MULTIOBJECTIVE EVALUATION OF CONSTRUCTION METHODS ALTERNATIVES

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ABSTRACT

MULTIOBJECTIVE EVALUATION OF CONSTRUCTION METHODS ALTERNATIVES

Multiobjective evaluation methods are used to analyse alternative construction methods in order to select the construction method which is most appropriate given available resources to achieve or partially achieve technical, economic and social objectives.

A hypothetical project using four alternative methods of construction is evaluated with respect to nine objectives to test whether weighting methods, attribute rating methods and final evaluation procedures are practical for application to choice of construction methods.

The direct weight assessment methods tested are those using ranking and rating weighting. The attribute rating methods tested are use of maximum and minimum values of an objective, anchoring of one extreme objective value and anchoring of two extreme objective values. The final evaluation procedures tested are; weighted summation, weighted summation with elimination and weighted summation with pre-evaluation weights and performance weights.

The results of this work indicate that the use of the multiobjective evaluation procedure with the following steps is practical. The objectives set must have clear definitions and measurement scales. Relative value weights are derived using the ranking procedure.

Comparison of the alternative construction methods is made by analysing the methods to estimate their achievement with respect to the decision objectives. Maximum and minimum values of an objective are used to transform the objectives' achievement scores into attribute ratings. Weighted summation with pre-evaluation weights and objectives' performance weights is used to select the best method.

The evaluation method is appropriate for general application over a range of project conditions to select the construction method that achieves or partially achieves the technical, social and economic goals.

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CHAPTER 1

INTRODUCTION

1.1 THE PROBLEM

Lack of adequate infrastructure development and maintenance is a major constraint on most economic activities required to overcome many problems of development. This means that construction services required to provide the infrastructure play a very important part in any development process.

Due to the desire to bring about fast national development, most developing countries have already made considerable progress in providing the infrastructure. However, in most cases, the construction industry has been operating in a framework transferred from the industrialised Countries. The transferred construction technology has not taken into account the technical and socio-economic conditions of the countries to which it is transferred. In some instances, it has been felt that the construction industry did not effectively utilise resources, particularly the abundant and relatively cheap labour resource. This is evidenced by problems and difficulties in construction implementation. Consequently ways and means have to be considered to overcome these problems and get maximum benefits from the available resources and enable the construction services to serve more of the development needs.

1.1.1 Construction Methods

The development of alternative feasible construction methods represent a significant potential for a better use of the resources in the construction industry. Construction technology is flexible in that different construction methods can be used to produce the given output. Different combinations of resources can be used to define the construction methods, e.g. capital intensive, labour intensive etc. Consequently, investigation of the wide range of construction methods is needed to determine feasible methods. In particular the use of more labour based methods (given the abundant labour resource and scarcity of capital) is considered a more appropriate and effective utilisation of resources in many instances. A great deal of work has been done in the development of viable labour based and intermediate construction methods based on technical and price comparisons.

1.1.2 Development Needs - Multiple Objectives

Previously, ideas of technical change in developing countries have involved the introduction of new "superior" systems and organisations to replace "ineffective" existing ones. The technical changes were based on engineering efficiency (defined mainly from the point of view of industrialised countries) without considering the socio-economic factors unique to the developing countries. Recently most development agencies have come to view development, especially rural development, as a process whereby the total (rural) system is to be taken into account. This is achieved by understanding the nature of the (rural) development problems, existing social technical structures and the beneficiaries of the development.

Sustained development and growth (the major development goal) can only emanate from local development. In the investigation of viable construction methods, it becomes necessary to take into account that the need for appropriate construction methods is brought about by the overall development need. All development activities (including construction projects) should relate to appropriate development objectives to enable sustainable development and growth. Typically construction projects take up a high percentage of development expenditure which could be used for both technical efficiency and for improvements in social and economic welfare. The construction project is therefore in itself multiobjective and the development of the construction methods should be oriented to multiple objectives.

Examples of objectives include; minimisation of cost, generation of employment, development of human resources through training, less dependence on foreign imports and a more equitable distribution of income.

The use of multiple objectives requires a stronger capacity to evaluate and select from a range of feasible alternative construction methods. It is also desirable to adopt a rational framework for the process of selecting the best method to be used after a comparative analysis of the construction methods options.

1.2 THE AIM OF THE WORK

This work concentrates on the multiobjective aspect of the development and choice of construction methods. In particular road construction methods are considered. Due to scarcity of resources, decisions to commit resources to a project require feasibility studies and economic evaluations to be done prior to decisions being made. Consequently consistent project evaluation methods have been developed to assist choice between many proposed schemes. This work will aim to validate available methods of project evaluation as suitable and effective decision making methods for the construction industry and in particular for the choice of construction methods.

1.3 OUTLINE OF THE WORK

1.3.1

The first part of this work (Chapter3) develops the conceptual framework for evaluation. The conceptual framework gives an understanding of the basic components that describe construction technology, what needs to be evaluated and what can be evaluated. The following are some of the considerations that make a conceptual evaluation framework necessary.

1 The multiple objectives being considered may sometimes be in conflict, e.g. minimisation of cost may conflict with maximisation of employment.

2 The scarcity of resources may also limit the objectives that might be considered.

3 The accuracy and reliability of any data input necessary for an evaluation must be defined. The development of a conceptual evaluation framework is necessary to help determine the suitability of potential evaluation methods.

1.3.2

The significance of the application of potential evaluation methods is considered in detail after the development of the evaluation concept.

The possibilities of using the evaluation methods and difficulties that may be encountered in implementing such methods are investigated in Chapters 4 & 5.

1.3.3

From the review of evaluation methods, an evaluation procedure is proposed in Chapter 6.

1.3.4

Finally using data from a real project situation, a hypothetical project has been developed. The hypothetical project is used to illustrate the proposed evaluation procedure and to test it. (Chapters 8 & 9). Conclusions are drawn about the validity of the evaluation methods as decision making methods for the choice of construction methods.

CHAPTER 2

LITERATURE REVIEW - TECHNOLOGY CHOICE

2.1 GENERAL

The importance of technology choice in Developing Countries (DCs) is a subject that has received a great deal of interest in recent years due to problems and difficulties of construction encountered. Subsequently a substantial amount of work on the subject has been done and is thus a subject of considerable literature.

Due to the desire to bring about development as quickly as possible, the construction sector in DCs have had to operate in a transferred framework from industrialised countries. This has led to many constraints and a hold back in the development of the domestic sector. Thus the search for successful construction technology, imported, adapted or developed, given the wide range of technologies available has received considerable attention. International Development Agencies like the ILO, IBRD and the World Bank plus both academic and engineering concerns have all contributed to the study of the problem of technology choice. Some of the work done in this field is briefly reviewed below. From this review, an indication of where this work fits in will be described.

2.2 THE NEED FOR CHANGE

Basically to apply a technology which is appropriate for a particular project given its requirements, conditions and circumstances is an undisputed engineering principle. In the industrialised countries (ICs) the technology choice is one of choosing from among a set of feasible alternatives given a proven developed construction sector (though not just as simply stated). In the DCs given the existing socio-economic environment and problems in the developing construction industry, the feasible set is itself an issue. A number of reasons or forces on the need for an appropriate technology choice especially in the context of the DC's have been tendered some of which are reviewed below.

2.2.1 Employment

Employment is by far the major force on the need for appropriate technologies. Most of the DC's are what can be termed as labour surplus countries as evidenced by high unemployment and underemployment. The construction industry in most DC's is a near carbon copy of IC's and thus based on assumptions of machine based methods. Though supposedly with an oversupply of labour, studies show that employment in construction per 1000 population in DC's is much lower than in IC's. (ILO). The productivity and skill of the labour (underemployment) is also low. Thus there is a need to increase employment and skills for locals. (EDMONDS 1984) Construction being technologically flexible and the high unemployment has lead to a growing appreciation of the potential role of the industry in helping alleviate unemployment. (WORLD BANK 1983) Thus the need for employment generation, equitable income distribution and social welfare has been a driving force at a search for labour based methods. This has been as due to the fact that the activities of construction are to a great extent especially so in DC's controlled by the central governments.

2.2.2 <u>The Planning Process</u>

Most construction projects are growth related (e.g. roads) to develop the necessary infrastructure. The planning process has usually emphasised the output objectives a great deal with little or simplified input on technological details. Thus most development plans usually describe the expected outputs e.g. kilometres of road without the attention to the inputs required to produce the outputs. Failure to achieve planned targets with increasing gaps between expectations and achievements has resulted in a desire to find solutions to constraints affecting the industry and practical measures (the technological choice) to enable it to meet the demands placed on it. (BHALLA 1983, EDMONDS 1984) The solution is not more money especially with a growing debt situation but a reorganisation of the use of available construction resources. Thus in the DC's with the influence of lending agencies like the World Bank, a shift in emphasis to the study of technological details is being recommended. To some extent the planning process aims at matching construction output demand to construction capacity with to have policy measures matched with available resources.

2.2.3 Economic Growth

The creation of fixed assets or capital by construction enable other economic activities to take place. Thus construction is used by governments as a regulator for promoting or suppressing economic growth. (WB 1983) The construction industry in DC's is patterned after the one in IC's which does not necessarily mean it is the most suited to the developing country. The differences in operating environments have resulted in many problems to overcome in order to implement the construction programmes. Thus the need for a better framework for construction.

2.2.4 Balance of Trade (Foreign Exchange)

The construction industry has a significant contribution to the economic balance of trade by importation and exportation of plant, materials and services. In IC's, the balance of trade is usually in their favour. The capital used in DC's in most cases is usually imported. Construction equipment accounts for a big percentage of all imported equipment in DC's with the amounts growing every year. The need to alleviate the trade imbalance by more use of locally available resources has lead to a rethink on construction technology. (WB 1983)

2.2.5 Development of Local Construction Sector

The desire for fast development has meant a dependence on foreign based and owned contractors. With increasing foreign controlled costs and no developed local industry, there has been a requirement for strengthening local industry development. This can only be done by strengthening of or adaptive change on existing structures as opposed to increased spending on imports while guiding local contractors. Activities at which local contractors are good, e.g. rural road construction, are given priority over large scale projects. A shift in emphasis from expensive trunk roads, which already have been constructed to some extent, to minor roads and maintenance has also helped the need for appropriate technology. (WB1983)

The need for development of the local sector has also been helped by new concepts of development. Sustainable development and growth can only emanate from local development as opposed to previous views of technological transfers which mean wholesale transfer of technology developed elsewhere. DC's have gone for sophisticated equipment in the earnest belief that this would result in technological transformation (transfer of technology). In actual practice, due to the socio-economic environment, operational and management techniques and technical skills have proved that imported technologies are not necessarily good. (EDMONDS 1984, GUPTA 1981)

2.2.6 The Local Construction Industry

By nature of contracting, whereby continuity of work is not assured and too many contractors are chasing too few jobs, insistence on too much equipment results in underutilisation and by implication a surplus of imported machinery. Thus a tendency to more labour based methods. (EDMONDS 1981) Insistence on equipment as indispensable, results in a diversity of makes and types. Inadequate maintenance facilities and the resultant short life make some equipment inappropriate. Investing in equipment with insufficient foreign exchange to meet running costs makes little sense. (UEZE-UZOMAKA 1981) Given the level of sophistication of local contractors, both technically and financially, methods employed elsewhere may not be appropriate. (WORLD BANK 1983)

The above points show the necessity to look for options to make the construction sector meet more of the needs of their countries.

2.3 CHOICE OPTIONS

Before a focus on technological choice is made, a set of feasible options have to be made. Existing organisational and social structures, institutional arrangements, attitudes and values all act to determine the options for change. Determining suitable process changes, especially in an industry that has been described as conservative, is not a simple undertaking. Added to this is each project's uniqueness and the difficulty in foreseeing the effect of policy and administrative measures. An understanding of the constraints and opportunities for change helps in studying or making technological choices. Reviewed below are some of the possibilities investigated for change.

2.3.1 Contractual Framework

Though described as a conservative industry, (SCOTT 1983) especially in the IC's, the contractual procedures are developed, modified and improved in relation to the emerging needs of the industry itself and the change in social and economic circumstances. The contractual framework in most DC's can best be described as undefined with attempted similarities to foreign systems. The transferred approach (well proven in their home environment) and modelled after foreign needs has few concessions to local customs, experience and needs.

The compartmentalization of construction procedures, i.e. the responsibilities for design and construction, inhibit the technical and management innovation. (EDMONDS 1984) Thus though perfect in the IC's setting with capable contractors, limitations in resources in DC's mean that compartmentalization tends to slow down projects. Experience that compartmentalization should not be so rigid tend to enable chances for innovation. Such practices as labour only contracts and contract supervision aimed at training and helping local contractors means that engineers have a chance to implement innovative construction methods.

2.3.2 Standards and Specifications

Ideally in a developing country, specifications should define and promote appropriate technological choices arising from the diversified demands. These should allow the introduction of appropriate specifications, not only in indigenous resources available, but to take account of the construction methods applied. Unfortunately specifications are transferred with minimum or no revision from IC's e.g. British Standards. The specifications tend to suggest the use of construction skills developed elsewhere and thus limit or discourage technological choice. Bias removal allowing a wider choice of methods, materials and standards may increase documentation and design costs but may help to achieve appropriate technology. (GREEN 1981) Field design which is more sensitive to the the availability of materials and methods can be employed to reduce documentation which the local contractors cannot understand in the first instance. There have been suggestions of contract documentation by unit rates, especially for materials, labour and equipment, to enable small inexperienced contractors to tender more effectively and enable more flexible choice of methods. (EDMONDS 1984)

2.3.3 Execution

The structure for execution of contracts can be divided into large contractors, medium contractors and small contractors. The large contractors usually are of three types i.e. international contractors, joint ventures and local contractors usually working on large contracts. The large contractors operating in a competitive market with a high demand for skills have a vested interest in restricting membership and are therefore resistant to change. Also as most are multinational, they operate as those in IC's with an emphasis on labour saving. (WB 1983, EDMONDS 1984) Small contractors are a difficult group to define and are usually not associated with continuous ventures due to the easy entry-easy exit nature of construction. The technical and managerial experience of most small contractors is limited and so is their tendency to innovate. (AUSTEN 1980) Their relatively small sizes and usually informal company structures, make it difficult for them to obtain the necessary resources for the pursuit of technological change and it may not give them much market power over the others. However viewed in the context of a national construction industry, development and attempts in most DC's to promote technological development, can be a preoccupation of government agencies. (WB1983)

In execution the biggest option for change is in the medium-sized ethnic contracting and government direct labour units. These are usually adequately managed; most with professional staff. Their sizes make their commitment to construction long term and they can gain most advantage from construction innovation.

2.3.4 Financing

The source of finance is also a major determinant of technology. Some of the financial sources common in DC's and their scope for innovation are:-

Bilateral financing and Donor aid financing provide limited scope for innovation. Usually the projects are designed by by the donor's engineers to their standards sometimes with insistence on donors contractors and materials. Such aid has sometimes being described as aid to the donor. (SCOTT 1983)

World Bank and Regional Development Banks In recent years they have had an interest in the development of local contracting sectors with the insistence on appropriate technology especially for rural roads.

Local financing With pressing needs and shortage of resources especially for projects that do not attract foreign donors, it offers the best opportunity for innovation. Longer durations associated with such labour based methods and thus spreading of payments over a longer period ensure that financing can be more favourable to the clients. In fact when considered on bid present value, the late payments are a reduction in cost. (PERRY 1981)

2.3.5 Labour

In many instances, appropriate technology infers making more use of labour based methods. However, though not all road construction activities can be executed economically using labour based methods, the methods are viable for a wider range of activities than presently used. There has been a reluctance to discriminate between labour based methods and plain inefficiency. Overmanning inefficiencies have given rise to a feeling that labour based methods are by nature inefficient. (EDMONDS 1981) The other problem is assumed cheap labour availability especially in the rural areas given the high unemployment. Planning is much more difficult when the casual nature of employment and seasonal variations make construction seem not a lucrative employment but a transition to other jobs.

For rural people, employment is limited to unskilled labour with outside contractors, with materials and skilled manpower from urban centres. This does not contribute much to the attractiveness of labour based methods and may have effects on productivity. Government policies on labour employment, laying off and union collective bargaining in view of construction business demands, may prove a disincentive to more use of labour and a drain of skilled manpower to other lucrative employment. Labour based methods offer the most scope for innovation but there is need to identify and verify assumptions on labour availability and productivity. Their efficiency should also be measured against specific objectives in particular contexts and not by universal standards.

2.3.6 Machinery

Machinery usage presents a significant scope for innovation viewed in the context of the capabilities of the industry and resource endowment. Most of the machinery is imported. There is a diversity of types and makes of machinery found in construction sites, with attendant operating and maintenance difficulties, coupled with skill requirements. The productivity of this equipment is sometimes as low as ten percent of the maximum quoted by the manufacturer. In cases it has been noted that management of machines is harder than labour management. (McCUTCHEON 1980)

Given the high cost of machinery and scarcity of work per contractor, establishment of rental agencies, preferably government sponsored contractor development agencies, would provide a pool of equipment. The type of equipment purchased should be viewed critically vis a vis their performance and initial and operating costs. Quasistandardisation would also facilitate establishment of adequate spare parts, servicing facilities and operator and mechanical training. (EDMONDS 1984) Ideally given the overall objectives of appropriate technology, cheap machinery accommodating substantially more labour as well as requiring less skill, should be the aim.

2.3.7 The Role of the Government

The majority of the jobs done have government bodies as clients. The government also has regulatory control over the private jobs through control of labour relations and general trade. Thus government policies are able to provide sufficient effect on the choice of technology. Given the importance of appropriate technology and the wide range of options available, the major need is to overcome the obstacles in implementing them.

2.4 WORK DONE ON TECHNOLOGICAL CHOICE

Substantial work on the use of appropriate methods covering most areas has been done. Reviewed briefly below are some examples of the work done.

2.4.1 Viability

Emphasis on appropriate technology stems mostly from the fact that methods used in DC's are inappropriately capital intensive and that labour based methods could be used effectively and efficiently. There is also the fact that labour based methods are useful alternatives in labour creation, with distributional and poverty alleviation objectives. Consequently, a lot of literature has been concerned with the establishment of the technical and economical viability of these methods. (EDMONDS 1981) That is trying to establish a set of feasible techniques from which to choose. The studies have investigated most areas of civil engineering, including roads, buildings and irrigation projects, (e.g. KRISHNAN 1983). Some significant conclusions can be drawn from these studies.

Labour can be used to a great extent while still compatible with technical and economic efficiency. There exists a range of technically and economically feasible methods varying from the most labour intensive through intermediate techniques to the most equipment intensive depending on the project circumstances. Traditional labour intensive civil works are inefficient and economically inferior to capital intensive works except at extremely low wage levels. This is generally because tools, equipment, techniques and organisation are invariably inefficient. For labour based methods to succeed, better management as applied to capital intensive work is required. (HOWE 1980) Thus there is a general consensus that in most cases a choice among methods does exist. However studies of the institutional framework in which these methods are to be implemented find that implementation of labour based methods is not very common. (SCOTT 1983) This has been in part due to constraints and a number of studies have been directed at an effort to remove these constraints.

2.4.2 Managerial and Organisation Structure

The major studies have been on labour based construction given the requirements of management of men versus the management of machines. A number of manuals have been written on the subject based on experience gained on labour based projects (e.g. ILO Manual on the construction of labour intensive roads). This has been by institutions like the ILO, the World bank and governments which have labour based methods. A number of studies have also been done on the subject of the construction industry in relation to managerial practices. (WB 1983)

2.4.3 Tools

For labour based methods, the main means of production are the tools and light equipment used by the workers. The use of traditional tools is a major cause of inefficiency. Well designed hand tools can significantly increase the productivity of workers while at the same time making the work less arduous. A number of designs and improvements to traditional tools have been proposed. For major government programmes, tendering for the supply of hand tools by design specifications has been proposed and tried. As an example the wheelbarrow; one of the most useful pieces of equipment for haulage. Experimentation has produced a number of designs from the traditional handcart to conventional wheelbarrows. (HOWE 1980)

2.4.4 Machinery

It is granted that labour is not efficient in all construction purposes, e.g. road construction compaction and long distance hauling. Development and adaptation of machinery to supplement labour based method has received considerable interest. (HOWE 1980, GUPTA 1981)

Application of appropriate machinery is a major part of methods innovation. Appropriate technology should be aimed at choosing labour-machinery mixes to satisfy project requirements. However, most machinery is imported, and in some cases may not be appropriate. There is a considerable need to improve existing methods and efficiency.

Given the limited capabilities of local manufacturers to produce the machines, the option that exists is the innovative use of working units even from non construction activities to further extend the choice of technically and economically feasible methods. Of these the agricultural tractor has been the most notable in the range and flexibility of its development. In road construction, with other simple attachments, it can be used as a trailer for hauling, dozer attachment for excavating, compacting with roller and water bowser. The Kenya Rural Access Roads Programme has used agricultural tractors with considerable success. Experiments have been made with animal drawn implements like bullock carts usually with improvements to the traditional modes. Experimental work of ILO has shown, that under the right conditions, animals can be a most appropriate source of power for haulage in road construction. (HOWE & BARWELL 1980) Although studies and soundly based ideas have shown the potential for improved machinery technology, the implementation of development and testing has been slow. Where implemented they have especially improved construction efficiency.

2.4.5 Contractual Procedures

A lot of work has been done to study the construction process in DC's. (WB 1983) This has usually been done within the framework of the adopted foreign standards. The studies show that mostly no concessions are made to the different national objectives, physical and socio-economic operating environment or construction industry development needs. Despite the studies, only limited attempts have been made to modify contract procedures to suit local conditions.

