AN EXPERT SYSTEM APPLIED TO EARTHMOVING OPERATIONS AND EQUIPMENT SELECTION

by

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DEDICATION

To the soul of my father **Toma Alkass.** *A great father and greater teacher, who passed away during the final stages of this work on the 14th of September 1988 sadly missed.*

and

my mother

DECLARATION

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

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ABSTRACT

The thesis represents an effort to assess the current and future development of expert systems relating to civil engineering problems. It describes the development and evaluation of an Expert System (ESEMPS) that is capable of advising on earth allocation and plant selection for road construction similar to that of an expert in the domain.

Knowledge for this particular domain was acquired from field practitioners such as planning engineers and equipment specialists.

The development of the appropriate knowledge acquisition techniques are covered in details together with evidence provided on suitable methods for interpreting the information gathered into a form capable of being manipulated by computer programme.

The system was tested both with practitioners and novices and the concept of the a consultation validated. It was also tested against a real data from a road construction project under construction.

During the evaluation of ESEMPS on site it's decisions were considered acceptable to the practitioners who reviewed them.

The system has significant potential for making an immediate contribution to inexperienced engineers as well as to the practitioners in the field of the road construction.

While not all the decisions were equal to those of experts, this should be expected because no two experts will usually arrive at the same decision at the same way.

ESEMPS will have a significant benefit if used in developing countries where experts are rare and very expensive to employ.

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CHAPTER ONE

INTRODUCTION

1.1 General matters

Expert knowledge relating to construction is in the main held personally by experienced practitioners and therefore accessible only piecemeal. An expert system is an attempt to counter this disadvantage by bringing together as many strands of expertise as possible structured in a manner that facilities a user to steer a step by step course in learning and so solve problems which are largely judgement dependent. To capture an expert's knowledge is time consuming, laborious and complex, but when successfully achieved and superimposed onto a well designed computer system can simulate a consultation as though the computer was a tutor and the user a pupil [1, 2, 3, 4, 5, 6, 7].

To demonstrate this concept this thesis describes a system for earthmoving allocation and selection of earthmoving equipment in road construction.

Planning a large earthmoving project requires sound judgement in choosing equipment and resources, combined with detailed analysis of the sizes and numbers of each type to complete the job on time and cost. The soil conditions, weather, equipment performance, labour, size of the job, quality of the work, time scale, location, equipment availability all impact on the decision making process and must be weighed for importance. Unfortunately, information, guidance, etc. on such matters is at best held personally by practitioners, who are rarely accessible outside their own company department, while books, reports on past projects etc. are generally not appropriate.

Most companies thus rely on experience gained from previous contracts to base equipment selection decisions. The common procedure involves different members of a team such as estimators, planners, equipment engineers, site managers, procurement officers etc. offering suggestions on potentially suitable items of plant, their advice usually being based on rules of thumb. This is the kind of knowledge that forms the core of the system (EXPERT SYSTEM) described in the thesis.

In contrast conventional programs derive their problem-solving capability from collections of algorithmic statements written specifically for dealing with particular problems eg. optimisation. Thereafter it is usually difficult to make modifications for handling other types of situation.

Indeed this kind of approach has other major weaknesses an important one being the inability to explain ***how*** a conclusion was reached and ***why*** it requires a certain input. Users have to infer these for themselves by looking at the output of the program and using their knowledge of the way the program is structured. This is perhaps the most serious drawback because it places an unnecessary burden on the user.

Furtherone as programs become larger and more complex, the task of understanding takes up an increasing proportion of the user's time and effort. It is also possible that the user's model of the way a program works could be incorrect or incomplete.

Finally, users often treat such programs as magical 'black boxes' that will hopefully give the right answer when supplied with the right input.

1.2 Expert systems

In comparison an Expert System or Knowledge Based System as it

is also called is "a set of knowledge stored in a computer in away which could be consulted as would a human expert do." [8].
Many types of expert systems are possible within such a definition and they are used in various economic, medical, industrial, and civil engineering areas. For instance, in medicine, MYCIN [9] diagnoses blood infection and recommends antibiotics therapy. In business, expert systems have been developed for marketing [10], while in chemistry, DENDRAL [11] interprets mass spectro-graphs. In civil engineering, expert systems have been used to assist in structural design [12], and for geology, PROSPECTOR [13] identifies probable sites of deposits of mineral core. In construction decision making has to be largely based on heuristics i.e. rules of thumb are needed [14, 15, 16, 17, 18, 19, 20], which are extremely difficult to define for the computer. Nevertheless this thesis attempts to show that for the earthmoving operations an Expert System approach is viable.

1.3 Earthmoving operations and expert systems

Earthmoving operations in road construction involve a wide spectrum of activities related to:

* Planning
* Design
* Transportation
* Management and control

Such activities are needed in deciding the means for the safe and efficient movement of equipment and other resources, to provide basic mobility as well as accessibility to work places., also to execute the project within minimum cost. In these respects computers can be of help for analysing alternative options, however, far too many activities lack explicit numerical algorithms, and are often too complex or ill-defined for most conventional computer programs, and only broad solutions can be put forward to be supplemented by **human judgment and experience.** In this latter sense Expert Systems are designed to capture the knowledge of an expert, or group of experts, in a particular problem domain. Such systems are primarily applicable to situations requiring specialised knowledge, skill, experience or judgement, where the problem is usually said to be ill-structured, in that a numerical algorithmic solution is not available or is impractical. Road construction in particular, is full of such problems where human behavior, social and economic considerations, and complex decision-making are involved. Because so many of the problems are of this kind, it can be said that the potential is high for knowledge based systems to become useful tools for the practicing road engineers. One can envisage such systems functioning as expert consultants, capable of explaining their reasoning and why they arrive at certain conclusions.

1.4 AIMS OF THE RESEARCH

Against this background the most obvious conclusion is that some completely new approaches are required.

The elements of earthmoving operations are in deciding the amount of material to be moved or dumped, from where to where, and selecting the most appropriate equipment to do that efficiently. The new approach therefore is to develop and test an expert system to aid the selection processes involved in order to satisfy the following main and secondary objectives:

1.4.1 Main objectives

i) To obtain a precise understanding of the methods of analysis and decision-making used by those personnel involved in road construction and equipment hire companies.

ii) To arrange the knowledge gained into a form capable of advising the inexperienced on the most appropriate methods of construction and equipment selection from both technical and economic standpoints.

iii) To apply flexible computer techniques formulated as an Expert System to plan and control earthmoving operations.

iv) To show that expert systems could successfully assist in providing expert knowledge relating to road construction.

1.4.2 Secondary objectives

i) To collect information and data from real road projects.
ii) To test the expert system using this information.
iii) To use the system as a tutor for inexperienced engineers as well as for students.

1.5 Work undertaken

To satisfy these objectives the following work was undertaken:

Firstly, previous research and literature on both expert systems and road construction were assessed and critically reviewed. The variables affecting equipment selection were identified.

Secondly, many domain experts were interviewed, their methods of equipment selection, and reasoning behind their decisions were recorded and transferred into rules and stored in a computer system as a knowledge base.

Thirdly, the system was demonstrated to the experts and improved according to their suggestions.

Fourthly, nonexperts were selected to use and criticise the system.

Lastly, the Mass-Hall diagram and optimisation methods, which are traditionally used to calculate the amount of cut and fill along a road project, were completely revised to incorporate heuristic rules and simple calculations and tested for accuracy.

1.6 Main achievements:

The two main achievements were the development of:

a) A knowledge based system for advising on the selection of earthmoving equipment, and use in site control.

b) A rule based system, to aid the calculation needed to define cut and fill areas and material quantities along the road.

(a), was successfully achieved after detailed collection of specific knowledge from different sources, mainly domain experts. The final system proved capable of assisting the inexperienced in selecting the most appropriate equipment for earthmoving operations.

To achieve (b), existing conventional programming methods were reviewed and criticised and a new approach introduced using a combination of heuristic knowledge and simple calculations, to allocate fill and cut along a road project.

To support this work the important factors were identified and the literature relating to the existing methods reviewed and criticised. Also a case study of a major road construction project was applied to the new method to check the output results.

1.7 GUIDE TO THE THESIS

Chapter two, presents a background on the nature of the construction industry, it's computing and practitioners, and the industry's conventional programs. Desirable characteristics of both construction industry computer programs and expert system are also reviewed. Lastly a review of current methods for planning earthmoving operations and the techniques proposed in the research are also discussed.

Chapter three, presents a detailed literature review of the concept of using expert systems to emulate the thought processes of human experts and how this knowledge can then be utilised to execute and control external computer models. State-of-the-art knowledge acquisition techniques is also be discussed in this chapter.

Chapter four, presents a detailed literature review of the earthmoving operations for road construction. A detailed evaluation of the current methods applied by the contractors to earthwork is also discussed.

Chapter five, presents detailed discussion of the selection and implementation of the methodology used in constructing the present expert system for material allocation and earthmoving plant selection. The development of the heuristics used to build the knowledge base is discussed and the process used to arrive at the final decisions on equipment selection is reviewed.

Chapter six, contains a discussion of the methods used in evaluating the performance of the expert systems in general, and reviews the methods used to evaluate the expert system developed in this research. The results of that evaluation are then presented.

Chapter seven, first presents the conclusions drawn from the development of the expert system during the research. A discussion is then provided on how the developed system offers a contribution to the construction industry in general and the field of road construction in particular. Lastly the chapter presents a discussion on how future research should enhance the system's performance.

The Appendices, contain a sample of a consultation of the system ESEMPS. A list of different Expert Systems applicable to the construction industry is also content in the Apendices. An example of a linear programming alpplication as well as a sample of the external progame are included.

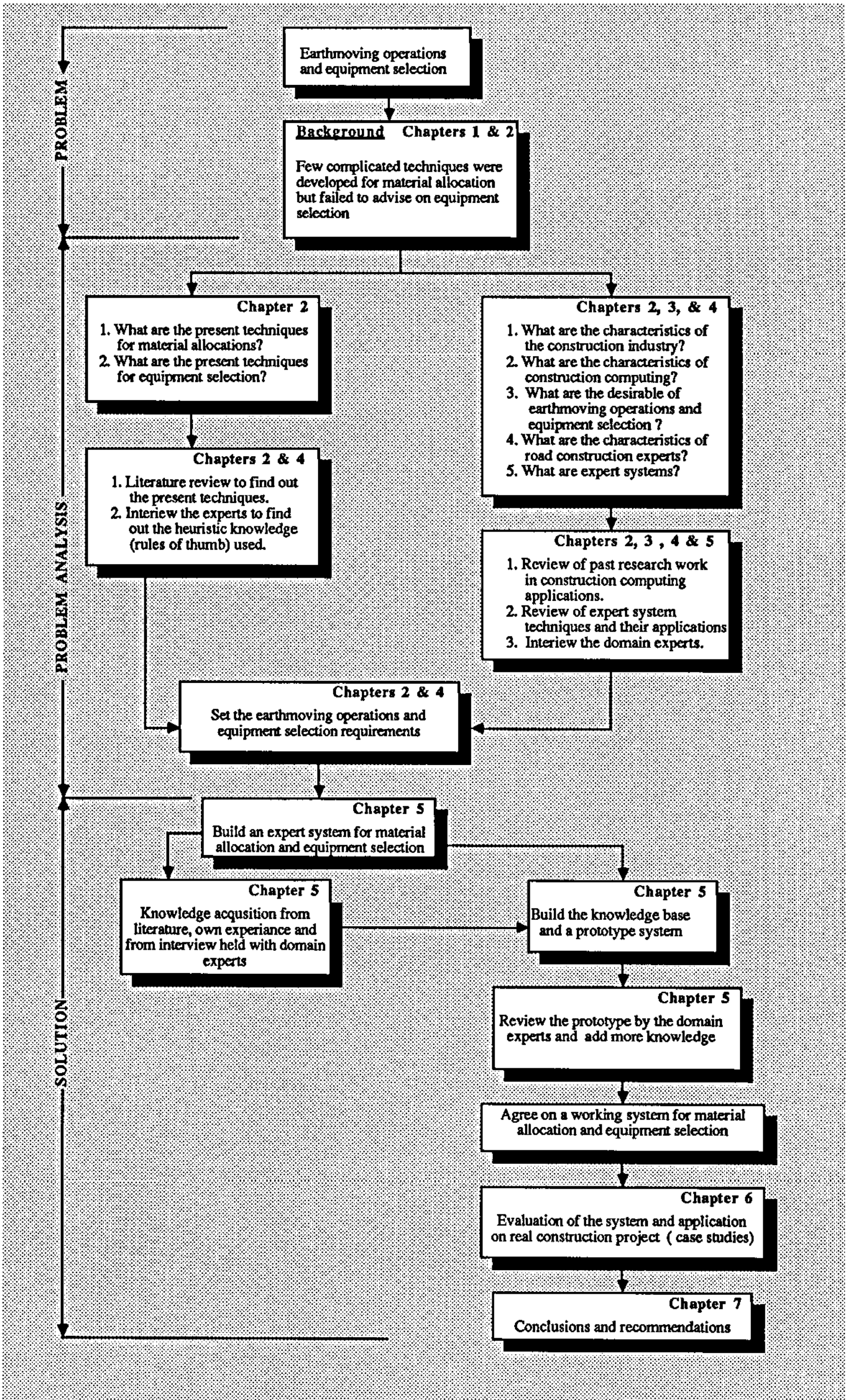


Fig 1.1
Thesis layout diagram

CHAPTER TWO

BACKGROUND

2.1 The nature of the construction industry
2.2 Construction computing
2.3 Construction industry practitioners
2.4 Conventional computer programmes
2.5 Desirable characteristics of construction industry computer programmes
2.6 Expert sytems chararcteristics
2.7 Evaluation of current methods for planning earthmoving operations.
2.8 Planning techniques used in this research and recommended methodology
2.9 Reasons for using expert systems in earthmoving operations

2.1 The nature of the construction industry

The construction industry is multidisciplinary and interrelated in a way which probably makes it unique. No other industry has such a wide variety of mostly one-off projects nor such long established (though not necessarily sensible) divisions between those who design and those who build . Teams from the various disciplines generally come together in an adhoc manner in order to produce a single project and then disappear and reform with others for the next. Building components (sometimes standardised, sometimes purpose made) from a wide variety of sources, and manufactured to incompatible tolerances, are bought in and assembled insitu, often in less than adequate working conditions. Both design and construction are carried out within the framework of largely empirical rules and regulations designed mainly for ease of implementation and checking. Prototyping and full-scale mock-up construction (quite common in other fields), is unusual, so any new construction technique or material has to be tested in use. On completion of the project, little follow up research is carried out on the way it was used or on the way in which the assumptions made in its design were born out in practice. These, and other factors, relating to both one-off production technology, and external influences, such as weather, regulatory agencies, and the like, make it difficult to assemble a body of industry-wide recorded experience. In the main knowledge of this kind is held personally by practitioners largely unavailable to other experts, trainees and students. Hence overall improvements in quality and efficiency remains low and mistakes are repeated many times before their effects becomes apparent.

Despite such practical and organisational peculiarities, however, the construction industry is frequently capable of producing excellent work of lasting value and it is one of the objectives of this thesis to show how a new form of computing might assist in making this excellence more widespread.

It aims to achieve this mainly by bringing together as many strands of expertise as possible in a discrete subject area (road construction in this case) distilled from the collective experience of practitioners and incorporating these into a particular computer system known as an expert system.

2.2 Construction computing

Because of the diverse and fragmented nature of the industry, it's computing needs have necessarily been met by a wide variety of different programs[21], typically:

i) Management, payroll and accounting.
ii) Quantities and stock control.
iii) Time scheduling and man-power allocation.
iv) Word processing.
v) Design and draughting.

Although all such programs perform some calculations, in many cases this is not their major function. Thus to assist in relating them to expert systems, it is useful to subdivide the programs into five overlapping categories:

i) programs in which calculations play a major role. For example beams, slabs, and columns design.
ii) Programs in which manipulation of text plays a major role. For example, word-processing and specification writing.

iii) Programs in which graphical manipulation play a major role. For example, draughting and perspective drawings.

iv) Programs in which data base creation and information retrieval play major roles. For example, design, stock control and quantities.

v) Programs in which logical operations play major roles. For example, design, management, and control.

In common with computer operations generally, these programs work in one of the two distinct modes:

a) **Batch**: In which, once started, the programs proceed without further intervention by the user. This independence implies that all information for proper working is available to the computer at the outset of the task. Management, payroll, quantities and accounting programs tend to be of this type.

b) **Interactive**: In which the course of the operation is determined by the user who either answers questions posed by the computer or gives it instructions as the work proceeds. Many design and drafting programs work in this manner where the interaction is sometimes performed by means of drawings in addition to text and numbers,(a process known as graphical interaction).

All these programs embody detailed knowledge of the particular tasks they are designed to carry out.

Beam and slab calculation programs for example often hold details of the relevant codes of practice.

Useful though these programs are, they generally have characteristics that make for two sorts of difficulty:

i) The difficulty of non-experts in understanding their working, and hence, accepting the validity of their output.

ii) The difficulty of making alterations to suite changes of circumstances or new requirements.

These difficulties come about mainly from the way in which conventional programs, both batch and interactive, have to be written and the way in which the knowledge of the tasks they are to deal with is embodied. To date, the needs of efficiency of computation have tended to be paramount so that programmers have had to devise their programs to suite the computer rather than the person wishing to read and understand the program. In addition, details of the necessary calculations and processes are frequently scattered about the program and couched in terms accessible to the machine but less so to the user, who might have considerable knowledge of the subject area but little of computing language and methods. For these reasons it is generally necessary to take the results of computer working in trust. Whilst, a great deal of testing against experience and manual methods will be carried out during the program writing stage, the correct performance of such a program has by it's very nature to be an article of faith, the computer itself having no method of justifying its conclusions and the user having no way of checking through all the steps the computer might take.

Thus, although one often gets from the computer information similar to that obtainable from a very knowledgable and experienced consultant, the programs have little ability to act in the way consultants or experts do, a factor that lessens the value of their advice as will become clear when comparing the characteristics of conventional programs with those of expert systems.

2.3 Construction industry practitioners

* Their skills arise from the possession of knowledge and experiences in specific subject areas. These skills develop as more experience is gained.
* They can explain and, if necessary define the advice they give and are aware of its wider implications.
* The tasks they perform are not of an algorithmic, step by step nature, but require the exercise of judgement and a flexibility of approach which allows them to take any unusual circumstances into account.
* They can, and frequently have to, act with partial information.

In order to supplement this, they ask only sufficient and relevant questions to allow them to arrive at a conclusion.

2.4 Conventional computer programs

* They are usually complex and difficult for any one other than their designers to understand.

* They cannot justify their results nor generally suggest to users why they need a particular piece of information (nor whether the information they request is vital or merely supportive). This is because they have no concept of the meaning of their actions.

* Even in the interactive case, it is customary for the program rather than the user to determine the order and manner in which the tasks are to be carried out. This order is often fixed and inflexible regardless of the particular circumstances in hand.

* In most cases, they require information to be input in a standardised and sometimes, coded manner and cannot work with incomplete data.

While these characteristics often do not result in computer programs too flawed to be useful, they nevertheless, militate against widespread use of computing in industries, such as construction, where practical experience, judgement, and craft skill are more fruitful sources of knowledge than scientific investigation or mathematical expertise. Thus computers in construction have been used as low-grade assistants rather than intelligent consultants as they might.

The question therefore arises, what are the desirable characteristics of computer programs which can better serve construction interests?

2.5 Desirable characteristics of construction industry computer programs

It can be taken as axiomatic that the primary aim of computer programs for construction is that of encapsulating the knowledge of experts in various relevant fields and making this available in the manner of a consultant advisor to those with more limited experiences. To be of the most practical use, this knowledge must be embodied into the programs in a way which the experts can check and readily modify by additions and deletions, without the need for detailed computer-orientated skill.

The object of this feature is not only to make the knowledge based rules of which the system operates transparent to the experts who composed them, but also to others whose own experience might lead to further modifications. The advice given by the programs should be presented in natural, though perhaps, specialised language and, as far as possible, the programs should be capable of interpreting natural language input (including graphics where appropriate).

This is to say that interaction with the machine should be in a conversational form not dissimilar to that carried on with a human consultation.

As far as practicable, the users rather than the programs should be in control of the sequence of the operations determining the order in which things should be capable of working with limited user-supplied information. If the information to hand at a given time is too limited to allow any useful work to be performed, then only sufficient questions should be put to enable matters to proceed. Further, at all times the programs should also be able to justify the results they display or advice they offer and be capable of convincing the users of their correctness and appropriateness.

This feature is of particular significance in design programs where users need some assurance of the validity of any information they incorporate into their designs especially where intuitive 'feel' for the outcome is difficult to achieve.

These desirable characteristics, of course, are not limited to programs devised for construction industry use, and it is no accident that they closely resemble the characteristics of EXPERT SYSTEMS.

2.6 Expert system characteristics

Many authors have written on the characteristics of expert systems, and could be summerised as follows:

i) They contain a great deal of knowledge in specific domains, such knowledge being acquired possibly from recorded experience but more likely, directly from experts.

ii) They can arrive at a conclusion, and advise the user in a manner of a consultation, also the reasons behind conclusions can be explained.

iii) Their knowledge is embodied not in the form of conventional programs but frequently by means of models containing sets of rules of thumb with corresponding actions. This feature makes the correction of errors in the knowledge base possible as well as the adding of new knowledge as it becomes available.

iv) They can give their advice in probabilistic, rather than absolute term to deal with the uncertainty.

v) The questions posed by expert systems are directed to ones relevant to a particular line of reasoning. Thus, at any time the system finds there is sufficient information to arrive at a conclusion, the line of questioning is curtailed.

vi) Expert systems can explain and justify their reasoning in a similar manner to an expert hence nonexperts can learn piecemeal.

Several robust expert systems already exist and many more are under active development, as listed in Appendix [A]. From an examination of many of these examples, it is possible to suggest that they perform best where the following conditions hold:

* Performance of the subject task is based on factual knowledge rather than computational methods.

* The area of interest is specialised but limited.

* It is possible to build up a knowledge base in a piecemeal fashion over time.

* The area of interest is one in which experts exist and are available for knowledge elicitation.

Expert Systems on this basis seems appropriate for construction industry applications.

2.7 Evaluation of current methods for planning earthmoving operations

2.7.1 Estimating stage

One of the major bid items of any heavy or highway construction project is the earthmoving operation, and small errors in estimating may greatly affect the profit margin. The increasing competition in the construction industry today not only calls for lower bid prices but more importantly accurate estimates and contractors must therefore continuously strive to improve estimating techniques.

Much of earthwork estimating currently in use is conducted in a deterministic manner, and assumes that definite values can be obtained for cyclical time elements comprising the earthmoving operation. A summation of these elements establishes the total time for the entire operation.

Many of the large equipment manufacturing companies recommend this approach when using their equipment. However, by estimating in this manner, the random variations within the cycle elements are not fully considered. Indeed Gaaraslev [22], showed that nonstochastic or deterministic analysis of a number of construction materials handling systems led, in all cases, to estimates of production rates significantly different than actual production rates. He further suggested that these actual rates could be more closely approximated through analysis by recognising the stochastic nature of the time involved.

Clemmens [23], also supported this view and recommends that in relatively simple conditions a mathematical modeling approach could be applied to examine stochestic variations, but for complicated situations, a more effective means of dealing with randomness is needed, principally by computer simulation methods. Several models [24, 25, 26] have been partially or fully developed specifically for earthmoving operations.

2.7.2 Traditional construction planning methods

A few basic questions immediately face project managers at the planning stage such as "how much earth should be moved " and "from where to where?". During construction, a second category of problems arise namely " how can optimal productivity be reached and maintained" or " how should the resources, eg. trucks, bulldozers, etc. be utilised for maximum efficiency?"[27]. And during planning and control of the project a variety of further routine problems arise continuously. Since the optimal solutions sometimes require precise data and analysis, construction managers generally prefer to make decisions based an experience and less on systematic approaches. However piecemeal advancements in technology are opening new ways for better control of the construction process [28, 29], by involving automated data collection. For example earth quantity take-off procedures are today largely standardised, and can be assisted by various computer software packages using data obtained from ground surveys and borehole logs. Thereafter grades and planned elevations of cut and fill sections can be determined by one of several methods; typically average end areas or prismoidal formulas. Additional information concerning the soil type(s), swell and shrinkage factors are also necessary. With this information the planner then determines the earth distribution plan using the mass diagram technique.

Other methods include mathematical optimisation methods using linear programing, in which allocation of cuts and fills along a construction project are based on a transportation algorithm minimising the fixed unit cost [30, 31], or variable unit cost [32], of material hauling proportioned according to haul distance. This technique is best applied when Linear Scheduling Methods (LMS), are appropriate[33], or in simulating road construction programs [34].

2.8 Planning techniques used in this research and recommended methodology

Researchers realise that traditional planning methods generally lack a detailed analysis aspect, and have attempted to bridge the gap with mathematical models but sofar with the limited success when applied on site. Even the mass haul diagram method, though an effective tool in many situations, has several disadvantages [35]. First, the average haul distances must be computed from the centre of mass of cut to the centre of mass of a fill, which often leads to inaccuracies in estimating distances if the cuts and the fills are not relatively equal in size or if there are other irregularities in the mass curve. Secondly, the mass diagram is not easily adapted to handling other variables such as different soil types, staged construction or haul route obstructions.

On other hand the methods where mathematical optimisation such as linear programing are involved, the required computer memory for even small sized projects can prohibit the use of micro computers, moreover in the optimisation method, the allocation of cuts and fills along the road, being based on minimising the costs of hauls, requires a prior knowledge of the cost of transporting a unit of material along a given haul distance. **Thus, the equipment resources would by implication have already been decided. Inexperienced personnel are clearly unable to reach this decision.**

A more practical method combining heuristics and mathematical techniques to design an earth distribution plan has thus had to be introduced in this research. The approach relies on well founded principles requiring cut and fill sections be carefully evaluated after which the appropriate equipment selections are made using rules of thumb ie. type of knowledge acquired from the domain experts and stored in an expert system. Both data base information and algorithms for making routine calculations are also linked to the system.

2.9 Reasons for using expert systems in earthmoving operations

As described the planning of earthmoving operations often must deal with uncertain and unreliable data concerning soil properties and loading conditions when experienced judgement would be of much more practical value than algorithmic modeling. An expert system approach could thus be justified on the following grounds:

i) Earthmoving equipment selection is experienced based

a) Earthmoving equipment selection is impacted by many variables resulting from both its one-off nature and from external influences such as weather, soil conditions and the like. For these reasons, a structured approach to decision making is difficult to develop. Nevertheless decision rules applicable to equipment selection can be broadly stated in terms of **IF**....condition..... **THEN**....action, and are similar to rules that are employed to represent knowledge in **rule_based** expert systems.

b) The present lack of reliable data on, for example, cycle time distributions of earthmoving equipment, greatly limits the applicability of formal methods of calculation and are best dealt with by "rules of thumb" approaches. Also automated data capture on construction sites has proven valuable[36].

c) These factors tend to promote the value of knowledge based on experience rather than knowledge of formal decision_making.

ii) Decisions must be made quickly

Decisions taken during the design, planning or estimating stages are generally urgently needed and become pressing when large numbers of equipment are already engaged in work on site, perhaps best summed by Levitt's[37], adage that, "any decision is better than no decision"or"ask forgiveness not permission".

The ability to deal with situations of this kind would be clearly of value if captured in an expert system.

iii) Site decisions involve managerial issues

Managerial issues, by their nature, involve variables that are more qualitative and subjective than those associated with straightforward technical matters and generally call for less reliance on algorithmic methods, with more emphasis on analogy or use of rules of thumb decision_making.

vi) Some construction operations can be automated

Fixed programmable robots such as those used in factory automation at present have fewer applications in road construction compared to a factory environment. Nevertheless, Rehak[38] and Paulson[39], conclude that with computer programs designed to respond to changes, for example dimensions, site conditions etc. some conventional road making equipment, eg planing machines and the like could perform routine tasks.

v) Incremental improvement to the knowledge base

Even when an expert system has been developed to an acceptable level subsequent "gaps" in the knowledge base, could appear without necessarily invalidating previous work. In contrast conventional programs often fail when a single program statement is changed or omitted. Indeed an expert system's performance should improve with additions to the knowledge base just like human learning.

vi) <u>The system can explain what is happening</u>

Many of the better computer programs on which the knowledge base is developed facilitate a reprise of the knowledge path used and how a conclusion was developed.

vii) **<u>The system's knowledge base can be corrected easily</u>**

The system is designed to select those items of information or knowledge sufficient to provide answers and provide explanations to the user. Gaps and errors in the knowledge base are therefore often obvious to the user.

CHAPTER THREE

THEORY OF EXPERT SYSTEMS

3.1 Introduction

3.2 Introductory papers

3.3 Origin of expert systems

3.4 Definintions of expert systems

3.5 The structure of expert systems

3.6 Building an expert sytem

3.7 Why build an expert system

3.8 Acquiring knowledge for an expert system

3.1 Introduction

Following the wave of Fortran in the 1950's, Problem_oriented languages in the 1960's, and CAD in the 1970's, the recent development of knowledge base systems has also generated same interest within the civil engineering industry computing community[40].

Unfortunately expert systems evoke expectations of full blown Artificial Intelligence programs that adapt, learn, invent, and accumulate the combined wisdom of a profession which at present is too optimistic a view.

This chapter therefore is an attempt to define and clarify expert systems in terms of knowledge structure, knowledge representation, control and development. Also their role and impact on construction will be discussed.

