set of weights reflecting the relative im-
portance of each criterion on this project. This
priority profile and other project conditions will
adjust the target values of chosen performance in-
dicators as in Figure 4 - B of the Thesis.
PLEASE PRESS F8 to CONTINUE.
TEXT Evaluator has adjusted all
The evaluator is given the opportunity to change the criteria, indicators & their target values. The system will re-adjust after pointing out any inconsistencies and redundancies.

Please enter "TRUE" if this facility has been used, or knowingly by-passed (default values accepted)

DISPLAY Project conditions
The foregoing project conditions, with the project priorities to be identified in the next stage, would model the project profile & adjust the target values of the chosen indicators.

Please press F2 to continue.

DISPLAY Alternative 1
The information is inadequate for complete advice. However if satisfied with approximate advice, select an approximate answer to the last query when you re-run the system.

Please press F3 to re-run

DISPLAY Alternative 2
The information is inadequate for complete advice. However if satisfied with approximate advice, select an approximate answer to the last query when you re-run the system.

Please press F3 to re-run
or press F2 to see interim conclusions.

END

This pilot model is designed for use in the buildings sub-sector, to help develop:

(a) a set of project specific questionnaires to assist in modelling a project profile;
(b) a Basic Project Framework of category specific performance criteria and related indicators; and
(c) a Project Evaluation Framework of selected criteria and indicators with project specific target values.

Please press F3 when you are ready to commence the session.

On pressing F3, a menu asks to
'Select what describes:
The building:
an Apartment block
a Shopping complex
etc'.

On selecting 'a shopping complex':

This statement will be replaced by a chain command which would connect another database of questionnaire segments & integrate the specific segment designed for this particular building category, with the core general questionnaire.

When you are ready to continue, please press F2.

On pressing F2:

This statement will be replaced by a chain command which would connect another database of questionnaire segments & integrate the specific segment designed for this particular building category, with the core general questionnaire.

When you are ready to continue, please press F2.
On pressing F2 again:

This statement will be replaced by a chain command linking the database containing Circle II modules as in Figure 7-B, & selecting the appropriate module of criteria, indicators and general target values designed for this particular building category; & also linking the related tools module from Circle V.

When you are ready to continue, please press F2

On pressing F2; a menu asks to:

'Select what describes:
The project stage:
  Complete
  Construction ongoing; design complete, etc'.

On selecting 'complete':

This statement will be replaced by a chain command linking the database containing Circle III modules as in Figure 7-B, & selecting the appropriate module of criteria and indicators designed for this particular building category; & also linking the related tools module from Circle V.

When you are ready to continue, please press F2

On pressing F2 a menu asks to:

'Select what describes:
the evaluation purpose:
  for client to assess management effectiveness
  for client to assess management effectiveness & efficiency
  for contractor,...
  etc'.

* On Selecting ' for client to assess management effectiveness':

This statement will be replaced by a chain command linking the database containing Circle IV modules as in Figure 7-B, & selecting the appropriate module of criteria and indicators designed for this particular building category; & also linking the related tools module from Circle V.

When you are ready to continue, please press F2
On pressing F2:

This statement will be replaced by a chain command linking a knowledge base that helps the evaluator to appropriately integrate the three database modules of criteria, indicators & target values as selected from the Circles II, III and IV, and also the three corresponding database modules of related tools from Circle V in Figure 7-B. The knowledge base will suggest deletions, additions and adjustments, as well as test the evaluator's own inputs for compatibility, consistency and redundancies.

When you are ready to continue, please press F2

On pressing F2 again:

At this stage, queries are made as to:

(a) TYPE OF CONTRACT
(b) TYPE OF CLIENT
(c) TYPE OF PROJECT MANAGER
(d) TYPE OF DESIGNER
(e) TYPE OF CONSTRUCTOR
(f) THE PROJECT COMPLEXITY
(g) TYPE OF TECHNOLOGY

Having confirmed the above, selection is requested from menus displayed for:

(h) number of storeys
(i) the foundations (type)
(j) finishes level
(k) project value
(l) building location

** Once the foregoing are identified:

The foregoing project conditions, with the project priorities to be identified in the next stage, would model the project profile & adjust the target values of the chosen indicators.

Please press F2 to continue.

On pressing F2, the system asks if project priorities have been weighted. If clarification is needed, an option key explains what is needed here.

*** On confirmation:

The system next queries if the evaluator has used or knowingly by-passed the facility to over-ride the criteria, indicators or target values suggested by the system. On confirmation the following message appears

The suggested Project Evaluation Framework incorporates relevant criteria, indicators & target values as adjusted to suit this particular project

If you wish to see a summary of the stages of this evaluation please press F2
The summary lists all interim and final conclusions from 'Building category is identified' to 'Project Evaluation Framework is formulated'.

In the case of the developed system, it would list the selected criteria, indicators and target values in the form of the Project Evaluation Framework.

**ALTERNATIVE * **
Alternatively, for example, if the user responds at stage * that the evaluation purpose is 'unknown', then the following message appears:

The information is inadequate for complete advice. However if satisfied with approximate advice, select an approximate answer to the last query when you re-run the system.

Please press F3 to re-run.

**ALTERNATIVE **
If the user responds at stage ** in the foregoing, for example that the location is not identified, then the following message appears:

The information is inadequate for complete advice. However if satisfied with approximate advice, select an approximate answer to the last query when you re-run the system.

Please press F3 to re-run or press F2 to see interim conclusions.

If F2 is pressed for interim conclusions, the Basic Project Framework is suggested, being a set of typical criteria and Indicators for that category of project and in the specified circumstances.

**ALTERNATIVE ***
Alternatively, for example, at stage *** in the foregoing, if the user responds that project priorities have not been identified, then the following message appears:

The information is inadequate for complete advice. However if satisfied with approximate advice, select an approximate answer to the last query when you re-run the system.

Please press F3 to re-run or press F2 to see interim conclusions.

If F2 is pressed for interim conclusions, the Basic Project Framework is suggested, being a set of typical criteria and Indicators for that category of project and in the specified circumstances.