2.4.6 Specifications

Some work has been done on the construction of cheap rural roads especially in DC's where appropriate technology is most applicable. While there have been suggestions made, for example in compaction standards, despite the studies, very little of the ingenuity in specifications is applied.

2.4.7 Classification of Contractors

Most implementing agencies, especially governments, have a sort of classification system for contractors according to the value and type of work for which they can tender. Requirements that contractors should own a large stock of plant and equipment for classification purposes runs counter to the policy of encouraging employment through labour based technologies. There have been suggestions that the level of plant holding criteria be related to the economic circumstances of the developing country where reliance on equipment is economically untenable. (EDMONDS 1984) The level of plant holding criteria is also used for financial requirements by lending institutions. This leads to a tying up of capital in equipment.

2.4.8 Engineers

Although there is an availability of methods, their use is not very common. Engineers' decisions on the labour-equipment ratio are usually biased in favour of equipment. This is due to education and training and engineers would not benefit from making proposals which imply delayed execution or slower than anticipated progress while exploring alternative techniques. (KADEN 1981) With increased experience of labour based methods and the shortcomings of other methods, the question of appropriate technology divorced from labour creation objectives is becoming more favourable. Seminars and workshops on technology choice have served to provide a good education for engineers.

2.4.9 Private Contractors

The implementation of appropriate methods should prove to be profitable to private contractors in the long run. A great deal depends on education of the private sector which might require government intervention. Some measures have been suggested to help implement appropriate methods. These include:

Surcharge Increase in cost if the use of local methods should be preferred e.g. labour based methods are acceptable if the increase in cost is up to 10 percent more than equipment based methods. This already exists in World Bank sponsored projects where a 7.5 percent advantage is given to local contractors.

Increased tariffs on imported equipment.

Adjustment of the market rate of interest. Low interest rates imposed by governments in some cases, given high inflation rates imply a negative real interest on loans and thus equipment and adoption of capital intensive technologies become more attractive.

2.4.10 Economics of Capital/Labour Substitution

Government regulations with respect to trade, taxes, interest and exchange rates and labour laws are claimed to provide sufficient price distortions to explain technology choice. Thus with the assumption that market prices are a poor guide to resource allocation, shadow costs have been used in evaluating the real social cost of employing resources, especially labour. However desirable, the concept of productive efficiency should not be the sole basis for technological choice. Some methods which are inefficient under normal economic criteria may be regarded as socially desirable preferences. (BHALLA 1983) An evaluation of technology choice should consider trade-offs between the various objectives.

2.4.11 Case Studies

The ILO, IBRD, World Bank and other authorities in this field have made a number of case studies. These have ranged from simple projects to comprehensive studies of the whole industry. The case studies, though not reviewed separately here, have in many cases formed the basis for the arguments developed for the choice of construction methods reviewed elsewhere above.

2.5 THE NEED FOR EVALUATION

The concept of appropriate technology implies a satisfactory engineering solution which accords with the capabilities of a society. The underlying philosophy and motivation is the ability to solve problems in a way that fits cultures and resources. Appropriate technology does not specify particular levels of technology e.g. labour based, but rather that a technological problem ~~it~~ should be critically analysed and a solution that takes full recognition of the peculiarities of the situation should be evolved. (NILSON 1981) Most authors in the literature reviewed suggest the desirability of adopting a more rational framework for the choice process of the best method to be used. This framework suggests stronger capabilities for evaluating and selecting from alternative technologies. The authors also agree that there is scope to remove the constraints hindering the development of the construction industry and the consensus is that any decision should be based on objective criteria. The transition from indiscriminate choices, usually made on assumptions, to a more realistic multi-objective framework, which incorporate realistic trade-offs before the choice is made, is required. The area of decision making clearly constitutes a potential for technological choice with a recognition of the multiplicity of objectives. There are a number of areas where decision models can help.

2.5.1 Information and Understanding

Given the complexity and general lack of understanding of the problem, evaluation will help towards a proper solution. It is not always appropriate to pump in more money or call for a labour intensive programme if such a choice is not compatible with the conditions and economy of the particular situation. Management by trial and error, using solutions developed elsewhere, tend to lead to failure leaving countries in a situation where there is an increasing deficit.

Any effort to even marginally improve understanding of how more or less technology is chosen is bound to have a high payoff. The evaluation framework would add understanding to the factors affecting technology generation and help to identify areas in which understanding is particularly weak or the potential for policy intervention is particularly good. A decision model will also help to identify the potential benefits, risks and liabilities based on the technical requirements and attributes of the methods. The areas identified may just call for simple changes that can increase the benefits.

Evaluation will also serve as a measurement tool for construction methods and a way to systematically analyse and plan for specific construction operations.

Through training, the engineer should be able to consider alternatives. This happens in design to some extent. By implication, conscious evaluation of construction methods, as opposed to assumptions, will assist in the production of more viable designs and project construction. This can help to maximise output, minimise costs and realise perceived objectives.

CHAPTER 3

EVALUATION CONCEPT

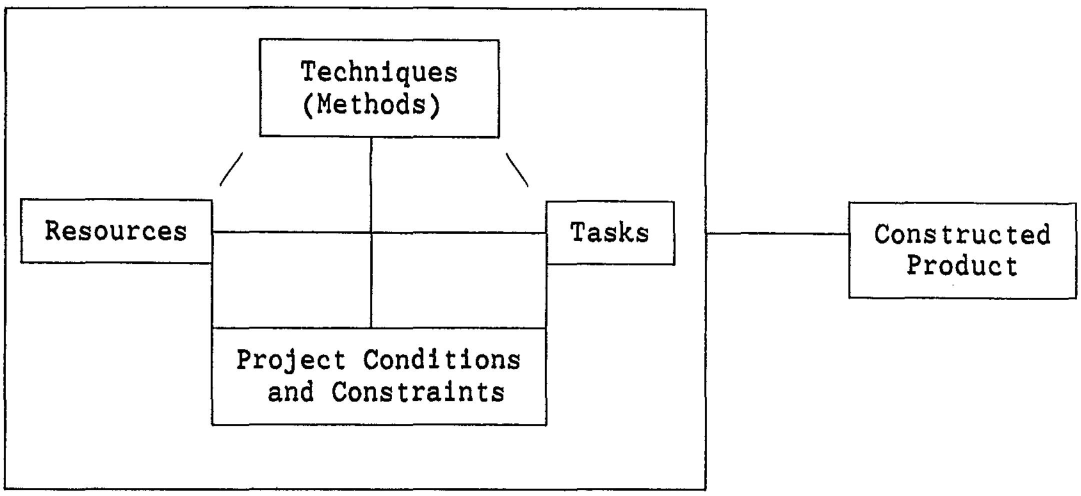
The previous chapter outlined research done on the construction industry and the need for evaluation. This chapter develops the evaluation concept.

3.1 THE CONSTRUCTION PROJECT (Overview)

To evaluate construction techniques, it is necessary to understand the basic components that describe construction technology. By identifying the basic variables or components that describe construction technology and their relationships it is possible to develop an evaluation framework for technology choice.

Construction technology can be described as a system which is a combination of tasks, resources, conditions and methods that produce the constructed product. These components all act in relation to the project environment to constitute the finished product. (Fig 3.1). The components can further be broken down into different elements. (TATUM 1988)

Fig 3.1 Construction system



3.1.1 Tasks

These are the activities that must be performed in construction operations, e.g. earthworks. Though the tasks are important in determining technology, they are basically the same for any method used.

3.1.2 Resources

Essentially the most important of the components that determine the project and the source of major construction problems in DC's. Resources can be subdivided to two major components viz:-

i) materials or permanent work resources and
ii) construction applied resources.

3.1.2.1 Materials

Materials quantities and other permanent works define the scope of the project. Consequently they have important implications for construction methods and provide restraints for construction operations, (e.g. placing hot asphalt). As observed in the literature search, materials also offer a great scope for innovation in construction. However, research on the use of different materials is not yet fully developed or accepted.

3.1.2.2 Construction Applied Resources

Applied resources are the additions to materials to produce the constructed product. The applied resources are the most important, especially in roadworks, in the determination of the construction methods. They contain several elements which are types of resources. Among these are:-

People - Often a key applied resource in efficiently performing construction operations. This includes the manual labour, skilled labour and supervisory staff. Admittedly skilled labour, or the lack of it, and supervisory staff, pose a major constraint in method choice in DC's.

Equipment - Machinery and Tools The type, cost and availability is used to define construction methods, e.g. capital intensive.

Money and Time - Usually the fundamental resources in delivering the project in the time required to complete construction with the amount of funds available.

3.1.3 Construction Methods

Construction methods define the way in which applied resources transform materials into the constructed product. These are by far the major focus of technology choice through methods improvement, innovation and productivity increase.

3.1.4 Project Conditions

Project requirements and constraints differ drastically among projects. They are the source of each project's uniqueness and thus a major determinant of the method chosen. Of the available construction alternatives, only a limited number may fit within the project conditions for use on the specific project. Many influences form the project conditions and constraints. Among these are project objectives, capabilities, practices and the resources available in the area, regulatory policies, climatic and physical conditions and overall socio-economic environment. The socio-economic environment is conditioned by the general structure and state of the economy, political organisation and the traditions affecting the manner in which business is carried out. (WORLD BANK 1983)

3.1.5 Evaluation

The above components, which are linked and interrelated, describe the total construction technology. However, though the major aim of this thesis is methods choice, all the other components act to influence that choice and are thus considered in the evaluation system.

3.2 CONCEPTUAL FRAMEWORK FOR EVALUATION

Essentially evaluation involves the selection of an alternative from a finite set of feasible alternatives that satisfy a set of objectives.

Fortunately for construction, a wide range of factor combinations can be used to suit each finished product. Normally selecting the most appropriate alternative is done by relying on experience and intuition. Compared to other types of economic activities construction work involves the risky allocation of resources under very uncertain conditions. (WORLD BANK 1983). With each project being unique, the organisation of logistics and technical inputs have to be determined for each project. The addition of multi-objectives to the project i.e. socio-economic and construction goals, requires a rational framework for making decisions. The aim of this work is the formulation of an evaluation framework within which the major factors that influence the methods can be analysed. The analysis of alternatives will determine the most effective way of achieving the multi-objectives and their impacts as viewed by decision makers. It should be noted that it is not a substitute for experience. Rather, it provides a rational framework to capture experience and test intuition. The preferred alternative is given confidence by evaluation when compared to the outcomes of other alternatives. The evaluation method will act as a decision model portraying the interaction of the different objectives.

3.2.1 Evaluation Framework

The first step in modelling the evaluation framework is the development of alternatives. This is determined by the work categories required. For every work category, general alternatives from which the outcomes are to be determined are generated. Fig 3.2 shows an example for earthworks.

Fig. 3.2 Alternatives for earthworks

ACTIVITY	ALTERNATIVES
Earthworks	Excavation, transportation, spreading by man
	Excavation and loading by man, hauling by trailer, spreading by man
	Excavation and loading by machine, hauling by trucks

As noted above, there is a wide range of alternative combinations. Clearly some of them are not viable for the project under consideration.

Analysing each and every alternative until their values are known is not viable as usually the resources and time to perform this analysis is not available.

A specific situation is required to fine tune the alternatives. The first alternatives may help in identifying what sort of problems may be expected and what data is to be collected.

3.2.2 Method Choice

Project characteristics provide a critical constraint on method choice. Availability of methods as feasible options does not necessarily mean that they are viable. There is a need to determine the major factors affecting the specific project viability and their possible effects both qualitative and quantitative. Consequently by taking into account the logistical and technical inputs of the project, their influences and outcomes, it is possible to have a definite choice of two or three viable alternatives. The following inputs are required.

3.2.2.1 Size and Location of the Project

Viewed in terms of resource mobilisation and availability at location.

3.2.2.2 Local Conditions

Climatic, geographical and geological conditions greatly influence the method choice especially for roadworks. Climatic conditions influence the working sequence and the number of unworkable days due to rainfall. They are also an influence on working hours as developed by local custom. As most materials are won on or around the worksite geographical and geological conditions influence the work. The terrain often influences the volume of earthworks required and places limitations on the work ability of both men and machines.

3.2.2.3 Labour

It has been common to assume labour availability and productivity in project areas; especially rural areas. Availability and productivity are linked to the attractiveness of work, earnings and local customs as viewed by area residents. Consequently, shortcomings when assumptions are proved wrong may make some labour based alternatives unattractive. The logistics for importing manual labour from other areas including transportation and housing may be forbidding.

3.2.2.4 Equipment

Availability, productivity and costs are affected by numerous factors including terrain, type of work, availability of skilled operators and servicing facilities.

3.2.2.5 Political Policies

Government policies and regulations in force at the time.

3.2.2.6 Interest Rates

Interest rates determine the cost of capital goods.

3.2.2.7 Currency Exchange Rates

Currency exchange rates for imported inputs.

3.2.3 Alternatives

With the determination of the inputs, constraints and problems both logistical and technical, it is possible to come up with two or more alternatives that can be employed to fulfil the project requirements. Apart from the technical inputs which are covered by the design, most of the other inputs have to be verified. Rapid appraisal methods can be used as a verification of assumptions and evaluating viability. The methods are discussed in the next chapter. With the determination of viable alternatives, evaluation can then be done to give the worth of the alternatives. At this stage a seemingly dominant alternative might appear. However, as the range of objectives employed increases, dominant solutions become less likely.

3.3 EVALUATION

3.3.1 Aim

The major aim of this evaluation is to determine the project's total worth as viewed by decision makers. As noted earlier, construction, especially in DC's, may be used to fulfil multiple objectives. Thus there is a need to determine whether the frequently called for solutions are effective in satisfying the desired objectives in the best way, e.g. labour based methods to alleviate unemployment and to develop the local construction industry. The following are some of the major issues that arise in an evaluation method.

i) How to compare different objectives which have different values both qualitative and quantitative.

ii) When compared to measures of effectiveness like cost-time, can the other measures be analysed at a comparable level.

iii) The nature and intensiveness of the evaluation.

To solve these issues, developed evaluation methods are investigated for suitability. The methods are discussed in the next chapters.

3.3.2 Proposed Objectives (Decision Criteria)

To use an evaluation method to assess alternatives it is necessary to develop the objectives or decision criteria. The list of objectives should be developed based on experience and giving adequate allowances for regional policy assumptions and local considerations. Thus the objectives may be different depending on the project nature and the environment. The following objectives are chosen as the decision criteria for this work. The objectives are definitely not exhaustive but were chosen to reflect both universal project objectives and objectives of particular concern to less industrialised countries.

3.3.2.1 Cost

Cost is a very important criteria everywhere. Different alternatives differ in costs depending on factor combinations inputs and prevailing prices. The cost differences are subject to different weightings among projects.

3.3.2.2 Time

Alternative methods differ in the time required to complete construction. Time is also important in relation to coordination with other activities. Even where a specified completion time is not rated too highly, the coordination of all activities must be taken into account.

3.3.2.3 Finance

Cost and time perhaps play the the most important role in financing the project. As most projects are financed by government agencies, payments to contractors are subject to government cashflows and mostly budget anticipated. To ensure smooth uninterrupted output, it is best to programme cash flows to a level that is probable given the source of finance. Also as noted earlier, barring cost escalation, payment over a long period is a saving, especially for multi year contracts, when considered on a net present value.

3.3.2.4 Employment

Due to the ability to vary factor inputs, construction can be used to provide gainful employment to alleviate unemployment. This has been a major force in the use of more labour based methods. However, to rate employment in any evaluation, some considerations have to be taken into account.

i) Type of employment

As much of the demand is often met by taking unskilled labour from rural areas, will the employment adjust to the labour needs of agriculture, especially in planting and harvesting seasons and other economic activities (WORLD BANK 1983).

ii) Intersectoral linkages

Construction can provide a growth stimulus to the economy through intersectoral linkages. Thus the rating for employment should also consider the impacts of alternatives as it concerns both forward and backward linkages. In the backward linkage raw, semi-processed or processed materials may be provided by labour based methods. (WB 1983) In the forward linkage labour payments may enhance the consumer goods industry and provide additional employment.

3.2.2.5 Retain Foreign Exchange Within the Country

Lack of external currency and the need for facilities requires the use of resources within the country. However specific situations must be individually evaluated. Foreign exchange for items such as spare parts is vital if maximum use is to be made of already available plant.

3.3.2.6 Quality

If a choice of materials is included in the choice of techniques, the available options are far wider than if the materials are constant. Assuming the materials are constant, the important aspect of method choice is the finished quality. The quality differs for different alternatives within limits for the same material depending on limitations or capacities of input, plant or labour. The rating of quality as an objective differs, especially for rural roads where the major issue is providing effective facilities where they are non-existent or inefficient.

3.3.2.7 Income Distribution

Economic distribution between regions of the country and among the population is a major objective of the political process. In construction methods, the distribution objective can be achieved through employment and entrepreneurship. As in employment it has been noted that mechanised methods tend to be associated with relatively high wages while labour intensive techniques generate low incomes among those that they employ. (STEWART 1983) Also depending on socio-economic conditions like opportunity cost of labour, local patterns of income use and consumer goods capacity, labour payments may enhance the internal market or cause an inflationary process over the economy of the low income sector that it aims to help. The distributional objective has to be viewed in the context of the particular region.

3.3.2.8 Training (Technology Transfer)

A lot of the problems associated with construction in DC's is the lack of skilled manpower both technical and managerial. This has also been a hindrance to the development of a local contracting industry. (EDMONDS, WORLD BANK 1983) With the increased costs of foreign contractors it is necessary to increase the capabilities of the local construction industry by improvement of the human resources through training. Any alternative should be considered in the context of training for more demanding jobs. The training should be viewed in the wider scope of industry development.

3.3.2.9 Control over the Project

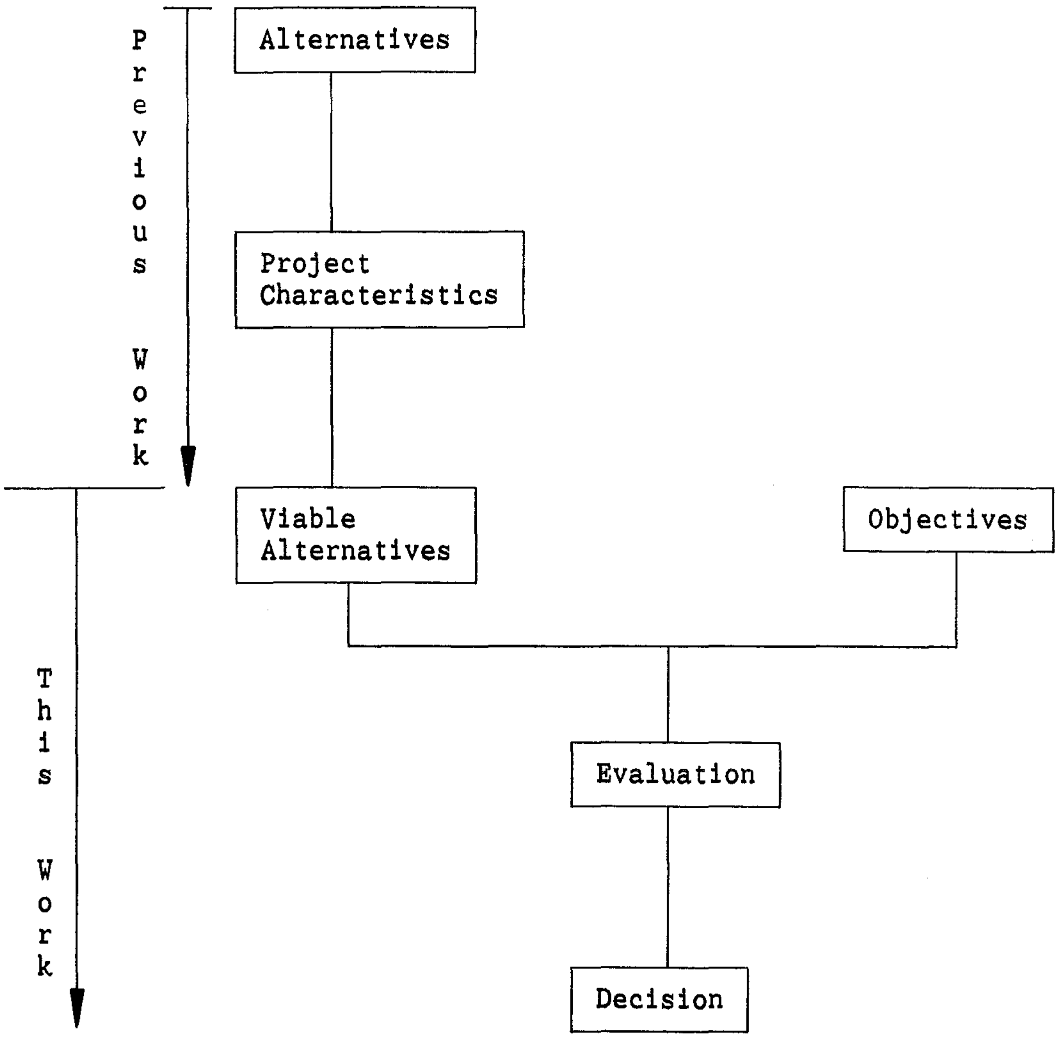
This is considered given the organisational capabilities of the implementing agency. This occurs over both extremes of methods considered i.e. labour intensive and capital intensive methods. For a large project, a large labour force may require considerable organisational control in order to ensure effective production. Alternatively where projects are awarded to big foreign consultants and contractors the local body may not be able to control or even understand it.