3.2 Introductory papers

Artificial intelligence has been a topic of discussion among engineers and designers, particularly in academia, for over two decades. Only recently has it matured and the sub topic of expert systems appeared as a valuable approach to areas not previously thought appropriate[41]. Authors have described what constitutes an expert system in a variety of forms [42], some have focused upon the characteristics [43], others have tried to tie them into a general topic [44], and yet others to use the historical approach [45]. Some have presented the material as an introduction to books and conferences [46, 47, 48, 49,50], while some reports are even concentrating on the details of one particular application [51].

Many of the introductory papers are simply surveys, for example, Wager and Marksjo [52, 53], covered expert systems in the construction industry in the United Kingdom, while Finn [54], focused upon experience in the United States, particularly in engineering firms. Some summarise the application of expert systems in structural engineering, [55, 56, 57, 58, 59, 60], with others concentrating on architectural design, [61, 62, 63].

A particularly active topic deals with knowledge collection and knowledge base structure [64, 65]. Lately models in a specific domain of civil engineering and construction have come to the fore[66, 67, 68, 69, 70], together with issues debated at conferences [71, 72, 73, 74, 75], dealing both with specific models and techniques in general. Particular languages such as Prolog [76], are currently under examination along with custom shells [77, 78]. Yet other papers are addressing specific programming approaches for the development of models [79].

It is pleasing to note that most papers begin with a general overview helpful to the novice, but recent trends appear to be avoiding the routine introductions.

3.3 ORIGINS OF EXPERT SYSTEMS

Expert or (knowledge based) systems emerged only recently from decades of research into problems traditionally associated with human intelligence, called **Artificial Intelligence (AI)**. The method is in essence a way of trying to make a computer function intelligently [80] by reproducing how people think when making decisions and solving problems. Most researchers try to break the thought processes down into basic steps, and then design a computer program to reflect those same steps.

As a consequence AI developed as a branch of computer science, adjoined to other branches such as languages interpretation, data structuring, operating systems and numerical algorithms. It is worth noting that civil engineering computer users have significantly benefited from the later branches of computer science research, in the form of improved algorithmic language, data bases etc.

3.3.1 What is AI ?

The current ideas for modeling intelligent human behavior developed from the fields of engineering, psycholinguistics, computer science and cognitive psychology [81]. The initial concepts came from a combination of ideas dealing with mathematical logic and computation.

Baerr and Feigenbaum [82] pointed out that, It was not until the creation of the "intelligent" machine, which could actually begin to carry out and test theories, set by the first pioneers, such as Ferge, Whithead, Russel, Weiner, Turing and Babbage, that (AI) begins.

Alan Turing is said to be the "father of the (AI)". He developed what is commonly referred to as the "Turing test" or, as he called it "Imitation Game". This was the first non-numerical model of computation. Turing, was one of the first to argue strongly the possibility for designing machines to be intelligent and developed his model as an answer to the question "can the machine think?"[81]. Since the time of Turing, AI has come to be regarded as a separate field of computer science. Indeed researchers have developed computer programs with the ability to perform like humans in certain instances [84], the ultimate goal being to develop expert consultants or intelligent agents which will one day be self sufficient machines [85].

The early AI efforts dealt with representation and processing of symbols (other than numbers) and evaluation of information processing, including learning of humans. These solved tasks ranging from puzzles to proving of theorems using only minimal sets of general problem solving tools, such as heuristic searches, and means_end analysis. All domain dependent knowledge was "learned" by these programs as they solved tasks. The trailblasers on this frontier were Newell and Simon, at Carnegie_Mellon University, USA, 1957; and their work culminated in GPS, the 'General Problem Solver'[86]. Central to this approach was the notion of heuristic search. They believed that human thinking can be accomplished by coordination of simple symbol manipulating tasks such as comparing, searching, modifying a symbol and the like, ie. the kind of things a computer can also do. They viewed problem solving as a search through a list of potential solutions, guided by heuristic rules which helped direct the search to its destination.

GPS system concentrated on general problem solving with the ability to add additional rules as necessary. However as the rules were added to the system and the system became "smarter", it also became considerably slower to the point where it was no longer useful.

By the 1970's it became clear to AI researchers that the simple problem solving methods were not sufficient and the first generation of expert systems emerged, by dealing with specific domain knowledge, notably MYCIN AND PROSPECTOR [9, 88].

3.4 Definitions of Expert Systems

Expert systems have been variously described as knowledge based systems, intelligent based systems, ruled based systems (after the method of reasoning used) and expert or intelligent assistants. Each depends on whether the subject is being approached from a performance or a methodological point of view, ie. whether one is interested in what the system does or how it does it. In a purely technical sense an expert system might be defined as a computer system which operates by applying an inference mechanism to a body of specialist expertise in the form of knowledge.

The Expert System Group of British Computer Society have expanded on this to suggest the following widely adopted definition [89],:

"**An expert system** is a means of capturing the knowledge of experts in the form of programs and data where disagreement among the experts are settled by mediation and results refined so as to extract the essence of their knowledge in such a way that it can be used by less experienced people within the field. The usage of such a system can be monitored so that adjustments may be made semi-automatically under the guidance of the experts. The expert system is a tool and means of coherent communication of the latest views of the experts to the users who may well be the experts themselves. The use of the system combined with a measure of importance provided by the experts gives a measure of the utility of what is being communicated. This recorded utility may then be used by a program to vet the knowledge so that the channel does not get closed with redundant material"

(BCS Special group on expert system 1981)

Many writers in the field for example, Michie, Holroyd, Goodall, [90, 91, 92], feel this definition is unnecessarily restrictive and does not reflect the true potential of expert systems, particularly in its specification of ruled based systems, which effectively dismisses those applications which are using alternative methods of knowledge representation.

Most researchers prefer to concentrate on the capabilities of the system and have therefore suggested looser and more widely applicable definitions, such as Bremer's [93], " a computing system which embodies organised knowledge concerning a specific area of human expertise sufficient to perform as a skillful and cost effective consultant".

Holroyd [91], preferred the more imaginative definition, "a system which, as far as the users are concerned, displays expertise in some aspect of problem solving which is useful for them". This, Holroyd claims," frees us from an over_rigid identification of expert systems with inference based systems which we believe might be more properly viewed as one method of designing an expert system".

Goodall [92], suggests that an expert system is" a computer system which performs functions similar to those normally performed by human experts" , and expands further to convey the nature of the system with" a computer system that uses representation of human expertise in a specialist domain in order to perform functions similar to those normally performed by a human expert in the domain.

Feigenbaum [94], gives a more accessible definition " an expert system is an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution. The knowledge necessary to perform at such a level, plus the inference procedures used can be thought of as a model of the expertise of the best practitioners in the field".

Since much of the debate about what constitutes expertise or knowledge or intelligence in relation to an expert system is distracting, those involved in industrial applications of expert systems for example, do not involve themselves in such academic debate, they are interested in systems that solve a problem at work, whatever they be called.

For the purpose of this thesis, the Alkass and Harris [1], definition of expert systems will be adapted. They define the expert system as" a set of knowledge incorporating judgement, experiences and "rules of thumb" in a specific domain stored in a computer system in away that could provide expert advice supported by explanation and reasoning".

Despite the wide range of different definitions they all share the principle of requiring of knowledge in a specific domain, stored in a computer in a way that can simulate a consultation.

The first reaction of many professionals active in conventional computing programing to the above definitions seems to have been one of boredom and impatience. After all, conventional programs for engineering applications have become increasingly interactive, they have always incorporated expertise in the form of limitations, assumptions and approximations, with output long ago being accepted as advice, not as an answer to the problem.

There is a need therefore, to add an operational definition to distinguish the new wave of expert systems from conventional algorithmic programs which incorporate substantial amounts of domain dependent heuristics. The distinction should also not be based on implementation languages alone eg., Fortran, Pascal or Lisp (after all Savior is written in Pascal, and several expert systems frameworks are now available in "Fortran" or "C" implementation), or any absolute separation between domain dependent knowledge base and generic inference engine (for example, in frame based knowledge representation there is no generic inference engine).

Adeli [95], outlined the differences between expert systems and conventional programs on the following basis:

i) Expert systems are knowledge intensive programs.

ii) In expert systems, expert knowledge is usually divided into many rules .

iii) The rules forming a knowledge base are separated from the methods of applying the knowledge to the current problem, referred to as an inference engine mechanism, reasoning mechanism, or rule interpreter.

iv) Expert systems are highly interactive.

v) Expert systems have users and a friendly intelligent user inference.

vi) Expert systems to some extent mimic the decision making and reasoning process of human experts. They can provide advice, answer questions, and justify their conclusions.

Point (i) of the above list is a frequently cited difference, but can be missleading,because in algorithmic programs a small amount of knowledge (eg. the knowledge of matrix multiplication) can be intensely used by repetition.

Point (ii) is a consequence of point (i), but moreover, it applies only where rule based representation methods are used.

Points (iv) and (v), are not restricted to expert systems, any programs can be made highly interactive and very user friendly [96].

3.4.1 Extended definition of expert systems

Adeli's list could be extended further to clarify the separation of expert systems from algorithmic programs as follows:

i) **Separation of knowledge and control:**
In an expert system there are facilities for manipulating the knowledge base (displaying, searching, modifying) separate from the method of control (inference engine) which executes the knowledge base.

ii) **Transparency of dialogue:**
There is also some form of explanation facility to convey to the user the inference process actually used. Conventional "Help" facilities do not qualify, as these are separated from actual execution, also they are used to assist in execution of the program but not to explain the reason behind decision making or the answer.

iii) **Transparency of knowledge representation:**
The domain dependent knowledge incorporated in the program code should be reliable and understandable to some degree, while that not incorporated does not therefore qualify.

iv) **Incremental growth capability:**
An expert system can be used with a subset of its ultimate

knowledge with the additional potential for extention over a period of use without major restrictions.

3.5 The structure of expert systems

In developing all expert systems, the soliciting of expert knowledge and its transfer to a computer could be broadly separated into two aspects, namely human and machine as shown in fig (3.1).

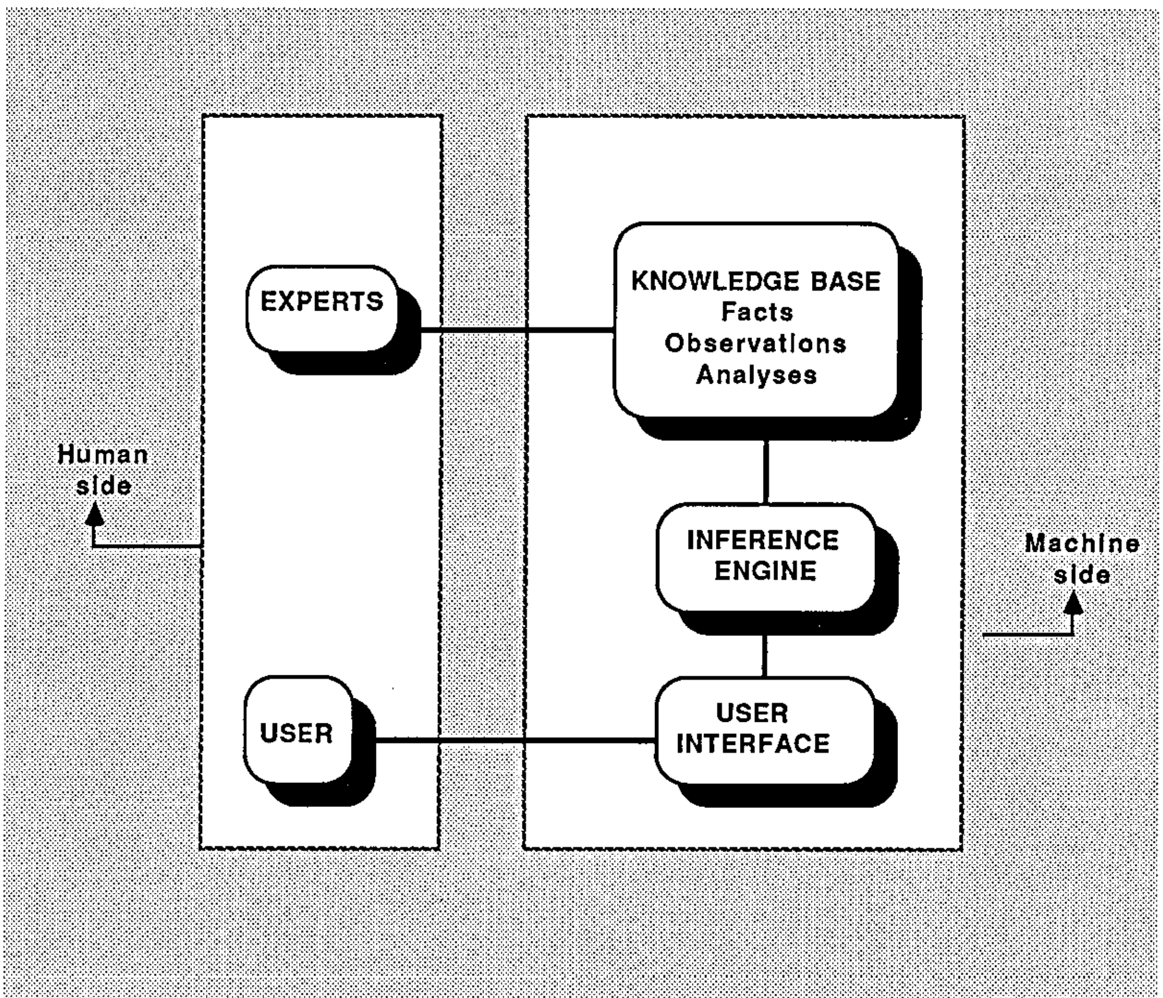


Fig (3.1)
The elements of an expert system

3.5.1. <u>The machine side</u>

At the heart of every expert system is a powerful body of explicit and organised knowledge called a knowledge base , and a clearly separated reasoning mechanism called an inference engine, which manipulates that knowledge to hopefully provide imaginative, accurate and efficient answers to problems. Fig (3.2) shows the elements of the machine side.

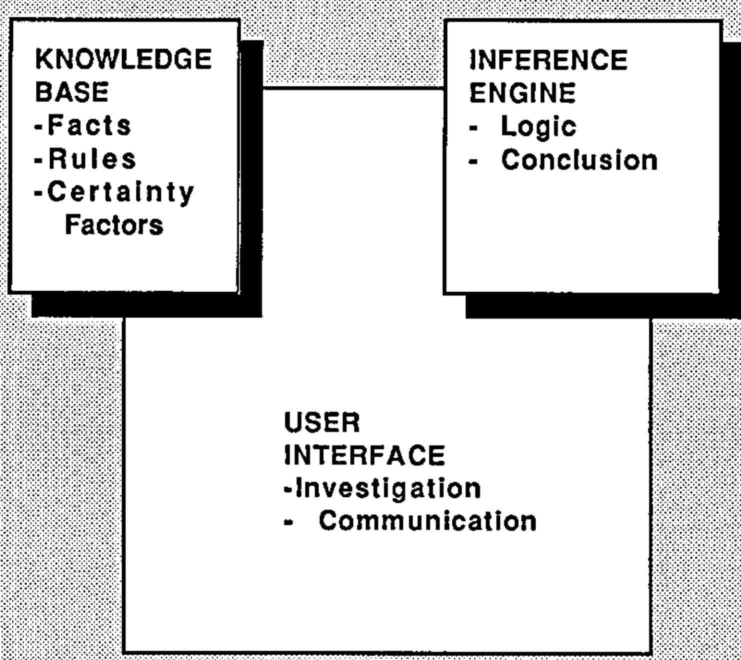


Fig (3.2)
The machine side of an expert system

3.5.1.1 <u>The knowledge base</u>

The knowledge base contains facts about the subject, expressed as objects, attributes, and conditions. Besides descriptive representations of reality, it also consists of expressions of contingency ie. the limitations that contribute to the validation of facts.

In this respect it can be distinguished from a conventional data base by it's symbolic, rather than numeric or literal content. When data base information is processed, it is generally only retrieved, stored or calculated, whereas the content of a knowledge base is processed, and rigorously manpulated according to predefined rules or logic. Consequentially, a knowledge base has to deal with classes of objects derived from consultations, text book authors, researchers, expert themselves or from their works.

Foster [97], suggests that in seeking sources for a knowledge base situational rather than academic experience is more useful since a practitioner who relies on long term observations of events in a particular domain is more likely to produce a usable knowledge base than an analytical expert with only a grasp of external phenomena. To be appropriate such information and knowledge needs to translated into a computer program, commonly represented in the knowledge base in three particular ways [98]:

i) **<u>Factual (declarative knowledge)</u>** is that gathered through dialogue with the user to establish the facts of a particular case. This may be short term information which can change rapidly.

ii) **<u>Procedural knowledge:</u>** Long term information collected in advance from the domain practitioners about how to generate new facts or hypotheses from what is presently known. This knowledge forms the core of the knowledge base and the reasoning part of the system. Procedural knowledge is usually written in the form rules of the " If a THEN b" variety. Procedural rules can generate facts on demand and factorial and procedural knowledge is therefore interchangeable.

iii) **<u>Control knowledge:</u>**
The system needs a variety of control strategies available to it so that different alternatives can be tried out at run time to cope with failed attempts.

3.5.1.1.1 **<u>Knowledge representation</u>**

Knowledge representation is crucial to the expert system as it affects the speed and ease with which the program uses the knowledge. The most commonly used forms are ***production rules, semantic networks, frames and logic representation,*** linked together. The simplest being propositional links of elementary sentences such as *and, or* and *not* known as "boolean logic" after the 15th century mathematician George Boole.

They are used in conjunction with predictive logic, comprising statements built from blocks of objects with relationships commonly expressed by such phrases as " ***is a, has, owns, needs*** " for example, John ***is a*** man, John ***has*** two legs, John ***owns*** **a** car.

In this manner an expert system's predicative logic can be seen in the expression of "if **a** then **b**" rules.

3.5.1.1.2 <u>**Production rules**</u>

Knowledge is stored in the knowledge base by using production rules, consisting of a set of conditions and corresponding actions.

If all of the conditions in a rule are true, then the actions are executed. Conditions are contained in the "IF" part of the rule, and the actions in the "THEN" part, thus:

IF condition_1	**IF** the haul distance is greater than 2 miles.
AND condition_2	**AND** there are few large rocks.
OR condition_3	**OR** there is a road crossing.
THEN action_1	**THEN** eliminate scrapers.

Because practitioners are not always certain about these rules, the ***conditions*** and/or ***actions*** may have certainty factors associated with them to allow for more realistic representation.

Defining the degree of certainty can cause considerable disagreement and experience indicates the assignment of values should be relative, indicating the relationship of one association to another, rather than the absolute probability of any given association. Furtermore if an assertion has been made, and the same assertion is an action of a second rule, then the existing certainty factor must be combined, in some manner, with the new one. Many methods are used to perform this combination, for example, by averaging the two values, so, if it has already been asserted that ***action_1*** is a possibility, with certainty factor of 50% and a new rule indicates that ***action_1*** is possible with 25%, then the new associated certainty factor for ***action_1*** would be 37.5%, in between the value of the two rules.

In another method (which has been adopted for the purpose of this research), a modified probabilistic formula is used to calculate the new certainty factor. This formula reads [99]:

$$CF = (1-((1- CF1)(1- CF2))).$$

This approach is based on the assumptions that the confidence factors are absolute probabilities that each assertion is true, and that rules are independent. The formula expresses the probability that one or both are false.

So using our previous example, applying this formula would yield the certainty factor of 65%. Unfortunately there is no theoretically correct method for combining confidence factors.

Nevertheless the second method has more support in that it seems reasonable to believe that if a conclusion is reached by two paths, then the confidence in its validity should be greater than if it had been reached by only one path. A rule would be applied either when the preconditions were satisfied leading to further subgoals. Thus in a rule based system each rule links items of knowledge and do not change from case to case,however the items of the knowledge they link often will of course.

3.5.1.1.2.1 The control cycle of the rule

The inference engine will search through the rules in order to solve a problem using either ***forward*** or ***backward chaining*** [100], depending on the job to be done. Both methods can be incorporated together.

Goal directed backward chaining is best used for diagnostic problems [100], where a declared goal or hypothesis or one possible solution is assumed. The procedure then attempts to prove that the assumption correct, by asking the user (or using it's own inference capabilities) to confirm all of the prerequisite conditions for this particular solution. If the solution is disproved, through the nonexistence of the prerequisite conditions, then the system chooses a different solution, and proceeds to prove this one in the same manner. An example of this approach is where a contractor owns a particular type of equipment and the system checks it's suitablility for the given job conditions. Because it is assumed that the goal is known, backward chaining systems are also known as ***goal-driven*** **systems.**

In forward chaining, the system has no prior knowledge of the possible conclusion, and the acquired information is simply used to evaluate the tree of possibilities, in progressing through the solution procedure with information gathered, until the list of possible causes of problem has been narrowed down as far as is possible. The method is also referred to as a ***knowledge-driven***, because it starts from given knowledge rather than from an assumed hypothesis. An example, is the selection of a particular item of plant suitable for given conditions.

3.5.1.1.3 Semantic Nets

Semantic nets are based on recall memory or the theory of societive memory, ie. memory triggered by association between concepts rather than rules, and was originally developed for use as psychological models later incorporated in Artificial Intelligence and Expert Systems [101], such sets rely on the concept of "arcs".

Arcs can be defined in a variety of ways, depending on the kind of knowledge being represented. Common arcs for representing hierarchies include ***is a*** and ***has part.*** Semantic nets used to describe natural languages and shown in Fig(3.3).

Such a network is organised hierarchically so that each object does not have to be connected to all the properties to which it bears a relationship. These qualities though are inherent in the net work. For example, a Fresian cow ***is a*** cow, ***which is*** a mammal, ***which is*** an animal. All animals *are* warm blooded and *need* Oxygen and all cows ***give*** milk and ***eat*** grass [100]. The knowledge base need only state The Fresian is a cow, and need not to say anything about legs or milk because these features are implicit. For clarity a semantic net is best depicted diagramatically and Fig (3.4), shows one reproduced from reference [100].

Semantic nets have been successfully used to represent complex sentences expressed in English [103].

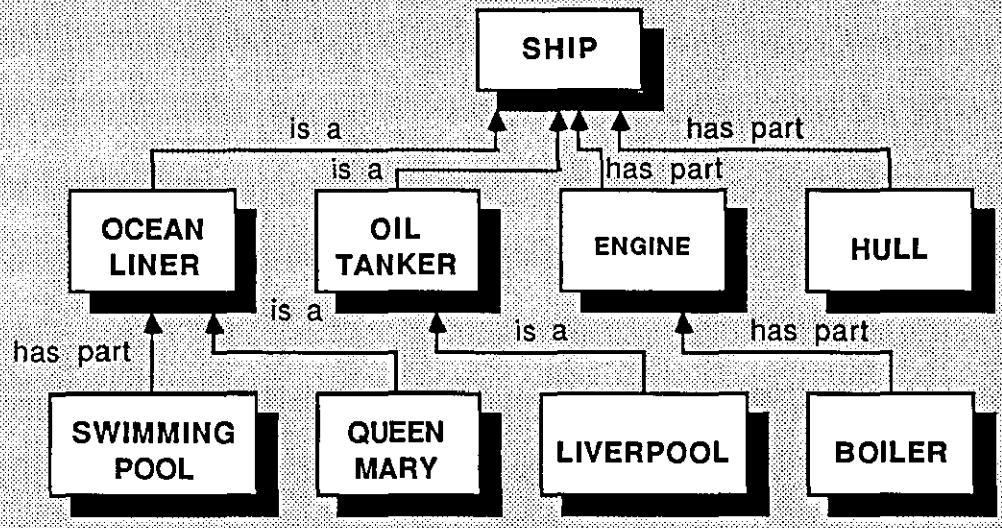


Fig (3.3)
Semantic Nets Example

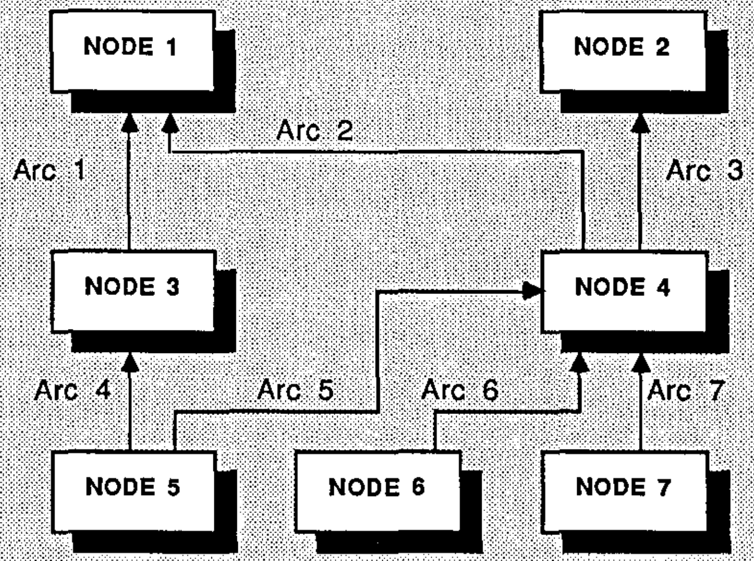


Fig (3.4)
The structure of Semantic Nets

3.5.1.1.3.1 Reasoning with Semantic Nets

In an expert system using a knowledge base formed as a semantic net, one part of the inference engine deals with rules by forward and backward chaining as in usual role based systems, while the other part handles the net operations invoked when necessary. The reasoning mechanism is that of matching network structures, looking first for a link and then connecting it to another object. For example in fig(3.3) the question " what ship has?" the system would look for "has" link and find "hull", "engine", and "swimming pool". The Prospector [104], uses this form of knowledge representation.

3.5.1.1.4 FRAMES

Another way to represent knowledge in a knowledge base is the use of ***frames*** as proposed by Minsky [105], as " a frame is a data-structure for representing a stereotype situation, like being in a certain kind of living room, or going to child's birthday party. Attached to each frame are several kinds of information, about how to use the frame, what one can expect to happen next and what to do if these expectations are not confirmed."

Frames are a network of nodes or slots and relations representing a collection of things and events, and may be considered as being at various levels each interlinked. In frame representation each project, action, or event is boxed in a frame containing slots and have associated procedures executed when the slots change. The system fills slots, if information is not offered by the user, by looking for appropriate words or features in the information as shown in fig(3.5).

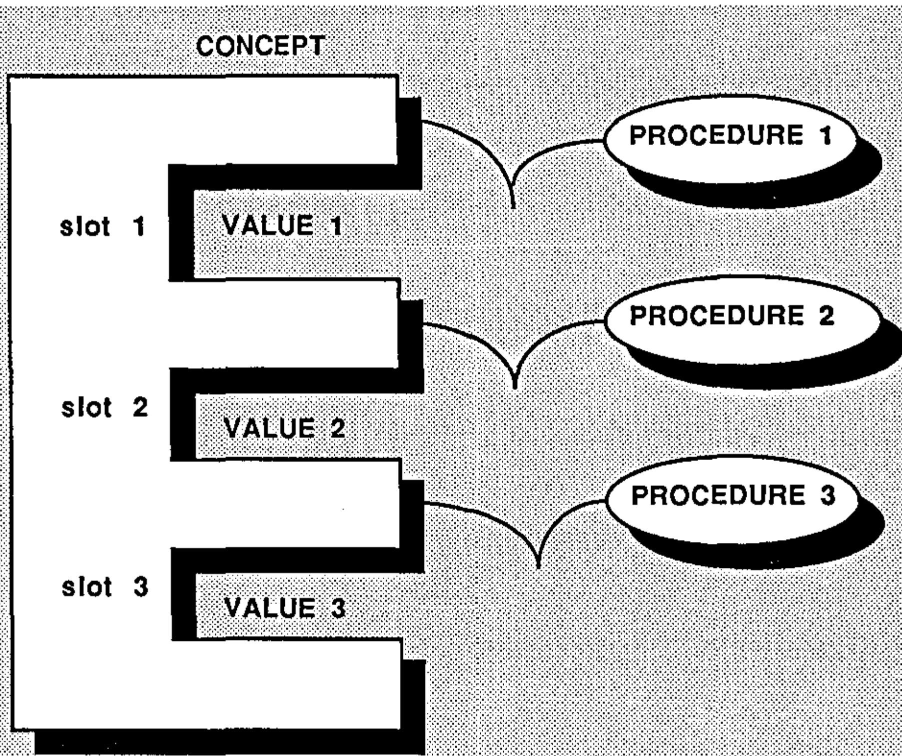


Fig (3.5)
A Frame Knowledge Base Representation

3.5.1.1.4.1 **Reasoning with frames**

Frames are organised much like a semantic net, in fact some researchers [110], consider both semantic nets and frames to be frame based systems, both containing information about major aspects of the objects or situations they describe, matching facts then matched against the knowledge base. The frame selected will be that with the greatest number of lower level slots filled in, the system then tries to fill out the other slots by demanding information from the user. If this fails, another frame is selected. Frames, like semantic nets, deal with inheritance, and reasons about typical features of frames, but they can be modified if exceptions to them are found. Fig (3.6) shows an example of frame representation.