3.3.3 Summary

As noted earlier, although these objectives are not exhaustive, they allow generalisation in the context of this work. The major aim is to investigate the viability of evaluation methods for construction technology. Through the evaluation, an attempt will be made to portray the factors that bring about methods choice and their potential impacts. The values will be selected for general applicability over a range of project conditions. Figure 3.3 shows the flow diagram for the evaluation model. The previous work done has dealt with the development of viable alternatives using price information. This work concentrates on the validation of evaluation methods for practical application; an evaluation framework from which an alternative can be selected from a set of viable alternatives.

The evaluation methods are discussed in the next chapter.

Fig. 3.3 Flow diagram for evaluation model



CHAPTER 4

EVALUATION METHODS REVIEW

4.1 INTRODUCTION

The major aim of this work is to investigate existing methods of project evaluation, to test their validity and evaluate their suitability and effectiveness as decision making methods for the construction industry. Following from this a suitable procedure for evaluating construction projects with respect to technical and social economic objectives will be formulated and tested. In particular, selection of the most appropriate construction method will be considered. The method will be designed to:

1 Determine and evaluate the effects of using a particular method.

2 Rank the project attributes being considered in terms of their relative importance.

3 Set out procedures for evaluation of the performance of individual project options with respect to the attributes being considered.

The method should be able to define:

1 The relationships among the objectives in describing the problem and as the decision variables.

2 The treatment of constraints on establishing the resource limits.

3 The method of ranking and selecting the alternative construction methods.

In addition to the above, the following should be considered:

1 The ease of use of the designed method by the users.

2 The practicability and reliability of the method for decision making.

4.2 METHODS REVIEW

4.2.1 Multiobjective Decision Theory

Standard decision theories have been concerned with the optimization of a single super criterion e.g. cost. However, with the increasing complexity of decision making, it has become evident that the overall performance of an alternative is not dependent on a single criterion but on a variety of criteria. This has given rise to multiobjective decision theories which aim to efficiently satisfy the multiple objectives and their consequences. The alternative chosen is that which best satisfies the multiple objectives.

As noted previously, (chapters 2 and 3) the planning and management of the allocation of resources in construction is almost, or should be, always multiobjective in scope. The major interests in the multiobjective approach, especially in resource allocation, are:

1 Providing decision makers with consistent and simple ways of sorting alternatives (projects) which have a significant proportion of unquantifiable costs and benefits. (SCOTT 1987) This is achieved by widening the range of objectives considered beyond those that are easily expressed in terms of money.

2 Fostering the explicit quantification of trade-offs among the different objectives. (COHON & MARKS 1975)

3 Helping to make value judgements in a rational and consistent way by providing sufficient information so that an informed decision can be made. (COHON & MARKS 1975)

Basically the multiobjective decision methods should be able to provide sufficient information for making decisions and the reasons for accepting them. The problem should be appropriately structured with objectives which are appropriate to the decision situation. The multiobjective methods help the conscious application of a systematic decision making process.

4.3 PROCEDURE

The multiobjective procedure can be considered as having three main parts. (D'AVIGNON 1986, SCOTT 1987)

4.3.1 Problem Definition

The first stage characterises the decision situation or establishing the overall policy. This includes:

4.3.1.1 Definition of the goals, objectives or purpose which the system is to fulfil

The goal, usually in the form of a basic statement helps keep the general problem in mind. The establishment or selection of objectives define the way in which the general goal is to be pursued.

4.3.1.2 Formulation of performance criteria

The performance criteria allow an assessment of the degree of realisation of the objectives. Ideally the criteria should be one dimensional with respect to the objective i.e. it should delimit one single aspect of the objective and should be measurable. It should allow the ordering of the different attainable levels as an objective. However, being measurable does not mean being quantifiable. (D'AVIGNON 1986) Measurement levels such as *bad* or *best* can be used.

4.3.1.3 Alternatives

The set of alternatives to be evaluated has to be identified, specified or developed. The set of alternatives can be described basically as either;

(a) a number of specific alternatives such as a list of projects to be appraised, or

(b) a set of alternatives characterised by variables modelled to meet the objectives such as a set of construction methods ranging from capital based to labour based methods.

The performance of the alternatives in terms of the different objectives is usually the context of the decision.

4.3.2 Evaluation

The second stage is the evaluation process. Each alternative is specifically assessed in terms of the objective's criteria. This results in alternative versus criteria combinations i.e. the performance of alternatives for each particular objective. The aim of the appraisal is to determine the achievement of each alternative in terms of the multiple objectives. To evaluate an alternative, subjective, statistical and technical data may be used. However, the performance of the different objectives does not have to be comparable i.e. comparable criteria. (e.g. Table 4.1(a)). Performance scores vary from factual, e.g. cost, to subjective, e.g. public opinion. Therefore the evaluation of the achievement of an alternative in relation to particular objectives on scales comprising a finite number of levels can be justified. i.e. Translate performance scores into a scale e.g. 0 to 10. This forms specific distributional evaluations which form evaluation tableaus (D'AVIGNON 1986) or attribute levels (DUCKSTEIN 1980). (e.g. Table 4.1(b)) The attributes are a means of translating objective performance scores into a scale measure so as to facilitate the inclusion of weights in determining the total relative worth of an alternative.

Table 4.1(a) Alternative vs Criteria Combination

CRITERIA		ALTERNATIVES		
		I	II	III
1	Cost ($1000)	100	101	103
2	Time (Months)	10	9.5	11
3	Quality	V.Good	Good	Fair
4	Public Opinion	High	Medium	Low

Table 4.1(b) Attribute Levels

OBJECTIVES		MEASURE	ALTERNATIVES		
			I	II	III
1	Cost	Minimum cost (Scale 0-100)	90	80	70
2	Time	Minimum time (Scale 0-100)	80	90	70
3	Quality	Highest quality (Scale 0-100)	90	60	30
4	Public Opinion	Highest (Scale 0-100)	100	50	30

4.3.3 Decision Proposals

Having determined the scores of the alternatives in the evaluation process, the next step is to make decisions and proposals. Different types of decisions and proposals are possible depending on who is the decision maker. (D'AVIGNON 1986) Typically the major decisions are:

4.3.3.1 Description of the alternatives

The evaluation process and the results (performance scores) present as a systematic and formal description of the alternatives and their consequences. For some problems, particularly when there is discussion by a committee, this is enough to make a decision.

4.3.3.2 Ordering the alternatives

The alternatives are put into an order with respect to other alternatives. This could be by sorting or ranking of the alternatives. Sorting the alternatives is by assigning them into different classes defined by some characteristic properties. For example the alternatives could be sorted into those accepted or those rejected. In ranking the alternatives are put into an order in relation to other alternatives.

4.3.3.3 Selecting alternatives

This involves the selecting of the best or most satisfactory solution from the set of alternatives. In most cases the existing methods have been developed for the problem of selecting one alternative.

To derive the decision proposals, especially the ordering and selection, information about the preferences of the decision maker is required and a scheme to aggregate the results. When applied to engineering projects multiobjective methods can be useful at both the management and technical levels. Where the engineer is not the decision maker, the management provides goal definition and makes the final choice. The technical level defines the alternatives and points out the consequences of any one choice from the view point of the various objectives.

4.3.4 Aggregation Methods

A number of methods exist that enable the comparison of alternatives. The assumption is, that with respect to the preferences of the decision maker, every alternative can be compared, even if two alternatives differ considerably with respect to some objectives.

4.3.4.1 Utility Theory

The utility of the alternative with respect to each objective is calculated. In the utility functions it is assumed that every objective is independent of the remaining objectives. Thus the utility of one objective can be measured without taking into account the remaining objectives. (D'AVIGNON 1986) This independence condition justifies the prioritising of alternatives by the use of total utility (or additive utility functions). By comparison of alternatives' utilities, the alternatives can be ranked or selected. However, generally when assessing the utility parameters, the estimation of weights for the objectives is required.

This theory can be illustrated in the following way. Given two alternatives A and B

Let a_i and b_i = the performance scores of alternatives A and B respectively for objective i with 1, ...n, objectives and w_i = derived weighting of objective i.

Define $u[A_1]$ and $u[B_1]$
$u[A_2]$ and $u[B_2]$
. .
. .
$u[A_n]$ and $u[B_n]$
where $u[A_i]$ and $u[B_i]$ for i = 1, ...n, is the utility of alternative A or B with respect to objective i.

Usually $u[A_i] = w_i * a_i$

Independence implies that it is possible to derive $u[A_i]$ or $u[B_i]$ for any i independently of any other objective utility.

Aggregating $u[A_i] = U[A]$ and $u[B_i] = U[B]$
e.g. by adding to get the total utility for alternative A and B

Thus for comparing A and B
$A > B$ if $U[A] > U[B]$ i.e. A is better than B
$A \sim B$ if $U[A] = U[B]$ i.e. A is comparable to B

4.3.4.2 Dominance

The concept of dominance is used as a method of prioritising. A multiobjective alternative X_i is said to dominate X'_i if X_i is at least as good as alternative X'_i with respect to every objective. The concept of dominance is usually used with multiobjective programming techniques. However the results are a set of non-dominated solutions and further ordering has to be made. This means that with just the dominance concept, the result is a set of technically feasible non-inferior alternatives. Since none of the remaining alternatives dominates the other, no ordering e.g. $X_1 > X_2$ can be made. For example

Assume a set of six alternatives $X_1 \ldots\ldots X_6$
Using the dominance concept results in say;
X_1, X_3 and X_6 as the non-dominated solutions.

To derive a relationship like $X_1 > X_3 > X_6$, where greater than implies better than, dominance is not enough and another method of choice has to be used e.g. utility theory. The concept of dominance is reasonable where a problem consists of finding the set of best alternatives.

4.3.4.3 Distance to a target point

The preferences are translated by means of a desired target point $Z = (t_1 \ldots\ldots t_n)$ for n objectives. Z is referred to as the ideal vector. The set of alternatives can then be put into an order with respect to the distance D to that point. A way of computing distance D between X and the target point Z, or how close the alternative is to the ideal solution, is by the use of vector geometry.

e.g.
$$D = \sum_{i=1}^{n} \left[w_i^{\,2} \left(\left(\frac{t_i - x_i}{t_i - t'_i} \right)^2 \right) \right]^{1/2} = \sum_{i=1}^{n} W_i \, D_i$$

where: t_i = ideal value for objective i,
t'_i = worst value for objective i,
w_i = weights derived for objective i
x_i = alternative's performance score for objective i
D_i = a measure of deviation from the ideal value

The alternative with the minimum distance from the ideal is selected. This represents a reasonable compromise between the objectives.

4.3.4.4 Objective ordering or lexicographic ordering

This requires that the objective function be ordered in a priority sequence. By sequentially optimizing the objective functions beginning with the highest priority, one objective starts to play a role for the comparison of alternatives if these alternatives have identical evaluations with respect to all the more important objectives.

e.g. Assume two alternatives X and Y with n objectives 1......n with 1 being most important and n being least important.

Let $X_i = Y_i$ for all objectives 1......i
then $X > Y$ if $X_j > Y_j$, irrespective of k, l, m etc.

Hence objective j starts to play a role in the comparison of the alternatives.

4.3.5 <u>Idea of Weights</u>

In the methods of choice described above it is evident that apart from comparing alternatives, the objectives have also to be compared to provide a value judgement for the objectives. The idea of weights (whether actually derived or just ordering the objectives from least important to most important) is commonly used to elicit preferences amongst objectives when confronted with a multiobjective problem. The objectives can then be ranked with respect to some weight or scaling constant. The difficulties in weighting approaches consist in the estimation of adequate weights. A number of methods have been used to produce weights for particular problems. (KOCAOGLU 1983, SCOTT 1987) For any method used, it is assumed that the decision maker can order the preference of the objectives.

4.4 EXAMPLES OF MULTIOBJECTIVE METHODS

A number of multiobjective methods exist. These methods cover a broad spectrum of analytical sophistication and range from simple non-mathematical techniques to complex computer based programming. Bishop (1976), in a review of multiobjective methods, categorised them into:

4.4.1 Visual Techniques

Visual techniques require little or no quantitative analysis. These are especially useful where the objectives have spatial significance.

4.4.2 Rating and Ranking Methods

Rating and ranking methods-providing a direct comparison of alternatives.

4.4.3 Matrix and Linear Scoring Methods

Matrix and linear scoring methods usually adopt a model that incorporates both performance measures and preference weightings.

4.4.4 Trade-off Displays and Analysis

These aim to organise quantitative information on the performance effectiveness of alternatives in either graphical or tabular forms which aid comparisons amongst alternatives.

4.4.5 Multiobjective Programming

This general class of multiobjective technique is based on mathematical optimization. Cohon and Marks (1975), in a review of these methods, evaluated them in terms of their computational efficiency, explicitness of trade-offs and the amount of information produced for decision making. They subdivided these techniques into generating techniques, techniques that rely on prior articulation of preferences and techniques that rely on progressive articulation of preferences. Each of the subclasses of techniques attempts to identify the non-inferior set through different approaches.

The general multiobjective methods are described above. They are applied in different problem contexts with unique resources and constraints. Because of the similarities in basic procedure the potential for upgrading or combining the methodology for a particular application exists. Most of the recent literature on multiobjective decision making applies to specific problems (e.g. DUCKSTEIN 1980, SCOTT 1987, TECLE 1988). Thus the selection and application of any technique has to be made while taking into account the resource constraints and the requirements of a specific problem.

4.5 DECISION BY ELIMINATION (EXCLUSION)

This work aims at evaluating viable construction methods with respect to technical and socio-economic objectives. The construction methods have different combinations of resource inputs particularly labour and machinery. By varying these resource combinations it is possible to develop many feasible alternatives. Hence it may be necessary to make a final selection from a reduced set of alternatives by progressively discarding some of the options in stages. A *decision by elimination model* (MATTAR 1978) is reviewed for the possibility of adopting the procedure for this work.

4.5.1 Structure

The general structure of the decision model follows three phases viz analysis, synthesis and evaluation.

4.5.1.1 Analysis

The analysis phase consists of the gathering of relevant information, the definition of constraints and objectives and, where feasible, the definition of relationships between objectives. Definitions of the performance requirements, the availability of resources, constraints and the environment are established by the collection of data. The precise specification of performance requirement results in performance objectives [Y]. The specification of performance objectives defines the explicit purpose to be served by the constructional system without restricting the decision maker in the solution he puts forward. This can be seen as defining what the ideal project should achieve and thus forms a suitable basis for the evaluation of the proposed alternatives.

The set of performance objectives may range from the precisely definable to the broadly general. Construction time is an objective that can be defined precisely (e.g. months) while what constitutes public opinion is broadly general.

The specification of objectives can also provide scope for the interchangeability of objectives and constraints. From the range of specified objectives, there are some alternatives which have to achieve a minimum acceptable limit to be viable. No benefit is derived from exceeding this limit. Others have a range through which they are still viable. Within that range they have different scores for the varying performance levels. A bridge design may have structural strength and aesthetics as objectives. The structural strength for the design load has to be achieved for any alternative to be viable. There are no extra benefits to be derived from exceeding it. Thus it is best treated as a constraint. The aesthetics preference, though a desired objective, can be varied over a higher range of acceptance so it can be considered as a performance objective with different options having varying scores. From the range of initial objectives, a choice can be made as to which performance objectives should be considered further and which are best regarded as constraints.

When appropriate, a performance criterion corrresponding to the least acceptable value of the variable is defined for each objective. The performance objective on each variable is defined either by a criterion (acceptable/unacceptable) or by a range of desirable limits (least acceptable to most acceptable). Whenever a decision exists preferences based on a system of values may be exercised. The values of a performance objective will vary between people, with circumstances and time. No methodology should be a substitute for the decision maker's identity of the objectives, definition of the limits of acceptability or the expressed preferences between objectives. However, by making values in the decision process explicit, the systematic and conscious exercise of judgement is assisted and the consequences of any changes in values can be studied.

4.5.2 Synthesis

To achieve objectives, a number of feasible and admissible alternatives are generated. This is known as the synthesis stage. The alternatives generated are referred to as *candidate solutions*. There are many systems which provide possible answers to the statement of performance objectives. Feasible solutions abound and modification of these may result in yet more alternatives. Consideration of different configurations can be used to generate alternatives.

For example in this work, we can consider labour based methods and capital based methods as constituting possible feasible alternatives. By modifying and altering the factor inputs including labour, capital, time and cost, more alternatives can be generated.

4.5.3 Evaluation of Alternatives

A large number of alternatives may be postulated as candidate solutions. Because of cost and the time required, solutions are eliminated in phases until the most acceptable solution is found.

The following steps are performed in the elimination procedure.

1. A check against the constraints, elimination of all alternatives that do not meet the constraints, e.g. available resources such as labour, or regulatory and practical constraints.

2. Modelling of the performance of the objectives in a suitable way. Reliance is placed on previous knowledge (historical data) of the behaviour of similar systems with respect to the performance variables. For example it is possible to estimate from historical data how many employees a particular construction method would employ. The performance of alternatives is predicted with respect to each objective. The predicted performance scores are then entered into the appropriate cell in a matrix of performance characteristics. Any alternative where the predicted performance for each objective variable does not comply with the least acceptable minimum is eliminated.

3 The alternative's predicted behaviour is then measured and normalised according to the previously defined range of performance objectives. The predicted performance score should be expressed on a common basis i.e. in terms of the corresponding utility. The predicted performance score is transformed into the appropriate utility attribute by means of a transformation function. The relationship between level of performance of a alternative i with respect to an objective j, Y_{ij} and the corresponding utility U_{ij} is given by the transformation function $U_{ij} = f(Y_{ij})$.

Together these transformed performance measures form the attributes matrix $(U)_{mxn}$ where U_{ij} refers to attribute of alternative i with respect to performance objective j. The alternatives whose attributes are dominated by other alternatives are eliminated.

4 Definition of priorities among objectives in terms of weights is performed. The choice between alternatives is made by the additive composition idea which is that the utility of a multi-attributed alternative compound equals the sum of the weighted utilities of its compound. The various components are assumed to contribute additively but independently to the alternative's total worth. The total value, or overall utility V_i, of an alternative is equal to the sum of the weighted component attributes.

$$V_i = w_i u_{ij} + \ldots\ldots + w_j u_{ij} + \ldots\ldots + w_n u_{in}$$

$$= \sum_{j=1}^{n} W_j U_{ij}$$

where W_j = the weight of the performance variable j.

The optimal solution is the alternative having the highest total utility. Thus through use of the *decision by elimination* method it is possible to make a final selection from a reduced set of alternatives with at least *"as good as"* conditions.

4.6 SUMMARY AND DISCUSSION

Although different methods which suit construction and development needs exist, (as noted in Chapters 2 and 3), the choice of a method or project should be made only after an objective appraisal has been done. This work aims at formulating a suitable procedure for evaluating construction projects with respect to technical and socio-economic objectives and in particular the selection of the most appropriate construction method.

When choosing an evaluation technique consideration should be given to:

i the source and quality of the data,
ii the relationship among the objectives,
iii the constraints on resource limits,
iv the method of ranking and selecting,
v the ease of use by the users, and
vi the practicability and reliability of the method.

In this section, the above considerations are discussed in relation to the evaluation methods.

4.6.1 Appropriateness to the Decision Situation

The decision situation can be considered as an objective appraisal when selecting a project and the methods of doing a particular project. Both the project and the method selected must satisfy technical and socio-economic objectives.

Infrastructure development and maintenance, particularly roads, take a very high percentage of national development expenditure. This expenditure can be used for both technical efficiency and improvements in social welfare. In particular, the aim is the selection of the most appropriate construction method given the technical and socio-economic goals.

The main purpose is to present information in a form that makes it easier to make rational decisions. However, it should be noted that the choice is usually focussed on a limited set of options brought about by preferences and already established procedures. As was noted in Chapter 2, several construction methods ranging from "traditional" labour based to relatively capital intensive are in use. In practice, the two extremes i.e. labour based and relatively capital intensive are more common. The range of improved methods ("intermediate levels") which offer more scope for innovation are not very well adopted.

The relationship among objectives, the constraints and the methods of ranking and selection should reflect the appropriateness of the designed procedure to the decision situation. i.e. the procedure should enable;

- the determination and evaluation of the effects of a particular method,
- the ranking of project attributes being considered in terms of their relative importance, and
- the evaluation of the performance of individual project options with respect to the attributes considered to enable a choice to be made.

4.6.2 Effects of Using a Particular Construction Method

Multiobjective analysis (MOA) and decision by elimination approach the choice problem from a multiobjective perspective. Specifying the objectives defines what effects are desired of the construction method. i.e. The objectives form a set of measures which reflect impacts in their category, (e.g. employment). Thus the effects of the options become more apparent.

Determining the effects of a particular method consists of identifying and appraising features of importance in a particular situation, (e.g. for a project area or site). The designed appraisal method should be able to be applied in situations which allow variety in terms of objectives, construction methods available, resource availability, economic and other environmental parameters such as price constraints. The methods should be flexible enough in application to accommodate any changes in the decision situation. MOA and *decision by elimination* could be applied to these varying decision situations so that any objectives that become irrelevant can be discarded and new factors introduced.

MOA and *decision by elimination* allow the translation of objectives into a measure of value. This means that (at least) analytically, the correspondence between the technological options and the relative fulfilment of the various objectives can be derived.

4.6.3 Importance of Project Attributes (Preferences)

MOA and *decision by elimination* usually determine preference by weighting methods. In this way weights are the means by which the the importance of one attribute relative to another is determined. The weighting approach problem is in the estimation of adequate weights. A number of methods to infer weights exist.

However, despite the method of derivation, the weights are supposed to reflect the relative importance of the attributes. The concept of importance should reflect the trade-offs users are willing to make. A preference of one objective over another represents a sacrifice of some units of one objective to achieve more of the other. However the concept of importance may have little to do with the trade-offs people are willing to make. Some users may not give due consideration to the problem when making choices. e.g. Choosing a scale of 1-10 may not be an actual measure of how many units one is willing to trade off between objectives. Thus importance may not reflect willingness to accept a trade-off.

On the other hand the users may give due consideration to trade-offs and and their significance but still find the decision about acceptable trade-offs hard to make. In some cases decision makers may be simply unable to describe between certain weighted preferences.

In this work, experimenting with weighting approaches with regard to the evaluation methods being tested will show how the weighting approaches differ in appropriateness when ranking the project attributes.

4.6.4 Procedures for Selecting Alternatives

MOA and *decision by elimination* combine the scores and weights allocated to an objective and represent the decision values of alternatives. However, the difference is in the approach to procedures for the selection of alternatives.

Elimination rules drop any alternative that is not satisfactory in phases until there is a final choice between *as good as* alternatives.

MOA generally depends on a final selection procedure to sort out the alternatives e.g. total utility. Naturally the alternatives being evaluated must be viable.

This work aimed to experiment with and test evaluation procedures to ascertain whether a procedure for selection could make a significant difference in the choice of options. From this some conclusions can be drawn about which is the most appropriate procedure for this particular application.

4.6.5 Ease of Use

All the methods can allow for a wide range of sophistication or simplicity. The sophistication should be restricted by the

i resources available (e.g. data, cost, time and computing facilities),

ii experience of the users and

iii the complexity of the problem including a number of alternatives and objectives.

The decision methods need not be simple as the aim is to simplify decision making using a suitable technique. With computer facilities the method can be sophisticated yet still simplify decision making provided the decision maker is acquainted with the method and has access to suitable information.

4.6.6 Practicability and Reliability

Practicability should refer to how well the technique suits or applies to the concept it is supposed to appraise. Choosing a practical technique to choose projects is difficult enough when all impacts can be expressed in money terms. If the decision maker is provided with conflicting objectives, (quantifiable and intangible), as compared to the quantitative measurements of the sort that engineers are comfortable with, then the task becomes all the more difficult.

e.g. Application of a cost-benefit analysis for the choice of construction methods may be ambitious and misguided due to the imprecise nature of the data available and the question of non-quantifiable and social aspects. The method may be more practical for a post project evaluation when all information has been recorded.

All the above methods could be practical for the purpose considered. There could be sources of invalidity due to a some of the following reasons:

i Measuring an incorrect concept during derivation of objective scores and weighting. e.g. users choosing not to express their true preferences and/or not thinking of the trade-offs they are willing to make when rating each technique could result in a wrong concept being measured.

ii Having an evaluation procedure that is inappropriate for the value structure e.g. In summing weighted attribute scores, good performance scores in one attribute may make up for bad performance scores in another. This may not reflect the desired situation like when it is required that any bad performance should be disallowed.

iii Theoretically irrelevant aspects of a technique, such as the phrasing of a question, which could affect a decision.

The impracticalities of these methods can be minimised especially when the decision maker has become familiar with the problem and the values so that it is easy to determine what is wanted. When the users are sure of their values, have a correct choice of decision rule and an adequately structured problem, the methods can give a reliable appraisal.

4.6.7 Summary Conclusion

All the techniques being tested have their strengths and weaknesses. A major cause of misapplication would be the lack of information about the strengths and weaknesses of the methods. It is hoped that by examining and experimenting with these methods, some attempt can be made at the derivation of this information. This may lead to the design or development of an improved procedure.

CHAPTER 5

RAPID RURAL APPRAISAL METHODS
(A REVIEW OF AN INFORMATION GATHERING TECHNIQUE)

5.1 INTRODUCTION

The decision on choice of construction methods involve technical and socio-economic objectives. Apart from the technical inputs that are covered by the design most of the other inputs involve the gathering or verification of data. Rapid rural appraisal methods can be used for the gathering of information and for verification of data and assumptions used in the evaluation process.

Most of the development projects in DC's are in rural areas. In recent years, development agencies have come to view development in terms of the total rural system. Instead of being based solely on technical efficiency, as is usual elsewhere, consideration is given to the socio-economic factors unique to the project area. The development projects (defined as units of purposive planned interventions in the process of development by the commitment of resources, (CHAMBERS 1980)) therefore have to satisfy or achieve technical and socio-economic objectives.

To achieve project objectives, decision makers require information that is relevant, timely, accurate and usable for appraisal. This information may be:-

* institutional and organisational patterns that determine project characteristics and what issues it can tackle.
* socio-economic and technical constraints that relate to the project.
* timely data of direct relevance to planning thus allow considerations of alternatives.

5.2 THE PROBLEM (OF INFORMATION GATHERING TECHNIQUES)

Information gathering and appraisal inherently require the commitment of resources. The success or failure of projects rely greatly on the type of information available to decision makers at any one stage of the project development. There is a need to obtain the information in ways that are efficient and cost effective. Some of the types of information gathering techniques used in the rural setting are inappropriate. The types commonly used can be described as "quick and dirty" and "long and dirty" where dirty means not cost-effective. (CHAMBERS 1980)

Quick and dirty - The information is gathered during a brief rural visit by an urban based professional. While this can be cost effective as regards the time spent in collecting information, the information gathered can prove costly for the project as it can be seriously misleading due to biases i.e. it may underestimate or fail to understand the nature of the problem.

Long and dirty - Collection of massive volumes of data. In field situations, the long delays in collection, analysis and reporting mean that the report is little used and thus proves costly.

5.3 RAPID RURAL APPRAISAL (RRA)

There is a middle zone between the two methods described above which has a greater cost effectiveness. In general, methods that seek optimal trade-offs in collection, learning, accuracy and actual beneficial use have come to be known as RRA methods. RRA methods are never the same in all circumstances. People in many disciplines have been using trade-offs in information gathering. These were never written up as it was assumed that that such methods of data acquisition were not proper given their professional training. In recent years, documentation of RRA methods in rural research has led to their emergence as accepted methods.

The two main concepts linked with RRA are:-

* Optimal ignorance - the importance of knowing what is worth knowing and thus avoiding the overkill in information gathering.

* Appropriate precision - avoiding degrees of accuracy which are unnecessary in the data collected.

Thus, in general, RRA is organised common sense or common practice freed from the chains of inappropriate professionalism. Due to the wide range of disciplines and professions in rural development, RRA principles are a valuable supplement to the older more established methods i.e. a systematic activity designed to draw inferences in a limited time period.

5.4 RRA PRINCIPLES

Although still evolving as a research methodology, some of the major RRA principles are;

5.4.1 Triangulation

Approaching desired information from several intentionally different view points. Often there is no one best way to obtain information, or the best way cannot be foreseen in advance. This helps both to cross check and to fill in the picture thus improving accuracy.

5.4.2 Exploratory and Highly Interactive Research

Must be ready to abandon old hypotheses, form and explore new ones based on information. i.e. the direction should change with new evidence e.g. if planning for a labour intensive project, new information may indicate that agricultural employment is more attractive than roadworks; therefore change basis of planning.

5.4.3 Rapid and Progressive Learning

RRA should not be designed as a comprehensive fixed research but as a process to determine problems with progressive learning.

5.4.4 Substantial Use of Indigenous Knowledge

Research work is carried out as close to the source as possible. Local perception and understanding of resource situations and problems is important in learning and comprehending. This enables development of viable and acceptable solutions.

5.4.5 Interdisciplinary Approach and Teamwork

With rural complexity, understanding all factors to produce appropriate and viable solutions requires teamwork, consultation and the close interaction of various disciplines to provide additional learning.

5.4.6 Flexibility and Use of Conscious Judgement

Careful planning, preparation and organisation are prerequisites for successful research. However the plan should be flexible enough to allow for modification and creativity where appropriate. Flexibility includes the allowance of choice, alteration or combination of methodological options, tools and techniques, or even invention of new tools. Flexibility requires the use of conscious judgement to make effective and appropriate decisions while taking into account the types and degree of precision of the required information.

5.5 RRA METHODS, TOOLS AND TECHNIQUES

In practice, as noted previously, RRA involves the deliberate selection and combination of a number of research methods, tools and techniques to suit the particular research needs. Therefore the best methods depend on purpose and circumstances.

The following are some of the techniques and tools used for RRA.

5.5.1 Existing Information

A lot of information exists in annual reports, surveys, academic papers and government statistics. Use of such information usually saves the need to collect new data.

5.5.2 Use of Key Indicators

Some key indicators may combine several variables, e.g. housing may indicate the extent of poverty or prosperity and thus the need for labour intensive work. Taking such indicators into account may provide a shortcut which avoids more expensive, direct and time consuming investigations.

5.5.3 Semi-structured Interviewing

Semi-structured interviews are those without preset questionnaires but with an agenda to be covered. The flexibility offered means that it is possible to diagnose problems and opportunities in a short time whereasthe results from a questionaire interview have to be analysed and new questions designed to cover shortcomings.

5.5.4 Direct Observation

Multiple checks on information assumptions like customs and practices. Simple direct measuring tools, such as a crop calendar, may help in determining rural labour schedules and values for planned labour intensive projects. Maps and aerial photographs are especially useful for certain types of natural resource surveys.

5.5.5 Local Researchers

Information gathered by local residents. A researcher with links in the rural area may serve not only as a key informant but can also very quickly and efficiently find out what needs to be known.

5.6 CONSIDERATIONS AND AREAS OF APPLICATION OF RRA METHODS

RRA methods differ depending on their purpose. Their usefulness is their timeliness for decision making and they have been used succesfully for action.

5.6.1 Considerations

The following are some of the considerations when using RRA methods.

5.6.1.1 Human Resources

Experienced people who can undertake the RRA as otherwise it would become counterproductive.

5.6.1.2 Intended Use of the Information

The constraints should be known. Sometimes the method is better used to improve design and to complement or supplement other methods.

5.6.2 Application Areas

The following areas are particulary suited for RRA use.

5.6.2.1 Exploration

Exploration, identification and diagnosis of problems and issues where planning is hindered by limited knowledge and data.

5.6.2.2 Project Design, Implementation, Monitoring and Evaluation

In identifying the sort of projects which will be appropriate it helps the recognition and identification of unfounded assumptions.

5.6.2.3 Policy Formulation and Decision Making

Gathering the additional information which is frequently required, often qualitative rather than quantitative, but needed to make or justify decisions, especially those dictated by a political process.

In summary, RRAs should be taken into account whenever it is appropriate for particular situations and projects.

CHAPTER 6

EVALUATION PROCEDURE

6.1 GENERAL

The procedure that follows is intended as an experiment for the application of evaluation methods in the evaluation stage of the choice of construction methods. The selection of a satisfactory construction method for road projects is the major aim. A number of viable and admissible methods to suit the construction needs exist. However, because of different technical and socio-economic objectives, and the project's environment e.g. availability of resources and constraints, some methods used may not be appropriate. Chapters 2 and 3 emphasised the need for an objective appraisal before a choice of method is made. Thus since the selection of the construction method is influenced by many objectives, the evaluation procedure should enable a conclusion to be drawn about which construction method best satisfy most objectives.

Hence it will:

- determine and evaluate the effects of using a particular method,
- rank the project attributes being considered in terms of their relative importance and,
- evaluate the performance of individual project options with respect to the attributes being considered.

This procedure is derived from the multiobjective and decision by elimination procedures reviewed in chapter 4. The procedure will systematically examine the effects of weighting methods and decision rules on the choice of alternative construction methods.

6.2 PROJECT ATTRIBUTES (DEFINITION AND IMPORTANCE)

6.2.1 Establishment of Objectives

It is necessary to establish the objectives that will fulfil the desired goals or the purpose for the methods choice. In this work, nine objectives were established as examples for application. These were chosen to reflect both universal project objectives and objectives of particular concern to developing countries and hence the need for the choice of construction methods. (Chapter 3) A more detailed explanation of the objectives is presented in appendix 2.

6.2.2 Identification of the Requirements

Identification of the requirements, desired specifications and constraints are the essential objectives for the attainment of the desired goals.

6.2.3 Evaluation Criteria

It is necessary to select evaluation criteria that relate system capabilities to specifications and hence to objectives.

6.2.4 Measurement Scales

Measurement scales should describe the range of possible values (quantitative) or relative position (qualitative) which an alternative construction method can attain in terms of a particular objective.

The results are presented in a tabular form.

Objectives	Specifications	Criteria	Scales
Cost	Total Project Costs	Least Cost	Ksh/1000

6.3 IMPORTANCE (WEIGHTING)

There are many ways to derive weighting factors to reflect the importance of an attribute to the decision maker. The direct assessment of each attribute's importance is proposed for this work.

Two different approaches are to be used to derive the weights. After considering the objectives, weights can be derived using the following procedures.

6.3.1 Ranking Approach

i) List objectives in order of importance.

ii) Weight the objectives. Start by assigning the lowest ranked attribute a value of one. Consider the next lowest. How much more important is it than the last objective? Give it a number that reflects the ratio of importance between the two objectives (2 = twice as important, 1 = same). Continue up the list and assess how much more important each objective is when compared to the objective immediately below it.

iii) Sum up importance values and divide each by the sum. Adopt this result as the weight for the objective.

6.3.2 Rating Assignment

i) Define and develop a scale of 0-10 with 0 representing the lowest weight factor and 10 the maximum.

ii) For any attribute decide the weighting factor by selecting a number on the scale. The number placing should reflect (the belief in) the importance of the attribute on a scale of 0-10.

iii) Repeat step (ii) and assign weights to all the other attributes.

6.4 ALTERNATIVES (OPTIONS)

To attain the desired objectives it is necessary to develop alternative options. This is achieved by generating viable and admissible alternatives which fulfill the objectives.

As an illustration of this procedure, data from some actual projects is re-analysed to create a set of candidate options. The problem is the choice of the best construction method for a hypothetical project. In deriving the alternative construction methods, information on available technologies, resource availability and constraints is used. As was noted in in the literature review (chapter 2) a lot of work has been done to establish the technical and price viability of alternative methods of construction. The use of the decision making procedure advances this by combining technical options and price information. In this example application of the procedure, the alternatives are not being evaluated for any specific project. However, use of actual project data should represent average conditions in Kenya and thus presents a degree of realism. The main objective is to illustrate how the procedure could be used to evaluate the choice of construction methods which fulfill multiple objectives.

6.5 PERFORMANCE SCORES (ALTERNATIVE ACHIEVEMENT LEVELS)

The alternative construction methods will be analysed to estimate their objective criteria achievement levels (performance scores). The performance scores will be derived with respect to every objective. The outcomes will be presented in an evaluation table in the form of an alternative vs criteria.

No.	Objective	Performance Scores Alternative			
		I	II	III	IV
1	Cost	5330959	5899381	5704387	6336187

Presentation of the results in a table will make it easier to perform the other steps in the evaluation procedure.

6.6 ATTRIBUTE PERFORMANCE RATINGS

The alternatives-objectives performance and scores have both qualitative measurements and quantitative measurements. To enable aggregation of impacts and the incorporation of weights, the objective's achievement levels are transformed into attribute ratings. Also, numbers are more easily manipulated than qualitative measurements and thus make calculations easier. The following procedures are used to estimate the attribute outcomes.

6.6.1 Rating Assignment Method A - Use of Minimum and Maximum Likely Values of an Objective

A1 For each objective identify the maximum likely and the minimum likely outcomes which are expected to occur and where necessary the most desirable and the least desirable.

A2 Define a rating scale of 0 (minimum) and 10 (maximum).

A3 Transform all the alternative-objective achievement levels into achievement ratings on the scale of 0-10 with respect to each objective.

A4 Summarise the results into the table of outcomes.

6.6.2 Rating Assignment Method B - Anchoring of one Extreme Value.

B1 Consider the set of alternative objective performance scores. For each objective there are extreme points which represent both the preferred value and the worst value. Anchor the extreme point that represents the preferred value for the objective and compare all the other values to this value. In this work a percentage of the preferred value will be used.

B2 Repeat for all the other objectives and adopt these results as the attribute outcome ratings.

6.6.3 Rating Assignment Method C - Anchoring of Two Extreme Values

C1 Anchor the two extreme values for each objective criterion.

C2 Using the two anchor points as the basis for comparison, rate all the other values by interpolation. For this work, a scale of 0-10 is adopted with 10 representing the best value and 0 the worst. The criterion ratings can be represented by:

$$\frac{P_{ij} - P_{wi}}{P_{bi} - P_{wi}}$$

Where P_{ij} = performance of alternative j with respect to the i objective,

P_{wi} = worst (extreme) performance score with respect to the i objective, and

P_{bj} = best (preferred extreme) performance score with respect to the i objective.

The above implies that there is a zero impact for at least one alternative in each objective.

6.7 EVALUATION PROCEDURES FOR DETERMINING THE ALTERNATIVE'S TOTAL RELATIVE WORTH

The final step in the evaluation framework is the combining of the objectives (criteria) for each method into a value structure from which the decisions can be made. After a review of the available methods (chapter 4 & 5) and given the nature of the evaluation problem, the following procedures were adopted for use in this work.

6.7.1 Method A - Weighted Summation

Given the weights derived for the objectives and the alternative's achievement ratings for each objective:

A1 Multiply the weight of the objectives with the achievement ratings for each objective.

A2 Add the weighted value for each alternative to derive the total weighted value.

A3 Accept the alternative with the highest total value points.

6.7.2 Method B - Weighting Summation with Elimination

B1 From the alternative objective's achievement levels table, exclude all alternatives that do not meet desired performance scores with respect to any one objective.

B2 Perform steps A1-A3 above on the remaining alternatives.

Note: In this work no alternative can be excluded on the basis of a weighted summation as defined above.

6.7.3 Method C - Weighting Summation with Importance Based on Pre Evaluation Weights and Performance Weights.

The outcomes of the alternatives (performance scores) are a relevant influence on the objective's weights i.e the importance of the difference between alternatives with respect to the criteria. Thus, the weighting importance attributed to the objectives will be based on the weights derived before knowing the performance values and after derivation of the performance values.

C1 Derive the pre evaluation weights to represent the importance of the objectives.

C2 Derive the importance rating that reflects the importance of the difference between alternatives with respect to the criteria.

C3 Combine the two weights. In this work the two weights will be combined by multiplying.

i.e $$W = \frac{w_i' \times w_i}{\sum_{i=1}^{m} w_i' \times w_i} \qquad i = 1.....m$$

C4 Adopt this weight as the weight assigned to the objective.

C5 Using this weight, perform a weighting summation as in steps A1-A3 above.

6.8 SUMMARY

The procedures described above were tested on a hypothetical project situation to determine whether they are practical for application in the choice of construction methods. The direct weight assessment methods tested are ranking and rating weighting approaches. The attribute rating methods tested use maximum and minimum values of an objective, anchoring of one extreme objective value and anchoring of two extreme objective values. The final evaluation procedures tested are weighted summation, weighted summation with elimination and weighted summation with pre evaluation weights and performance weights.

CHAPTER 7

PROCEDURE DISCUSSION

7.1 INTRODUCTION

The evaluation procedure for use in this work is presented in chapter 6. This chapter discusses the ideas developed in that procedure in so far as this particular evaluation problem is concerned. The choice of objectives, the construction methods and the influence and importance of the outcome will be discussed.

7.2 CHOICE ANALYSIS

The construction techniques being considered are basically different combinations of labour and capital resources in construction. Road construction can be broken down into a series of tasks. The tasks are made up of activities. Considered at the activity level, resource factor inputs to produce a required constructed output, can be specified and measured. In this methods choice problem, the choice analysis then is which combination of factor inputs represents the best method for producing the required output.

The previous work done uses the idea of construction costs (price information) only to compare the different techniques. Consequently the technique selected is the one characterised by the lowest cost. However, many factors, (objectives), are involved in the selection of the preferred solution. Apart from the costs, other technical and socio-economic objectives are considered. These have both an importance rating (weighting) and a performance rating. The importance is in relation to other objectives. The performance rating is also relative to the other alternatives. If the objectives are considered as sub problems to be solved by the choice of construction method, the range of alternatives can be searched for possibilities for responding to these problems.

Multiobjective decision models seek to express a problem in terms of a number of objectives each of which is independent of the other. In the case being considered, a variation of these models will be used but the objectives are interconnected, i.e. the choice options in one objective is affected or constrained by a choice in another. Each objective describes an opportunity for choice which can be selected as a course of action, i.e. for each objective a number of different courses of action can be defined. The objectives can be used to express the decision areas for a choice of technique.

The collection of objectives can then be used to define the alternatives, e.g. labour based. The links between the objectives may;

(a) indicate conflict - thus a trade-off is required and the achievement of one objective would require a sacrifice in the other,

(b) be mutually enhancing - then it is possible to attain an increase in objectives as any objective that is is increased would enhance (promote) the other as well,

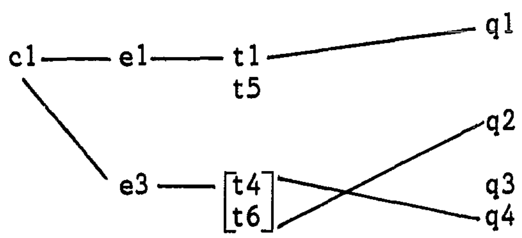
(c) or independent - the achievement of any objective does not influence the others.

e.g. Objectives

Cost		Employment		Time		Quality	
Low	c1	High	e1	Fast	t1	High	q1
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
High	cn	Low	ex	Slow	tx	Low	qx

The combination of feasible objective links is used to describe the options.

e.g. Options



The links above are possible links representing alternative objective scores, e.g. Cost - c1, Employment - e1, Time - t1, and quality - q1.