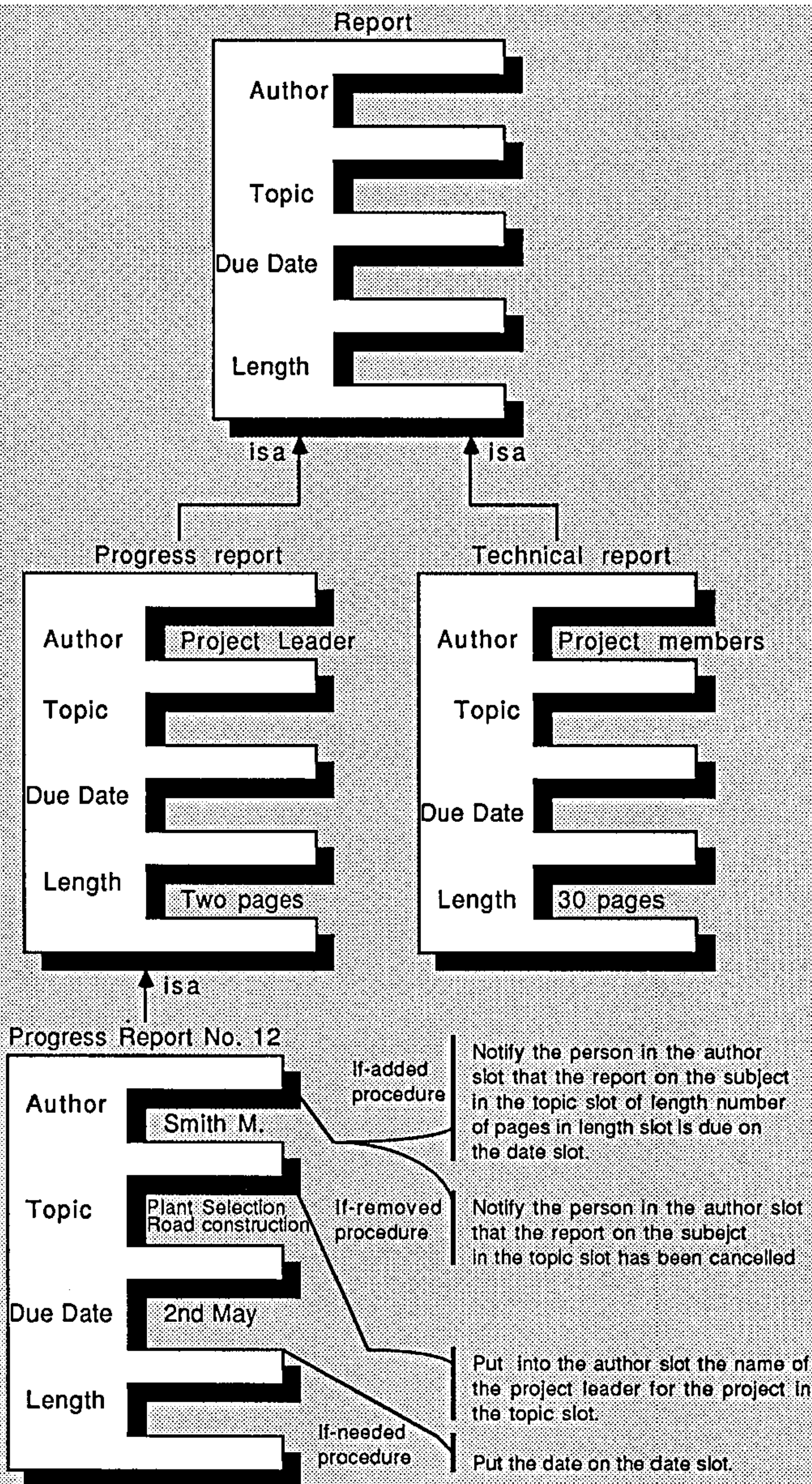


Fig (3.6)
Frame Representation - an Example
[source of information ref. 128]

3.5.1.1.5 Blackboard

Blackboards are a form of representation little used at the moment, apart from military applications. They are general purpose methods of knowledge representation suitable where forward and backward chaining are inadequate and most appropriate when the knowledge sources are independent modules, and problem specific. "The blackboard is a location within the computer memory in which information that is stored within an expert system is posted so that any other expert system can refer to it if it needs the information contained there to reach its goals" [80]. It provides a means of expressing information processes that are best represented as a number of semi independent knowledge sources with some being be used all the time, and others only when they are needed.

3.5.1.2 The Inference Engine

At the heart of the expert system is the mechanism that applies the rules of rational logic to search the knowledge base for the solution. This "inference engine" is spurred to action whenever a user initiates a query. It then performs the following tasks:

i) Compares information supplied by the user query with information in the knowledge base.
ii) Seeks specific event related goals or causal relationships.
iii) Evaluates the relative certainty of facts, based on the respective confidence values associated with each fact.

As the name implies, an inference engine's main job is to draw inferences. The effect is similar to the reasoning of an expert who evaluates a problem and poses hypothetical solutions. However the inference engine also has a number of other functions or subsystems described by D'Agapeyeff [108], as:

i) Knowledge acquisition - or the gathering of information and building the knowledge base.

ii) Knowledge up-dating - it has ability to update the domain model if further expert knowledge is available and rules fired.

iii) Explanations - is able to explain, the information in the knowledge base and if required, how or why decisions about certain recommendations were obtained.

3.5.1.2.1 **Sequence of Operation**

The most common way of deciding the sequence of operations is through goal trees. Each mode in a tree corresponds to a rule or question to be asked by the user. The system may choose to move across the tree structure from mode node (breadth first searching) or alternatively vertically down one branch then return to the top and search down the next (depth first). The system will generally choose a depth first approach when the problem is likely to produce many blind alleys. When a set of choices at each node is not too large, a breadth first search might be better. If the system is faced with a choice of rules to use, it will generally choose the most specific first. In large systems this is obviously too simplistic and for this reason the more developed systems have meta rules, i.e. rules about the rules, advising when it is most appropriate to use them, how long they are likely to take, etc. Although meta rules are necessary in large systems with lots of rules and choices, unfortunately they do affect the sequence in which all the other rules are called and slow down the system considerably.

3.5.1.2.2 **Reasoning with Uncertainty**

In some expert systems it is possible to specify the likelihood of some situation, given insufficient or imperfect data, or an approximate rule. The expert system is usually built with a distinction between those facts which can be deduced from other data and those which must be obtained from the user. The knowledge engineer decides which questions are askable of the user and the degree of certainty to be specified, for example, on a scale of (-5 to +5)where (-5) is definitely false and (+5) is definitely true. The system will then offer advice with a calculated degree of accuracy based on the user input and the probability already given to some of the rules in the knowledge base. This feature enables an expert system to deal with uncertain or missing data when conventional systems would not be able to function. An expert system can therefore make an intelligent guess based on supplied assumptions.

3.5.1.2.3 **Explanatory Interface**

One of the most important features of an expert system, and a major difference between them and conventional programs is the ability to explain a line of reasoning to the user, otherwise known as the ***transparency*** of the system.

Michi [109], considers that an expert system must be open to interrogation and inspection, since a reasoning method that can not be explained to a person is unsatisfactory. A good explanation facility essential in making the system more intelligible (and psychologically acceptable) to the user, and to uncover shortcomings in the knowledge base and thereby help with debugging.

Unfortunately the explanation facilities in expert systems are still rather crude. Kidd and Cooper[110], point out, that most merely print out a trace of the rules being used, and are not treated as a tasks requiring intelligence in itself. They suggest that future systems must include "not only knowledge of how to communicate effectively an understanding of the particular problem solving process to the user", ie. ***IF a THEN b*** but also explain ***IF a THEN b BECAUSE c***, particularly if the system is to be suitable for the less experienced.

To have a really informative explanation facility at present is probably unreasonable and would take up too much space in the computer system, although there is no doubt that as the technology develops this will become less of problem.

3.5.2 The Human Side

Fig (3.7), adopted from (ref. 97) shows that, several groups of people are involved on the human side of the expert system:

i) Management - who establish the need for an expert system, point out what subjects should be encompassed, and determine precisely what benefits the organisation expects to derive from it.

ii) Knowledge engineer - to extract information for the knowledge base, assimilate relevant data, and organise the information heuristically. Alkass and Harris [19], suggest that the knowledge engineer should have some knowledge of the problem to be solved, otherwise a lack of respect on the part of the expert providing the knowledge for the domain may hinder the prospects for developing a good relationship. A sound knowledge of the computer system (shell) is important, but paramount is the ability to interpret the expert's advice into rules or other methods of representation, to order these in to a logical pattern, and to explain the reasoning behind decisions subsequently made by the system.

iii) The prospective user - provides input concerning how the system will be used, what type of problem should be solved, and in what fashion the program should communicate with the operator.

iv) Expert or team of experts - expert(s) in the specific domain supply knowledge, both in form of factual information and in relation to the analytical methods they use to solve problems in the field. Normally people respect, trust and believe them. In short, we assume that they know what they are talking about, as evidenced by:

a) Personal experience, whereby after consultations we can be confident theirs is correct or helpful advice and solves problems satisfactorily.

b) Reputation and standing from recommendation by other people. We may have read their books.

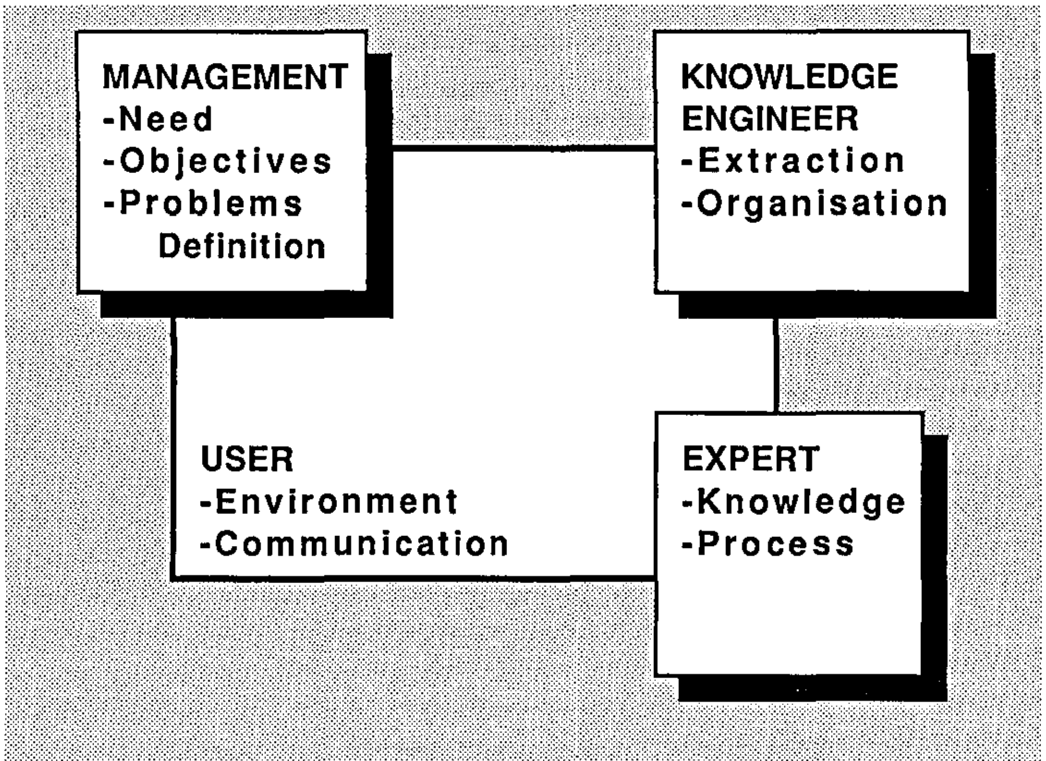


Fig (3.7)
The human side of an Expert System

3.5.2.1 <u>The role of the Expert</u>

Experts have a body of knowledge which is usually unfamiliar to the layman. Furthermore they have a proven track-record of bein gable to use that knowledge successfully[114], characterised by the following factors:-

- **Effectiveness** : the experts are able to use their knowledge to solve problems with an acceptable level of success.
- **Efficiency** : they can also solve problems quickly and efficiently, deducing probable solutions using the most relevant information, often through the means of analogy with past examples or cases.
- **Awareness of limitations:** experts are generally confident of their subject and are aware of grey areas, and what needs to be referred to someone else.

Much professional expertise is creative or interpretative and mostly based on experience. To illustrate this point Fig (3.8), which has been adopted from [111], shows a diagramatic view of the shift that occurs in professional development away from text books, knowledge and general theories towards knowledge gained from experience. By its very nature the latter is not made explicit to the same degree and is therefore more difficult to capture, as highlighted in Fig(3.9), where the professional development of an expert from having no knowledge to being regarded as an expert is depicted. This situation however is often aggravated in management problems where many professionals are involved. Indeed Blanning [112], states "it is an area where the goals, the possible actions of managers, and the relationships between management decisions and their consequences are not easily made explicit."

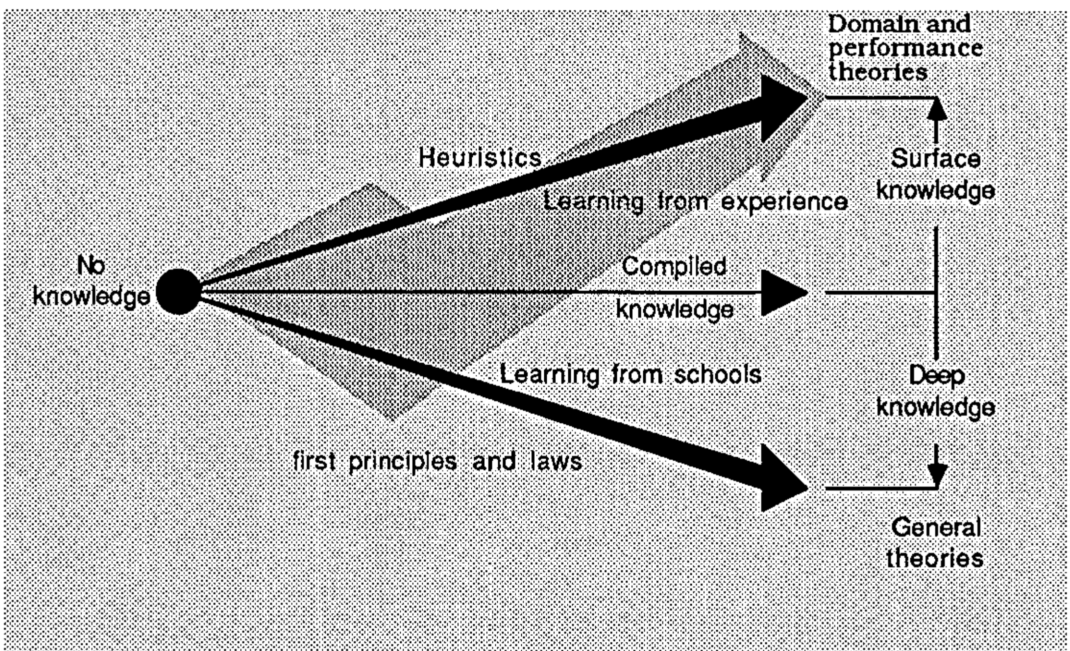


Fig (3.8)
Shift in professional development
[Source of information ref. 111]

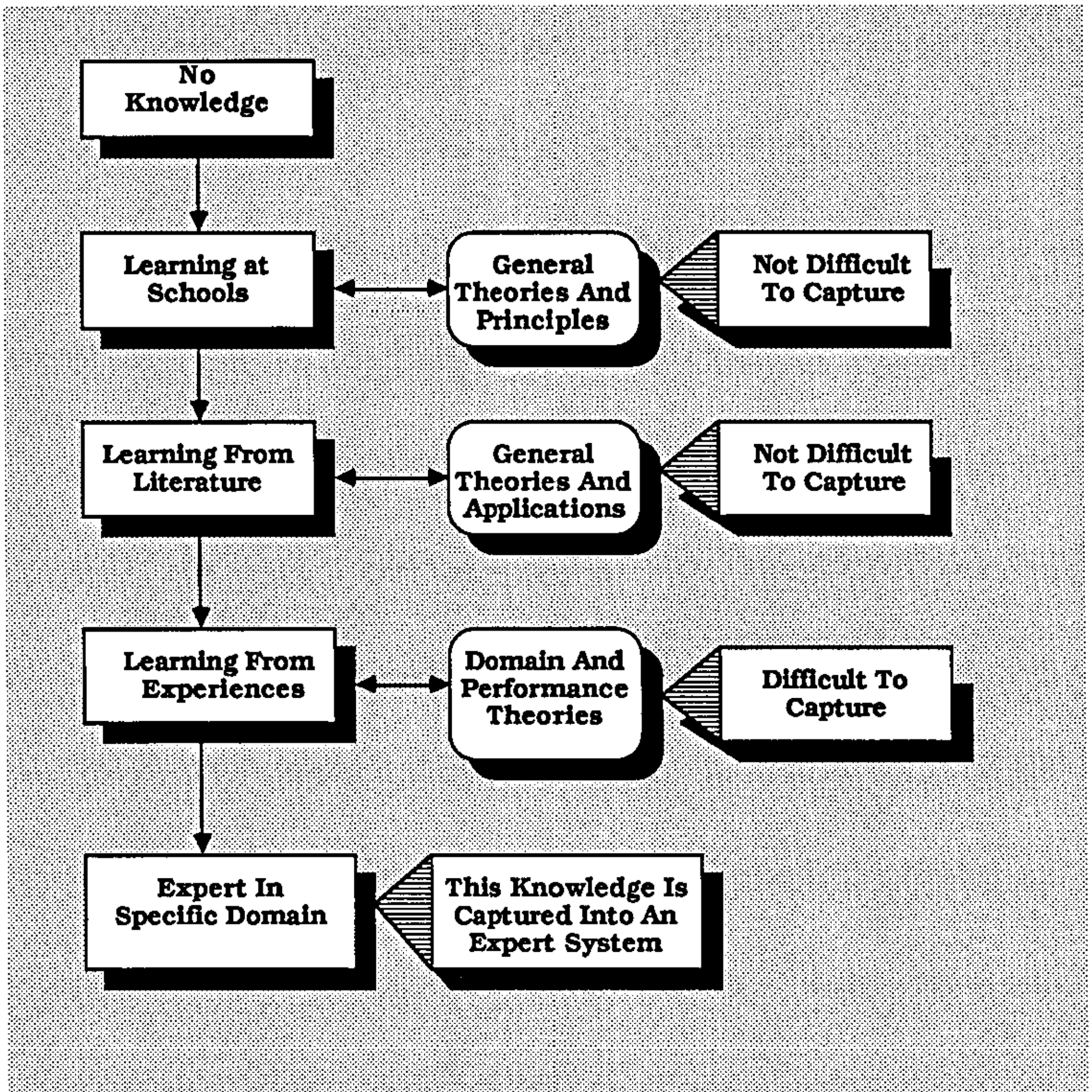


Fig (3.9)
Professional development

3.6 Building an Expert System

The management team decides on the problem, while the knowledge engineer elicits expertise from many sources, and thereafter converts the knowledge gained into rules, and facts, for storage in a knowledge base using an appropriate representation method. Also the knowledge engineer will design the inference engine to search through the knowledge base, in a manner acceptable as means of simulating a consultation, typically by the user responding to questions posed by the system. Like in most diagnoses a simple YES, NO, DO NOT KNOW, response allows progression through the rules. Uncertainty is normally answered by indicating a number within a given range eg. (-5) for definitely not, and (+5) for definitely yes. Having answered the question(s) the system locates the applicable rules by comparing the answers with the knowledge base and produces a decision giving a likely solution to the problem in hand,. for example, to use a ***single engined elevating scraper*** when the following rules are satisfied [113]:

IF scraper can be used
AND soil moisture is less than 20%
AND there are few rocks and their sizes are less than 6 inches
AND road grades when scraper empty is less than 6%
AND the job conditions are favourable

During the consultation the user could ask for explanation of why a particular question was asked or how the decision was reached. Alkass & Harris [1] suggested the following diagram for the relationships in an expert system.

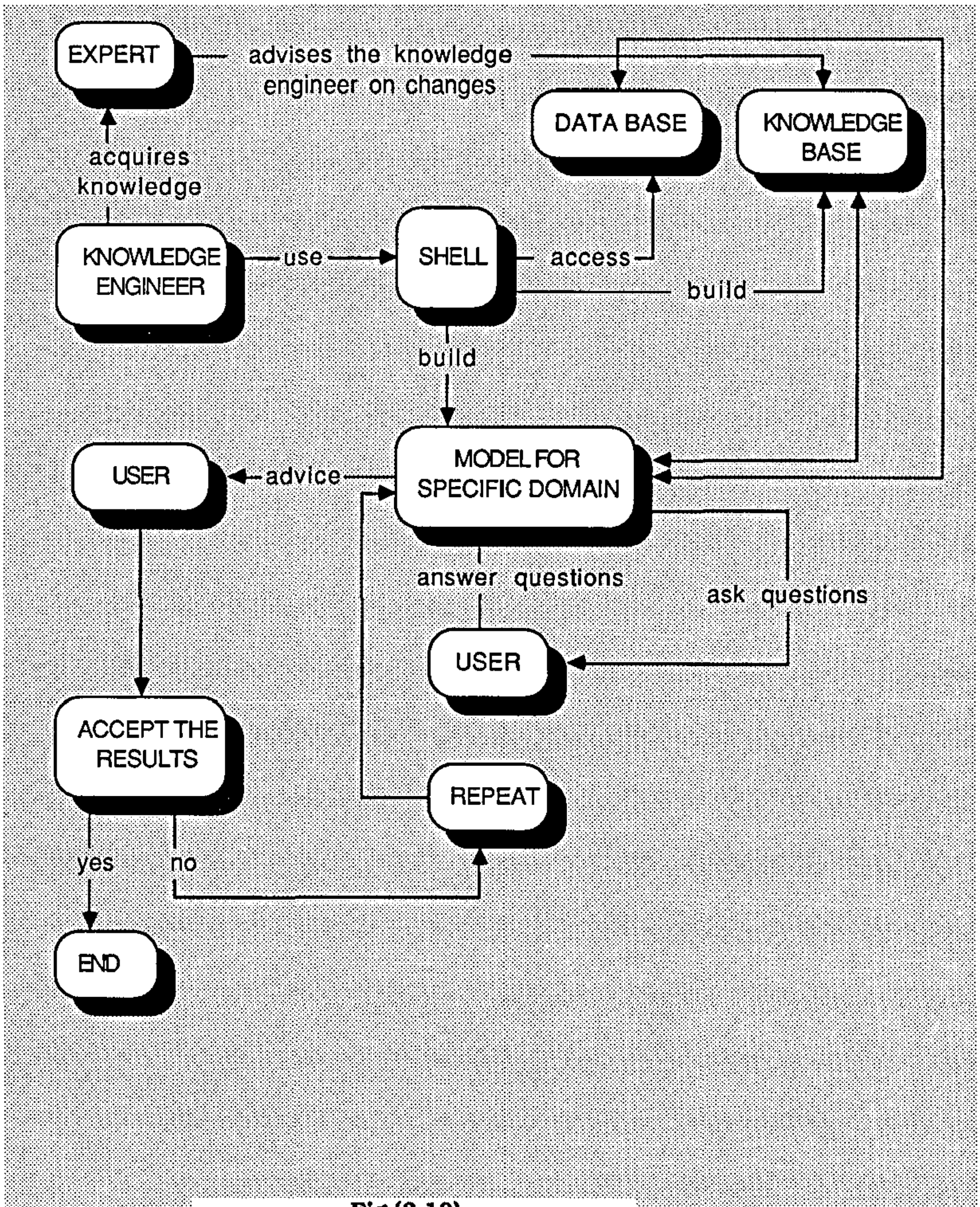


Fig (3.10)
Relationships in an expert system
(source of information, ref.1)

3.7 Why build an Expert System?

Expert systems can be useful because practitioners are fallible and scarce, and some means of recording and disseminating their expertise would usually be of benefit.
Davis [114], suggested that the strengths of expert systems could be summed up as:

i) They contain large amounts of knowledge.
ii) They provide simple representation of this knowledge.
iii) They have a separate inference mechanism.
iv) they can explain their conclusions.

Clearly such a limited range falls far short of human capabilities or services and indicates to show the scale of development needed before they can begin to show intelligence.

3.7.1 Computer aided decision making

Notwithstanding these shortfalls a computerised approach can aid decision making as evidenced by the following:

i) People forget things, experts also forget possible diagnoses, and fail to ask relevant questions, and so on. Indeed, Kleinmuntz[115], found improved performance by a physician when using a system with just 16 rules. Feigenbaum and McCorduck [116], report a case of failure of a power generation plant with the problem taking the technicians days to resolve. They had overlooked the correct line of reasoning as revealed in a later reconstruction with an expert.

ii) People do not always take account of negative information, for example electronic repair technicians generally locate faults in circuits by looking at elements that are not working often ignoring those functioning well [117].

iii) People are not normally comfortable with probabilities, and cannot easily work out the implications of uncertain evidence, characterised by delays in making a decision, wasting valuable time or ordering costly tests to verify a conclusion [122].

iv) Decisions often involve difficult computations.

3.7.2 Scarcity of expertise

Over the centuries little improvement in the means of transferring knowledge has taken place, with traditional teaching techniques still holding sway, but struggling against the growth of even more specialisms split into sub-specialisms, each with fewer experts.

Furthermore human expertise is fragile and transient, practitioners often leave their firms, taking their unwritten knowledge with them, even when available they only have a finite amount of time.

Thus to trap expertise in shifting fast-moving fields and make it more widely available would be invaluable.

3.8 Acquiring knowledge for expert systems

Acquiring the knowledge and structuring it into a usable form is one of the primary bottlenecks, primarly because other unsolved issues in knowledge representation[118] are involved. At present few automatic methods for constructing rules from examples are available with the possible exception of the relatively elementary elementary Expertise package[119]. Most of the time of a knowledge engineer is thus taken up in communicating with experts to try and formulate their rules for decision making.

Knowledge acquisition has been described by some as falling into distinct stages: **1)** structuring the domain initially, **2)** extracting the fixed working model, **3)** and debugging and refining it [122]. Also by others as four stages of initial structuring, first working stage, debugging and testing [123]. However, many do not refer to this aspect at all but Bennet [119], suggests that first the structure of the domain should be well understood, followed by choosing an appropriate representation method with all the relationships between parameters detailed, then the system can be tested and debugged.

In my experience this may not be the most efficient procedure, as it is useful to get a system working as soon as possible, to keep the expert interested. To build something even if this means choosing poor representation and capturing a very small fraction of the knowledge in the domain, and accept that the system will have to be rewritten many times over is probably the best approach at least for cases relating to construction.

Indeed it may not be possible to separate out the three stages so clearly when a system is being written from scratch. The process can go through many iterations with entire sets of rules written and described, a preliminary structure settled on, and refined piecemeal thereafter.

3.8.2 Choosing an expert

The first priority is to find an expert, Waterman[100] suggests that, one could rely on the opinion of peers and other knowledgable people to choose a competent, open and articulate expert who is enthusiastic about the potentialities and benefits of computer technology. They must be realistically advised as to what will be expected of them over the coming months and be willing to give time and commitment to the research.

There is a variance of opinion as to whether single or multiple experts should be consulted and at what stage extra advice should be brought in. Much depends on the nature of the problem being tackled, the time available, resource and scope of the application. Mittal[123], considers it useful to first interview a diverse collection of experts in the field to get a full overview of the problem in hand. Also Ellman [124], comments that using more than one expert is effective during the early interviews as the experts will probably be relaxed with each other at that stage. Frosty [125], on the other hand suggested that it is better (and less time consuming) to start with one expert to define the nature and limits of the problem and then offer the results of these interviews and later the prototype to other experts in the field for comments, criticism and augmentation. This procedure has been found to be very effective in that experts often enjoy criticising each other's work and find this easier than producing something themselves. My experiences support the view that interviews should form simple concepts, the knowledge base gradually developed, augmented, and updated as new material becomes available.

3.8.3 **Knowledge Elicitation**

My work has concluded that the major difference between knowledge acquisition and knowledge elecitation is that knowledge acquisition yields programs whereas knowledge elecitation produces actual competence models of human expertise.

Although there are many sources of expert knowledge such as textbooks, reports, etc.the dominant source has to be domain experts themselves with the knowledge obtained through direct interaction, as shown in fig(3.11).

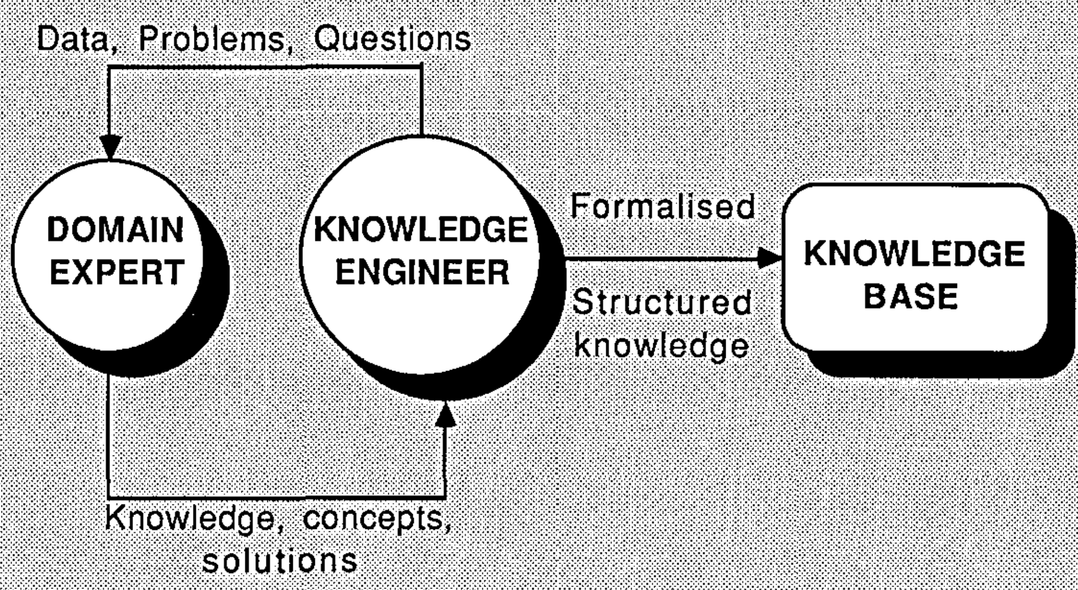


Fig (3.11)
Knowledge Acquisition procedure

Most of the authors in the area including myself agree on the following methods of knowledge elicitation [126]:

i) Interview.
ii) Observation.
iii) Case studies.
iv) Prototype system.
v) Rule indication.

I personally found when acting as the knowledge engineer that thorough preparation before meeting the expert is essential, especially in being fully aware of the nature of the expert's work, terminology used, etc. I also relied on Grover's[127], useful recommendations, and consequently produced a hand book to acquit myself with the domain area containing:

* A general description of the problem.
* A bibliography of the relevant documents.
* A glossary of terms.
* A list of experts in the field.
* Some reasonable performance matrices.

Each of these was discussed in turn with the expert to ensure that the nature of the problem, its scope and the terminology used were clearly agreed and understood. This also gave the expert confidence in our dealings and set a level for ensuring reasonable dialogue, and avoided going over too many basics.

3.8.3.1 Interviewing

One of the many problems discovered when interviewing experts was that the more experienced exhibited difficulty in seeing and appreciating the difficulties of my lack of knowledge in their fields,since many were several steps removed from the initial basic learning process and almost appeared unaware of their reasoning processes. Small details extremely important in the building of the knowledge base often passed into their subconsious,missing out without thinking or analysing the steps involved . It was also extremely difficult to structure an interview to elicit this type of knowledge. My approach was thus to present the expert with a realistic problem to solve, of a kind suitable for the type of expert system to be designed. For example, in selecting earthmoving equipment in road construction, the knowledge engineer might provide the expert with a description of an actual case, including quantities of material to be moved, type of soil, job conditions, and a haul distance. After studying the material the expert might then suggest the type of machine suitable for the particular case. The knowledge engineer then questions in further detail about the effects of the changes in the case facts and notes the expert's reactions. It is also seldom effective to ask directly about specific rules or methods as experts usually have great difficulty expressing opinion on such matters[135] and prefer to make decisions on complex issues rapidly, without laboriously examining and retesting each step in the reasoning process. The pieces of the basic knowledge are commonly assumed and are combined quickly.

Waterman, John, and Welbank [128, 129, 130], and myself believe that some of the difficulties of knowledge acquisition seem to be due to the use of computer technology. Building a system to perform an expert's task means organising a body of knowledge well enough to copy an expert's reasoning, which itself is a formidable task. Also, the domain expert may find difficulty in understanding the terms used by knowledge engineers, although being an engineer myself I found this aspect to be fairly unproblematical and conducted and transcribed my interview in several ways:

i) Unstructured interview:

A suitable method of handling the initial session is to clarify the problem, set the parameters for the work and build up a relationship with the expert. To achieve this it is sensible to tape-record in the hope of extracting useful information from the transcript.

In my experience, this usually produces a mass of highly detailed technical information with the expert trying to impress, leaving the knowledge engineer with little idea of what are the important principles. However, the method can be used by the inexperienced and will at least allow the concept of the domain to be identified.

ii) Critical incident interviews:

This is a technique first described by Flanagan[131], and much used in applied psychology. The approach is to ask the expert about memorable events giving actual experiences at the time. The aim is to get most accurate recall possible. My results when occasionally using this approach caused experts to generalize and theorize.

The problem of using this technique alone is that memorable events will not be the usual type of problem encountered in practice and may have required unusual or uncharacteristic types of reasoning. It is dangerous then to presume that everyday problems will be solved using the same methodology.

iii) Classified interview

The most common forms of classified interviews are based on Kelly's personal construct psychology[102]. Kelly devised a Reportory Grid test to analyse client's character traits. Role models were listed along the top of the grid called "elements" and clients were then asked to compare successive sets of the elements and list the traits that distinguished any two of the elements from the third. The process continues until there is a full collection of elements, traits and ratings, referred to as a rating grid, which is then analysed manually through further interviewing.

This methodology has been adopted by some knowledge engineers to characterise a domain[132], who similarly present the expert with a set of three objects from the domain and ask them to say which features separate any two from the third. The identified features are then used to produce a definition of the problem domain. Alternatively the expert may be shown all the domain objects at once and asked to groups. Although the technique is helpful in graphically displaying the expert's knowledge it can be criticised as being time consuming and unwieldy with more than six objects. Also it elicits only the expert's opinion or attitudes about objects and not their knowledge of them and for this reason was not adopted in my work.

iv) Teachback interviews

A technique being developed by Johnson & Johnson [133], at Brunel University, England, teachback interviewing aims to build a competence model of human expertise, i.e. a model of what experts know, not what they do (ie conceptual structure rather than just procedural skills). Their techniques are based on Pask's conversation theory [134], and involve the expert describing a procedure to the interviewer and the interviewer then teaching it back to the expert in the expert's terms and to the expert's satisfaction. When both agree that they are carrying out the procedure in the expert's way it can be said they share the same concept, although not necessarily the same thought processes.

The topics are chosen by the expert, with the minimal criterion for acceptance being the ability to specify at least one link from the chosen topic to some other in the domain.

Johnson & Johnson claim that this technique keeps the expert's interest and is non-judgmental so avoiding a threatening atmosphere It is also extremely tiring mentally for the knowledge engineer, however, and the lack of direction from the knowledge engineer means that the interview can stray off target.

There are also specific strategies for directing, structuring and refining the expert's knowledge after the initial fact-finding interviews.

v) <u>Distinguishing goals:</u>

For diagnosis applications one can take possible diagnoses one by one and ask the expert what evidence is necessary and what is sufficient to distinguish each one from the others. Clancey[135], says that experts often found it easy to give a typical case for each of the main diagnoses, and this established what evidence was needed to support each diagnosis, and what evidence was needed to rule out competing hypotheses.

vi) Reclassification:

This involves asking the expert for goals and reclassifing each goal into a set of facts which provide evidence for it. These facts themselves are then reclassified until those that are directly observable by the expert are found.

Grover[127], compared four methods of knowledge elecitation and found this method was the most effective one in building a frame-based system, in which each goal was a frame with slots for the evidence that would support it.

vii) Symptom-to-fault-links

All possible faults and all possible symptoms are listed and the expert is asked to specify matches.

viii) Intermediate reasoning steps:

Rather than just listing symptoms and faults, one may interpose intermediate steps, and then establish what evidence at each stage points to what conclusion at the next stage.

Bennett[119], says that identifying an "inference structure" of this type can make the difference between easy and difficult knowledge acquisition.

ix) Cases and prototyping:

While many of the above techniques have been reported as being possible modes of the knowledge elicitation, my experience of dealing with practitioners in the construction industry only produced effective results through case studies and prototyping. Once a few example cases had been posed, detailed discussion thereafter with the expert quickly revealed comments. If the system produced unexpected responses, a trace back through the rules identified where the fault, illogically or false inference lay. In deed I found building a knowledge base from my own experience and text books, followed up by thorough assessment with an expert allowed careful refinement and augmentation to progress with out having to waste too much time on the basic concepts. However, there is a danger that less obvious points may get overlooked, also the illstructured system may lead the expert to lose interest, as being to trial. Hence the need for the knowledge engineer to be conversant in the domain.

x) **Paper model:**

When using a paper model the knowledge engineer creates a document detailing the rules elicited updated as knowledge acquisition progresses. The document at least records the status of each rule, i.e. finalized, tentative, needs review. A natural language format is best adopted so that the paper model can in many cases be reviewed by the domain experts. I found this review process encourages further knowledge acquisition.

3.8.3.2 Observation

It has already been mentioned that people often find it easier to talk about specific examples of problems than to deal in abstract terms with observations best centered around setting an example problem for the expert to work through. In construction offices I was sometimes able to watch the experts while carrying out their jobs, I then asked them to explain what they were doing. Some times a tape record was made and later transcribed and analysed.

This later method has the advantage that the task situation is completely natural and can also be run without taking up much of the expert's time. This is important in companies where it is often not possible to take the expert off the job. Furthermore observation can be used to check that the expert performs tasks in the way they claimed during interview sessions, and not simply a discussion how the job ought to be done.

3.8.3.3 Debugging

Once the knowledge has been gathered, analysed and represented in the prototype, the program can be run to identify gaps, check the rules and put in any new information. It is often discovered at this stage that rules are not strictly independent and have subtle hidden assumptions in the way they are linked.

The following suggestions might be helpful:-

* If a rule is too long it is wrong;
* If two rules are similar there may be a useful underlying concept;
* Track down one problem at a time;
* It is easier to check for faults where a conclusion has been given when it should not have been, than when a conclusion did not appear when it should ;
* Give records of reasons for writing /changing any rules, with details of the author and data, the rules involved, any changes and the case where the fault was diagnosed.

3.8.3.4 **Difficulties in knowledge acquisition:**

The purpose of this section is to itemize both my findings and review the comments of others, this is not to suggest that hard solutions can be offered, as unfortunately the process is likely to remain largely ad-hoc for some time to come.

3.8.3.5 **Problems encountered**

Some experts were found to be unco-operative, unavailable, bored, tired or unenthusiastic, especially after three or four interviews of many hours coseted with the interviewer whose ignorance of the subject domain could also cause some alienation together with interruptions and constantly repeating questioning. Occasionally the experts became defensive when their reasoning was inadequate, incomplete or something could not be explained, almost reaching aggressive behavior, if pushed to make very difficult explanations. The following list offers a guide to try to overcome some of these problems:

a) Resistance

Domain experts may fear that, giving up their knowledge, may lessen their standing and unless some incentive can be engineered little progress is likely to be achieved. Indeed Trimble[136], mentioned that "organisational resistance may also arise and has been observed in the Community Clubs established in Britian by the Alvey Directorate, for example one club member may provide an expert but then realize that commercially valuable skills could be transmitted via the system to a competitor". However, it should be noted on the other hand, that positive motivation may be encountered when an expert is bored with providing personal advice in one subject and would welcome the chance to have this process automated.

b) Accessibility and prejudicing response

An expert may have the necessary knowledge and motivation but may have other duties that prevent the spending of an adequate amount of time with a knowledge engineer. As already mentioned the responses can be prejudiced by over-structuring interviews and by offering detailed prototypes too early. However, the methods that prejudice responses are usually quicker so some compromise will often be necessary.

c) Cues and examples:

It became apparant during my investigations that experts are often better at doing things than explaining what they are doing and why.

Thus it is sometimes preferable to watch the expert at work and draw independent conclusions especially when relationships have become intuitive.

d) Rapport and roles:

Clearly the knowledge acquisition process will proceed more smoothly and effectively when rapport is established between the knowledge engineer and the domain expert. As a corollary to this, it is usually better to separate the tasks of the knowledge acquisition from those of coding the information for the computer. This enables the knowledge engineer to concentrate on the knowledge as preceived by the expert and on establishing good relationships.

During this work, I believe my engineering background enabled me to develop a rapport with the domain experts more easily than would have otherwise been the case. However a knowledge engineer in this situation must be careful to avoid distorting the expert's knowledge by introducing personal ideas.

e) Reasoning:

Experts often demonstrate shallow reasoning, especially when unsure, and frequently rely on hunches or intuition, resenting being pressed to explain or justify conclusions. They also often give only major steps and forget to mention mundane details and presume the knowledge engineer knows the basics.

f) Problems with words:

Expert readily misuse words for example, I found "big", "small", "quite", "rather", had qualitatively different meanings depending on context and were open to misinterpretation. It could be that the expert was just trying to vary vocabulary, or I did not properly understand the terminology of the domain. It was also extremely difficult to estimate probabilities and any scales suggested by the expert by and large had considerable latitude.

g) Problems with the knowledge engineer:

On a few occasions when using the assistance of fellow students, new to the task and entering interviews with the attitude of: "if I can understand, it can't be that difficult", frequently led to impatience of the part of the expect accompanied with slow or laboured reasoning resulting in deletion of important parts which could be relevant. Although it is necessary to enter the discussions with some general knowledge structure in mind, in order to give direction to the interview, the knowledge engineer must be prepared to adapt or discard this structure if it becomes evident that the expert's information is not going to fit in, for instance if the knowledge engineer has a fixed system in mind before starting sessions everything may be viewed too simply in terms of "if-then" rules. This is a particular danger when constrained by the knowledge representation system offered by a particular shell, and culminates in something unrecognizable to the expert.

h) <u>Problems of recognition and recall:</u>

As far as the experts were concerned the more context given, the better the recall; with specific questions providing more recall cues than abstract ones. I firmly believe that if a specific list of questions cannot be assembled then at least a strong conceptual model of the domain should be formulated to assist in directing the discussions. Also some experts can only remember relevant information when the system does not work and a prototyping development was therefore essential so that the expert could identify and correct the gaps in the knowledge.

i) <u>Problems of "tacit" knowledge:</u>

A vast amount of knowledge is "tacit", that is, of the kind that has not been taught or learned but absorbed into the consciousness and has never been articulated. Collins[137], calls this the "soup" of knowledge, in sofar as explicable facts, can be put in context and given meaning. I simply found it impossible to rely on perseverance, diligence, tools and techniques to elicit the whole of the expert's knowledge. This seems likely to remain a problem for the foreseeable future and as such has limited the reliability of the expert system constructed for this thesis.

CHAPTER FOUR

EARTHMOVING TECHNIQUES IN PERSPECTIVE

4.1 Introduction

4.2 Literature review and sources of information

4.3 Current earthwork operations techniques

4.4 Factors affecting earthmoving operations

4.5 Assesement of current planning methods for earthmoving operations in road construction

4.1. Introduction

One of the major bid items on any heavy or highway construction project is the earthmoving operation. A small error in estimating this item may greatly influence the profit margin to the contractor. The increasing competition in the construction industry today not only calls for lower bid prices but for accurate estimates as well. Therefore, contractors must continuously strive to improve their estimating techniques, and plant selection methods. Indeed in any large civil engineering project up to 25% of the cost of the project may be associated with the provision of the contractor's plant and double the above figure if the project is road construction[138], yet the selection and management of such plant is still given a relatively minor place in the training curriculum of the average civil engineer.

The past twenty years have seen a gradual change in the organisation of construction companies, aimed at focusing management expertise on plant operations. Contractors with large equipment holdings have formed plant companies which offer hiring services of various kinds often with a priority plant provision service to the parent company. Furthermore independent plant hire companies have proliferated to the extent that they now form the major portion of the market. These firms have professional managers able to offer advice on plant selection, but for the average client there is always the possibility that the advice may be biased by the fact that certain plant is available within the company rather than by consideration as to the most efficient and economical way of carrying out the task. In addition, it is possible that the plant manager approached is only knowledgeable in a very limited range of types of plant.

The proper selection of equipment is important for several reasons. The first and most obvious is that of achieving the lowest cost of carrying out the construction task. Using inappropriate machine or one of unsuitable capacity can result in a high cost operation, e.g. too small a unit may suffer frequent breakdowns from overloadings. In particular road construction operations being dependent on equipment and downtime need to be at the minimum.

The aim of this chapter is to consider the basic earthmoving cycle, and factors affecting the plant selection. This involves the loosening and excavation at one point, and it's transportation to a second point where it is discharged, repeated innumerable times on any one project.

4.2. Literature review and sources of information

Earthmoving operations have been a topic of discussion among engineers and practitioners, particularly in academia. There are few sources of information in the literature, with some **textbooks** treating the subject in detail,[139,140, 141, 143, 161] While others only deal with earthmoving plant but not earthmoving methods [138,144, 145, 148, 149].

Estimating manuals are other source of information, and provide unit costs for earthmoving estimating based on on equipment manufacturers performance handbooks. Discussion with different earthmoving contractors, however, indicates that this source of information is seldom, if ever used. Most viewed the manufacturer's performance data as a "selling motivator" and felt that the use of this kind of information inevitably results in overly optimistic cost estimates that would produce losses. While these handbooks indicate how to compute the elements comprising a cycle of earthmoving operations, they do not provide any information or rules regarding fleet composition, quantity take-off or cut/fill distribution.

Journals, are the other important source of information on earthmoving operations. Several articles have appeared in different journals, some addressed elements of earthwork estimating [24, 154, 155], while others dealt with earthwork logistics and transportation [30, 32, 161, 162].

Finally **theses** are also a useful background information on the earthwork topic. Clemmence [24] analysed scraper operations using simulation and regression analysis to approximate a relationship between haul distance and cycle time. He also carried out research on cycle time prediction. However Clemmence focused on only this one small aspect of earthmoving operations.

Love [154] developed a system for deterministic estimating, while Neil[155] also developed a system for estimating, by concentrating on minimising estimated errors. Finally Thomas [156] went a little further by analysing uncertainities in estimating an earthmoving fleet's production potential.

4.3. Current earthwork operations techniques

Earthwork operations consist of activities, such as ripping, excavating, loading, hauling and compaction. The process for a contractor begins with receipt of a set of plans and specifications and ends with selection of the plant and constructing the job after the submission of the bid and success in winning the contract.

The first step in the process is to review the plans and specifications, thereafter determine the level of the detail required. The contractors next step requires a "quantity takeoff" in which the amount of material to be excavated, ripped, trenched, loaded, hauled, deposited and compacted is determined. Finally, the plant is selected and production rates (eg. cubic yards/hour) estimated in order to compute the unit cost.

Several computer programmes have been developed to estimate such earthwork logistics and costs. For example, Mandgankar [157] and Mayer and Stark[30], studied the problem of earthwork transportations and illustrated the use of linear programming formulation. Indeed Mandgankar, formulated the cut/fill distribution as a classical transportation problem. It was not evident how Mandgankar accounted for the swell and shrinkage from cut to fill areas and the possibility of borrow/waste sites were not discussed. Subsequently Mayer and Stark expanded the original formulation suggested by Stark and Nicholls [142] and incorporated the swell/shrinkage factors and the use of borrow and waste areas, and then applied linear programing techniques to calculate the amount of material to be cut, filled, borrowed or wasted from any area on the project to the another by minimising the unit cost of hauling material, using a constant unit haul cost. Eassa [32], expanded on this research by applying a nonconstant unit cost for earthwork allocations.

SEMCAP [154] is another computer program developed to assist in earthwork estimating, and uses manufacturers manuals performance handbooks to estimate the cost of the equipment. While these systems could be of value in estimating, advice received from earthwork contractors indicates very little demand for such systems. The reasons being:

i) Earthwork contractors do not believe in the validity of equipment manufacturers performance books.

ii) They do not normally keep the type of historical data neededby such programmes.

iii) Such programmes depend on the prior selection of equipment which need decisions of an experienced kind (not always available).

On a more practical point contractors often maintain historical production data for their various equipment fleets, usually expressed in average production figures ie. cubic yards/day, and furthermore rely mainly on their own particular methods of estimating.

Indeed most contractors interviewed considered their plant selection techniques and their production rates to be confidential and were highly sensitive to divulging any information that could possibly reach a competitor and provide a bidding advantage. When this confidentiality is combined with a hectic work schedule during the construction, it is not difficult to understand the magnitude of the problem associated with data gathering.

4.4. Factors affecting earthmoving operations

There are many factors affecting the components of the earthmoving cycle ie. the quantity of the earth to be moved, and from where to where? Also how can the optimal productivity be reached? and how should the resources be utilized most efficiently?.

In order to arrive at the cost and time taken to move a unit quantity of earth, the contractor must know or be able to estimate the cycle time, ie. the time taken to load, travel to and from the discharge point, and to discharge. The productivity of each machine and the hourly cost of owning and operating the machine should also be known.

The factors affecting this earthmoving cycle can be subdivided into six main groupings, namely are the properties of the earth to be moved, the haul length and surface conditions, the mechanical performance of the hauling equipment, travel constraint, the performance of the loading and ancillary equipment, and the efficiency with which the whole operation is managed.

4.4.1 The material

4.4.1.1 Type

The time taken to load the haul unit will vary with the type of soil. So also will the type and amount of ancillary equipment required for loosening and assist in loading.

4.4.1.2. Density

The density of the material will affect the weight of the load the haul unit carries, the higher the density the heavier is the load, hence the less amount of material which can be carried by a particular category of haul unit.

4.4.1.3. Cut and fill factors (swell and shrinkage)

A cubic unit of undisturbed soil will, in general, occupy a larger volume after it has been excavated. The phenomenon is known as bulking. The material will be in this bulked state when being transported. A reduction in its volume will occur when it has been spread and consolidated.

The Cut Factor (swell) is the ratio of the density of the undisturbed to the bulked condition. It is usually greater than one. The Fill Factor (shrinkage), is the ratio of the density of the undisturbed to the compacted one, except for rock this is usually less than one. The magnitude of these factors varies with the type of material. They will affect the number of trips the haul unit has to make. For instance a truck with 10 cubic yard capacity will require to make 12 trips to move 100 cubic yards of undisturbed earth that has a cut factor of 1.2, and 14 trips if the cut factor is 1.4. This will affect the contractors cost when paid per cubic unit volume in either its undisturbed or compacted state, and but not in the bulked state.

4.4.2 The haul length and surface conditions

4.4.2.1 Length

The time taken by the haul unit will vary directly with the distance to be covered assuming constant speed.

4.4.2.2 Grade

The grade will, because of gravity, affect the rate at which the haul unit can accelerate and the maximum speed at which it can travel. Whereas a downhill grade will assist the unit, an uphill, or positive grade will hinder it and lengthen the cycle time. Grades normally are expressed as percentages, i.e. a +2% grade represents a vertical rise of 2 units in 100 units horizontally.

The approximate effect of each percent of grade is to increase or decrease the required rimpull by 10 unit weight per 1000 unit weight of the total haul unit weight.

4.4.2.3. **Rolling resistance**

This is the resistance encountered by a wheel of a vehicle when moving over a road or surface. It includes the resistance due to friction in the wheel bearings, flexing of the tires under load, and by penetration of the tires into the surface.

The rolling resistance varies with the type of surface and wheel. It is usually expressed in unit weight per unit of gross vehicle weight, for example, for a rubber-tired wheel on a tarmac surface, could be 70lb per ton.

The effect of increasing rolling resistance is to reduce the rate at which the vehicle will accelerate and travel, and hence to increase the cycle time.

4.4.2.4 **The traction coefficient**

This may be defined as the factor by which the total load on the driving wheels, or tracks, that can beexerted before slipping will occur.

This value will vary with the type and condition of the surface. It will be low for slippery surfaces such as ice and loose dry sand, and for surfaces such as dry rough concrete.

Its effect is to place an upper limit on the engine power that can be usefully employed. This can reduce rates of acceleration and can prvent the vehicle from moving.

4.4.3 Mechanical performance

4.4.3.1 Rimpull

This is the pulling force an engine can deliver to the tyres or tracks, at their point of contact with the ground. It is dependent on the torque of the engine, the mechanical efficiency of the transmission system, the radius of the driving wheel or track, and the gear ratio. Thus as the speed of the vehicle increases, and a higher gear is engaged the available rimpull will decrease.

If more detailed information is not available from the equipment manufacturers approximate values may be found by using the following formula:

$$\text{Rimpull} = \frac{375 \times \text{Horsepower} \times \text{Efficiency}}{\text{Speed}}$$

where:

Rimpull is in unit weight and the speed in unit distance per hour.

It is the rimpull force in excess of the grade and rolling resistance forces, that cause the vehicle to move on a specified haul surface and is that point which equals the sum of the grade and rolling resistances.

4.4.3.2 Altitude and ambient temperature

The available horsepower, and hence rimpull from an engine is dependent upon both the altitude and ambient temperature at which it operates. As the effect of these will vary with the type and design of the engine, reference should in general be made to the manufacturer for any correction factor to be applied to the normal rimpull figures.

4.4.3.3 Transmission system

At every change of gear, there is a short period of time during which the vehicle will not accelerate. Thus every gear change will increase the time taken to reach the ultimate speed, and hence the cycle time. However this time increase can be ignored for earthmoving equipment fitted with torque convectors or powershift transmissions.

4.4.3.4 Load capacity and distribution

The nominal load capacity of a vehicle is usually expressed as a struck or heaped volume, in a loose, bulked conditon. It can be converted to weight by multiplying by the bulk density of the material. In practice the actual load carried lies between the strack and heaped values.

In order to calculate the rolling resistance and the limiting tractive effort, it is necessary to know both the percentage of the total weight on wheels or tracks. These two percentages will usually vary between the loaded and unloaded conditions, but are generally available from the manufacturer's specification sheets.

4.4.3.5 Braking and retarder system

In order that the time during which the vehicle is decreasing speed can be calculated, it is necessary to know the rate of deceleration. This can not normally be obtained from the manufacturer's advice sheets, therefore a value must be assumed, based on experience.

O'Neil and Manula [26] have used the figure 2.94 feet per second per second when simulating the movements of a dump truck in an open pit mine.

The solution adopted in this research is to impose a maximum speed limit of (10 miles per hour) on any slope where the sum of the grade and rolling resistance is negative.

4.4.4 Travel constraints

4.4.4.1 Maximum speed

In addition to the haul route conditions, it may be desirable to restrict the maximum speed on various sections of the journey either for safety and driver comfort, or to limit wear and tear on the vehicle. Such instances would be at sections approaching junctions, at sharp curves, and when approaching the points of loading and discharging.

4.4.4.2 Maximum permissible acceleration

The theoretical rate at which a vehicle can accelerate is given by an equation of the following form:

$$\text{Acceleration} = \frac{\text{Rimpull - Grade resistance - rolling resist ance}}{\text{Total vehicle weight}} \times G$$

where "**G**" is acceleration due gravity.

4.4.4.3 Maximum permissible deceleration

The maximum rate at which a vehicle can decelerate is when the brakes are applied and the engine is idling. It is given by the following formula:

$$\text{Deceleration} = \text{BRKF} + \text{grade resistance} + \frac{\text{rolling resistance}}{\text{total vehicle weight}}$$

where **BRKF** is the rate of deceleration produced by applying the brakes.

4.4.5 Performance of ancillary equipment

Ancillary equipment in use at the loading point may perform the whole operation, as is the case with dump trucks or may only assist as is the case with scrapers. In both cases though, it's performance will help to determine the time taken to discharge the load.

A point to note when operating scrapers is that in the initial stages there is a rapid build up of load, but thereafter, the increase is very slow. A typical load Vs time curve is shown in fig(4.1).

Because of the higher speeds at which a vehicle can travel, and the shorter loading time, it may often be more economical only to load the haul unit to approximately 80% of the rated capacity. It will also mean a shorter cycle time for the loading unit, and hence more haul units can be served.

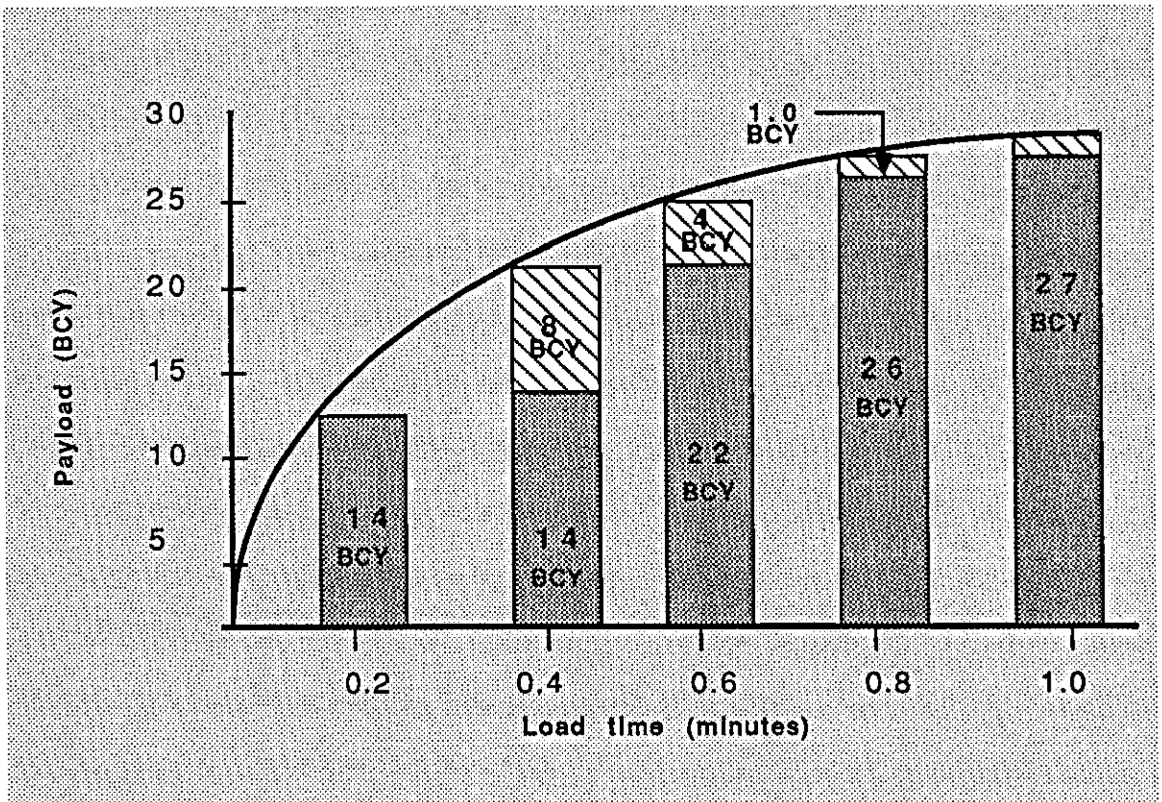


Fig (4.1)
Typical relationship between payload and time of loading

4.4.6 <u>**Management of the project**</u>

It should be noted that an allowance must be made in the loading and discharging times for time spent in turning and positioning the haul unit, and in waiting for ancillary equipment. Poor site management can therefore contribute to longer cycle times and hence reduced output.