Only feasible and viable options should be considered for evaluation. The choice of objectives and decision criteria reflect the considerations in the choice of technique and thus form a degree of independence.

7.3 ANALYSIS OF INFLUENCE OF OUTCOMES ON IMPORTANCE

The method proposed for use in this work is derived from the multiobjective procedures reviewed elsewhere in this work. The method requires that objectives be set, and weightings or importance of the objectives be assigned. The alternatives are then evaluated with respect to the individual attributes to provide the preferred solution.

In mathematical terms:
with i objectives (attributes) $i = 1 \ldots\ldots m$

w_i = weights attaching to performance variables $i=1 \ldots\ldots m$

X_j alternatives where $j = 1 \ldots\ldots n$ alternatives,

Then alternative $X_j = (X_{ji} \ldots\ldots X_{jm})$

where X_{ji} is the status of alternative X_j with respect to the ith attribute.

For evaluation, $X_j = \sum_{i=1}^{m} w_i X_{ji}$

where X_j = total worth of alternative j.

The preferred alternative is the alternative having the highest total overall worth.

Evaluating alternatives using the multiobjective methods is usually attractive as it is conceptually simple where choice is concerned. In evaluating the multiobjective alternatives, certain independence conditions among attributes are required. Then an overall preference structure among the attributes is derived. This can be seen as identifying what really matters in the decision process. Evaluations on the individual attributes are then obtained as independent subsets of the overall preference structure. In the multiobjective evaluations, apart from the performance scores of the attributes, the set of feasible alternatives does not play a part in the determination of the preference structure.

e.g. Consider three objectives A, B, C.
Based on the consequences of employing them, the following weights are

derived by direct assessment. C is the least important thus a value of 1, B is twice as important as C thus a value of 2 and A is 1.5 times as important as B thus a value of 3. Therefore by summing up the values and dividing by the total, the weights are; A = .5, B = 0.33 and C = 0.17.

If the objectives are independent, then any variation in A will not affect B or C. To evaluate any alternative, only the performance scores (outcomes) with respect to the particular objectives are required and the overall worth can be determined. i.e. the performance scores are assumed not to effect the overall preference structure.

In this work the independence of the objectives from the others is assumed. This is necessary because they describe an opportunity for choice which can be selected as a course of action. Thus although weights corresponding to the general preference structure are important, the preference structure also depends on the particular outcome ranges for the alternatives(feasible set). i.e. there is a change in weights (importance) reflecting their dependency on a particular set of feasible alternatives.

e.g. Consider the following examples. (Table 7.1) Each of them can be considered a feasible set of alternatives. They all have the same objectives but are considered to represent different decision situations. e.g. different projects in different areas. Two objectives, cost and employment are considered.

The assigned weight, based on cost, is 1.5 times as important as employment. Therefore $C = 1.5 => W_c = 0.6$

$E = 1 => W_c = 0.4$

TABLE 7.1

	PROJECT U			PROJECT V			PROJECT W		
Alternatives	A_u	B_u	C_u	A_v	B_v	C_v	A_w	B_w	C_w
Cost	(10)	10.6	11	(10)	20	30	(20)	26	30
Employment	50	60	(75)	100	110	(115)	100	130	(150)

Encircled are the best performances given the set of feasible alternatives. In the example above the trade-offs between the two objectives can be easily evaluated. Considering the outcome ranges and using percentages,

U: A 10% increase in cost results in a 50 % increase in employment,
V: A 200% increase in cost results in a 15 % increase in employment,
W: A 50% increase in cost results in a 50 % increase in employment.

If we assume that the decision on importance is independent of the outcomes, the weights as derived initially would be used to select the preferred solution. i.e. 0.6C + 0.4E.

However, what could be expected is a re-assessment of weights and a shift in the importance values in spite of what might have been the initial weight. i.e. the decision process would involve the constant re-assessment of weights to get the appropriate weights for a particular situation. e.g. possibly for the above examples,

For U. A 10% increase in cost results in a 50% increase in employment. Cost may be considered to be not significant and the importance of employment in the decision increases.

For V. A 220% increase in cost results in a 15% increase in employment. Cost may be considered to be very significant and the importance of employment in the decision decreases.

For W. A 50% increase in cost results in a 50% increase in employment. In this case the initial weights as derived could hold as the differences in both costs and employment are significant.

Before any choice of alternatives is made it has to be carefully examined against the range of potential solutions to the problem. The importance of the objectives is both a function of value judgements and factual information presented by the alternative outcome ranges. For the practical application of the method, there is a need to constantly re-evaluate or reassess the importance of the objectives given the performances ranges of the alternatives. This needs a systematic method of reappraisal.

7.4 APPROACHES

Some possible approaches to this problem are:

7.4.1 Derive Weights for Different Ranges of Outcomes

In this approach, different weights are derived to reflect the importance of the difference between the alternatives with respect to the criteria being considered. e.g. for cost, if the cost difference between the alternatives is, 0 - 10% then weight is W_1, 10 - 20% then weight is W_2.

This is practical especially if only two objectives are being considered. e.g. A method already used in practice is as follows. In contract tender evaluation, the lowest tender by a prequalified contractor forms the basis for the tender award. In some cases, it has been the practice to award the contract to a local contractor if the tender sum is within 10% of the lowest tender and the lowest tenderer is foreign. In this case, considering cost and development of local contractors as objectives, the following weights based on outcome ranges where local contractors are favoured can be inferred.

i) Range > 10% : importance of cost is very high thus the major criteria for selection of contractors.

ii) Range < 10% : Cost is still important for the general situation but for this particular situation the favouring of local contractors is the major criteria as the difference in cost is "insignificant".

When considering many objectives, this method may be impractical because without knowing the performance values getting the appropriate weight or deciding on the relative importance of the criteria is difficult. The performance values are determined only after analysis of the feasible set.

7.4.2 Analysing Trade-offs

Trade-offs are analysed by pairwise comparison with all objectives and the importance of the objectives for the particular application are derived. This may be done in a similar way to the example in Table 7.1 above. However, this may be impractical as with many objectives the trade-off analysis could become too complex and confusing, e.g. for this work with 9 objectives, 36 comparisons are required if no objective combination is to be disregarded.

7.5 POSSIBLE PRACTICAL APPROACHES

Possible practical approaches would be to use modifications of the above two approaches whereby in addition to the initial weight structure, the importance can be reassessed depending on the outcomes for all attributes. i.e. all attributes can be considered at the same time. The following two methods will be considered.

7.5.1 Derive Initial Weights and Performance Weights by Direct Assessment

In this method the initial weights before the data on attribute ranges is available and the the weights reflecting the differences in alternatives performance scores are derived in the same procedure as below.

7.5.1.1 General Weights

Direct assessment methods are used to derive the general weights reflecting the value structure of the decision (initial weights) for each objective before the data on performance ranges is available. This gives the preference structure for the general situation.

7.5.1.2 Revised Weights

The objectives weights are derived using the same procedure as above after the data on attribute ranges is available depending on the information content transmitted. By comparison with the initial weights it can be determined whether the performance scores can significantly influence the importance rating of the attributes.

This method implies constantly having an overall view on the alternatives outcomes when reassessing and checking for likely effects on the other objectives. i.e. when checking for possible trade-offs between two objectives, the likely effects of these trade-offs on all other objectives outcomes are considered at the same time. This method could be practical especially when familiar with the problem as the decision is being considered for and with the derivation of weights. The familiarity required, and hence suggested reliance on a knowledgeable professional, could also be a shortcoming for the method in what should be essentially an analytical procedure.

7.6 CALCULATION OF RELATIVE IMPORTANCE

Another approach is to use the method proposed by Zeleny (1977). In this method Zeleny proposed the use of a measure of relative importance or "attention level" associated with any attribute.

Define W_i as a measure of relative importance or attention level associated with the ith attribute. Then W_i incorporates two distinct components,

w_i = a relative stable component of the attributes importance representing the decision maker's value judgements, and

w_i' = a changing concept of the situational importance or the attention level based on a particular problem structure as it is reflected in the composition of the set of feasible alternatives. These weights change with the set of feasible alternatives and with changes in the information generated by the feasible set. It reflects the importance of the difference between alternatives with respect to the criteria.

The two components are then combined by multiplying.

$$W_i = \frac{w_i' * w_i}{\sum_{i=1}^{m} w_i' \, w_i} \qquad i=1 \; ..... \; m$$

The weights assigned to the attributes as a measure of importance for a given decision situation reflect both the general value judgements and the factual information presented by the set of feasible alternatives. i.e. initial weights and revised weights as a result of performance assessment.

7.6.1 Derivation

Define W_i = importance (weight) for the ith attribute for a specific situation

w_i = importance rating reflecting value judgement for attribute i

w_i' = changing (situational) attention level reflecting the information content for the particular set.

X = a set of feasible alternatives.

w_i is determined by the direct assessment of weights.

7.6.2 Derivation of w_i'

w_i' is the measure of the contrast intensity of the ith attribute, i.e. the more distinct the individual attribute scores the larger the corresponding w_i'. This infers as in the example above (in A), cost is the most important attribute but if all costs are within the range of less than 10% it is no longer considered the most important criterion in selection, i.e. w_i' tends to zero.

$x_i = (x_{1i} \ldots\ldots x_{ni})$ describes the set X in terms of the ith attribute.

X has m objectives 1 ..... m and
n alternatives 1 ..... n

Individual x_{ji} (alternatives performance scores for the ith attribute) represent the transformed performance based on the best performance.

To each x_i assign a measure of contrast intensity denoted by $e(x_i)$

Also define $$X_i = \sum_{j=1}^{n} X_{ji} \qquad i=1 \ldots\ldots m \qquad (1)$$

Since X is a finite set, an entropy measure is adjusted to measure $e(x_i)$ as: (ZELENY)

$$E(x_i) = -K \sum_{j=1}^{n} (x_{ji}/Xi) \ln (x_{ji}/Xi) \tag{2}$$

where K = a constant > 0 and $e(x_i) >= 0$
if all x_{ji} are equal to each other for a given i,
then $x_{ji}/Xi = 1/n$ and $e(x_i)$ takes on the maximum value e_{max}.
Then $e_{max} = \ln n$.
Setting $K = 1/e_{max}$, we get $0 =< e(x_i) =< 1$ for all x_i.
The above is a normalisation of $e(x_i)$ which makes it easier for comparative purposes

From the above, the total entropy of X is defined by

$$E = \sum_{i=1}^{m} e(x_i) \tag{3}$$

The measure of contrast intensity of the ith attribute can be transformed into a weight of importance as a function of (2) as follows

$w_i' = [1 - e(x_i)]/(m - E)$ where m = number of attributes.

A change in X is thus reflected in a new set of w_i'. i.e. changes in $_{ji}$'s trigger changes in contrast intensities of individual attributes.
with w_i' and w_i

$$W_i = \frac{w_i' * w_i}{\sum_{i=1}^{m} w_i' w_i} \qquad i=1 \ldots\ldots m$$

7.6.3 Application Example

With three objectives, cost, employment and ADT = f (quality).

The following initial weights are assigned by direct assessment. Ranking from least important to most important, ADT = 1, Employment thrice as important as ADT = 3 and cost = 2*E = 6. Summing 1 + 3 + 6 = 10. Dividing the values by the sum to get weights,

$w_{c1} = 6/10 = 0.6$
$w_e = 3/10 = 0.3$
$w_q = 1/10 = 0.1$

Consider four feasible alternatives with the following achievement levels (table 2).

TABLE 7.2

OBJECTIVES	ALTERNATIVES				
	w_i	U	X	Y	Z
Cost	.6	(10)	10.5	11	11.5
Employment	.3	110	100	90	(150)
ADT	.1	500	500	(600)	400

Alternative U could be an intermediate method tending towards a labour based method.

Alternative X could be an intermediate method tending towards a capital based method.

Alternative Y could be a relatively capital based method.

Alternative Z could be a labour based method.

Encircled are the best performance scores given the set of alternatives. Converting the above performance scores into attribute scores where 10 is the best score and the others are expressed as fractions of the best in this example, table 3 results.

TABLE 7.3

OBJECTIVES	ALTERNATIVES					
	w_i	U	X	Y	Z	$=X_i$
Cost	.6	10	9.5	9	8.6	37.1
Employment	.3	7.3	6.7	6	10	30
ADT	.1	8.3	8.3	10	6.7	33.3

Calculate $e(x_i)$ according to 2
$K = 1/e_{max} = 1/\ln 4 = 0.7213.$

TABLE 7.4

	x_i/X_i			$x_i/X_i * \ln(x_i/X_i)$		
ALTERNATIVES						
	1	2	3	1	2	3
U	0.270	0.244	0.249	-0.354	-0.344	-0.346
X	0.256	0.223	0.249	-0.349	-0.335	-0.346
Y	0.242	0.200	0.300	-0.344	-0.323	-0.361
Z	0.232	0.333	0.242	-0.338	-0.366	-0.323

From (2)

$$e(x_i) = -K \sum_{j=1}^{n} (x_{ji}/X_i) \, 1N \, (x_{ji}/X_i)$$

Thus $e(x_{cost}) = 0.999$, $e(x_{emp}) = 0.986$ and $e(x_{adt}) = 0.993$.

From (3) $E = 2.978$, therefore $m - E = 3 - 2.978 = 0.022$.

But $w_i' = [1 - e(x_i)]/(m - E)$ where m = number of attributes.

Therefore

$$w'_{cost} = 0.046 \quad \text{and} \quad W_{cost} = 0.108$$

$$w'_{emp} = 0.636 \quad\quad W_{emp} = 0.765$$

$$w'_{adt} = 0.318 \quad\quad W_{adt} = 0.127$$

from

$$W_i = \frac{w'_i * w_i}{\sum_{i=1}^{m} w'_i \; w_i} \qquad i=1 \; \ldots\ldots \; m$$

The two sets of weights are used to compare the alternatives overall worth by summation of weighted attributes (Table 5)

TABLE 7.5

ALTERNATIVES							
OBJECTIVES	w_i	U	X	Y	Z	$=X_i$	W_i
Cost	0.6	10	9.5	9	8.6	37.1	0.108
Employment	0.3	7.3	6.7	6	10	30	0.765
ADT	0.1	8.3	8.3	10	6.7	33.3	0.127

$w_i \; x_{ji}$	9.02	8.54	8.2	8.83
$W_i \; x_{ji}$	7.72	7.21	6.83	9.43

From the results, alternative U is chosen if the weights independent of the performance scores are chosen. Alternative Z is chosen if the weights are dependent on the performance scores. From the above it can be inferred that the marginal distribution of costs among the alternatives is not significant and thus the alternative that creates the most employment is the preferable one. Thus the employment objective can be given more weight for this particular application.

7.7 SUMMARY

In this chapter a method for calculation of the relative importance of objectives based on the performances of the set of alternatives has been presented. Since the aim of this work is to validate the evaluation procedure, application of a hypothetical example to a real project situation, with more objectives than the above example, will determine whether the method is appropriate for application in construction.

CHAPTER 8

APPLICATION (THE DERIVATION OF PERFORMANCE SCORES)

8.1 THE PROJECT INVESTIGATED

A hypothetical road project is to be investigated by applying the evaluation methods developed in Chapter 6. The project location is not restricted to any particular site although it represents typical projects being undertaken. The size and location (assumed to be linking population centres) has been chosen so that there are no significant effects or constraints on the construction methods being considered, such as special provisions for worker accommodation and travel. In order to compare the suitability of the available construction methods, it is necessary to know the amount of work to be done, i.e. the output required. From this information the resource inputs each construction method needs in order to achieve the given output can be determined. This forms the basis for the determination of the performance achievement of the objectives by the different construction methods.

8.2 DESCRIPTION OF THE WORK

Usually the amount road construction work is described by a number of different items. These items normally appear in the bills of quantity, e.g. excavate to fill in soft material. The items refer to the construction tasks to be undertaken. The items could consist of one task or can be broken down into different tasks, e.g. *excavate to fill* may be broken down to freehaul and overhaul as different methods may be used for the two haul distances. The tasks consist of a number of separate activities; *excavate to fill* includes excavation, loading, hauling, unloading, spreading and compacting. (ELHUSC)

A description of the works, taken from the items that would appear on bills of quantities, is necessary before a choice of methods can be made. The items listed are the ones that offer the most scope for the use of different construction methods particularly the substitution of labour for capital.

The major work items are:

the construction of an 8.5 kilometre road with a 6.5 metre carriageway and 1 metre shoulders.

The work will consist of:

site clearance, earthworks, culverts and drainage works, gravel base and shoulders.

For the purpose of this work the following items, although common in roads, have not been included. (An estimate will be made which is based on percentages of other work items to arrive at a total project cost.)

i) **Preliminary and general items**
These are usually for the provision of services and as such do not have much effect on the construction method.

ii) **Bituminous surfacing**
Surface dressing (treatment) is the major option used for bituminous surfacing. Specialised equipment (e.g. bitumen distributors and pavers) are required for this operation. This equipment is particular to this operation and is not used for any other operation. Consequently it is assumed that it does not affect any construction method.

iii) **Road furniture**
Posts, markers and signs. There is very little scope for the use of different methods in this operation.

The work quantities are listed in Table 1 in Appendix 1. The quantities listed have been derived to represent as far as possible the quantities in a practical project.

8.3 CONSTRUCTION METHODS OPTIONS

General

As noted in previous chapters, there is a number of feasible and viable construction methods which can be used to construct roads. Basically these methods consist of the substitution of factor inputs and in particular capital and labour. The method which is appropriate is the one that efficiently utilises resources given the various factor endowments. The development of the different construction methods is considered an engineering problem and the methods considered will be the ones that are technically efficient and also socially desirable.

In this work, terms such as labour intensive and capital intensive are considered inappropriate. The above descriptions imply inefficient adoption of techniques without considering the possibilities of combining the different resources as is the practice. For example, capital intensive means over-reliance on techniques developed in industrialised countries at less than efficient rates leads to machines which are a complicated version of what can be done manually. Lack of operators, low utilisation rates (as compared to manufacturers recommendations) and lack of spare parts tend to make these techniques inefficient.

Labour intensive
Use of labour linked to employment creation schemes without consideration of the technical efficiency. There is a wide scope for substitution of labour in construction but the use of labour in some tasks is inefficient. e.g. in roadworks, hauling and compaction. The use of such techniques have led to the belief that labour based techniques are inefficient.

The use of mainly labour based construction methods, given the availability of labour and lack of capital, by the substitution of as much labour as possible leads to technically efficient construction methods and also achieves the social objectives.

8.3.1 Construction methods considered

In this work, four construction methods will be considered. These are:

i) mainly capital based,

ii) capital based but with labour substitution in some activities,

iii) labour based but with capital substitution in critical activities,

iv) efficient although mainly labour based.

Development (generation) of the above construction methods will be based on the use of the various factor inputs to produce the given output. The achievement of the construction methods will then be evaluated for performance as per the objectives.

Table 4, Appendix 1 lists the various methods with the quantities of resources required to produce the given outputs.

8.4 PRODUCTIVITY OF FACTOR INPUTS (RESOURCES)

8.4.1 General

Productivity can be defined as the amount of output produced by the inputs per time period. Using the above definition,

Labour productivity = Output/hours of labour input
Machine productivity = Output/hours of machine input.

A knowledge of productivity of the input factors for the different activities is necessary for the determination of the resource inputs required to perform a work task for the different construction methods. From the productivity, both the amount of resources (e.g. size of labour crew) and duration of activities can be determined.

The determination of reliable productivity rates is usually a difficult task. This is mainly due to lack of accurate productivity data as often records are either unavailable or where available their accuracy is questionable.

Variation of productivity rates with conditions of operations both for men and machines. These include;

- environmental conditions,
- physical features,
- uniqueness of many projects such that there might be differences in doing any activity for two projects,
- workers' skills and motivation,
- availability and allocation of resources,
- management in both planning and supervision.

To enable an assessment of the different methods of construction to be made, the productivities of the various factor inputs have to be estimated. The estimation of the productivities can be made by the use of available data sources. In this work, productivity rates will be based on data accumulated in studies in Kenya and similar studies elsewhere.

8.4.2 Sources of Productivity Data

Productivity information can be acquired from various sources, some of which are listed below.

i) Analysis of productivity on the project site. This may involve correcting data over a long period of time or the use of "scientific methods" such as work sampling, motion analysis and time study. These methods may provide the most reliable data. The fact that the analysis is carried out during project execution may make the methods inappropriate for the planning situation.

ii) Use of manufacturers recommended productivity rates modified to a particular situation.

iii) Use of historical data from government departments or contractors.

iv) Data from studies from organisations especially those concerned with similar work to this study. These are such organisations as the ILO, IBRD, The World Bank and Transport and Road Research Laboratories(TRRL).

Sources ii, iii and iv will be used in this work. In particular, the fourth source can be considered most appropriate, (especially for studies in substitution of factor inputs), as the studies have used data derived from all the other sources providing empirical analyses of ongoing projects and historical data. The productivity data is then presented in an easily available and usable form. For the purpose of this work, the productivity data from these other studies can be considered adequate. For labour productivities, especially the Kenyan situation, the data from the Rural Access Road Programme (RARP) can be considered reliable for the scope of this study. For machine use where the data is not readily available, modified manufacturers' ratings and utilisation rates will be used.

It should be noted that given the aim of this study, the productivity data used is not an exhaustive study of the subject but data taken to reflect real project productivities so that the investigation of the evaluation methods can be performed.