Loss of output can also occur due to delays from weather, maintenance and repair of haul road and haul units, congestions and lack of operators.

In total these can represent a very large percentage of the total available working time, as is evidenced by special report of a Committee of the American Highway Research Board[158]. A study undertaken by the committee, found that for rubber wheeled scrapers operating on a number of rural highway jobs, 72% of the total available working time was lost through delays. These were classified as shown in table (4.1) :

Loss due to major delays (i.e. greater than15 minutes)	% of total available working time
Weather: rain, cold, wet grade	54
Open up cut, trimming, etc.	4
Maintenance and rtepair of unit	3
Lack of operatores	3
Others	1
Total	65%
Net available working time	35%

Loss due to major delays (i.e. less than 15 minutes	% of total available working time
Awaiting pusher	12
Maintenance and repair of unit	2
Maintaining haul road	1
Personal	1
Others	2
Total	19%
Actual productive time = (100 - 19) X 35 = 28%	

Table (4.1)
Time lost through delays

Though this percentage of time is higher than a contractor would normally expect on a large earthmoving contract, the figures do demonstrate the necessity of good planning and management control for reducing the time lost through major delays, and for ensuring that the most effective use is made of the equipment when it is available to work.

4.5 Assessment of current planning methods for earthmoving operations in road construction

Almost every contractor interviewed used a different method in planning earthmoving operations, although certain steps were fairly consistent among all. The following perhaps in slightly different order, are used by the majority of earthmoving contractors:

* Site investigation and drilling.
* Plotting rock/soil diagram and calculation of volumes.
* Determining cut/fill distribution.
* Obtaining fleet unit cost.
* Plant selection, fleet composition and costing.
* Applying production rates.

4.5.1 Site investigation

A site investigation is an essential first step in determining data about the depth and type of rock in cut areas, and in achieving familiarity with the project site. The task is of paramount importance because it provides exclusive (not available to competitors) information that aids in reducing the uncertainty related to earth/rock composition, hence achieving the proper selection of equipment.

During the initial stages of planning or bidding for a highway contract, enough information can often be obtained by site reconnaissance and by consultation with existing records. This information can be obtained from governmental and other institutions sources in any country. As far as United Kingdom is concerned, Dumbleton and West[160] have described the geological maps as probably the most important depository of preliminary information. These give a good indication of the types of material and the structures occurring in the locality and are published by the Institute of a Geological Sciences. Whilst they are useful more detail is provided in the Handbooks of British Regional Geology for England, Wales and Scotland. Information on ground-water conditions, required when cuttings are proposed, can be obtained from the Water Supply Papers of the Institute of Geological Sciences. Records are available of existing boreholes and wells,giving details of the strata encountered.

A further source of ground conditions are the maps and memoirs of the Soil Survey of Great Britain. Aerial photographs may be available for all or part of the route. In addition site investigations using boreholes and trial pits and testing of the soil both in-situ and laboratory testing of samples by the contractors themselves can provide useful answers to the following questions:

> **a)** Is the succession of the strata known over the whole site,is the correlation across the site understood,including the relation to the units shown on the geological map? Are key measurements of the depth of peat or soft strata or the depth to bedrock required?

b) Are the different starta fairly homogeneous over the site or do local variations exist that require investigation? Are the characteristics of the material present familiar, or are there factors that need special examination? Are there areas of material unsuitable for use as fill?

c) Will any part of the route be subject to flooding? Are there likely spring-lines or seepages in the area of work? Will ground water lowering or special drainage measures be required during excavation or to stabilise slopes?

In practice all contractors interviewed as part of the research do not conduct site drilling because there generally isn't enough time available during the tendering stage and more important it is costly and often not worth the expense especially in the bid process. In the main, contractors rely on information supplied by the client's site investigation carried out as part of design stage. Thereafter unexpected ground conditions are commonly dealt with as claims even when the contractor is responsible for site investigation under the terms of contract conditions.

4.5.2 Plotting the rock/soil diagram and volume calculations

The next step, of plotting rock lines, involves using the data obtained from site investigation and drilling, as well as any information available from the drawings i.e. soil profile,topographic or contour maps etc, to approximate the location of rock layers. The purpose being to quantify the amount of rock in cut areas, as well as to determine the quantity of material and the distance it is to be moved.

Contour maps, show lines connecting points of equal elevations. From the spacing of the contours one can tell if the lay of the land is steep, flat, gradually falling or rising.

Hills and valleys can be readily observed. All earthmoving projects such as highways are concerned with either raising elevation (i.e fill), or lowering (i.e. cut), ground elevation or both. Based on this knowledge it is possible to design elevations with reasonable accuracy, as shown in fig(4.2). To estimate the elevation for example, of point X, imagine contours as shown by broken lines, the elevation of X is 792 because it lies 2/5 distance between the 790 contour and the 795 contour.

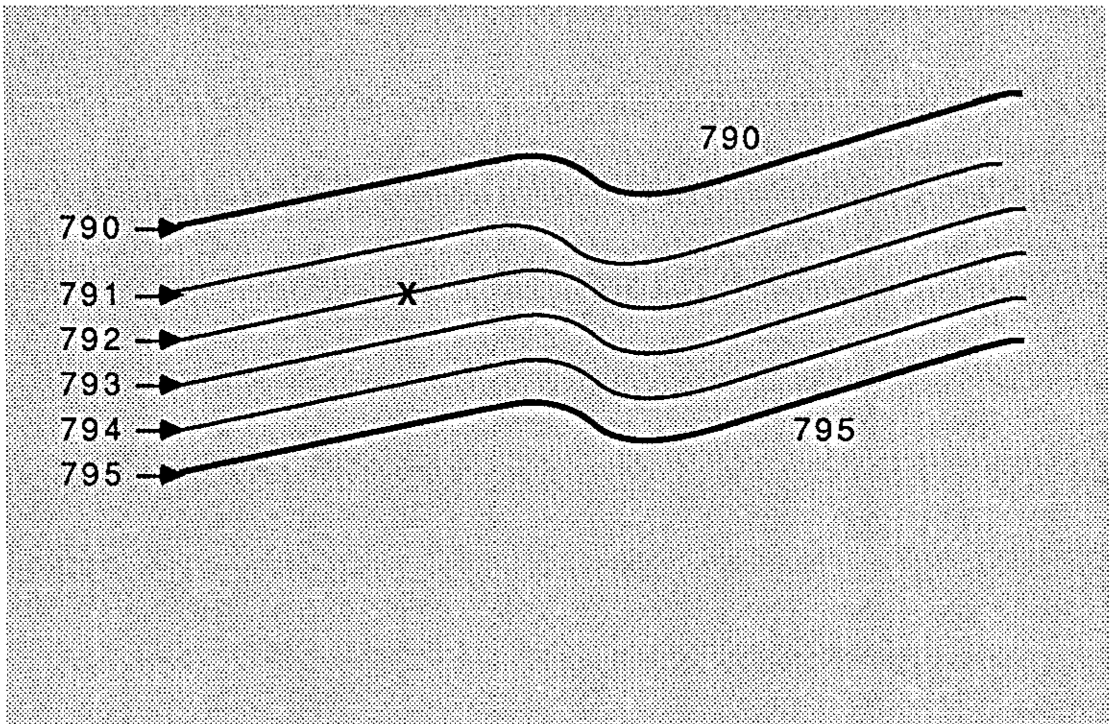


Fig (4.2)
Elevation contours

Figures(4.3) and (4.4) further illustrate the usefulness of topographic maps in plotting profiles of any cross section desired. A profile can be readily plotted using the points of intersection between the contours and line of the project under examination.

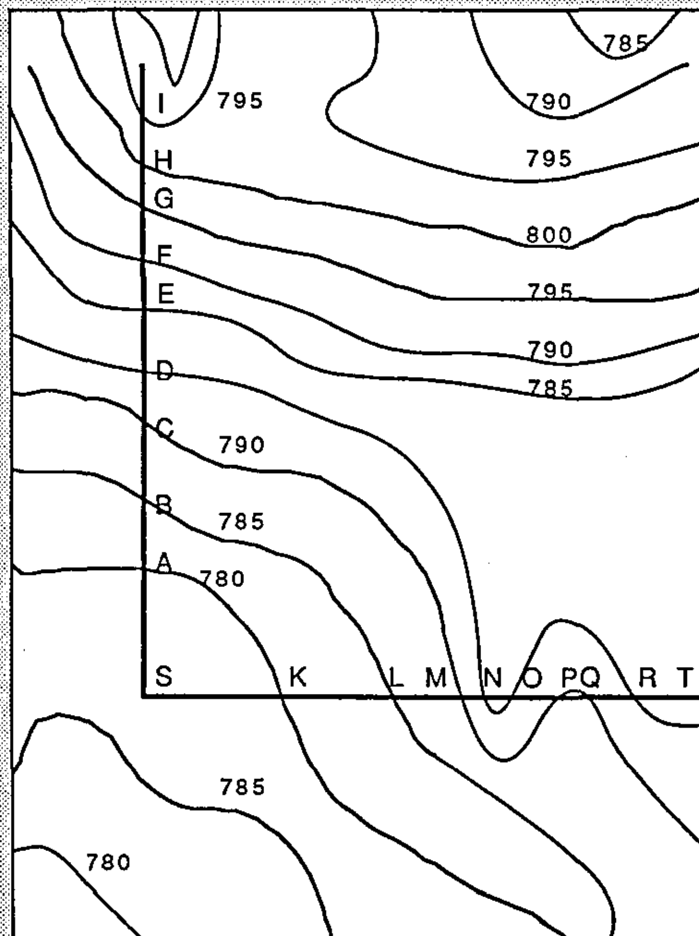


Fig (4.3)
Topographical Map

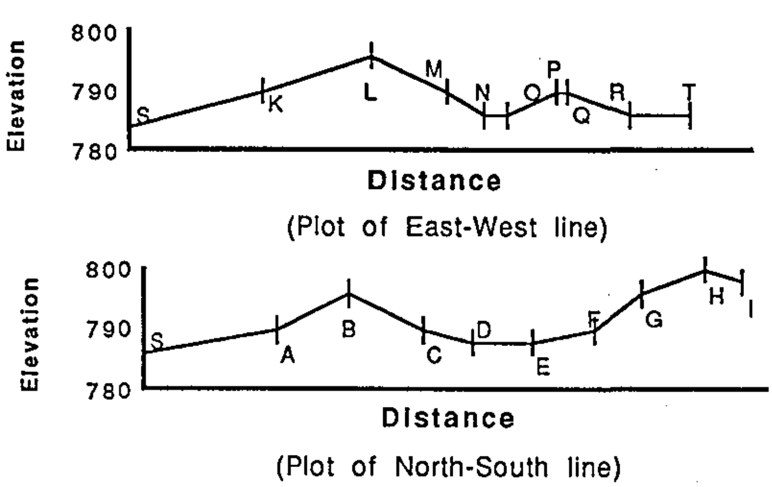


Fig (4.4)
Cross sections for the topographical map

Next the corresponding cross-section drawings are obtained and the field drilling data is superimposed. Ideally, enough data points should be available to establish the rock lines at a regular interval on the cross-section. Once the rock lines are established, the cross-sectional areas can be computed.

This may be done either manually or electronically with a digitizer, and the volumes computed. The most common method of volume computation is the average end area method using the following equation:

$$V_i = D\,(A_{1i}/2 + \dots\dots\dots + A_{(n-1)i} + A_{ni}/2\,)\;/\;27$$

<u>where</u>:

V_i = Volume in bulk cubic yards (BCY)

D = Distance between cross sections in feet.

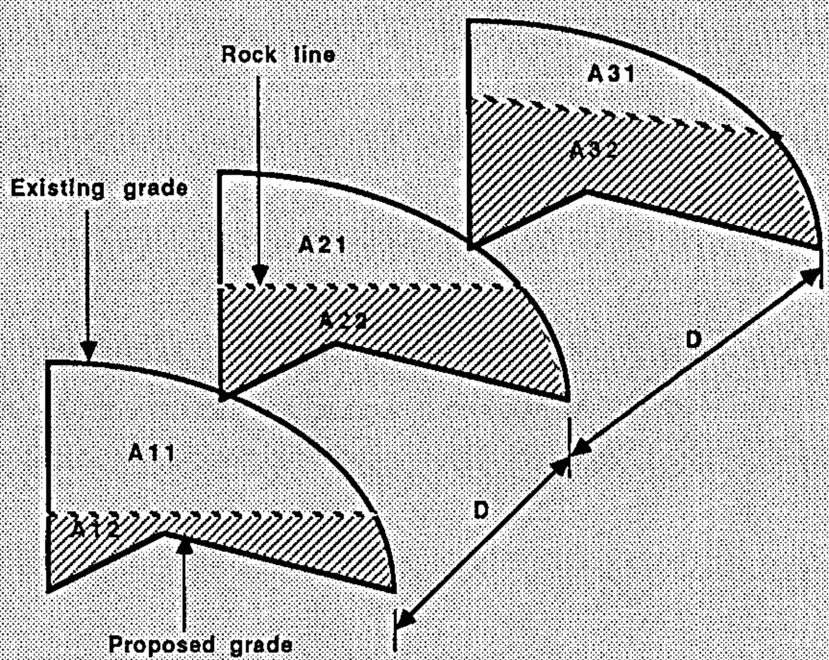
i = Type of material

A_{1i} .... A_{ni} = Area of cross sections in ft^2 and n is the number of the section.

27 = Conversion factor from ft^3 to BCY.

Fig (4.5) illustrates the application of the end area method for a section consisting of cross-sectional areas (i.e. n=3). The average end area method however, is not exact and tends to slightly overestimate the actual volume.

Church [140] indicated that the precision is in the order of $\pm$ 1%, which is normally considered adequate for earthwork estimating.



Soil volume, V1

$$V_1 = \left[\frac{A_{11} + A_{21}}{2}\right](D) + \left[\frac{A_{21} + A_{31}}{2}\right](D)$$

$$V_1 = \left[\frac{A_{11}}{2} + A_{21} + \frac{A_{31}}{2}\right](D)$$

Rock volume, V2

$$V_2 = \left[\frac{A_{12} + A_{22}}{2}\right](D) + \left[\frac{A_{22} + A_{32}}{2}\right](D)$$

$$V_2 = \left[\frac{A_{12}}{2} + A_{22} + \frac{A_{32}}{2}\right](D)$$

Total Excavation Volume = $\left[V_1 + V_2\right]$

Fig (4.5)
End-Area Method for Measuring Earthwork

4.5.3 Determining Cut/Fill distribution

This is the third general step in earthmoving planning. Fig(4.6) illustrates a typical profile and mass-haul diagram for a highway project.

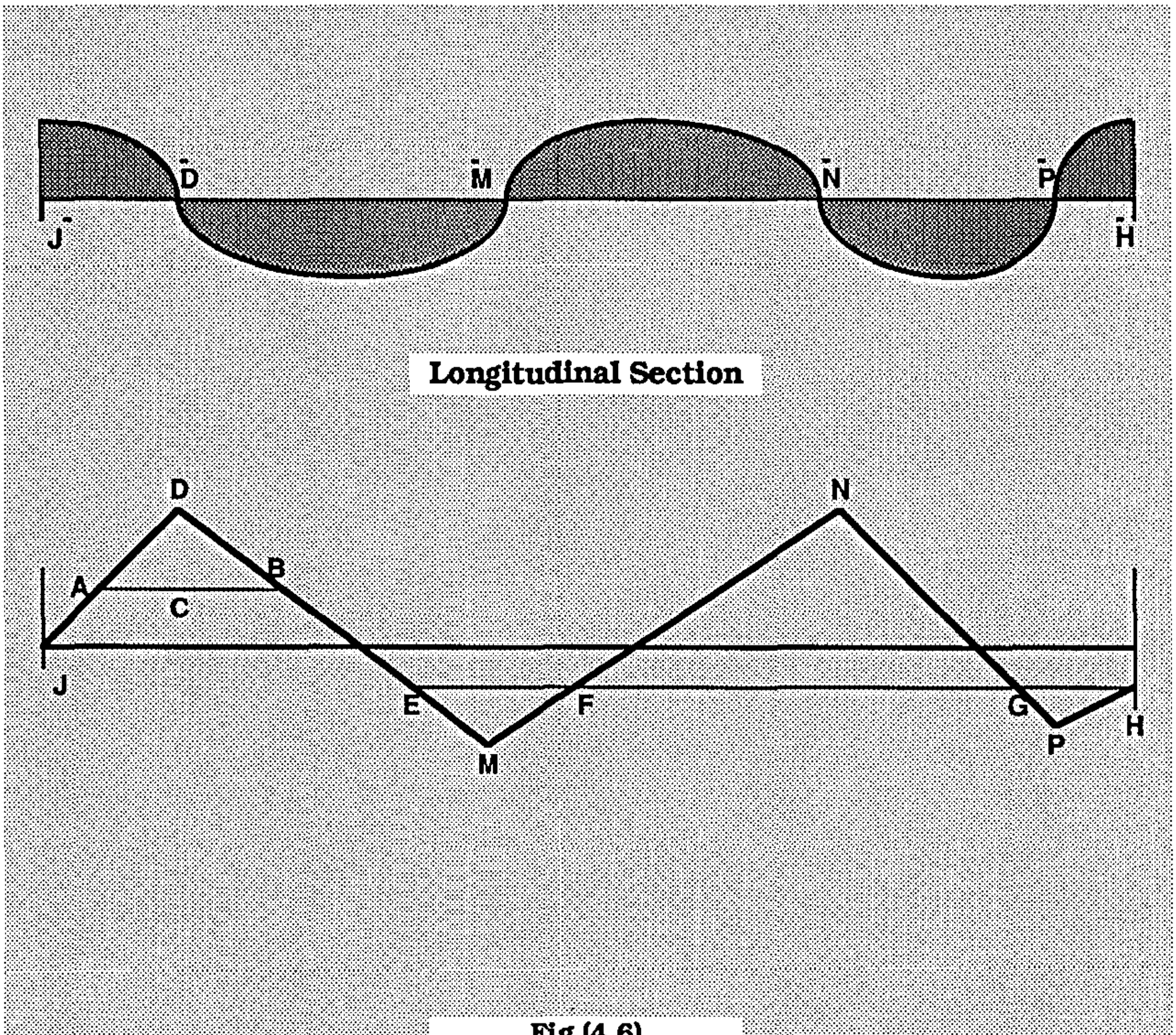


Fig (4.6)
Mass-Haul Diagram

The typical highway job involves alternate zones of cut and fill along the route. There may also be dump areas where surplus or unsuitable material may be deposited, and borrow areas from which extra material may be obtained. These locations will be connected to the highway by planned haul roads.

The traditional method used for earthmoving allocation is indeed the mass-haul diagram, composed of a curve plotted on a distance base, the ordinate at any point of which represents the algebraic sum up to the point of the volumes of cut (+ve) and fill (-ve). Mass-haul diagrams have been discussed in details in many textbooks [139, 143, 159, 161], but relevant points to be noted are:

a) Any horizontal line, such as **AB**, intersecting the curve indicates a length over which the cut and fill are balanced.

b) The area of the loop **ADBC** indicates the haul involved in balancing the earth between **A** and **B**. Haul is the sum of the product of each load and the distance it is hauled.

c) The total volume to be hauled between **A** and **B** is represented by **CD**.

d) The average haul distance is given by dividing the haul by the volume

$$\text{i.e.} = \frac{\textbf{area ADCB}}{\textbf{CD}}$$

e)If it were decided to balance the cut and fill over the length **EH** as well as between **A** and **B**, then the fill required for the length **BE** would have to be borrowed from a borrow area. The surplus cut between **J** and **A** could also be transported to **BE**.

The most economical scheme for the job is found by considering different arrangements of balancing lines so as to find that which will give the minimum haul along the route, from the borrow areas, and to dump areas.

It will be noted that little account is taken of grades and the differences in haul conditions between the highway route and haul roads to the borrow and dump zones.

4.5.3.1 An alternative method for the highway problem

Although the mass-haul diagram is the commonly accepted technique for accomplishing the cut/fill distribution, none of the contractors interviewed used the method. Instead one of the following techniques was used:

4.5.3.1.1 Arrow allocation diagram method:

This method which is widely used by earthmoving contractors determines the cut/fill distribution. An illustration of a arrow allocation diagram, using the same example as the mass-haul diagram in fig(4.7) is shown in table (4.2). The arrows represent the movement of material from the **cut** (tail of the arrow) to the **fill** (head of the arrow). The arrows are drawn based on the simple principle that cut is distributed to nearest available fill. Experience is required, however, to complete an arrow allocation diagram in a particular manner. Decisions must be made as to the maximum haul length and locations for waste areas if there is an excess of cut. For example, it could be more costly to haul material a long distance to a fill location rather than to dump it in to a tip and borrow some other for the fill. The arrow allocation diagram, in addition to showing cut/fill distribution, can also be used to compute the average haul distance as shown in table(4.2). The average haul distance is an important parameter because it dictates the fleet composition needed to accomplish the cut/fill distribution determined by the arrow allocation diagram.

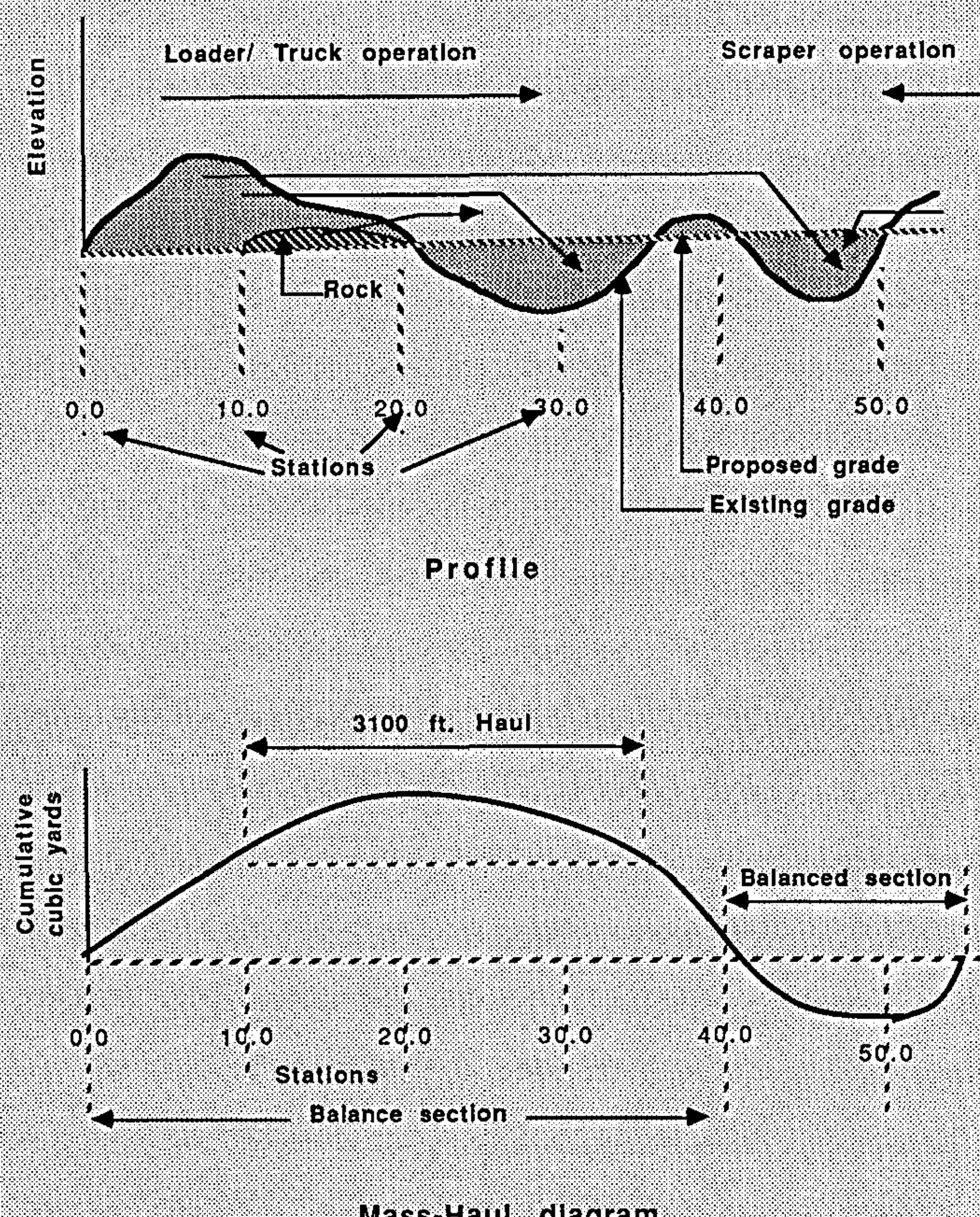


Fig (4.7)
Typical Profile and Mass-Haul diagram

Notes on figure (4.7)

i) The arrows on the profile indicate the proposed movement of material.

ii) A loader/truck operation was selected for the longer haul while scrapers were used for the shorter haul.

iii) The average haul distances are graphically constructed from the mass-haul diagrams as follows:

   a) Vertical lines are drawn from the maximum ordinate points to the abcissa.
   b) Horizontal lines are drawn to bisect the lines drawn in step (a) and extend to the mass-haul curve.
   c) The distances between the intersection points of the lines drawn in step (b) and the mass-haul diagram are scaled along the abcissa and represent the average haul distances from cut to fill sections.

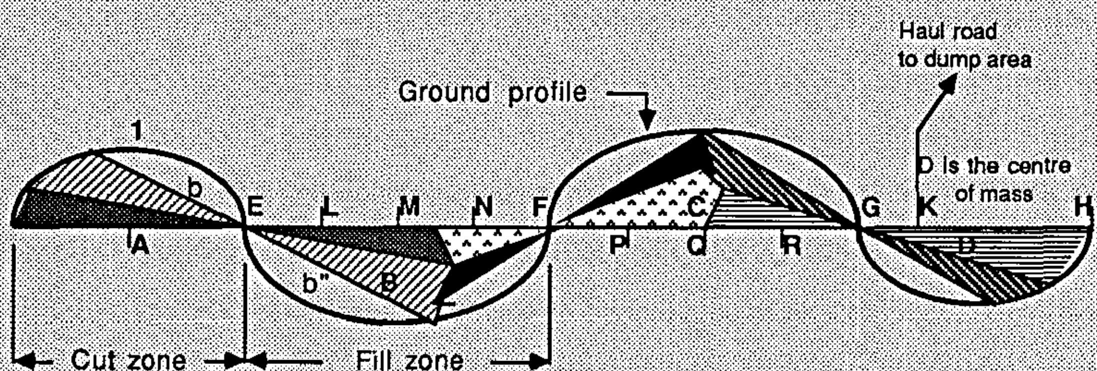
iv) The mass-haul diagram below is perfectly balanced (i.e. no excess waste or borrowed material is required).

Station (100 ft)	Excavation (cut in cubic yards)		Embankment (fill in cubic yards)	Remarks
0.00 10.00	31,400	5,000	5,000	500 ft. haul
		400		1500 ft. haul
		20,000		2500 ft. haul
		6,000		3500 ft. haul (No rock in this section)
10.00 20.00	340,000	161,600	400	45,000 BCY rock
		178,400		
20.00 30.00	43,000	43,000	63,000	9,500 BCY rock
30.00 40.00	27,000	27,000	194,600	
40.00 50.00	3,000	3,000	420,000	
50.00 60.00	-283,600	283,600		
		45,000	45,000	15,000 BCY rock
Totals	728,000		728,000	69,500

Table (4.2)
An Example of a typical Arrow Allocation Diagram
[Source of information (ref. 156)]

4.5.3.1.2 **Sequence of operations methods:**

In this technique, the excavation and fill usually proceed in thin approximately horizontal layers. The typical movement of earth on a highway project being illustrated in fig(4.8) In general most of the material will be moved to the nearer half of the adjustment zone, but there will be a good deal of intermingling at the center.



Longitudinal section

Notes

i) Typical movement will be from cut segment (b) to fill segment (b").

ii) Segments will intermingle towords the centre of the zone.

iii) The centre of mass of a zone is not always representitive of the average position of the loading point for each segment.

Fig (4.8)
Typical movement of earth for a highway

To assume that the material is concentrated at the centres of mass will for fill zone 1 and cut zone 2, mean that the assumed haul length is greater than the actual average.

However, it has already been indicated that the vehicles have to travel beyond their actual loading points in order to turn, also any very large zone can be sub-divided. My experience with the technique which has been adopted in the second part of the research is practicable for on site planning.

When applying this technique the haul unit route must be decided in advance. In a case of adjacent cut and fill zones, the assumed profile of the route that the haul unit will travel, when transporting earth between adjacent zones, is from the centre of the mass of the cut, through the intersection point, to the center of mass of the fill. For example along the lines **AE**, **EB**, the return journey would be **BE**, **EA**. Whereas for non-adjacent zones such as cut zone 1and fill zone 2, it is assumed that the vehicle will travel from the centre of mass of the fill (**A**) to the point (**E**) on the final formation at the end of the zone. Thereafter it will follow the profile of the final formation until it reaches point (**G**) at the beginning of the fill zones 2, from where it will travel to the centre of the mass (**D**).

In practice most of the movement will be between adjacent zones, and can therefore be assumed that no movement will occur between non-adjacent zones, until theintervening cut and fill zones have been completed. As the top level of the earthwork in these zones will be within a foot or so of the final formation, it is therefore a realistic assumption for the vehicle to follow the formation profiles. To carry on this technique efficiently proper notice should be made to the following assumptions:

i) Routes to dump and borrow areas:

For vehicles travelling from a cut zone to a dump area it will be assumed that the haul unit will leave the highway route from a specified point on the formation level, such as point **K** Thus the route from cut zone 1 would be the line **AE**, the formation profile from **E** to **K**, and thereafter the specified route of the haul road. The return journey is assumed to be the reverse of this.

A similar procedure is followed for vehicles travelling from a dump area to a fill zone.

ii) Lengths and grades of sections:

The intersection points between zones will generally be too far apart for the straight lines joining them to give a close approximation to the formation profile. Therefore the quarter points between the intersection points, i.e. **L, M, N, P, Q, R** etc., will also be used to define the profile.

Once the chainage and elevation of all these points, and also of the centre of mass of each zone, are known, it is possible to calculate the lengths and grades of all the sections of the journey from one zone to another, or to the beginning of the haul road.

iii) Haul conditions:

Besides the length and grade, it is also necessary to know the rolling resistance, traction coefficient, and maximum speed for each section before the journey time can be evaluated.

One set of values has therefore to be assumed whenever the vehicle is travelling between zones, i.e. along the formation profile, another set for when the vehicle is operating in the cut zone, and the third set when in the fill zone.

The same values can be applied whether the vehicle is loaded or on its return journey.

Because of the adverse conditions likely to be met at the loading and discharging points, lower maximum permissible acceleration values are introduced in the first sections.

iv) <u>Haul roads:</u>

The method adopted for defining a haul road is to divide it into sections, and then specify the slope length, grade, rolling resistance, traction coefficient, and maximum speed for each section. These sections must also be numbered in the order in which a loaded vehicle will travel over them.

In general laying out the haul route so that the least amount of work has be expended to complete the job is fundamental to minimising costs. Unnecessary work should not be done and yet, some contractors today actually increase the amount of work in a job through poor planning and little attention to these basic fundamentals. For instance, the following example illustrates how lack of attention to basics can substantially increase the time and cost required to complete the job.

Example:

Consider Fig (4.9), the best position for the stockpile from the following list of choices and quantities of earth to remove from storage?

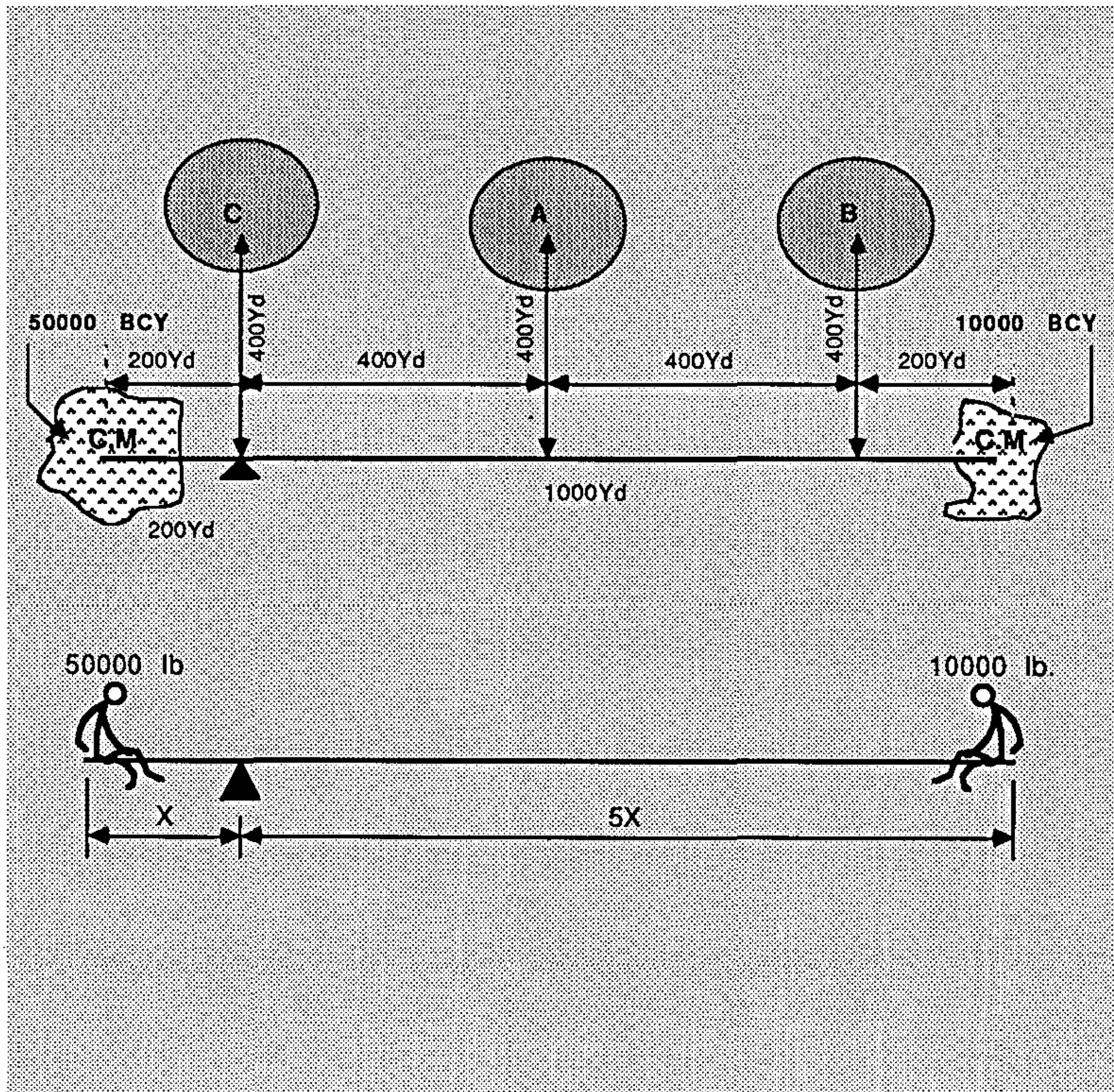


Fig (4.9)
An example for a haul route layout

Possible answers:

a) Midpoint A- 1000Yd to each mass.
b) Point B- 600Yd to 10000 BCY mass, 1400Yd to 50000 BCY mass
c) Point C- 600Yd to 50000 BCY mass, 1400Yd to 10000 BCY mass.

The answer is point **C** because maximum hauling efficiency will result from this selection thus requiring less time to complete the job.
The exact position of point **C** in this example can be compared with a pivot point for a see-saw. Assuming one weighs 50000 Ibs. and another weighs 10000 Ibs, where should the pivot be placed in order to balance the board? Because the 10000 Ib needs five times the clleverage as the 50000Ib, the lighter weight should be five times the distance from pivot than the heavier weight. Therefore, if a 1200 foot see-saw is used, the heavier man must be 200ft away from the pivot while the lighter man, in order for the board to balance, must be 1000ft from the pivot. This same principle applies to the preceding example except that material quantities are involved instead of people.

Using a single 11 Cubic yard scraper with the following production rates [166]:

Haul distance	Production
600ft	156 BCY/Hr.
1000ft	128 BCY/Hr.
1400ft	111 BCY/Hr.

$$\text{Machine hours required} = \frac{\text{Volume involved}}{\text{production}}$$

Applying the above equation to the example reveals:

Haul road selection	Distance (Yard)		Hours required
A	50000 @ 1000 Yd		390
	10000 @ 1000 Yd		78
		Total	**468**
B	50000 @ 1400 Yd		450
	10000 @ 600 Yd		64
		Total	**514**
C	50000 @ 600 Yd		320
	10000 @ 1400 Yd		90
		Total	**410**

We see from the foregoing that if the stockpile had been placed at mid point **A**, instead of point **C**, it would have taken an additional **58 hours** to perform with one machine the same amount of pay work. Even more critical would have been the placing of the stockpile at point **B** where **104 hours** work would have been wasted. **Haul distances are important but only when combined with the earth or rock quantities involved can they be effectively used in job planning.**

4.5.3.1.3 **Optimisation distribution using linear programing method:**

Linear programing is another technique applied to earthwork allocation in order to determine the quantities of material to be moved from each cut section (or borrow pit) to each fill (or deposit site).

A linear programing model for earthmoving allocation was first suggested by Stark and Nicholls [142], and later developed by Stark and Mayer [30], Nandgoanker [157], and Essa [32].

The technique is based on minimising the unit cost of material transported from one point to another. These costs are not likely to be constant, but they may and are often assumed to be approximately so. In practice, actual unit costs vary with several factors.

The one that is of primary concern in earthwork allocations by optimisation is the quantity of earth material moved from cut sections and borrow pits.

For movement between cut and fill sections or disposal sites, there are generally the four unit costs of; purchase the disposal sites, excavation, haul, and embankment. For earthwork between borrow pits and fill sections, there are also four unit costs of purchase of borrow pits, excavation, haul, embankment.

Having known unit time and cost, together with the volumes of earth to be moved, a linear programing allocation technique can be devised to determine the least total time or cost, and the optimum distribution of the earth. The basis of the technique is as follows [30 and 171]:

Let:

C_{ij} = the cost of moving a unit volume from **i** to **j**.

T_{ij} = the time to move a unit volume from **i** to **j**.

V_{ij} = the volume moved from **i** to **j**.

where:

i, is a supply point, in our case a cut zone or borrow area.

j, is a demand point, in our case a fill zone or dump area.

The total cost of moving the earth = **Z**

$$Z = \sum_{i} \sum_{J} C(i,J) \; V(i,J)$$

The total time for moving the earth = **T**

$$T = \sum_{i} \sum_{J} C(i,J) \; V(i,J)$$

With the summations over all values of **i** to **j**.

The optimum cost solution is that set of values of V_{ij} which gives the least total cost.

Similarly for the optimum time solution.

However, the V_{ij} must satisfy the following constraints.

i) Each V_{ij} must be grater or equal to zero.

ii) The total volume of earth in each cut zone must be removed.

Thus for each cut zone there will be an equation of the following form:

$$V_{n1} + V_{n2} + V_{n3} + \text{------} V_{ns} = CV_n$$

where **s** is the total number of demand points, i.e. the sum of the number of the fill and dump areas, and $\mathbf{CV_n}$ is the volume of earth to be removed from the cut zone **n.**

iii) Similarly for each fill zone an equation of the following form will apply:

$$V_{1m} + V_{2m} + V_{3m} + \text{-------} + V_{rm} = FV_m$$

where **r** is the total number of supply points.

$\mathbf{FV_m}$ is the volume of fill required at fill zone m.

iv) For each borrow area an inequality of the following form will apply:

$$V_{p1} + V_{p2} + V_{p3} + \text{-------------} + V_{ps} <= BV_p$$

Where $\mathbf{BV_p}$ is the maximum volume of earth that can be removed from borrow area **p**.

v) For each dump area an inequality of the following form will apply :

$$V_{1q} + V_{2q} + V_{3q} + \text{-------------} + V_{rq} <= DV_q$$

Where $\mathbf{DV_q}$ is the maximum volume of earth that can be deposited at the dump area **q**.

Because the volumes need to be in the same form in the above expressions, the excavation volumes are converted to their equivalent fill volumes, and the unit costs and times are for unit volumes of fill.

The objective of applying the linear equation is to minimise the total cost of earthmoving. The total cost is the sum of the cost of moving earth among sections, from cut sections or borrow pits to fill sections or disposal tips. In symbols, the objectives can be written:

$$\min Z = \sum_{i} \sum_{J} C(i,J)\, V(i,J) + \sum_{i} \sum_{q} C_q(i,q)\, V_q(i,q) + \sum_{p} \sum_{J} C_p(p,J)\, V_p(p,J)$$

An example using the linear programing optimisation technique is illustrated in Appendix [B].

4.5.4 Plant selection, fleet composition and costs:

The fourth step of the contractor's planning method consists of determining fleet composition and costs. This is strictly an individual matter among contractors, and depends on their employees experience and historical data from previous projects.

Factors that are considered include, size of the project, logistics (haul road, borrow and waste areas), type of material, weather, recent similar projects, available equipment, quotations from subcontractors and quality of the labour force. In practice however there are several other influences, one being **physical,** eg. a dragline can not doze material nor can a dozer load trucks. However, there may well be many choices of equipment capable of performing a given job . For instance, a dozer, scraper, or a loader-truck combination are all suitable for transferring material from one spot to another. Therefore to select a proper machine a prior knowledge and experience is needed. Another is **time**, eg. crawler tractors are powerful, but slow machines, while wheeled scrapers and trucks are built for speed. If time is available, however, a tractor-dozer combination may prove to be the cheapest combination depending upon the haul distance involved. Therefore, the deciding factor, after the physical and time consideration, should be **cost.** Production alone is not a total answer, since when several types of equipment are under consideration, selection of machine type that will move material at the **lowest cost per yard** is of prime importance.

To complicate matters however a contractor owning plant is faced with all kinds of costs, such as the initial purchase cost of equipment and then the expense of keeping it running. Nevertheless these can often be broken down into two main categories:

a) Direct equipment expenses.
b) Overhead costs.

Direct equipment expenses are only those items relating to ownership (i.e depreciation, interest, insurance, tax), plus operating and maintenance (i.e. fuel, oil, filters, grease, repairs, tires, operator's wages) and are usually kept on an hourly basis.

Overhead costs are all costs required to support the revenue producing machinery. Some of these are a repair shop, servicing trucks, mechanics and office supplies. These are necessarily incurred in conducting the business, but are not directly involved in producing revenue.

4.5.5 **Applying production rates.**

The final step consists of applying production rates to the fleet costs. For each fleet (i.e. scraper, loader/truck, etc.) the fleet cost (in currency/day or hour) is divided by the estimated estimated fleet production (in unit volume/day or hour) and the fleet unit cost (currency/unit volume) is obtained. Fleet production rates are estimated by contractors based either on historical data from previous jobs, or as adopted in this research from manufacturer's production manuals after being modified by management factor. Usually the estimator selects two or three average production rates to compute fleet unit cost. In effect, a range for fleet unit costs is created. Table (4.3) provides an example illustrating this procedure.

Number	Machine fleet	Daily cost Labour (£)	Daily cost equipment (£)	Daily cost fuel (£)
5	631 Scraper	900	2000	500
1	D9L Dozer	190	600	150
2	D9 Dozer	180	720	200
1	D8L Dozer	180	400	80
1	CC1 Compactor	170	200	70
1	G16 Grader	175	165	60
1	Water tank	60	40	15
1	Pickup	120	10	6
	Total	1975	4135	1081

Total daily fleet cost = 1975 + 4135 + 1081 = £7191

Fleet unit cost (£/BCY) = Total daily fleet cost/ Daly fleet production

Possible daily fleet production (BCY/day) = 5000

Fleet unit cost (£/BCY) = 1.44

Table (4.3)
Example problem illustrating the calculation of fleet unit cost
[source of information A42 road U.K]

CHAPTER FIVE

(ESEMPS)

Proposed Expert System for the Selection of Earthmoving Equipment in Road Construction

5.1 **Introduction:**

Basic managerial questions on earthmoving arise already at the planning stage of a road construction project, for example: "How much earth should be moved?", " from where to where?" and "how should the resources, be utilized most efficiently?", with further a variety of similar problems arise during the construction phase. Optimal solutions however generally require precise data and analysis, whereas construction managers commonly rely heavily on heuristical knowledge and experiences and less on a systematic approach[6].

The previous chapters provided background information on the methods and techniques applied by practitioners in the selection of appropriate equipment for earthwork operations. Theoretical models currently applied to road construction were also discussed. The purposes of this chapter are to: **(1)** outline the merits of the current analytical techniques used in deciding earth distribution quantities and resources, **(2)** discuss the assumptions made with regard to the design of the improved methods in the proposed expert system, **(3)** provide a complete description of the system including earth allocation and the equipment selection process, **(4)** illustrate the application of the developed system with a case example, **(5)** discuss the method of knowledge acquisition for the system, and **(6)** discuss the reasons for developing the system with the Savoir shell or inference engine.

5.2 **Earth distribution**(disadvantages of current techniques):

The current logistics of earthmoving were discussed in detail in the previous chapters with the primary tools available to the planner in determining earth distribution plan being the **mass-haul and arrow diagrams**. Although these two approaches are the commonly accepted techniques for accomplishing this step they pose several problems and limitations [35] namely:

a) The average haul distances are computed from the centre of mass of the cut volume to the centre of mass of the fill volume thereby leading to distance inaccuracies if the cuts and fills are not relatively equal in size or if there are any irregularities in the mass curve.

b) They cannot easily accommodate handling other variables such as different soil types, etc.

c) Hauling costs when not directly proportional to the haul distances cause severe complexities.

d) They are not suitable for situations where additional quantities of material are available, or conversely may be disposed elsewhere away from the road line.

e) The mass-haul diagram fails to provide the optimum distribution of material.

Linear programming, provides an alternative approach with the allocation of the cuts and fills along a road project based on a transportation algorithm minimizing the cost of material hauling depending on haul distances. The required computer memory needed however is generally excessive and moreover the method demands a **prior** knowledge of the cost of transporting a unit of material along a given haul distance. As a consequence the equipment resources would by implication have already been decided. Inexperienced personnel are clearly unable to reach this decision.

5.3 Proposed expert system (ESEMPS)

To overcome the disadvantages of these techniques this new method combines heuristics and mathematical techniques to aid the design of an earth distribution plan and to assist the user in selecting the appropriate equipment to carry out the plan. The system called (**ESEMPS**), Expert System for Earth-Moving Plant Selection is presented in fig (5.1).

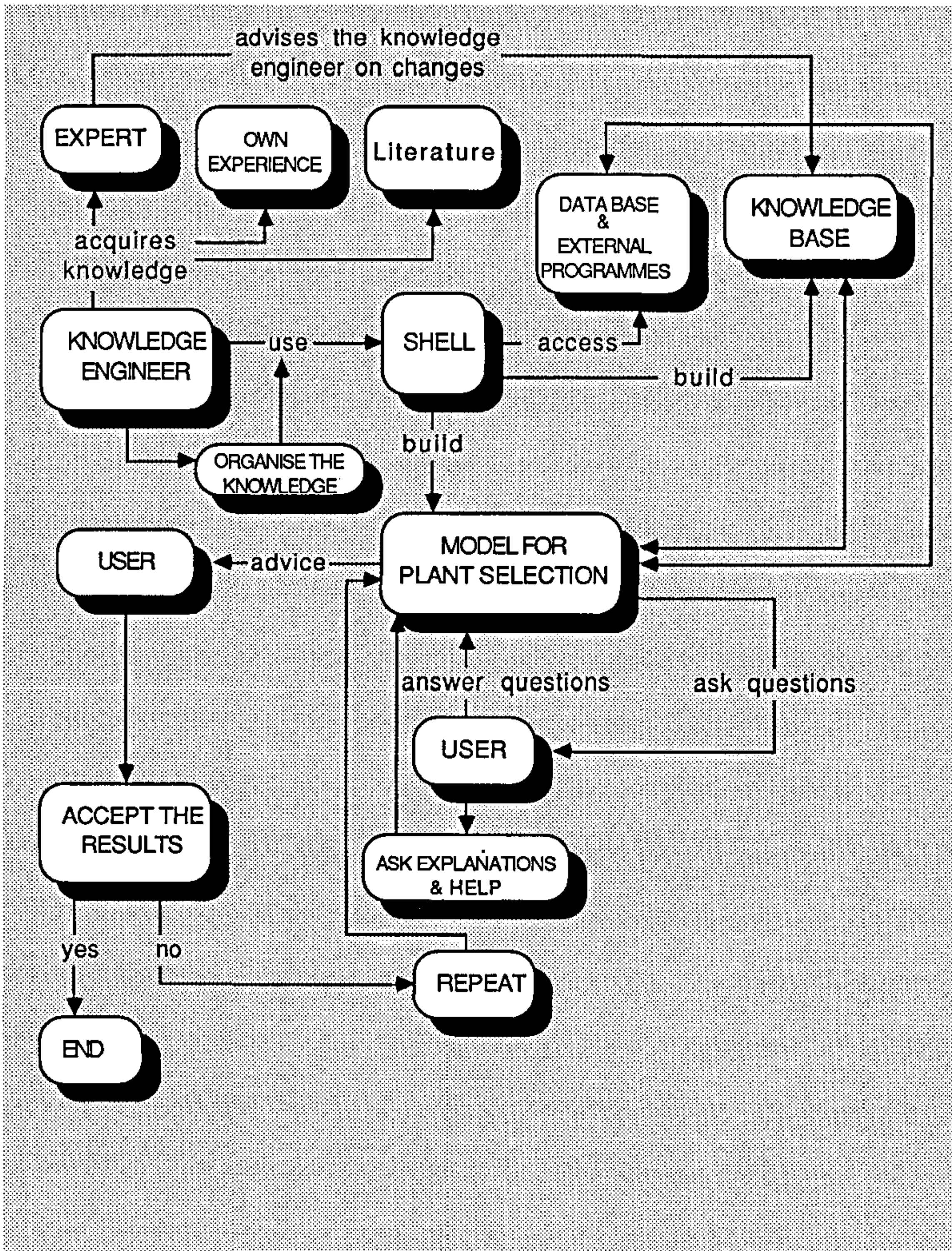


Fig (5.1)
Relationships in the Expert System
(ESEMPS)

5.3.1 Development of the prototype system

As an expert system develops, the size of the knowledge base becomes larger and larger, increasing the likelihood of inconsistencies between data structures and inference rules. The development of a prototype system is thus an important step in providing a vehicle for experimentation with different knowledge structures and inference engines to gain an understanding of the requirements of the complete system.[164]

As pointed out in the literature review and subsequently in chapters (2 &4), the first step in system development involves identification of the problem, it's characteristics, and subproblems, followed by explicit defining of the concepts and relationships.

Two way discussions person to person with practitioners proved most necessary in determining these stages for selecting earthmoving plant, especially in discovering the rules of thumb used in deriving acceptable fleet. Indeed experts do not normally allocate plant for the task, but instead, rely on judgement to identify those machines not meeting job goals, repeating the analysis until the acceptable fleet is reached. This procedure was incorporated into ESEMPS.

Another desired feature for ESEMPS was the use of natural English as the medium of communication, with the user permitted to type in a request, interpreted and responded in that form also.

In this manner little knowledge of computers and programming was necessary to facilitate efficient use of the system. Along this same line of reasoning, an explanation facility was also thought to be valuable, i.e. if the system forwarded a question or decision in a way that the user did not understand, then the option should be avaliable to find out why that question or decision was made.

In summary, the concepts developed were to construct an expert system that was capable of advising the inexperienced on earthwork logistics and plant selection after asking questions on the subject.

After formalising, a mechanism for implementation was needed. When this research commenced, the SAVOIR shell, written in Pro-Pascal computing language was readily available at the price that could be afforded and seemed compatible with the best available and so was acquired.

The logic for the system thereafter was developed after lengthy consultations with practitioners experienced in road construction and equipment management. By combining their experienced judgements, known facts on ground conditions, weather conditions from past records, machine performance, work study and cost data, a prototype computer system (**ESEMPS**) was produced. The essence of ESEMPS as in all other expert systems is encoding of expert knowledge in a form usable by non-experts, the inference mechanism being forward and backward chaining, and knowledge represented as rules. The mode of the operation consists of a series of questions linked by IF_THEN logic, the logic tree being sets of rules arranged to reflect the reasoning of the expert practitioner.

A consultation begins by the user responding to questions posed by the system. Like in most forms of diagnosis a simple YES, NO, DO NOT KNOW response allows progression through the rules, as illustrated in fig(5.2). Uncertainty is normally answered by indicating a number with a given range eg. +5 to -5.

Welcome to ESEMPS ____
A demonstration Expert System
knowledgeable about the selection of earth-moving equipment____
Have you used ESMPS before?
(Y..!..N or an option) Y

>> Is the task road construction?
(Y..!..N or an option) Y

>> Do you have a site investigation report ?
(Y..!..N or an option) Y

>> I shall later ask you some questions relating to distance.
Would you prefer to use:
1) Customary measures (i.e. miles, inches),
or
2) Metric measures (i.e. kilometers,centimeters) ?
For any enquires please type A.
(1 To 2, ! if not known or an option) 1

>> Do you want to use :
1-Factual (Yes, No, Numbers) answers? or
2-Probable (-5 to +5) answers?
(1..2, ! if not known or an option) 1

>> I am now starting to consider the type of soil, in particular, the kind of soil the machines will be dealing with on site. Please choose one of the following: For any enquiry please type (A)
1- Top soil, dry clay, or loam.
2- Pit run gravel, sand, soft shale, damp clay.
3- Heavy clay, single size aggregate,rock.
(1..3, ! if not known or an option) 1

Fig (5.2)
Sample of questions posed by the system (ESEMPS)

Having answered a question(S) the system locates the applicable rules by comparing the answers with the knowledge base and produces a decision giving a likely solution to the problem in hand, for example to use a SINGLE ENGINED ELEVATING SCRAPER when the following rules are satisfied:

IF Scraper can be used,
AND Soil moisture content is less than 20%,
AND there are few rocks and their sizes are less than 12 inches,
AND Road grade when the scraper empty is less than 6%.
AND The job conditions are favourable or good.
THEN Use single engined elevating scraper.

The system also allows the following additional facilities:

a) Handles uncertainty or fuzzy logic using probability theory.
b) Provides calculations routines.
c) Allows access to external programs and data bases.

Uncertain answers are measured as probability values with the system giving advice on machine type depending on the probability values.

In a real situation the user would generally want to discuss some points in detail with the expert, unfortunately the system is not yet sufficiently sophisticated to facilitate wide ranging communication and therefore at present only reports can be included to explain the reasons behind replies. But all the rules leading to a decision may be presented to the user. It is hoped that future developments of software will allow visual interaction with video devices to reinforce explanations.

In summary the system introduces the factors affecting the selection process by leading the user step by step through decision making, as indicated in the sample extract shown in Appendix (C).

5.4 <u>**The structure of ESEMPS:**</u>

The knowledge based expert system described in this chapter for the selection of earthmoving equipment has been developed using four main phases, as illustrated in fig (5.3).

These four sections reflect a typical analysis procedure progressing from broad generalisations to arrive at the selection of specific types, makes, and sizes of machines as follows:

* Identifying the task and defining the job conditions.
* Selecting machines by broad category.
* Out put estimating and machine matching.
* Selecting the final precise machines.

5.4.1 <u>**Identifying the task and job conditions**</u>: (fig 5.4)

Before entering the system,it is first necessary to derive from the drawings and site survey the quantities of material to move. In conventional practice the earthmoving sequences can be evaluated using the mass haul diagram or mathematically by linear programing, with the allocation of cuts and fills along the road being based on minimising the costs of hauls. Unfortunately these methods require a <u>**prior**</u> knowledge of the cost of transporting a unit of material along a given haul distance.

Thus the equipment resources would by implication have already been decided.