Note: The derivation and validation of productivity data is an area where *rapid rural appraisal methods*, discussed elsewhere in this work, could be used to minimise the cost of data collection. Examples would include the observed rate of agricultural work to reflect particular tasks in roadworks and site clearance.

8.4.3 Productivity of Operations

The productivities used in this work are given in Table 2, Appendix 1.

8.5 DURATION OF THE WORK

For each method of construction, the rate of work and the schedule of operations, considered at the same time, determine the total duration of the job. Both the rate of work and work schedule are dependent on the resources available to do the work and the time available to do the job if the resources are unlimited. In this work, equipment resources will be considered as limited and thus govern the duration of activities while labour will be considered surplus so that an activity can be performed at any rate. This can be justified on the basis of the literature surveyed whereby there is a labour surplus and lack of capital resources.

8.5.1. Rate of Work

To determine the duration of activities (in days, weeks or months), it is necessary to know both the utilisation rates of the resources and their availability.

8.5.1.1 Utilisation and quantity of output

Utilisation refers to the efficiency of the input factors in producing the output. Utilisation is dependent on the operating conditions, manouevring, waiting time and operator skills for machinery. Utilisation forms the basis of productivity and the duration of an activity can be be determined as;

Duration = Work Content / Productivity

e.g. For site clearance,

Quantity = 340000 m^2

Critical output = bulldozer = 340000/4500 m^2/hr = 75 hrs.

The duration of the activities, given the various factor inputs required for this work, are given in Appendix 1, Table 5. It should be noted that these durations are the actual working times required by the various factor inputs to produce the output, e.g. if the bulldozer is working for one hour then it will have produced that output. As in most cases the cost is based on the output, these durations help in determining the total inputs required.

8.5.2 Availability and the Actual Duration

The availability of resources refers to the times the resources are actually available to do the work. The resource availability is a factor of resource management or allocation. When applied to machinery this means the time allocation for a job including downtime for maintenance, breakdowns and repairs. Studies (e.g. Jones and Robinson, 1986) have shown that availability of resources is a critical factor in the determination of the duration of an activity. For any activity, the actual duration is the time required to do a job given the availability of resources. In this work, an availability factor of six hours per day will be adopted as this has been shown to be the average availability factor for Kenya.

For the example above

Duration = 75 hours. i.e. 75 hrs of work is required.
Actual Duration in days = 75/6 = 12.5 days.

The actual duration is important especially for labour as most wages are based on a daily rate.

8.5.3 Schedule of Work

The schedule of operations is the series of activities (operations) which must follow in order to complete the project. There are a number of techniques, each with varying degrees of sophistication, that can be used for scheduling operations. They include Barcharts and Critical Path Method (CPM). The CPM, which is based on a network diagram, is a powerful tool for scheduling construction operations. However, the network diagram may prove difficult to use in road construction projects because tasks are usually presented as total work per item while road construction involves the continuous output of finished work with most activities being carried out at the same time. Because of this aspect of road construction work, producing the detailed logic relationship, necessary for deriving the network for the different items, may prove difficult. Earthworks are a good example as excavation in normal and excavation in hard materials are given in quantities for the total project as two different items while in most cases both tasks take place at the same time and in most instances use the same equipment.

If the durations of the tasks are combined, the total duration of the tasks can be determined. In this work the scheduling of operations was based on limitations of equipment for tasks using similar equipment and start to start logic relationships for other tasks but without the use of network diagrams. From the schedule of operations, the total duration of the project was determined. Table 5, Appendix 1 gives the total durations of the different construction methods used in this example.

8.6 COST OF INPUT FACTORS

The costs associated with the different construction methods are necessary for determining total project costs as an objective for comparison and as a basis for determining other objectives' performances, particularly foreign exchange, income distribution and financing. These performances are determined by consideration of the cost of resources used in the project. The costs associated with material resources will not be considered as the aim in the evaluation of construction methods producing the same output. The following costs will be considered;

i) Equipment costs,

ii) Skilled labour costs,

iii) Unskilled labour costs,

iv) Cost of tools.

8.6.1 Sources of Cost Information

In this trial application of the evaluation method the costs will be based on the following;

- Hourly unit rates for equipment based on contract sources in Kenya,
- Prevailing wage rates for construction workers for both skilled and unskilled labour,
- Tools - costs of tools are usually 5-10% of the total of labour costs in labour based projects (EDMONDS 1982) and this value will be taken to apply to this work,

The costs used for this study are presented in Tables 3 and 4 in Appendix 1.

Use of Cost Information

With material costs being excluded, the cost information can be considered to be basic equipment costs and labour costs. This section deals with the use of this cost information for the purposes of this work.

8.6.2 Equipment Costs

Equipment costs can be divided into ownership costs and operational costs.

The ownership costs are the costs associated with owning the piece of equipment as an investment and include;

- depreciation and interest rates derived from the delivered price of the machine,
- insurance and taxes, and
- major maintenance costs.

The ownership costs are those costs involved in the actual running of the machine. They include fuel, lubricants, filters, routine on-site maintenance, tyre costs and operator wages.

In this work the hourly cost rate used is assumed to take into account all the above costs apart from the operator wages which are considered under skilled labour.

8.6.3 Total Project Cost Due to Equipment Cost

The listed equipment costs are taken to be the actual hourly use cost for each piece of equipment. The cost of equipment allocated to the project will be this hourly rate multiplied by the productive hours devoted to the project to produce the required output.

8.6.4 Foreign Exchange Cost

Foreign exchange costs are usually attributed to equipment costs and certain material costs. In this work, materials are not being considered for evaluation and the foreign exchange costs are attributed to equipment use only.

The foreign exchange cost allocated to the project will be based on the following;

i) no new machinery so the capital cost of the equipment will not be considered. It is assumed that the foreign exchange cost component has already being expended and need not be considered further,

ii) The foreign exchange cost is attributed to fuel costs and spare parts as all are imported. For an estimate of these costs, the factors will be used; (BEENHAKER 1987)

Fuel - 20 litres per machine horsepower per month for single shift work,

Lubricating oil - 0.5 litres per machine horsepower per month for single shift work.

Spare parts (repair factor) 0.10 multiplied by hourly cost (less fuel and lubrication cost) for wheeled vehicles and 0.12 multiplied by hourly cost (less fuel and lubrication cost) for tracked vehicles.

8.6.5 The Shadow Price of Foreign Exchange

The official foreign exchange rate is assumed to be often distorted as a result of government policies. The shadow price of foreign exchange values foreign exchange in terms of the price domestic consumers are willing to pay for a foreign exchange unit worth of imports. The value of a unit of foreign exchange can be expressed in terms of local currency by the value of imports it makes possible. The shadow exchange price of foreign exchange used in this work is based on the following relationship (McCLEARY 1976)

$$S^F = P^F \text{ [1 + average import tariff + average export subsidy]}$$

where P^F = official exchange rate.

The writer has taken the average export subsidy as zero as there are no direct export subsidies. The average import tariff is 30%. This is an estimate used for this work taking into account tariffs, business taxes and exemptions granted to certain imports for development purposes such as agricultural equipment.

From the above,

Shadow price of foreign exchange = 1.3 times the official exchange rate.

8.6.6 Labour Costs

The cost of labour in this work affects mainly the total project cost and income distribution.

8.6.6.1 Total Project Cost

The labour rates used are the prevailing wage rates in Kenya. In this work, the costs are daily wage rates. The cost to the project is the number of man-days work multiplied by the wages.

8.6.6.2 Income Distribution

For the purposes of this work, the income distribution will be taken as the average wages earned per project at market rates and converted to a shadow rate.

8.6.7 Estimation of Shadow Costs for Skilled and Unskilled Labour

8.6.7.1 Unskilled Labour

The shadow wage rate for unskilled labour is the determination of the real cost of employing an additional worker on the project. To derive the shadow wage cost it would be necessary to know the following;

- the alternative output foregone,
- the marginal propensity to save of taxpayers and workers. The shadow price of savings which involves determining the social discount rate and the marginal interest rate.

The determination of the above is at best difficult given the lack of explicit data. Assuming that the unskilled workers are unemployed before the project, determination of the output foregone is difficult to ascertain given the informality of any work they might have been doing. This applies especially in the rural areas. Studies have shown that the shadow wage rates for urban and rural unskilled labour are between 0.5 and 1.0 of the market wage rates. Given the scope of this work and the questionable derivation of the actual shadow wage rates, a shadow wage rate estimate of 0.75 of the market wage rates will be adopted, i.e. halfpoint between 0.5 and 1.0.

8.6.7.2 Skilled Labour

Using the argument above, the real cost of employment of skilled workers can also be taken as the shadow wage rate. In this work, since the shadow wage rates are not known, the above estimate of 0.75 of the average market rate is adopted.

For the income redistribution objective purposes, the total shadow wages are taken as the income redistributed. If it is assumed that the project is financed by taxes, then the taxpayer loses to provide income for the workers.

e.g. For Construction Method 1

Total Man-days Skilled = 2988 Average wage = 65.57
Total Man-days Skilled = 2967 Average wage = 43

Income redistributed
Skilled = Man-days by average shadow wage rate = 2988 *65.57 *0.75
= 146942.

Income redistributed
Unskilled = Man-days by average shadow wage rate = 2967 * 43 * 0.75
= 95686.

8.7 DISCUSSION AND SUMMARY OF INPUT DATA

To undertake the evaluation, the performances of the different construction methods with respect to the objectives form the basis for comparison. The derivation of these construction methods is in turn dependent on the input data used. This section discusses the significance of the input data on the results of the evaluation. The discussion will deal with the technical and socio-economic input data.

8.7.1 Technical Data

The construction methods are identified by the resources that are used in achieving the construction output. The resources that were used for the construction methods in this work are listed in Table 5, Appendix 1. The use of these resources is dependent on a number of variables. The basic variables are productivity, cost and availability. Identifying and measuring these variables and their relationships is necessary before they can be used as a basis for describing construction methods. The construction methods involve labour and equipment substitution. In this discussion, it was felt necessary to discuss the two elements separately. Appendix 1 - Tables 2 and 3 and section 8.3 describe the input data used in this work and the sources of the data. The following are observations on the input data used.

8.7.1.1. Equipment Input Data

The input values that have a great significance on equipment performance scores are the productivity, choice and cost of the equipment.

Productivity

Productivity figures for machinery vary significantly. Using information from various sources e.g. ILO and RARP (Appendix 1, Table2) productivity was found to vary between 60% to as low as 5 or 10% of the manufacturers' recommended ratings. Due to this variation, a choice of productivity could easily affect the suitability of any construction method. A detailed study to develop allowable input values for productivity per task is necessary.

Choice of Equipment

Choice of equipment is necessary when defining construction methods. In the work reviewed in this report, equipment choice is considered by task, and the choice of motorscrapers illustrates this. The motorscrapers are a very efficient means of earthmoving but are used only in earthworks. By considering equipment by task, a diversity of specialised equipment could fill a resource list. A choice of equipment based on flexibility and versatility in most tasks would be more appropriate. There could be fewer equipment resources but extra versatility and a smaller spare parts inventory would allow better management.

8.7.1.2 Labour Data

A labour surplus and the possibility of substituting labour for machinery in many construction operations has led to development of viable labour based methods. In this and other work the procedure for setting up labour based methods is to determine labour productivity, the crew size and use prevailing wages to cost the alternatives. Lack of information relating to the relationship between crew size, performance and wages has prevented the investigation of many potential alternative labour based methods. To adequately define and fairly compare labour based methods it is necessary to determine the following before a decision on productivity and wages (costs) can be made.

- Availability and willingness to work (instead of assuming availability)
- Diligence of the workers
- Effects of incentives on output

If the above are taken into account, then labour based methods can be fairly compared to other methods.

8.7.2 Socio-economic Data

A number of objectives used for the evaluation require the use of socio-economic data inputs, e.g. income distribution. Owing to lack of reliable data, the derivation of objectives' performance scores were based on a number of assumptions even in areas where there seems to be data available, e.g. shadow wage rates require output foregone by employing workers. Instead of assumptions more reliable data could be collected resulting in an adequate definition of the socio-economic problem such as the need for employment.

More reliable data could be collected especially in the following areas;

- the number unemployed,
- the casual occupation and average income of the unemployed, and
- the need for income distribution based on average standards of living.

Rapid rural appraisal methods (reviewed in Chapter 5) can be used for gathering this information before an evaluation is done.

8.7.3 General

The following comments are applicable to all input data that is required for defining and identifying the choice of construction methods.

1 A great deal of information is available. However the information is rudimentary and most results are based on interpretations of this information and assumptions. There is a need for a more adequate study of the productivities and limitations on the use of any construction method - especially labour based methods. The information derived from such studies should be presented in a form that will enable better use of the information for construction methods development.

2 **Static Analysis**
In this work the construction methods have been identified by use of available information and considering several alternative situations in given conditions. The performance are determined from these construction methods. As one of the aims of the evaluation is to support technological advancement, the acceptance of this static situation does not help the search for technically efficient and socially desirable construction methods. There is a need to take into account possible changes in the prevailing conditions and construction methods.

3 There is a need for long term collection of reliable data on the alternative methods of construction. The study will identify the resources defining construction technology and the relationship between these resources and the performance objectives. The general trend of the alternative construction methods can be determined, e.g. the number of people employed by any labour based method per kilometre, or the percentage of foreign exchange used for any construction method (given a money value such as for every million shillings). The determination of the general trends, as above, will result in a faster evaluation of a choice of construction methods. The performance of the objectives can be translated to equations like the following.

Performance = Constant * Function of output

e.g. The number employed for any construction method per kilometre = K * Output.

8.8 SUMMARY

The input data used has a significant effect on the results of the evaluation. Adequate input information can enable the investigation of many potential alternative construction methods especially labour based methods. The availability of information can also result in a faster evaluation for a choice of construction methods.

CHAPTER 9

PRESENTATION AND DISCUSSION OF RESULTS

9.1 GENERAL

This chapter presents the results of the testing of the project evaluation procedure outlined in Chapter 6. The procedures were tested by using the input data derived from the hypothetical road project developed in Chapter 8. The evaluation procedure was also tested by two engineers. Tests were done on the following.

1 The objectives.
2 The weighting methods.
3 The attribute rating methods.
4 Evaluation procedures for combining evaluation results into an alternative's total relative worth.

The comments and issues raised in the testing of the evaluation procedure are also discussed.

9.2 OBJECTIVES

Nine objectives were set for use in this work. (Chapter 3) The summary of the decision objectives and their measurement scales are presented in Table 9.1. A detailed explanation of the objectives is presented in Appendix 2.

TABLE 9.1 DECISION OBJECTIVES

	OBJECTIVES	CRITERIA	PERFORMANCE REQUIREMENTS	SCALES
1	Cost	Total Project Cost	Least cost	Kenya Shillings
2	Time	Project Completion Time	Least Construction Period	days/months
3	Employment	Total Man-days Skilled Labour Total Man-days Unskilled Labour	Employing the Highest Number	Man-days Man-days
4	Training	i) Management Skills ii) Labour Skills	Training Provided in Executing the Project	Low to High
5	Foreign Exchange	Foreign Exchange Cost	Least Cost	Shadow Price Cost
6	Quality	Quality of the Finished Product	High Quality	High-Low
7	Financing (Cashflow)	i) Cost/Time ii) Net Present Value	Budget Anticipated Savings When Discounted	Cost
8	Control Over the Project	Degree of Control	Full Control Barring Uncertainties	Scale 1-5
9	Income Distribution	Benefits to Target Group	High Benefits	Shadow Price of Benefits

9.2.1 Discussion on Objectives

The following issues were observed to be of relevance in this work as they concern the decision objectives used in the evaluation procedures.

9.2.1.1 Number of Objectives

The objectives identify the goals which will be achieved or partially achieved by the choice made. The number of objectives indicate the areas which are perceived to be of particular importance. Choice of the construction method using an evaluation procedure of the type described here is appropriate because:

1 Any number of objectives can be used as long as the units in which they are measured can be defined. How many objectives are used may depend on the available data or the ease with which data can be collected.

2 The objectives contribute additively to the total worth of an alternative. The number of main objectives can be reduced to broad policy objectives. Each of these broad policy objectives can be analysed with as many sub-objectives as required. e.g. A social objective with employment and income distribution as sub-objectives. The sub-objectives contribute additively to the performance of the broad policy objective. In this work, the nine objectives used were found adequate for the evaluation.

In summary the number of objectives used need not be restricted as long as an objective is perceived to be a goal and can be measured.

9.2.1.2 Independence of Objectives

A requirement of multiobjective methods is the condition of independence of objectives to avoid the problem of double counting. The problem of independence is closely related to the definition of objectives and the measurement of performance, e.g. consider two objectives used in this work -total project cost and employment. The two objectives are interrelated in that wages paid to workers contribute to the total project cost. Employment refers to the quantity of job opportunities. The measurement scale used to assess the achievement of the employment objective is the number of man-days employed. It is possible to vary the number of jobs created without varying the total project cost, e.g. many jobs at low wages or few jobs at high wages. By definition of employment as the number employed, the objective can be considered separately from the total project cost.

Therefore the problem of independence of objectives can be avoided when using interrelated objectives by the clear definition of the objectives and a choice of measurement scales.

9.3 WEIGHTING METHODS

Two direct assessment weighting methods were considered in this work. (Chapter 6) The methods are a ranking approach and a rating assignment method. The following weights were derived using the two weighting procedures.

9.3.1 Ranking Approach

The objectives were listed in order of importance. Values were assigned to each objectives by comparing it to the one immediately below it. The importance values were summed up and each divided by the sum. This result was adopted as the weight for the objective. Table 9.2 lists the derived weights and the values used in their derivation.

TABLE 9.2 RANKING WEIGHTS

OBJECTIVE	IMPORTANCE VALUE	WEIGHTS VALUE/65.5*10
Cost	20	30
Time	10	15
Employment	10	15
Quality	10	15
Foreign Exchange	5	8
Income Distribution	5	8
Financing	3	5
Training	1.5	2.5
Control	1	1.5
Sum	65.5	100

9.3.2 Rating Assignment

The following weights (Table 9.3) represent the weights derived using the rating assignment procedure. The numbers reflect the importance of the attributes on a scale of 0-10.

TABLE 9.3 RATING WEIGHTS

OBJECTIVE	WEIGHT
Cost	10
Time	6
Employment	6
Quality	6
Foreign Exchange	4
Income Distribution	4
Financing	2
Training	2
Control	1

9.3.3 Discussion of Weighting Methods

The weights derived are presented in Tables 9.2 and 9.3 above. The following comments deal with the significance of the weighting approaches in determining a value structure for the objectives.

9.3.3.1 Rating Assignment Method

The rating assignment method implies that the importance of the objectives be derived independently and rated on a scale of 0 -10. Due to the inter-relationships of the objectives a relative weight value is required. The rating assignment method may end up with inconsistent results because the weights are derived independently of each other.

9.3.3.2 Ranking Approach

In the ranking approach, the objectives are listed in an order of importance. Weights are assigned to the objectives by comparing them to the one immediately below it. The weights so derived imply a relative value is determined. Due to the inter-relationship of the objectives, the weights required are relative weights. e.g. in this work, cost is rated as twice as important as time. By use of the ranking approach method, consistent relative weights reflecting the value structure are derived.

In summary, the ranking approach is considered appropriate in the choice of construction methods. It should be emphasised that weighting is a value judgement and the judgement as to whether the final weighting for a particular objective is appropriate will depend on the decision maker.

9.4 PERFORMANCE SCORES

Four alternative construction methods were analysed to estimate their objective criteria achievement levels.

The four alternatives were:

Alternative I Relatively capital based.

Alternative II Capital based with labour substitution in some activities.

Alternative III Labour based with capital substitution in critical activities.

Alternative IV Efficient relatively labour based.

Listed below in Table 9.4 are the performance scores of the alternatives with respect to every objective.

TABLE 9.4 PERFORMANCE SCORES

NO.	OBJECTIVE	PERFORMANCE SCORE ALTERNATIVES			
		I	II	III	IV
1	Total project costs - materials	5330959	5899381	5704387	6336187
2	Completion time in weeks	37	41	44	48
3	Employment Generation				
3a	Man-days - skilled	2988	4091	3813	3543
3b	Man-days - unskilled	2967	7590	24169	51888
4	Training				
4a	Management	2	2	2	2
4b	Labour Skills	2	2	2	2
5	Foreign Exchange Shadow Price Cost	1657492	1869564	1263649	842670
6	Finished Quality	High - Medium	High - Medium	Medium	Medium
7	Financing				
7a	Monthly payments	404423	402884	363006	369610
7b	Savings on NPV	220309	364405	283948	340307
8	Control over the Project	High	High	High	High
9	Income Distribution				
9a	Skilled workers	146942	183052	162490	149206
9b	Unskilled workers	95686	244778	779450	1673388

9.5 ATTRIBUTE PERFORMANCE RATINGS

The alternatives-objectives performance scores have both qualitative measurements and quantitative measurements. To enable aggregation of impacts and the incorporation of weights, the objectives achievement levels were transformed into attribute ratings using the procedures in Chapter 6, section 6.6. Three attribute rating assignment methods were applied in this work. The three attribute rating methods used are:

A Use of maximum and minimum likely values of an objective.
B Anchoring of one extreme value.
C Anchoring of two extreme values.

Tables 9.5 to 9.7 represent the transformed attribute ratings.