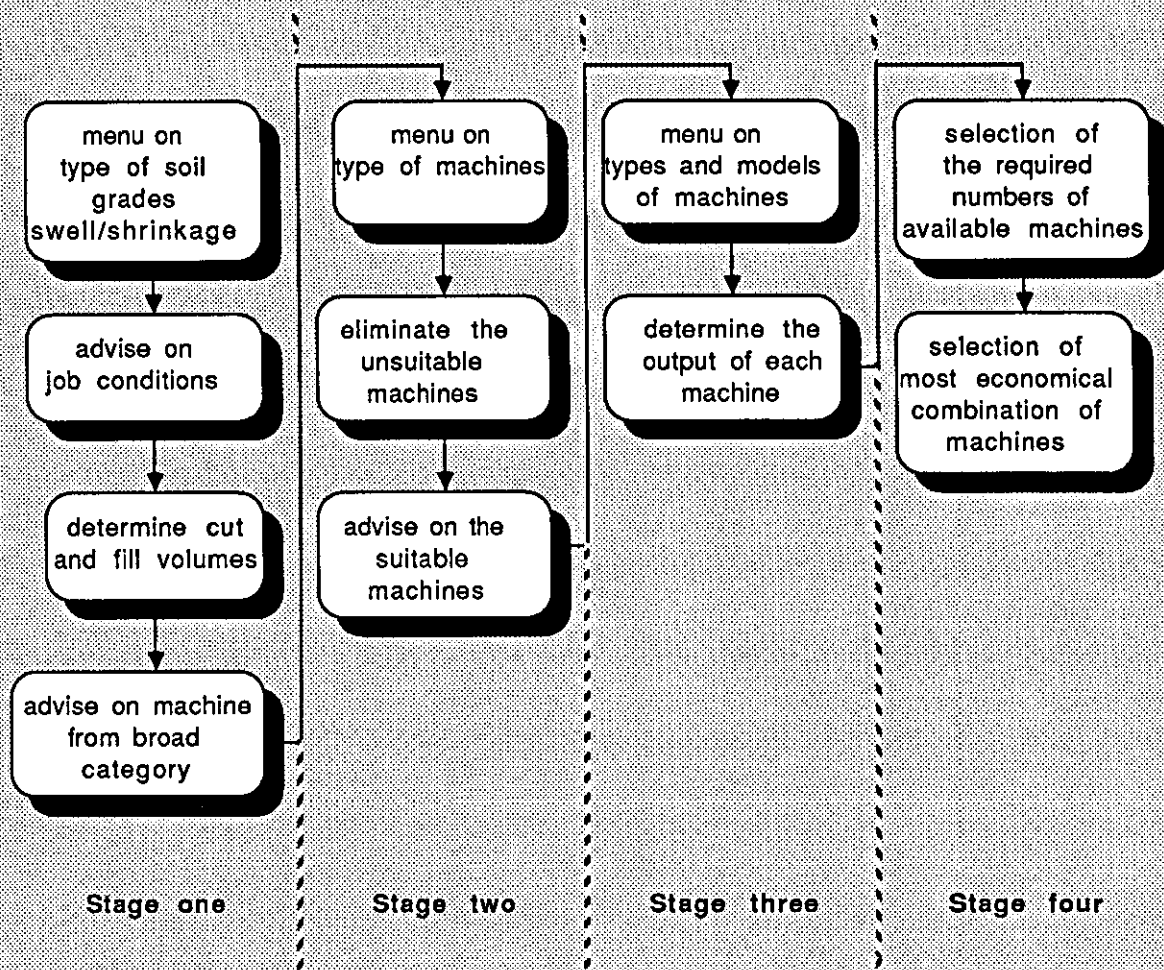


Fig (5.3)
Block diagram of ESEMPS

Inexperienced personnel are clearly unable to reach this decision. ESEMPS in contrast relies on an evaluation of cut and fill sections **after** which the appropriate equipment selections are made. Therefore a more simple and advanced method which combines rule of thumb and simple calculation technique has been introduced in this research to design an earth distribution plan. The central idea of the new method is to reduce the complexity of the problem, which is then handled using simple mathematical equations. Fig(5.5) describes schematically the two phases of problem solving in a typical profile. The first step of the solution is based on field practice or a domain specific rule. Excavation starts at the far left hand with material hauled to the adjacent fill areas any remaining material is then discharged to tip. In the case where additional fill is required then this is borrowed from else where. If different starting points or obstructions such as bridges along the road are involved the project is further divided into corresponding smaller sections. Fig(5.6), illustrates the rules, which are stored in a rule-based knowledge base of the system as follows:

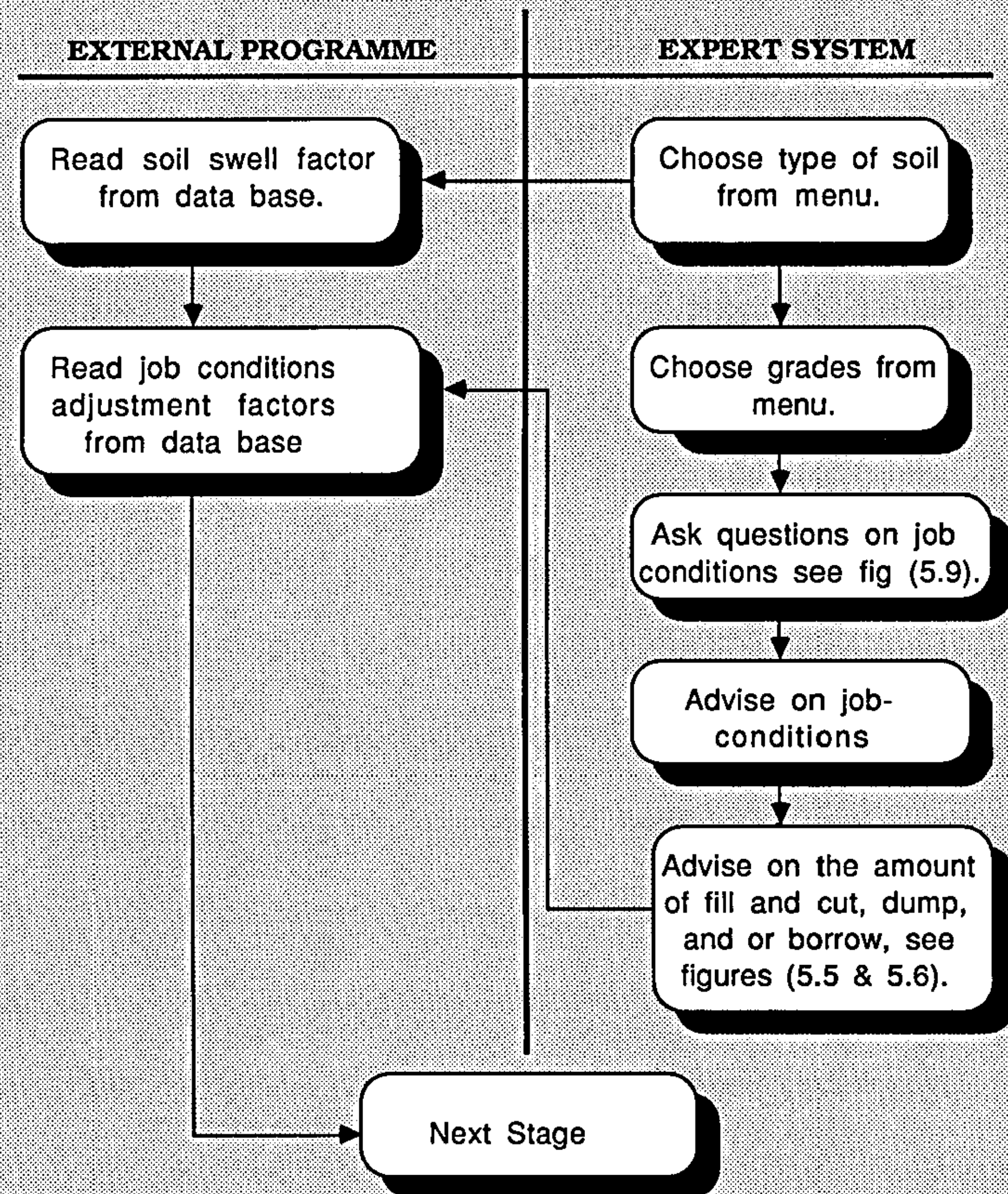


Fig (5.4)
Task identification and job conditions logic

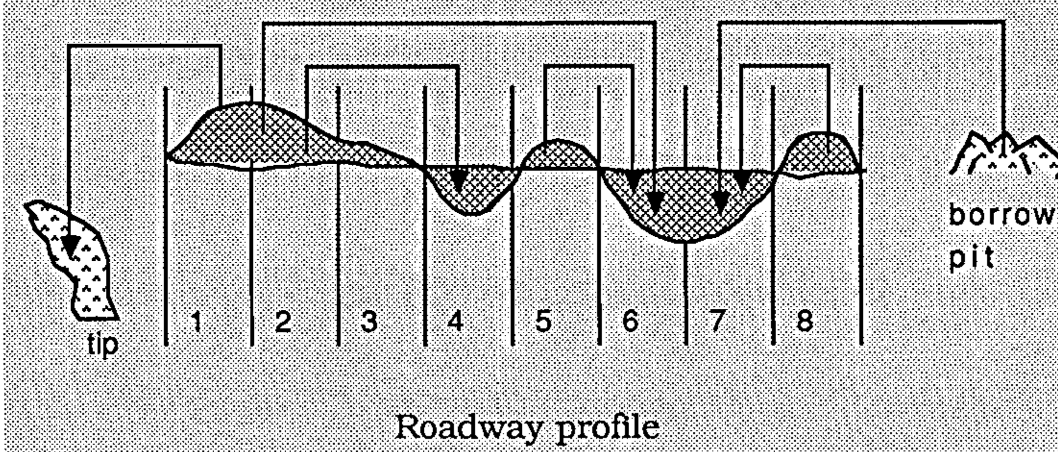


Fig (5.5)
Earth distribution in a road profile

RULE (1)

IF SECTION (A) IS CUT
AND SECTION B IS FILL
AND THE AMOUNT OF SUITABLE MATERIAL FROM (A) IS > MATERIAL NEEDED IN SECTION (B)
THEN TRANSPORT THE AMOUNT OF (B) FROM SECTION (A) TO (B).
AND TRANSPORT THE AMOUNT OF (A-B) TO SECTION (D)

RULE (2)

IF SECTION (A) IS CUT
AND SECTION (B) IS FILL
AND THE AMOUNT OF SUITABLE MATERIAL FROM (A) IS < MATERIAL NEEDED IN SECTION (B)
THEN TRANSPORT THE AMOUNT OF A FROM SECTION (A) TO (B).
AND BORROW THE AMOUNT OF (B-A) FROM SECTION (C)

RULE (3)

IF SECTION **C** IS CUT

AND SECTION **D** IS FILL

AND THE AMOUNT OF SUITABLE MATERIAL FROM **C** > MATERIAL NEEDED IN SECTION **D**

THEN TRANSPORT THE AMOUNT OF **D** FROM SECTION **C** TO **D.**

AND TRANSPORT THE AMOUNT OF **(C-D)** TO SECTION **D.**

RULE (4)

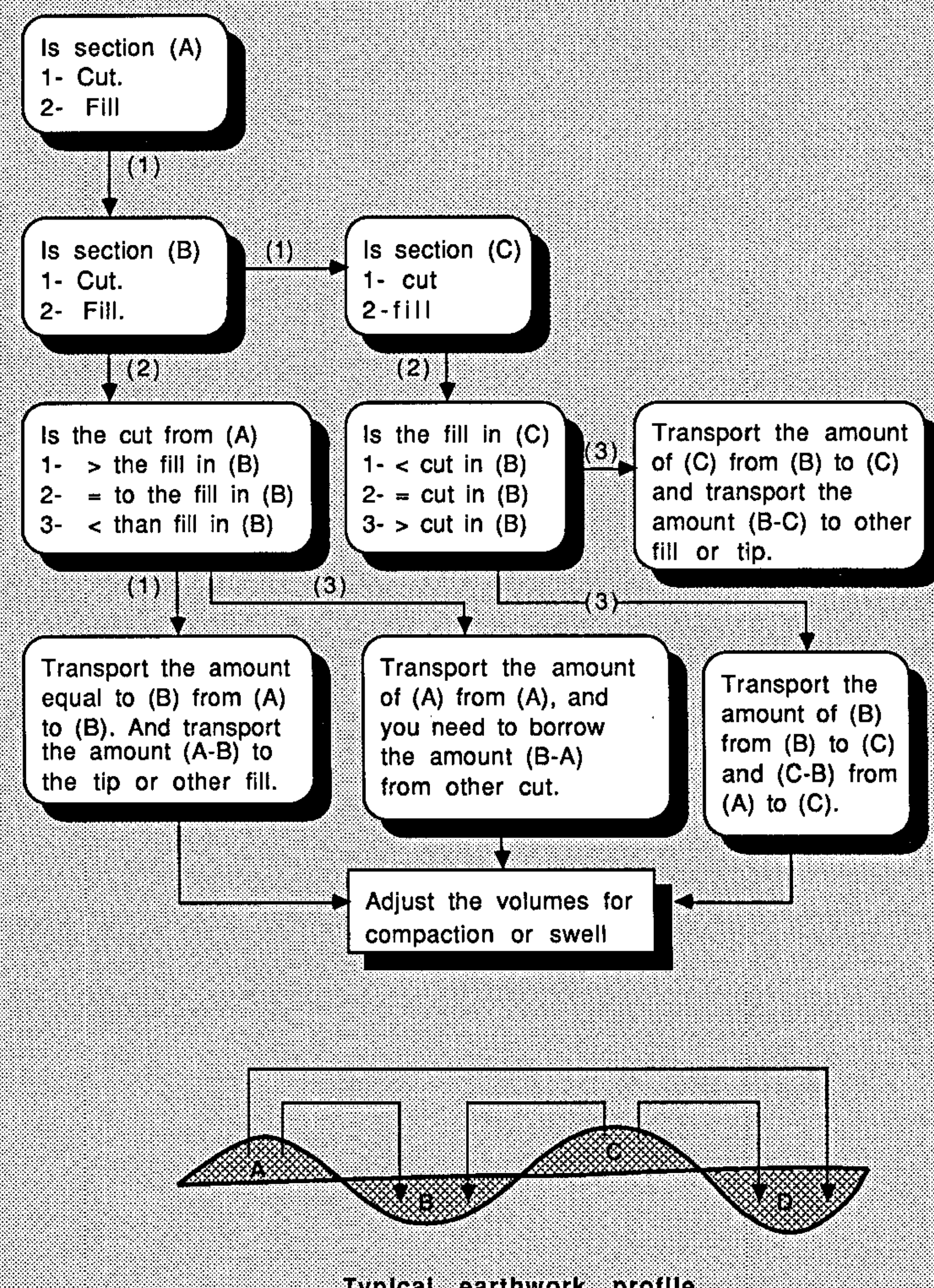
IF SECTION **C** IS CUT

AND SECTION **D** IS FILL

AND THE AMOUNT OF SUITABLE MATERIAL FROM **C** IS < MATERIAL NEEDED IN SECTION **D**

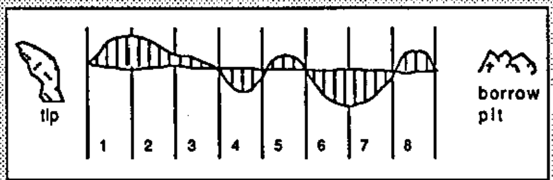
THEN TRANSPORT THE AMOUNT OF **C** FROM SECTION **C** TO **D**.

AND BORROW THE AMOUNT OF **(D-C)** FROM SECTION **A** OR FROM BORROW PIT.



Fig(5.6)
Part of rules for earthwork allocation

EXAMPLE



Road way profile

Road Sections	Estimated quatities (in cubic yards)		Type of soil
	Cut	Fill	
1	30000		Common
2	25000		Common
3	10000		Rock
4		35000	
5	20000		Common
6		25000	
7		25000	
8	15000		Common
Borrow	available		
Tip	available		

soil characteristics
source of information (ref.16)

START

How many sections are there along the road?

(1 To 8, I if not known or an option) 8

Is section one :

1- Cut
2- Fill

(1..2, I if not known or an option) 1

Answer please the volume of cut in cubic yards from sectionone.

(0 To 1000000, I if not known or an option) 30000

Is the soil:

1-Rock or,
2-Common.

(1..2, I if not known or an option) 2

Etc., Etc.

Is the soil:

1-Rock or,
2-Common.

(1..2, I if not known or an option) 2

SUMMARY

SECTION	CUT	FILL	SWELL	Shrinkage
1	30000	0	1.30	0.80
2	25000	0	1.30	0.80
3	10000	0	1.00	1.00
4	0	35000	0.00	
5	20000	0	1.30	0.80
6	0	25000	0.00	
7	0	25000	0.00	
8	15000	0	1.40	0.75
TOTAL	100000	85000		

Do you want to repeat or change your answers?
(Y..I..N or an option) N

These are the agreed final quantities:

SECTION	CUT	FILL
1	30000	0
2	25000	0
3	10000	0
4	0	35000
5	20000	0
6	0	25000
7	0	25000
8	15000	0
TOTAL	100000	85000

The Report is:-

As you can see the the amount of cut material is greater than the amount of fill material, which implies you may not need to borrow any material from a borrow pit.

I am going to calculate the amount of material to be cut or filled for each section.

Please type in -Y- to continue
(Type Y only or an option) Y

You need to transport the amount of material between the sections as shown below:

amount C.Yard	from section	to section
10000	3	4
25000	2	4
6250	1	4
23750	1	TIP
20000	5	6
15000	8	7
10000	BORROW	6
15278	BORROW	7

FINISH

Fig 5.7
Example calculations

Fig (5.7), shows the calculations for a typical example using the above rules.

Other information required in the task identification and job conditions stage includes:

i) Time for the job, this is the fixed time for the contract to be completed. This will control the amount of material per unit time that should be hauled between cut and fill to meet the completion time and hence affects the numbers of machines to be employed on site.

ii) Road gradients, is another important factor in planning the earthwork distribution and haul route selection. Road gradients affects the cycle time of the plant for the time taken by a machine to travel on a haul route depends on the gradients, i.e. the higher the grades the slower the machine will travel, hence the longer cycle time needed, as is shown in Fig(5.8).

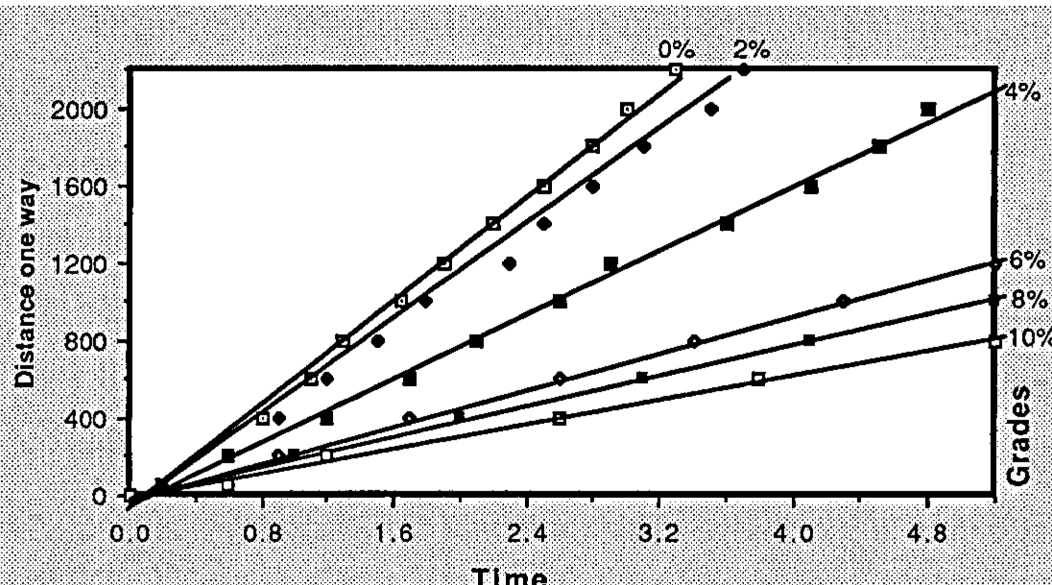


Fig (5.8)
Time Vs distance for loaded scraper operation
[sources of information (ref. 165)]

iii) **Material type**, affects the plant selection and earthwork distribution processes. A machine produces different loading times when dealing with different types of material, for example, a scraper needs more time to load a unit volume of hard clay than for the same amount of volume from soft dry clay. Also some kinds of material such as chalk and rock, need special machines.

iv) **Swell and compaction/(shrinkage) factors**, material that is excavated undergoes a change in volume and density, with more air voids increasing the volume and proportionally decreasing the density. This increase over the original undisturbed volume is called swell and is defined as:

$$S_w = \frac{V_1 - V_b}{V_b}$$

where:

S_w= swell

V_1= loose (after excavation) volume, usually expressed in unit of loose cubic unit volume for example loose cubic yard (**LCY**).

V_b= bank or original undisturbed volume, usually expressed in units of bank cubic unit volume, for example, bank cubic yards (**BCY**).

The significance of the swell is that loose volumes which, depending on soil type, can be as much as 50% more than bank volume.

Also when soil is subsequently compacted in fill section it usually occupies less volume in the loose state. This decrease in volume is known as shrinkage and is defined as:

$$S_h = \frac{V_b' - V_c}{V_b}$$

Where:

S_h = shrinkage

V_b = bank volume

V_c = compacted volume, usually expressed in units of compacted unit volume, for example, compacted cubic yards (**CCY**).

It should be noted that rock usually swells from the bank to the compacted state (i.e., compacted volume is greater than bank volume). The significance of shrinkage is that more material is needed for fill areas than that computed from physical dimensions.

To summarise, with a single illustration " 1 Yd^3 of earth in the cut section may use 1.25 Yd^3 of space in the transporting vehicle, and finally occupy only 0.85 to 0.65 Yd^3 in the fill section, depending on its original density and the amount of compaction applied."[159].

The volumes can be related by the swell or shrinkage factors, or they may be converted using the relative densities of the material. Consider the following basic relationships:

$$V_b B = V_1 L = V_c C$$

where:

- L = loose density
- B = bank density
- C = compacted density
- V_1, V_b, V_c = corresponding volumes

The above equation could be rewritten as:

$$V_1 = \frac{V_b B}{L} \qquad \text{and} \qquad V_c = \frac{V_b B}{C}$$

These two equations can now be used to relate swell and shrinkage to densities by substituting into the previous swell and shrinkage equations:

For swell

$$S_w = \frac{V_1 - V_b}{V_b}$$

$$S_w = \frac{\frac{V_b B}{L} - V_b}{V_b}$$

$$S_w = \frac{B}{L} - 1$$

For shrinkage

$$S_h = \frac{V_b - V_c}{V_b}$$

$$S_h = \frac{V_b - \frac{V_b B}{C}}{V_b}$$

$$S_h = 1 - \frac{B}{C}$$

An external programme was written using the above equations, which could be accessed by **ESEMPS**, calculate the swell and shrinkage and take their effects into account by converting volumes to a standard reference, hence avoiding inaccurate results where volumes have not been properly converted to common volumes (i.e., bank, compacted, or loose).

v) **weather conditions**, In construction weather is more than just a topic of conversation. Prolonged rain can speedily convert a profitable job into a loss-making operation. The possibility of this happening may be reduced by following detailed reports from the meterological office .

On badly drained sites and on cohesive soils, e.g. clays, output will be reduced and work eventually cease. Under such conditions only tracked machines can usually operate, wheeled versions simply do not have the traction in wet conditions. Even crawler tractor performance may be seriously hampered with slower speed, bucket pick up of water, reduced visibility and inaccurate placing of bucket or blade, and last but not least, operator performance may be badly affected.

In the absence of rain, weather can still affect the operation adversely, cold frosty weather makes the ground hard and difficult to dig. Tucker [138] pointed out that, quantitatively, the difference between an easy dig in good conditions and a reduced output dig because of a bad operational conditions can amount to a loss in output of at least 15%. It must be a matter for subjective judgement as the loss estimate for particular conditions, rating severe a 15% loss and moderately severe perhaps 10% loss, and a good at 0% lost output.

vi) **Job conditions:**

The job conditions fig(5.9) are evaluated in terms of being good or favourable for wheeled machines, a negative result ie. unfavorable leads to the selection of tracks, with the procedure taking into account soil conditions, loading and dumping area, accessibility, traffic flows, weather, type of supervision, length of workday and shift work.

Various types of equipment with associated relevant technical information are stored in an external programme designed as a data base [165, 166, 167, 168].

The knowledge base is logically structured so that factors such as haul distance, on-off highway and public roads requirements, traction ability, job conditions, swell factors and so forth can be considered. The user is posed with a series of questions and depending on the answers, the inference engine searches through the knowledge base and locates the appropriate rules and displays the decision(s) on job conditions and the appropriate equipment including alternatives.

The model then proceeds by asking the further questions regarding on-off highway or public roads since some of the types are not allowed to operate on such roads. The system eliminates those not suitable for the job requirements and gives advice on the appropriate ones as shown in fig(5.10).

The user is also asked to identify the soil types along the haul routes from a wide range together with grade resistance factors. The system then recommends equipment that should be used for the earthworks operation. Fig(5.11) illustrates a sample of consultation.

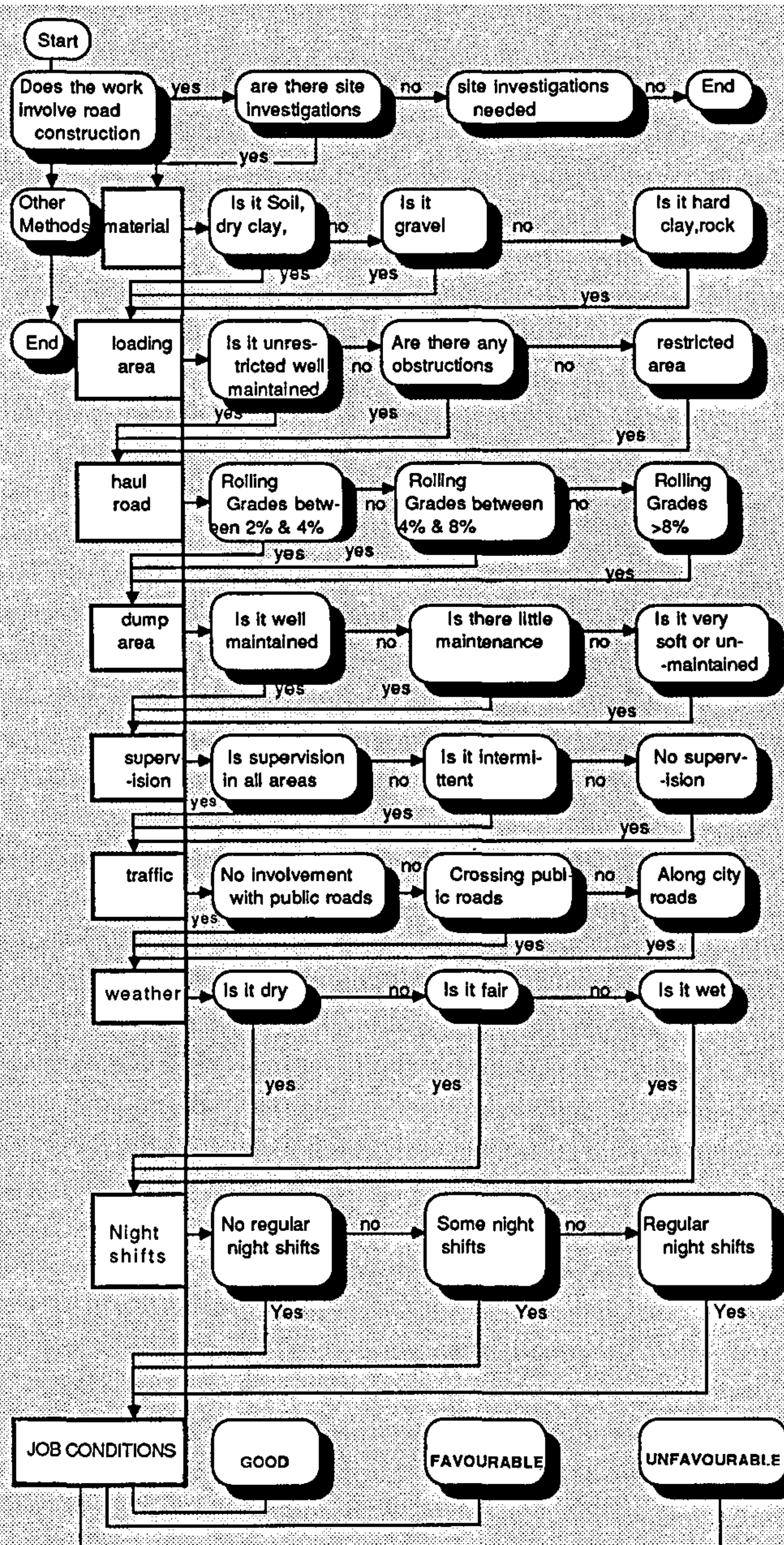


Fig.5.9
Identifying job conditions routine

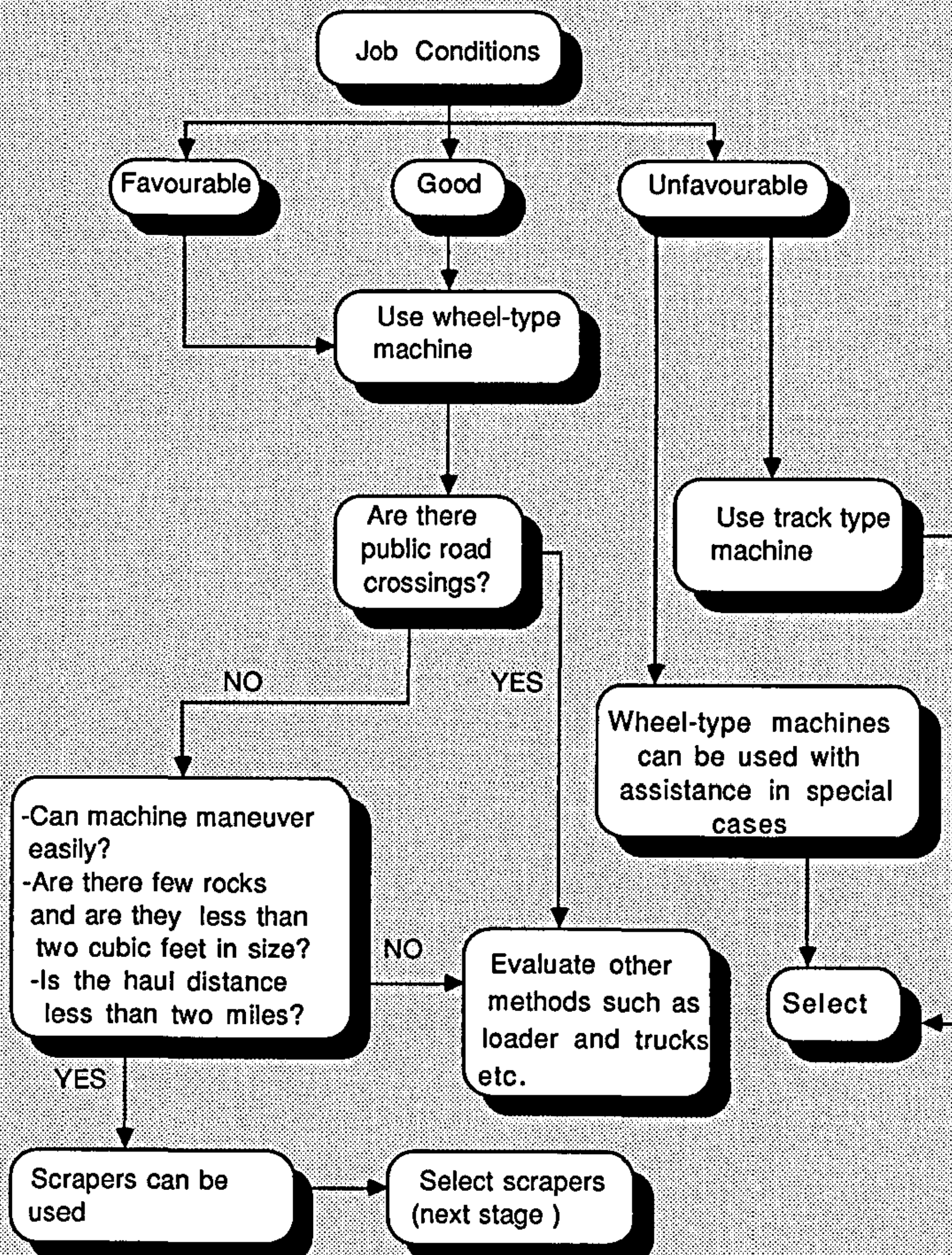


Fig (5.10)
Broad categories of machine selection

>> I am now starting to consider the type of soil, in particular, the kind of soil the machines will be dealing with on site. Please choose one of the following: For any enquiry please type (A)

1- Top soil, dry clay, or loam.
2- Pit run gravel, sand, soft shale, damp clay.
3- Heavy clay, single size aggregate,rock.