TABLE 9.5 USE OF MAXIMUM AND MINIMUM LIKELY VALUES OF AN OBJECTIVE (ATTRIBUTE RATING METHOD A)

NO	OBJECTIVE	BEST	WORST	ALTERNATIVE'S OUTCOMES SCALE 0 - 10			
				I	II	III	IV
1	Cost	5 m	7 m	8.3	5.5	6.5	3.3
2	Time	36	52	9.4	6.9	5	0.25
3a	Employment	5000	1000	5	7.7	7	6.4
3b	Employment	60000	1000	0.33	1.1	4.1	8.8
4a	Training (M)	5	0	4	4	4	4
4b	Training (L)	5	0	4	4	4	4
5	Forex	0	2 m	2.3	0.9	5	7.7
6	Quality	5	0	8	8	6	6
7	Financing						
7a	Monthly cost	300000	500000	4.8	4.9	6.8	6.5
7b	Savings NPV	500000	0	4.4	7.2	5.8	6.8
8	Control	5	0	8	8	8	8
9	Income Distribution						
9a	Skilled	250000	300000	0.48	6.6	5.6	5
9b	Unskilled	2 m	0	0.5	1.2	3.9	8.4

TABLE 9.6 ANCHORING OF ONE EXTREME VALUE
(ATTRIBUTE RATING METHOD B)

NO	OBJECTIVE	ANCHOR VALUE	ALTERNATIVE'S OUTCOMES ANCHOR VALUES = 100			
			I	II	III	IV
1	Cost	5330959	100	90	94	84
2	Time	37	100	90	84	77
3a	Employment Skilled	4091	73	100	93	87
3b	Employment Unskilled	51888	6	15	47	100
4a	Training Management	2	100	100	100	100
4b	Training Labour	2	100	100	100	100
5	Forex	842670	51	45	67	100
6	Quality	4	100	100	100	100
7a	Financing	363006	90	90	100	98
7b	Savings NPV	364405	60	100	78	93
8	Control	4	100	100	100	100
9	Income Distribution					
9a	Skilled	183052	80	100	89	82
9b	Unskilled	1673388	6	14	47	100

TABLE 9.7 ANCHORING OF TWO EXTREME VALUES
(ATTRIBUTE RATING METHOD C)

NO	OBJECTIVE	BEST	WORST	ALTERNATIVE'S OUTCOMES SCALE 0 - 10			
				I	II	III	IV
1	Cost	5330959	6336187	10	4.3	6.3	0
2	Time	37	48	10	6.4	3.6	0
3a	Skilled L	4091	2988	0	10	7.5	5
3b	Unskilled L	51888	2967	0	0.9	4.3	10
4a	Training (M)	2	2	0	0	0	0
4b	Training (L)	2	2	0	0	0	0
5	Forex	842670	1869564	2	0	6	10
6	Quality	4	3	10	10	0	0
7a	Monthly cost	363006	404423	0	0.4	10	8.4
7b	Savings NPV	364405	220309	0	10	4.4	8.3
8	Control	4	4	0	0	0	0
9	Income Dist.						
9a	Skilled	183052	146942	0	10	4.3	0.6
9b	Unskilled	1673308	95688	0	1	4.3	10

9.5.1 Discussion of Attribute Rating Methods

The results of the ratings by the three methods are presented in Tables 9.5 to 9.7 above. The following discussion is based on the results and comments on application of the attribute rating method.

9.5.2 Results

The aim of the test was to determine which of the three attribute rating procedures above is more appropriate for use during the evaluation of construction methods choice. Tables 9.5 to 9.7 represent the attribute rating values for the three procedures and Tables 9.14 represent the weighted summation values of the alternatives. Using the same weights for all the attribute ratings methods and considering the weighted summation results: Use of maximum and minimum likely values of an objective (attribute rating method A)and anchoring of two extreme values (method C) both rate alternative 1 with the highest score while anchoring of one extreme value (attribute rating method B) rates alternative 4 with highest score. The results of method A and method C seem to coincide because they both rate alternative 1 with the highest score.

9.5.3 Comments

The experimental results were intended basically to determine whether the methods are applicable to the decision situation in construction methods choice. The alternatives described are based on a hypothetical project situation and the following comments based on application and testing were made.

1 All the procedures are easy to understand and apply.

2 The major issue is the appropriateness of the rating procedures to the problem situation. The results of the rating procedure have an effect on the overall evaluation because using the same weights and performance score values, the rating procedures ranked two different alternative construction methods with the highest score. i.e. Alternative 1 and 4 as commented above (section 9.5.2).

9.5.3.1 Rating Method A: Use of Maximum and Minimum Likely Values of an Objective

For qualitative measurements the use of maximum and minimum likely values of an objective (attribute rating method A) is considered appropriate. It is appropriate to rate where a quantitative score falls on a scale because the level of achievement can be assessed on the scale of 0 to 10 by comparison with the maximum and minimum likely. For qualitative measurements, the decision on the rating is subject to individual perception and this can significantly influence the results. A scale of 0-10 was also considered inappropriate to rate the impacts. A scale of 0-5 may be more appropriate for these impacts. The impacts can be classified as follows with a corresponding factor.

None	Poor	Fair	Average	Good	Excellent
0	1	2	3	4	5

The attribute is rated by deciding the impact of each objective and adopting the factor that corresponds to it.

9.5.3.2 Rating Method B: Anchoring of One Extreme Value

In this method, one extreme value is anchored and all other values are compared with it. By fixing the anchor value and basing the ratings of the other values on it, a change in the anchor value will effect a change in all other values. In this work, an anchored time of 37 weeks was used. The ratings of the other three alternatives were based on the anchored time. If the anchored value is found to be incorrect, the ratings for all other alternatives will change despite their being correct. Construction involves operating under very uncertain conditions compared to other economic activities. (WORLD BANK 1983) Therefore while the method can be used for decisions of a definite nature with minimal expected changes, the method may not be appropriate for construction methods decisions.

9.5.3.3 Rating Method C: Anchoring of Two Extreme Values

Rating method C is basically similar to method A above in that the alternatives are compared to two values and performances rated on a scale of 0 to 10. By analysing the two extreme performance scores, a value judgement is implied before any evaluation is done, i.e. setting a value of zero excludes the alternative's performance scores from further consideration. The problem of excluding any alternative from further consideration can be solved by using a scale of 1 to 10. However, an incorrect choice of the anchor values will result in an incorrect rating for all the other values so the method may not be appropriate for construction because of its uncertain nature.

In summary, the use of maximum and minimum likely values of an objective (attribute rating method A) was found to be the most appropriate. With adequate analysis of construction methods, it is possible to arrive at standards for maximum likely and minimum likely performances, e.g. for maximum cost and minimum cost a scale of 0 - 5 should be used for the impacts of all qualitative measurements.

9.6 ALTERNATIVES' TOTAL WORTH

The following calculations represent the procedures followed in the determination of the alternatives' relative total worth.

The calculations are based on attribute rating method A and ranking weights.

9.6.1.1

The rated attribute values are summed for each objective in Table 9.8.

TABLE 9.8 RATED ATTRIBUTE VALUES FOR EACH OBJECTIVE

NO	OBJECTIVE	ALT I	II	III	IV	TOTAL SUM OF ATTRIBUTE SCORES
1	Cost	8.3	5.5	6.5	3.3	23.6
2	Time	9.4	6.9	5	.25	21.55
3a	Employment Skilled	5	7.7	7	6.4	26.1
3b	Employment Unskilled	.33	1.1	4.1	8.8	14.33
4a	Training	4	4	4	4	16
4b	Training	4	4	4	4	16
5	Forex	2.3	.9	5	7.7	15.9
6	Quality	8	8	6	6	28
7a	Cost/M	4.8	4.9	6.8	6.5	23
7b	Save NPV	4.4	7.2	5.8	6.8	24.2
8	Control	8	8	8	8	32
9a	Income Distribution	.48	6.6	5.6	5	17.68
9b	Income Distribution	.5	1.2	3.9	8.4	14

9.6.1.2

By the use of Zeleny's Method (Chapter 7) the performance weights are calculated as follows

i) The attribute values are divided by the attribute total value per criterion Table 9.9.

TABLE 9.9 ATTRIBUTE VALUES/ATTRIBUTE VALUE TOTAL PER CRITERION

.352	.233	.275	.140	1.000
.436	.320	.232	.012	1.000
.192	.295	.268	.245	1.000
.023	.077	.286	.614	1.000
.250	.250	.250	.250	1.000
.250	.250	.250	.250	1.000
.145	.057	.314	.484	1.000
.286	.286	.214	.214	1.000
.209	.213	.296	.283	1.000
.182	.298	.240	.281	1.000
.250	.250	.250	.250	1.000
.027	.373	.317	.283	1.000
.036	.086	.279	.600	1.000

ii) The values derived in Table 9.9 are multiplied by their natural logarithms (Table 9.10).

iii) By use of the sums in procedure ii) and relationships developed in Chapter 7, the set of performance weights is derived.

TABLE 9.10 ATTRIBUTE VALUES MULTIPLIED BY NATURAL LOGARITHMS

ATTRIBUTE VALUES MULTIPLIED BY NATURAL LOGARITHMS						NEW WEIGHTS
-.368	-.339	-.355	-.275	-1.337	.965	.030
-.362	-.365	-.339	-.052	-1.117	.806	.164
-.317	-.360	-.353	-.345	-1.374	.991	.007
-.087	-.197	-.358	-.299	- .941	.679	.272
-.347	-.347	-.347	-.347	-1.386	1.000	.000
-.347	-.347	-.347	-.347	-1.386	1.000	.000
-.280	-.163	-.364	-.351	-1.157	.835	.140
-.358	-.358	-.330	-.330	-1.376	.993	.006
-.327	-.329	-.360	-.357	-1.374	.991	.008
-.310	-.361	-.342	-.357	-1.370	.988	.010
-.347	-.347	-.347	-.347	-1.386	1.000	.000
-.098	-.368	-.364	-.357	-1.187	.856	.000
-.119	-.211	-.356	-.306	- .992	.716	.241
					11.819	
					1.181	

TABLE 9.11 WEIGHTS USED IN THE EVALUATION

w' is the derived performance weight
w is the weights derived in the ranking procedure
W is the revised weight by combining the two weights

TABLE OF WEIGHTS			
w'	w	w' x w	W
.030	30	.900	.102
.164	15	2.466	.279
.007	5	.037	.004
.272	10	2.718	.308
.000	1	.000	.000
.000	1.5	.000	.000
.140	8	1.120	.127
.006	15	.094	.011
.008	4	.030	.003
.010	1	.010	.001
.000	1.5	.000	.000
.122	4	.487	.055
.241	4	.963	.109
		8.825	

9.6.1.3 Weighting Summation

The weights were applied to the attribute values and the weighted scores summed.

TABLE 9.12

WEIGHTED SUMMATION WITH REVISED WEIGHTS

	.846	.561	.663	.337
	2.627	1.928	1.397	.070
	.021	.032	.029	.026
	.102	.339	1.263	2.711
	.000	.000	.000	.000
	.000	.000	.000	.000
	.292	.114	.634	.977
	.085	.085	.064	.064
	.017	.017	.023	.022
	.005	.008	.007	.008
	.000	.000	.000	.000
	.026	.364	.309	.276
	.055	.131	.426	.917
Weighted sum	4.075	3.579	4.815	5.407

TABLE 9.13

WEIGHTED SUMMATION WITH INITIAL WEIGHTS (RANKING)

	24.9	16.5	19.5	9.9
	14.1	10.35	7.5	.375
	2.5	3.85	3.5	3.2
	.33	1.1	4.1	8.8
	.4	.4	.4	.4
	.6	.6	.6	.6
	1.84	.72	4	6.16
	12	12	9	9
	1.92	1.96	2.72	2.6
	.44	.72	.58	.68
	1.2	1.2	1.2	1.2
	.192	2.64	2.24	2
	.2	.48	1.56	3.36
Weighted sum	60.622	52.52	56.9	48.275

The weighted summation of the attribute values was performed for all attribute rating methods and weighting procedures.

The results presented below are the results of the summation of the combined objectives attribute scores and weights for each method, combined into a total value structure.

TABLE 9.14

RESULTS OF EVALUATION PROCEDURES METHOD A

USE OF MAXIMUM AND MINIMUM LIKELY VALUES OF AN OBJECTIVE

ALTERNATIVES	I	II	III	IV
Weighted Sum (ranking)	60.622	52.52	56.9	48.275
Weighted Sum (revised weights)	4.07	3.58	4.81	5.41
ALTERNATIVES	I	II	III	IV
Weighted Sum (rating)	23.528	21.035	22.95	20.525
Weighted Sum (revised weights)	3.81	3.45	4.78	5.58

ATTRIBUTE RATING METHOD B

ANCHORING OF ONE EXTREME VALUE

ALTERNATIVES	I	II	III	IV
Weighted Sum (ranking)	321.1	319.3	329.7	358.35
Weighted Sum (revised weights)	13.98	21.23	50.36	98.93
ALTERNATIVES	I	II	III	IV
Weighted Sum (rating)	799.7	787.6	809.8	864.8
Weighted Sum (revised weights)	13.95	21.31	50.33	98.83

ATTRIBUTE RATING METHOD C

ANCHORING OF TWO EXTREME VALUES

ALTERNATIVES	I	II	III	IV
Weighted Sum (rating)	228	208.6	175.2	127.95
Weighted Sum (ranking)	616	521.6	450.3	289.3

9.6.2 Discussion on Evaluation Procedures

Evaluation procedures combine rated attributes and weights into a relative ranking of the alternative methods of construction.

Three procedures for ranking the alternatives procedures were tested in this work. The procedures were:

A Weighted summation,

B Weighted summation with elimination,

C Weighting summation with importance based on pre-evaluation weights and performance weights.

The results of the aggregation of the alternatives are presented in Table 9.14. All three procedures derive the relative worth of an alternative. The differences in the procedures are the number of steps to be performed before the relative total worth of the alternative is derived. The following discussion answers the question about whether the steps performed are appropriate.

9.6.2.2 Results

Four alternative construction methods were used in this work. More alternative construction methods were not derived because of the data available.

When testing the elimination procedure (Method B). no construction method was eliminated because all four alternative construction methods met desired performance scores with respect to all objectives.

However, it was observed that the evaluation procedure could be useful especially in situations where there were many alternatives.

Results of the evaluation procedure using revised weights (Method C) were not possible when using the anchoring of two extreme values attribute rating procedure (attribute rating method C). The procedure involved the use of natural logarithms and so could not be applied to zero values. (Chapter 7 Section 7.6)

Use of evaluation procedures and attribute rating method A: Alternative I was chosen for both weighting procedures by use of weighted summation. Alternative IV was chosen when using the revised weights.

Use of evaluation procedures and attribute rating method B: Alternative IV is chosen for both weighting procedures by use of weighted summation. Alternative IV is chosen when using the revised weights.

9.6.2.3 Comments

From the results of tests the following comments can be made. The main aim of the evaluation is the comparison of alternatives.

The use of the evaluation procedure using pre-evaluation weights and performance weights (evaluation procedure C) provides a facility for assessing the differences between alternatives with respect to each particular objective. The performance weights used reflect the difference between the achievement of the alternative methods of construction with respect to the objectives being considered. This means that the weights assigned are appropriate to the given set of construction methods (Chapter 7.) The steps performed in evaluation procedure C are considered necessary when evaluating alternative methods of construction.

In some cases there might be many feasible alternative construction methods. In such cases it might be necessary to make the final selection from a reduced set of alternatives by progressively discarding some of the options in stages. Therefore the use of evaluation procedure of weighted summation with elimination (evaluation procedure B) might become necessary if there are many alternatives.

9.7 SUMMARY DISCUSSION OF RESULTS OF TESTING OF THE EVALUATION PROCEDURE

The following comments represent a summary of this discussion.

1 Before an evaluation is done there is a need to investigate and become familiar with the construction methods.

2 The objectives set should have clear definition and measurement scales.

3 A ranking approach procedure for deriving weights should be used so as to derive the relative weights of the objectives.

4 The use of minimum and maximum likely values of an objective (Attribute rating method A) is more appropriate for translating attribute values. A scale of 0-5 should be used to rate qualitative values.

5 Use of the evaluation procedure using pre-evaluation weights and performance weights (evaluation procedure C) has the added facility of assessing the difference between alternative construction methods with respect to each particular objective. Decision procedure B should be used if there are many alternative construction methods.

CHAPTER 10

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

10.1 CONCLUSIONS

This work has been designed to validate available evaluation methods as practical and appropriate decision making methods for construction methods choice. The construction project is in itself multiobjective and therefore the development of construction methods should be oriented to multiple objectives. Evaluating and selecting the best construction method from the range of feasible alternative construction methods using a rational evaluation framework is desirable to assist in the comparative analysis of the construction methods options.

Chapter 3 of this work developed an evaluation framework for construction methods. After a review of available evaluation methods (Chapter 4), it was decided that the best approach to the solution was a conceptually simple and practical method. Several multiobjective rating procedures were proposed for application.(Chapter 6) The proposed procedures were tested on a hypothetical road project. The results of the testing are presented in Chapters 8 & 9.

The following conclusions are drawn.

10.1.1 Multiobjective Rating Procedure

From the results of the testing, a multiobjective rating procedure was considered appropriate. The following are the steps of the procedure:

(a) Establishment of the objectives that will achieve or partially achieve the goals of the construction methods choice. The objectives set should have clear definitions and measurement scales.

(b) Derivation of the weights of the objectives by use of a ranking procedure.

(c) Analysis of the alternative construction methods to estimate their objectives' criteria achievement levels (performance scores).

(d) Transformation of the objectives' achievement levels (performance scores) into attribute values using an attribute rating procedure. The maximum and minimum likely values of an objective are used to transform the alternatives-objectives achievement levels into attribute ratings on the scale of 0-10 with respect to each objective. A scale of 0 - 5 was used to rate qualitative values.

(e) The alternative construction method's total relative worth is determined by weighting summation with weights based on pre-evaluation weights and objective performance weights. The construction method with the highest total relative worth is selected. (Chapter 9.6)

10.1.2 Choice of Evaluation Method

The characteristic problem of choosing the best construction method investigated in this work can be considered as follows. (Chapter3)

- A range of different objectives with qualitative and quantitative values.
- Rudimentary nature of the input data used to define the alternative construction methods and especially labour based methods.
- A wide range of construction methods for which there is usually insufficient time and resources to collect data and analyse each and every alternative construction method.

When the characteristics of the construction methods choice problem are considered, the multiobjective evaluation procedure used in this work is appropriate because of the following.

1 For the relative comparison of alternative construction methods, the evaluation method will yield reliable results even where only qualitative information exists. Hence it is possible to accommodate objectives which are otherwise difficult to quantify.

2 Given the nature of the evaluation and the data available, other evaluation methods, e.g. cost benefit analysis, are hardly feasible and their use may be ambitious and misguided.

3 The major interest of the evaluation is to compare alternative construction methods' total relative worth as perceived by decision makers. The selection of an optimal combination of objectives is defined by the preferences of the decision makers between objectives. A commitment towards improving or achieving some objectives can only be achieved at the sacrifice of some other objectives. The multi-objective evaluation procedure described above enables the derivation and use of (sufficiently) accurate value judgements (weights) combined with factual (analytical) information (attribute scores) which makes it appropriate for the construction methods choice problem.

Because of the above, the multiobjective evaluation procedure is a simple and practical evaluation method for construction methods choice.

10.1.3 Objectives

Interrelated objectives are used in this work. The problem of independence of objectives required by multiobjective procedures is avoided by the clear definition of the objectives and a choice of measurement scales.

10.1.4 Weights

Combining of the objectives achievement values in any form without weighting is inappropriate. Therefore it is necessary to derive weights for the objectives. Since the objectives used in this work are interrelated relative weight values are required. Use of the ranking method (Chapter 9) to generate weights results in consistent relative weight values.

10.1.5 Attribute Rating Methods

The use of maximum and minimum likely values of an objective is an appropriate basis to compare the objective's performances for the alternative methods of construction. A scale of 0-10 is used to rate quantitative measurements with respect to each objective. A scale of 0 - 5 is used to rate qualitative values.

10.1.6 Final Evaluation Procedures

Weighted summation with weights based on pre-evaluation weights and objective performance weights allows the construction methods to be analysed in the two approaches. This is done by considering the overall preferences based on the decision objectives and the relative magnitudes of each of the objective's values for the set of alternatives. As the main aim is the comparison of alternative methods of construction, this approach is desirable as the differences between the alternative construction methods are considered with respect to the differences of each of the objective values.

10.2 RECOMMENDATIONS FOR FURTHER STUDIES

The use of the evaluation methods in this work have highlighted the need for further studies in construction methods. The following are recommended for further studies.

1 The input data used in this work has been derived from various sources. (Chapter 8) While the sources of the input data cover a wide range of the construction methods operations, there is a need for further work to develop a database covering all aspects of construction methods such as combinations of plant and labour, productivity and availability of resources and costs for the various construction methods. Such a database would provide accessible information for development of construction methods. This would speed up evaluation and increase the accuracy of results. The data base could be derived from post-construction analysis of construction projects.

2 One of the major aims of the evaluation in this work is to identify potential areas in construction technology that need improvement so that construction methods can relate to appropriate development objectives and a more effective utilisation of resources, especially labour. In this work, only the direct achievement of objectives by the construction methods have been considered, e.g. direct employment. There is a need for further work to determine inputs to the objectives by other sectors based on the construction method chosen. This would apply particularly when considering the social

and economic objectives, e.g. tool manufacture could provide indirect employment.

3 In this work, the evaluation is based on construction methods developed by several alternative situations in given conditions. The evaluation procedure requires further work to enable it to take into account possible changes in the prevailing conditions (uncertainty) and long term considerations whereby the construction method chosen will affect the suitability or otherwise of construction methods in the future.

10.3 GENERAL CONCLUSIONS

Given the aims of this work, the use of the multiobjective rating method presented in this work has enabled the determination of the implications of using any of the construction methods developed for the hypothetical project situation. The evaluation method can also be applied to any project situation. The evaluation method offers the scope for a better choice of construction methods which can be used to achieve or partially achieve technical, economic and social objectives. Therefore the method is practical for application to construction methods choice.

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APPENDIX 1

TABLE 1 WORK CONTENT

NO.	DESCRIPTION	QUANTITY
1	Site clearance (removal and disposal of all growth, bushes, tree stumps logs,roots etc)	340 000 m^2
2	Top soil stripping (grubbing, removal and disposal of topsoil, stumps and roots to at least 20 cm below ground level)	146 000 m^2
3	Cut to fill in Normal (soft) material (ELHUS) Average haul 500 m	63 000 m^3
4	Cut to fill in Hard material (ELHUS) Average haul 500 m	7 000 m^3
5	Cut to Spoil - haul varies	400 m^3
6	Overhaul of earthworks in excess of freehaul 1-2 km	3 686 m^3/km
7	Fill embankment Watering, compacting and finishing. (WCF)	70 000 m^3
8	Excavation for culvert trenches and outlet structures in soft material	800 m^3
9	Excavation for culvert trenches and outlet structures in hard material	120 m^3
10	Laying and joining pipes from 900 mm dia to 1200 mm diameter.	551 m
11	Culverts: Concrete beds and surrounds and all formwork	180 m^3
12	Concrete headwalls and wingwall and all formwork	50 m^3
13	Excavate mitre drains	1 600 m
14	Site clearance Quarry and access roads	40 000 m^2
15	Quarry removal of topsoil and overburden	12 000 m^3
16	Gravel for base, subbase and shoulders (ELHUS)	24 000 m^3
17	Gravel for base,subbase and shoulders (WCF)	24 000 m^3

TABLE 2 PRODUCTIVITY OF INPUTS IN ROAD CONSTRUCTION PER TASK

TASK/METHOD	INPUTS	PRODUCTIVITY
Site clearance		
I and II	Bulldozer Foreman Operator Workers	Critical productivity = 4500 m^2/hr by bulldozer Based on a travelling speed 5 km/hr modified for utilisation rates
III & IV	Foreman Workers Overseers	480 m^2/man-day = 60 m^2/man-hour RARP figure for medium bush
Top soil stripping		
I and II	Bulldozer Foreman Operator Workers	Bulldozer (D8) 129 m^3/hr = 860 m^2/hr (Harris modified for utilisation)
III & IV	Foreman Workers Overseers	Workers at 48 m^2/man-day = 8 m^2/hr
Cut to fill in Normal (soft) material (ELHUS) Average haul 500m		
I	Motorscraper Bulldozer Grader Foreman Operators Workers	48-90 m^3/hr use 60 m^3/hr Used for pushing where necessary 120 m^3/hr spreading by grader
II	Bulldozer Wheeled loader Lorries (3 m^3) Operators Foreman Workers Drivers	combined productivity 90 m^3/hr (Harris) = critical productivity (Bulldozer, Wheeled loader) 3 trips per hr at 3 m^3 = 9 m^3/hr per lorry Spreading by labour = 12-15 m^3/man-day = 2 m^2/hr
III	Bulldozer Operator Foremen Overseer Workers Tractor & Trailers Drivers	Excavation by bulldozer to stockpile = 90 m^3/hr Hauling by tractor drawn trailers at 3 trips/hr at 3 m^3 per trip Unloading and spreading by man at 12-15 m^3/man-day

IV	Foreman Overseer Workers Tractor & Trailers Drivers	Excavation by man 2-3.5 m^3/man-day = 0.6 m^3 per man-day Loading by man 2.0 m^3/man-hour Hauling by tractor drawn trailers at 3 m^3/trip Unloading and spreading 12-15 m^3/man-day.
Cut to fill in Hard material (ELHUS) Average haul 500m		
I	Motorscraper Bulldozer Grader Foreman Operators Workers	48-90 m^3/hr use 48 m^3/hr Used for pushing where necessary 120 m^3/hr spreading by grader
II	Bulldozer Wheeled loader Lorries (3 m^3) Operators Foreman Workers Drivers	(Bulldozer and wheeled loader:) combined productivity 72 m^3/hr (Harris = critical productivity 3 trips per hr at 3 m^3 = 9 m^3/hr per lorry Spreading by labour = 12-15 m^3/man-day = 2 m^2/hr
III	Bulldozer Operator Foremen Overseer Workers Tractor & Trailers Drivers	Excavation by bulldozer to stockpile = 80 m^3/hr Loading by man at 10 m^3/man-day Hauling by tractor drawn trailers at 3 trips/hr at 3 m^3 per trip Unloading and spreading by man at 12-15 m^3/man-day
IV	Foreman Overseer Workers Tractor & Trailers Drivers	Excavation by man 2-3.5 m^3/man-day = 0.6 m^3/man-day Loading by man 2.0 m^3/man-hour Hauling by tractor drawn trailers at 3 m^3 per trip Unloading and spreading 12-15 m^3 man-day
Cut to Spoil haul varies		
I, II, III and IV		Inputs and productivities as for other earthworks tasks respectively.
Overhaul of earthworks in excess of freehaul 1-2 km		Productivities are the same as in other earthworks operations apart from the following

I	Motorscraper	24 m^3/hr
II	Lorries (3 m^3)	2 trips per hr at 3 m^3 = 9 m^3/hr per lorry
III	Tractor & Trailers	Hauling by tractor drawn trailers at 2 trips/hr at 3 m^3 per trip
IV	Tractor & Trailers	Hauling by tractor drawn trailers at 2 trips/hr at 3 m^3/trip
Fill Embankment Watering, compacting and finishing (WCF)		
I&II	Self propelled rollers Water truck Operators Driver Workers	Productivity determined by rollers = 110 m^3/hr based on six passes per each 150mm layer
III & IV	4 ton tractor drawn rollers Water truck Drivers Workers	Productivity of roller = 75 m^3/hr
Excavation for culvert trenches and outlet structures in soft material		
I & II	Excavator Pedestrian Roller Operator Workers Foreman	Excavation by excavator at 28 m^3/hr
III & IV	Foreman Workers Pedestrian Roller	Excavation by hand at 3.5 m^3/man-day Pedestrian roller at 20 m^3/hr
Excavation for culvert trenches and outlet structures in hard material		
I & II	Excavator Pedestrian Roller Operator Workers Foreman	Excavation by excavator at 19 m^3/day Pedestrian roller at 20 m^3/hr

III & IV	Foreman Workers Pedestrian Roller	Excavation by hand at 3.5 m^3/man-day Pedestrian roller at 20 m^3/hr
Laying and joining pipes from 900 mm to 1200 mm diameter		
I & II	Excavator Operator Workers Foreman	Laying of pipes assisted by excavator for lifting and positioning Productivity = 8 m/hr
III & IV	Foreman Workers	By hand 8 m/man-day
All concrete works including formwork For all Methods		
		Concrete mixer and placing by hand Based on team of 10 men productivity = 3 m3/hr
Excavate mitre drains		
I & II III & IV		Grader 1.2 km/hr Labour 5 m^3/man-day
Site clearance Quarry and access roads		Inputs and productivities similar to road site clearance for the respective methods
Quarry removal of topsoil and overburden		Inputs and productivities similar to road topsoil stripping for the respective methods
Gravel for base, subbase and shoulders (ELHUS)		Inputs and productivities similar to cut to fill in Hard material (ELHUS) for the respective methods
Gravel for base, subbase and shoulders (WCF)		Inputs and productivities similar to earthworks for the respective methods

UNIT COST ESTIMATES

Listed below are the unit cost estimates for both labour and equipment used in this work. The labour costs are based on prevailing wages for construction workers in Kenya. The equipment rates are based on an analysis of contracts of two road projects of a similar size in Kenya. All the prices are expressed in Kenya shillings (Ksh).

TABLE 3 DAILY WAGE RATES FOR LABOUR

CATEGORY	RANGE OF WAGES	WAGES USED FOR THIS WORK
Foremen	86 - 100	98
Operators (heavy plant)	66.70 - 76.65	72
Drivers	50.25 - 56.30	53.30
Tradesmen	55.60 - 59.65	58
Overseers	47.75 - 56.20	51
Agricultural tractor drivers and light plant operators	47.75 - 54.60	51
General labour	41.75 - 45.60	43

TABLE 4 UNIT COST ESTIMATES FOR EQUIPMENT

EQUIPMENT TYPE	UNIT COST KSH/HOUR
Bulldozer (D8)	650
Motorised Scraper	600
Grader (140 hp)	500
Self Propelled Roller	150
Water Truck	240
Excavator	150
Pedestrian Roller	80
Poker Vibrator	60
Concrete Mixer	80
Lorries	120
Wheeled Loader Shovel	500
Tractor and trailers (48-85 hp)	150
Tractor Drawn Roller	150
Tractor Drawn Water Bowser	150
FUEL COST	**Ksh per litre**
Diesel	6
Lubricating Oil	20.50

TABLE 5 INPUTS FOR ROAD CONSTRUCTION PER TASK

NO.	DESCRIPTION AND QUANTITY	METHOD	INPUTS	TIME/HOURS
1	Site clearance 340 000 m^2	I & II	1 Bulldozer	76
			1 Foreman	76
			1 Operator	76
			5 Workers	76
		III & IV	1 Foreman	110
			50 Workers	110
			2 Overseers	110
2	Top soil stripping 146 000 m^2	I & II	1 Bulldozer	170
			1 Foreman	170
			1 Operator	170
			5 Workers	170
		III & IV	1 Foreman	185
			100 Workers	185
			2 Overseers	185
3	Cut to fill in Normal (soft) material (ELHUS) Average haul 500 m 63 000 m^3	I	2 Motorscraper	525
			1 Bulldozer	200
			1 Grader	525
			1 Foreman	525
			4 Operators	525
			5 Workers	525
		II	1 Bulldozer	400
			1 Wheeled loader	700
			10 Lorries(3 m^3)	700
			3 Operators	700
			1 Foreman	700
			45 Workers	700
			10 Drivers	700
		III	1 Bulldozer	700
			1 Operator	700
			2 Foremen	750
			1 Overseer	750
			90 Workers	750
			10 Tractor & Trailers	750
			10 Drivers	750
		IV	1 Foreman	875
			3 Overseers	875
			176 Workers	875
			8 Tractor & Trailers	875
			8 Drivers	875

4	Cut to fill in Hard material (ELHUS) Average haul 500 m 7 000 m^3			
		I	2 Motorscraper	73
			1 Bulldozer	73
			1 Grader	73
			1 Foreman	73
			4 Operators	73
			5 Workers	73
		II	1 Bulldozer	80
			1 Wheeled Loader	97
			8 Lorries (3 m^3)	97
			3 Operators	97
			1 Foreman	97
			29 Workers	97
			8 Drivers	97
		III	1 Bulldozer	90
			1 Operator	98
			1 Foreman	98
			2 Overseers	98
			76 Workers	98
			8 Tractor & Trailers	98
			8 Drivers	98
		IV	1 Foreman	100
			3 Overseers	100
			176 Workers	100
			8 Tractor & Trailers	100
			8 Drivers	100
5	Cut to Spoil haul varies 400 m^3			
		I	2 Motorscrapers	3
			1 Foreman	3
			3 Operators	3
		II	1 Foreman	3
			1 Wheeled Loader	3
			3 Operators	3
		III	1 Bulldozer	3
			1 Operator	3
			76 Workers	3
		IV	1 Foreman	8
			2 Overseers	8
			125 Workers	8

6	Overhaul of earthworks in excess of freehaul 1-2 km 3 686 m^3/km			
		I	2 Motorscraper	62
			1 Bulldozer	30
			1 Grader	62
			1 Foreman	62
			4 Operators	62
			5 Workers	62
		II	1 Bulldozer	48
			1 Wheeled Loader	76
			8 Lorries (3 m^3)	76
			3 Operators	76
			1 Foreman	76
			29 Workers	76
			8 Drivers	76
		III	1 Bulldozer	48
			1 Operator	48
			1 Foreman	76
			2 Overseers	76
			50 Workers	76
			8 Tractors & Trailers	76
			8 Drivers	76
		IV	1 Foreman	80
			3 Overseers	80
			140 Workers	80
			8 Tractor & Trailers	80
			8 Drivers	80
7	Fill embankment Watering, compacting and finishing. (WCF) 70 000 m^3			
		I & II	2 Self propelled rollers	320
			1 Water Truck	320
			2 Operators	320
			1 Driver	320
			5 Workers	320
		III & IV	2 Tractor drawn rollers (4 ton)	467
			1 Water Truck	467
			3 Drivers	467
			5 Workers	467

8	Excavation for culvert trenches and outlet structures in soft material 800 m^3			
		I & II	1 Excavator	30
			1 Pedestrian Roller	38
			1 Operator	30
			5 Workers	68
			1 Foreman	68
		III & IV	1 Foreman	94
			27 Workers	54
			1 Pedestrian Roller	38
9	Excavation for culvert trenches and outlet structures in hard material 120 m^3			
		I & II	1 Excavator	7
			1 Pedestrian Roller	9
			1 Operator	7
			5 Workers	16
			1 Foreman	16
		III & IV	1 Foreman	20
			27 Workers	11
			1 Pedestrian Roller	9
10	Laying and joining pipes from 900 mm dia to 1200 mm diameter 551 m			
		I & II	1 Excavator	70
			1 Operator	70
			5 Workers	70
			1 Foreman	70
		III & IV	1 Foreman	9
			25 Workers	9
11	Culverts: Concrete beds and surrounds and all formwork 180 m^3			
		I & II	1 Concrete mixer	60
			1 Concrete Poker Vibrator	60
			1 Foreman	60
			1 Carpenter	60
			10 Workers	60

12	Concrete headwalls and wingwall and all formwork 50 m^3			
		I & II	1 Concrete mixer	17
			1 Concrete Poker Vibrator	17
			1 Foreman	17
			1 Carpenter	17
			10 Workers	17
13	Excavate mitre drains 1 600 m			
		I & II	1 Grader	8
			1 Operator	8
		III & IV	10 Workers	15
14	Site clearance Quarry and access roads 40 000 m^2			
		I & II	1 Bulldozer	9
			1 Foreman	9
			1 Operator	9
			10 Workers	9
		III & IV	1 Foreman	14
			50 Workers	14
			2 Overseers	14
15	Quarry removal of topsoil and overburden 12 000 m^3			
		I & II	1 Bulldozer	95
			1 Foreman	95
			1 Operator	95
			10 Workers	95
		III & IV	1 Foreman	100
			50 Workers	100
			2 Oversees	100
16	Gravel for base, subbase and shoulders (ELHUS) 24 000 m^3			
		I	1 Bulldozer	300
			1 Wheeled Loader	500
			1 Grader	500
			8 Lorries (3 m^3)	500
			3 Operators	500
			1 Foreman	500
			10 Workers	500
			8 Drivers	500

		II	1 Bulldozer	300
			1 Wheeled Loader	500
			8 Lorries (3 m^3)	500
			2 Operators	500
			1 Foreman	500
			29 Workers	500
			8 Drivers	500
		III	1 Bulldozer	500
			1 Operator	500
			1 Foreman	500
			2 Overseers	500
			50 Workers	500
			8 Tractor & Trailers	500
			8 Drivers	500
		IV	1 Foreman	500
			3 Overseers	500
			140 Workers	500
			8 Tractor & Trailers	500
			8 Drivers	500
17	Gravel for base, subbase and shoulders (WCF) 24 000 m^3			
		I & II	2 Self propelled rollers	100
			1 Water truck	100
			2 Operators	100
			1 Driver	100
			5 Workers	100
		III & IV	2 Tractor drawn rollers (4 ton)	160
			1 Water truck	160
			3 Drivers	160
			12 Workers	160

APPENDIX 2

OBJECTIVES DESCRIPTION

Listed below are the objectives which were established for application in this work. They include an explanatory description and the measurement scales used to measure performance. (Note: The objectives are not presented in any order of importance.) In evaluating the alternatives the importance (weighting) relative to the other objectives and performance rating relative to other alternatives is required.

Objectives (Decision Areas)	Criteria	Performance
Cost (market money terms)	Total project cost	low..high

Remarks:

The total cost (in market money terms) is an aggregation of different factors brought about by policies in other objectives. Different combinations of factor inputs to produce a given output cost differently depending on prevailing prices. Market rates (financial costs) have been said not to reflect real costs but they form a major basis for choice. Government construction and maintenance organisations use financial costs when preparing the budgets for their activities including project costs, i.e decision makers want to know how much it costs in money terms. Hence cost can be considered an independent decision area.

Time	Project completion time	Fast..slow

Remarks:

Construction of the project is an investment to serve a particular need e.g. transportation. The length of the construction period determines when the project benefits can be realised. Completion time is dependent on other objectives like costs and resource inputs but it can be considered as a decision area in determining construction technique, i.e. when is the completed project required. The different techniques have different performance ratings on completion time.

Employment	Man-days unskilled labour Man-days skilled labour	Total man-days

Remarks:

As a decision area, different options are capable of creating employment: e.g.

Labour based	Employing large numbers of unskilled surplus labour,
Intermediate	Different combinations of unskilled and skilled labour and capital,
Capital based	Equipment and emphasis on labour saving.

As an objective, employment has interrelationships with other objectives e.g.
Total cost - wages paid to hired labour but less equipment cost,

Completion time dependent on employed inputs,

Quality - dependent on the level of effort and capabilities of those employed.

However, the aim is to satisfy technical and socio-economic objectives. In choice analysis, the commonly used criteria is the number of people employed. Although the effects of employment are reflected in other objectives, it can be treated as a separate decision area. Employment reflects the quantity of job opportunities and is not necessarily an indicator of socio-economic development, e.g. there might be many jobs but at very low wages.

Training	**Management Skills** **Labour skills**	**Subjective** **Scale 0-5**

Remarks:

Options: Labour based methods may provide labour and managerial skills.

Relative capital based projects enhance labour skills, e.g. from unskilled to skilled labour.

Training involves the acquiring of skill which can improve productivity or help prepare for more demanding jobs. The benefits of the increased productivity of skilled workers must be attributed to the project only if a necessity for training can be shown. In evaluation if it is not necessary to train, a zero weight is assigned which implies that training is not a decision area in method selection. Otherwise if it is necessary to train, weighting relative to other objectives and performance rating among alternatives is required.

Foreign exchange	**Foreign exchange cost** **(Shadow price rate)**	**Least cost**

Remarks:

As an interrelationship, foreign exchange can be considered as part of the total project cost. However, since there is dependence on choice of technique, a decision (independent of total project cost) has to be made on foreign exchange separately as it is scarce, there is a need for less dependence on foreign assistance and loans which inherently are used to finance it.

The aim is to minimise foreign exchange use in projects.

Decision Areas	Use labour based methods thus less reliance on foreign inputs.
	Use locally available inputs (e.g. machinery). These might be more expensive than imported ones when converted to local costs but no foreign exchange is used.
	Donor financed foreign exchange component which implies no use of foreign exchange.

To effectively evaluate the impacts of the use of foreign exchange, it is calculated at market prices then converted to a shadow price to reflect social cost or the sacrifice of using it.

Quality	Subjective Scale	High-low

Remarks:

The adopted construction technique affects the comparative quality of the finished product. Quality is related to costs, employment, time and foreign exchange etc. A separate decision has to be made on quality which will affect the suitability of available options. Thus quality can be considered as an objective by itself.

Project Financing	Cost/time	Budget Anticipated
	Net Present Value	Payments over Duration of Project Discounted to Present

Remarks:

i) With available money, there is no need to consider cashflow (cost/time). In this case then, a zero weight is assigned and thus it is not a decision area.

ii) When the cashflow budget is anticipated, the option that falls within the financing limits is chosen. Thus in this case weighting relative to the other objectives and the performance scores among alternatives is required.

If benefits foregone by not finishing early were to be ignored, payments over a long period can be considered as a saving when considered on Net Present Value (NPV) terms.

Control over the Project (by the implementing agency)	**Subjective**	**Scale high to low**

Remarks:

Control over the project (by the clients and engineers) is determined by the size of the project and the organisational capabilities of the implementing agencies. As an objective it is related to other objectives, e.g. cost overruns, time overruns and quality control. In the options considered in evaluation:

i) If a small project, control is not a problem and thus a zero weight is assigned implying that no decision is required.

ii) For large projects, both labour based and capital based and depending on the capabilities of the implementing agencies, weighting and performance scores are required to reflect the degree of control probable.

Income Distribution	**Benefits to target groups e.g. low income workers**	**High-low**

Remarks:

Income distribution is an accepted objective and should be included in project selection. Of the objectives considered, it is more dependent on value parameters than on factual parameters, i.e. weighted allocation of resources as opposed to unweighted allocation of resources. Thus it is more dependent on the weighted value policy makers and planners want to be assigned to benefits towards projects which confer relatively more benefits to target groups,.e.g. the use of labour based methods may make a significant contribution to reducing inequality by providing employment and income to low income unskilled workers at a higher cost than capital based methods. Weights assigned to payments to low income groups may be such as to indicate that such a sacrifice in extra cost is worthwhile in terms of the increased welfare it provides for the low income groups.

Classn:

MULTIOBJECTIVE EVALUATION OF CONSTRUCTION METHODS ALTERNATIVES

Ndekei J Kiarie

ABSTRACT: A multiobjective evaluation method to analyse alternative construction methods in order to select the construction method which is most appropriate given available resources to achieve or partially achieve technical, economic and social objectives.
Use of the method is illustrated by application to a hypothetical road project.

Department of Civil Engineering, University of Canterbury, Master of Engineering Thesis, 1989.