(1..3, ! if not known or an option) 1

>> Will the supervision on the site be:

1- Adequate in all areas.
2- Intermittent.
3- Little or no continuous supervision.

(1..3, ! if not known or an option) 1

>> Now I wish to know whether haul units will be involved with public traffic. Will you please choose one the following cases :

1- No involvement with public roads or railways.
2- Road crossing.
3- Haul always in city streets.

(1..3, ! if not known or an option) 1

>> I would like you to tell me if in general the weather is:

a- dry,
b- fair, or
c- wet

(Enter 1 Characters or an option) A

>> Are there any obstructions (ie. trees, buildings, or others) on the site?

(Y..!..N or an option) N

>> Please inform me of the haul gradient by selecting one of the following: For any enquiry please type (A)

1- Less than 4%,
2- 4% to 8% ,
3- 8% to 12%, or
4- More than 12%.

(1..4, ! if not known or an option) 1

The Report is:-

I have now completed my assessment of the GENERAL JOB CONDITIONS and I am pleased to tell you it is FAVORABLE. In general that means you can use either wheeled or tracked machines. We are going to find out the best one later when discussing the project in more details.

Fig (5.11)
Sample of consultation (ESEMPS)

5.4.2 **Machine selection by broad category** (Fig 5.10):

Depending upon the results for job conditions and the distance to be travelled, a particular type of machine can be recommended. Figure(5.12), illustrates the kind of questions required to arrive at for example the scraper option. Other choices such as bulldozer, ripper, dragline, backhoe, grab, elevator, pusher shovel, etc. would be examined on a similar basis.Unfortunately the choice at this stage may not always be the final decision as different machines can sometimes carry out the same tasks eg. both backhoes and draglines do similar jobs. Further analysis of specific machine performance including economic factors based on the length of the haul is thus needed to make precise comparisons.

5.4.3 **Output estimating** (fig 5.13) and **machine matching:**

When the suitable types of equipment have been selected for a particular earthwork operation, the next step is to estimate the production outputs of all the models of the selected types of the machines. These outputs are obtained as outlined in fig(5.13). Initially data concerning the models and sizes of the types of the machines selected in stage two are selected from the data base on models and sizes of the machines. Then from the knowledge base the height and the weight constraints, applicable to the construction site or haul road, are considered by requesting the user to assign limiting values to them, (for example on a site visited during the early stage of the research, the job conditions were good which indicated that all types of equipment could be used. However only a 12 cubic meters capacity trucks were operated, to avoid increasing the pore pressure in the soil with heaver equipments and thereby increasing the risk of damage to

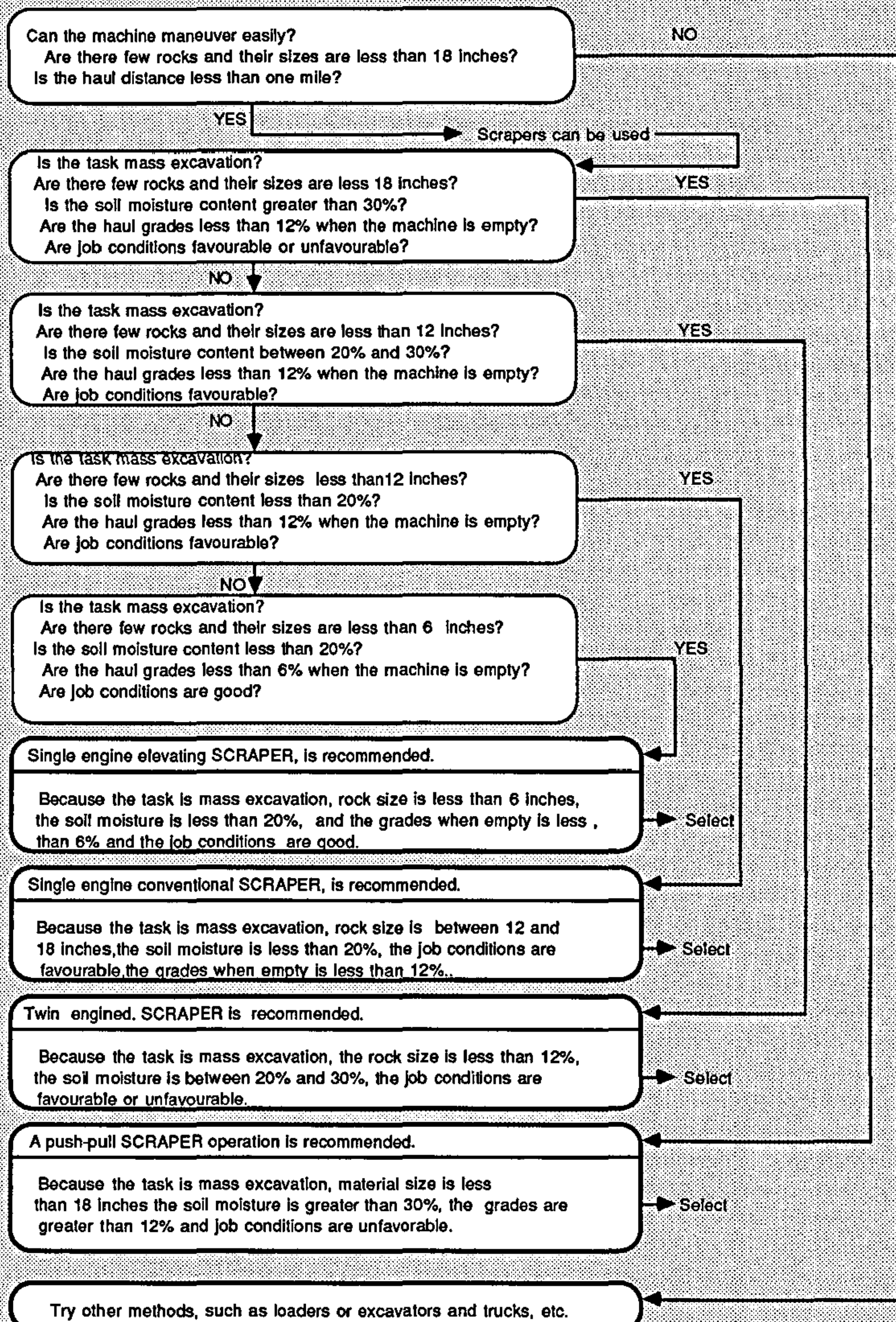


Fig (5.12)
Example of Rules for Scraper Selection

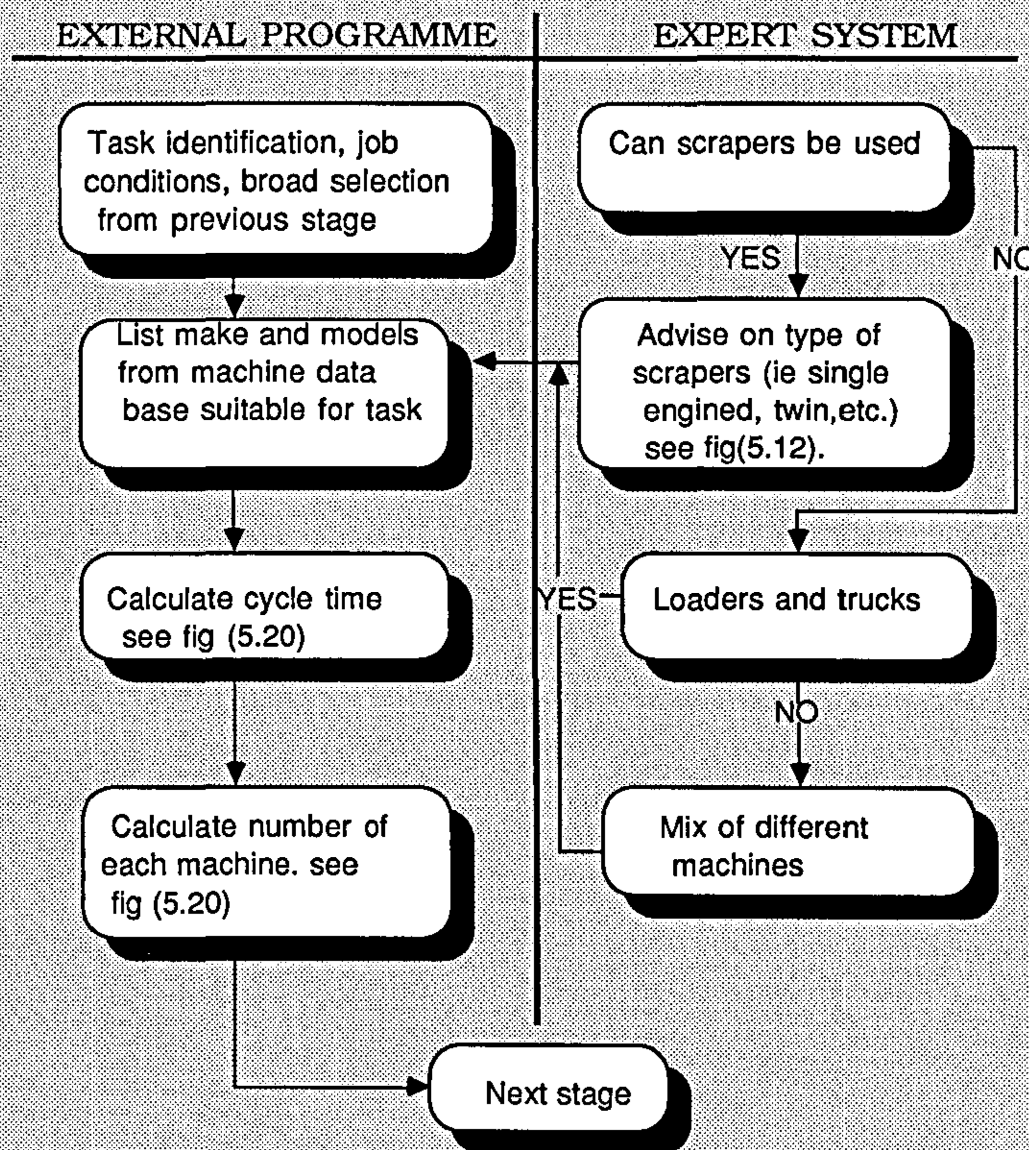


Fig (5.13)
Output estimation and machine matching logic

the embankment). The outputs of the chosen machines are then determined using the manufactures data stored in the data base after modification depending on the job condition determined in stage one.

The performance of different types and makes of machine is affected by different soils, operating conditions, terrain, operator etc, thus the ideal output rate eg.(cubic yards/hour) needs to be adjusted to reflect the conditions. Both field data and published sources (4, 11, 13) were used to derive realistic values for application in the system, and the following derating factors are included depending upon the replies to questions and rules subsequently generated by the system:

* Material swell factor.
* Type of work.
* Cycle time of the machines.
* Equipment conditions.
* Weather conditions.
* Operator efficiency.
* Design features and capabilities of the machines.
* maneuvering.
* Overall job efficiency.
* Terrain.
* Excavation configuration.
* Delays.
* Output of loading machines for trucks or the pushers for scrapers.
* Weather conditions.
* Operator efficiency.
* Design features and capabilities of the machines.
* maneuvering.

Most of the above factors have been described in previous sections, a brief description of other important factors are given below:

5.4.3.1 **Equipment conditions:**

Low engine output, worn or blunt teeth or tool points, inadequate lubrication and maintenance will reduce output. Earthmoving contractors try to maintain sound equipment as a breakdowns may result in periods of zero output. The possibility of a breakdown can be reduced by planned or preventive maintenance. Contractors normally keep one or two machines spare on site for such breakdowns. The number of machines suggested by ESEMPS includes a standby for such a breakdown.

5.4.3.2 **Operator efficiency:**

An operator who persistently fails to fill the machine's bucket, who moves the boom further than the job demands, who wastefully cuts with the dozer blade longer than is productive necessary, or who badly positions the machine in relation to the haul unit will not produce maximum output. Hence it may be necessary to include a factor for operating efficiency. The loss of output for a bad operator could reach 20% [138].

5.4.3.3 **Overall job efficiency:**

Is a factor compounded of many smaller constraints in the overall job efficiency. No machines on site work continuously 60 minutes every hour, hour after hour. Stops will be required for discussion, marking out, work checking, operator needs, wait for haul unit, etc. For this reason a job efficiency factor is introduced into output considerations and it simply reflects for every elapsed hour on site a machine works 50 minutes for good job conditions. When delays are likely to be frequent then a 40 minutes work hour would be more appropriate reducing to 30 minute per work hour for bad conditions.

Most of these factors are stored in external files, and called up when matching the sizes and number of machines, with the actual cycle times of the equipment calculated in an external programme.

5.4.3.4 Cycle time:

This is the time required for a machine to obtain its load, move to the place of dump and return to the loading point, and time is usually expressed in minutes. Total cycle time is the sum of fixed cycle time and travel cycle time. Fixed cycle time includes spotting, loading, turning, dumping and reversing direction of travel. Travel cycle time is the time taken by the machine while hauling the material. The travel times of the machines are affected by the travel speeds and the haul roads conditions and their grades.

5.4.3.4.1 Methods of estimating the cycle time:

i) Traditional method:

In this method figures for the fixed and travel times could be obtained from previous experiences of operating the equipment under similar conditions. Allowances should be also be made for time lost waiting at loading and discharge points. This however, is governed by the relationship between the cycle time of the haul unit and the ancillary equipment.

The travel time is variable depends on the haul length and conditions, grade, load carried, and the speed of the machine. The most common method adopted in estimating travel time is the use of performance charts supplied by equipment manufactures. These give the maximum speeds at which the loaded and unloaded vehicle will travel on various grades, after correction to include rolling resistance. The time is then calculated by dividing the haul lengths by the maximum speed. An allowances for acceleration and decceleration the vehicle is included.

ii) <u>Computerised method:</u>

In recent years computer programmes have been developed for vehicle simulation. These can give more accurate estimates of the travel time, by taking into account changing speeds.

Seger [169], introduced a programme which calculated the variable time for the haul unit leaving the loading point and arriving at the discharge point at stated velocities. The haul route could consist of a number of sections, each with it's own specified length, grade, rolling resistance, traction coefficient, and maximum speed. The section on the return journey has also to be specified, but need not be the reverse of the outward journey. Assuming a constant acceleration rate, the time taken for the vehicle to cover a short distance can be obtained using the equation shown in fig(5.14). The iteration can then be repeated until the whole round trip has been covered.

O'Neil & Manula [26] , used a similar interactive method. However instead of calculating the time taken to cover constant incremental distances, they determined the distance covered in the constant time of one second.

These two approaches however have not yet been applied on site because of the very complex nature of the method.

iii) <u>The method adopted in ESEMPS</u>:

As in the traditional method, the cycle time has been divided into fixed time and travel time. Fixed time is taken from the manufacturer's performance books for each type of equipment, with an allowance of one minute added to avoid the risk of any unexpected delays (as advised by the experts).

Travel time is calculated using travel charts from the manufacture's performance books [165, 170]. These are designed for machines working under ideal conditions and very optimistic, for example the recommended speed can not normally be achieved on site.
After discussions with practitioners, it was decided that the machine speed should be limited to to 12 miles per hour when the travel distance is up to two mile, and to 15 mile per hour when the travel distance is more than two miles taking into account the safety and route conditions. subsequent to

these suggestions the travel charts were redesigned using data adopted from previous work study undertaken at the Civil Engineering Department, Loughborough University[166], also from A42 road project under construction in the Midlands, England [79], using 12 and 15 mile per hour respectively and adjusted for intersection with particular grade curves or by using curve equations. Figures(5.14, 5.15, 5.16, 5.17, 5.18 & 5.19) show samples of such graphs.

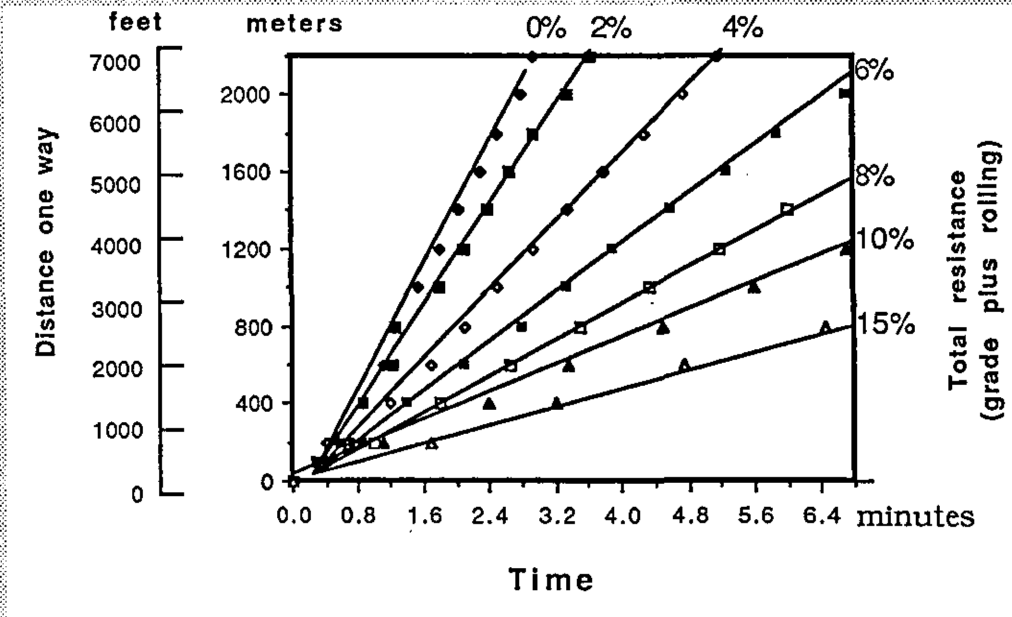
An external programme was written using the curves equations to calculate the the travel time of a machine depending on the haul distance and the total resistance (input by the userduring the consultation with the system). This travel time is then added to the fixed time to achieve the total cycle time of the machine. The system then finds the hourly output of each machine under the given conditions using the following formula:

$$P = E\,(I\,H \,/\, C)$$

<u>Where</u> :

P = Production in cubic unit volume (bank) per hour, (eg. Bank cubic Yard per hour).
E = Efficiency in minutes of work per hour, (eg. 40 minutes per hour).
I = Shrinkage factor for loose loaded material.
H = Heaped capacity of the machine in cubic unit volume, (eg. cubic Yard).
C = cycle time of the machine in minutes.

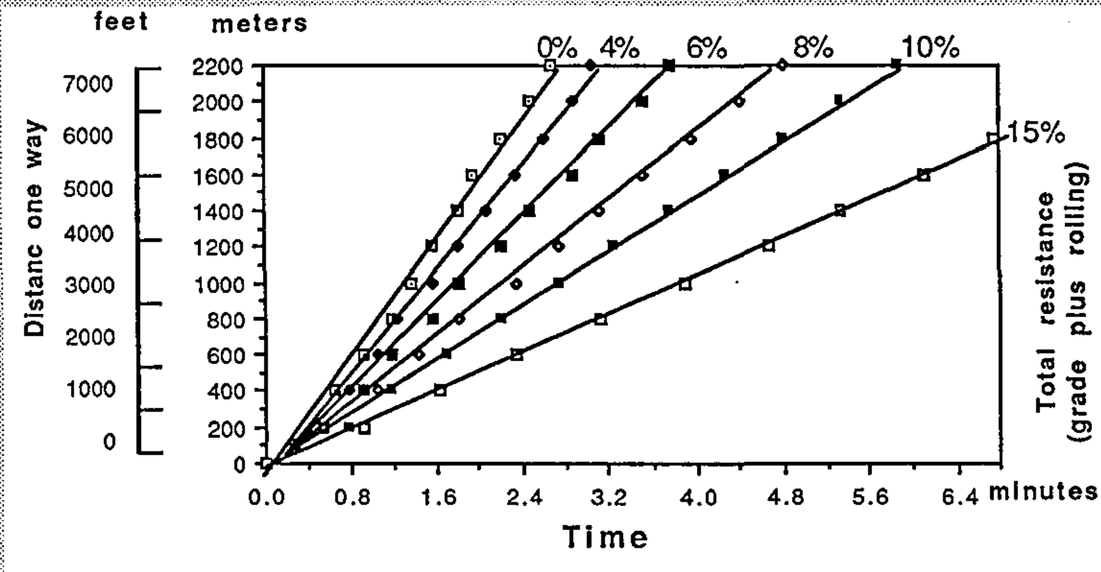
The number, capacity and make of the machines are then determined to enable the project to complete on time as illustrated in (fig 5.13). The procedure involves detailed analysis of the volume diagram (figures 5.4 & 5.5) defined in the stage one, giving full consideration to the location of borrow pits, tips and haul roads. Knowing the quantities of material to be cut or filled, the haul distances, and the output production of the machines, the numbers, types and makes of machines may be calculated in a conventional manner taking into account the derating adjustment factors, together with the cost of transporting a unit volume of material between the cut and fill zones with respect to each machine group. This part of the process is performed in an external program linked to the expert system returning only to make final selections.



<u>Equations for the curves:</u>

y = - 163.4836 + 770.4939x	Grades = 0%
y = - 99.5172 + 629.474x	Grades = 2%
y = - 48.61 + 429.1237x	Grades = 4%
y = - 28.3637 + 309.1633x	Grades = 6%
y = - 5.4022 + 232.428x	Grades = 8%
y = 11.4524 + 175.7887x	Grades = 10%
y = 21.979 + 120.1542x	Grades = 15%

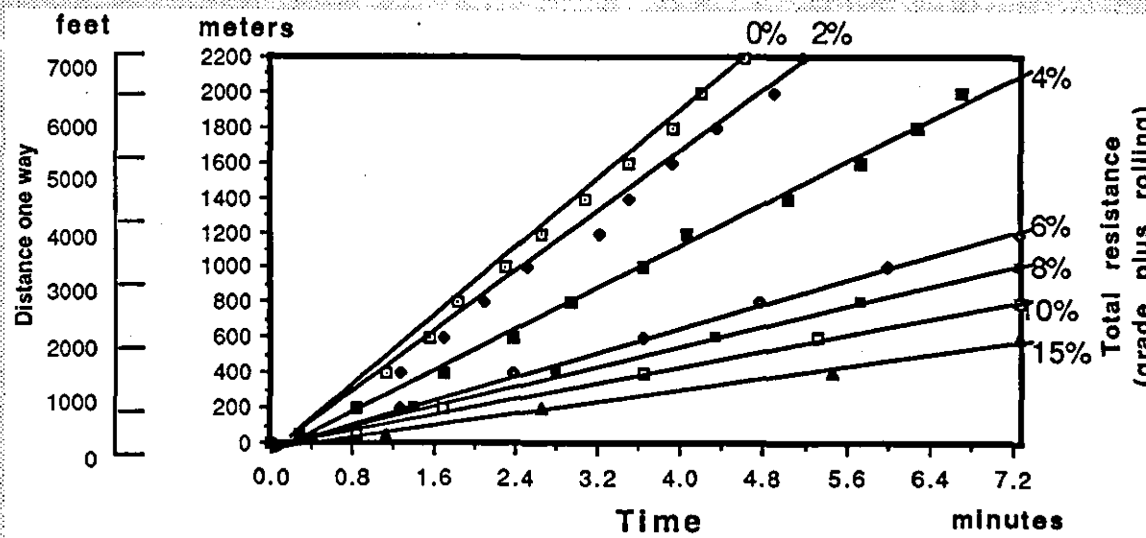
Fig (5.14)
Distance Vs Time
(Loaded truck operation)



<u>Equations for the curves:</u>

$y = -148.0902 + 867.5312x$	Grade = 0%
$y = -120.7827 + 737.974x$	Grade = 4%
$y = -82.9055 + 594.6142x$	Grade = 6%
$y = -41.9483 + 462.05x$	Grade = 8%
$y = -36.1201 + 381.0061x$	Grade = 10%
$y = -12.929 + 263.7996x$	Grade = 15%

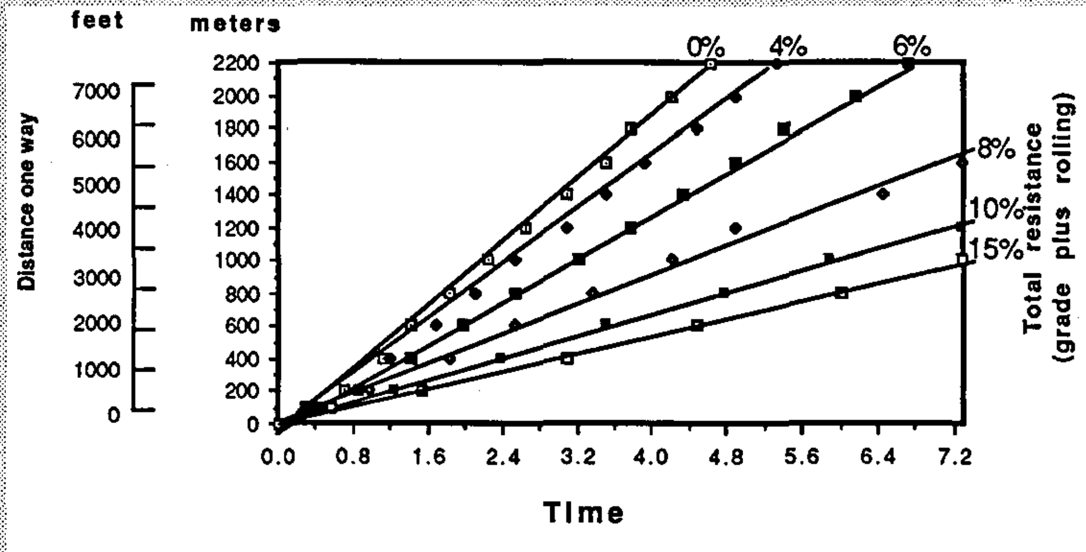
Fig (5.15)
Time Vs Distance
(Empty Truck)



<u>Equations for the curves</u>

y = - 116.2155 + 493.8374x	Grade 0%
y = - 100.2488 + 431.3348x	Grade 2%
y = - 51.6624 + 294.5469x	Grade 4%
y = - 26.6517 + 170.4818x	Grade 6%
y = - 22.0352 + 82.3351x	Grade 8%
y = - 16.1744 + 141.2152x	Grade 10%
y = - 10.5071 + 112.6355x	Grade 15%

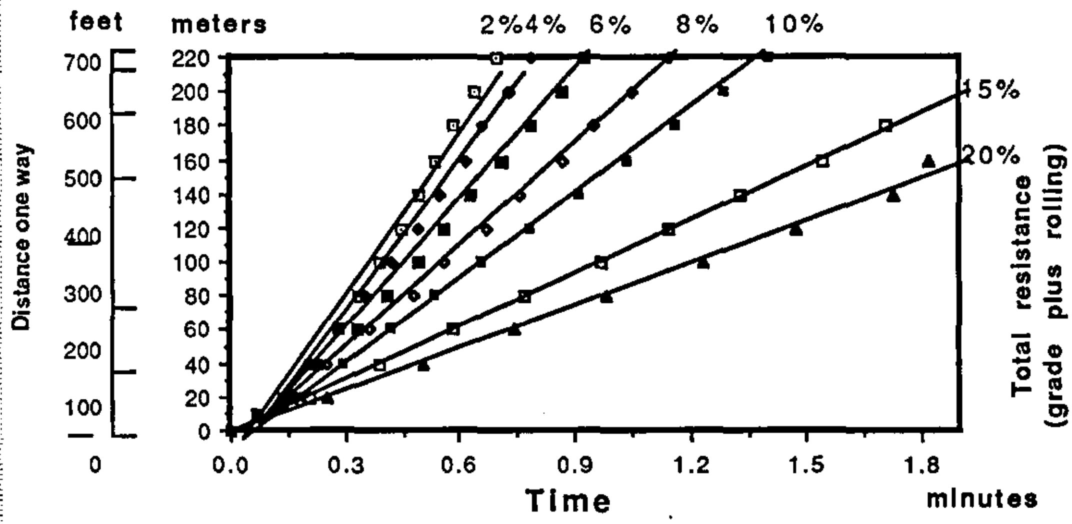
Fig (5.16)
Time Vs Distance
(Loaded Scraper operations)



Equations for the curves:

$y = -86.6143 + 424.9186x$	Grade = 0%
$y = -82.5008 + 488.8609x$	Grade = 4%
$y = -49.0935 + 334.651x$	Grade = 6%
$y = 11.4803 + 224.6076x$	Grade = 8%
$y = 4.0143 + 166.7664x$	Grade = 10%
$y = 1.5646 + 134.5404x$	Grade = 15%

Fig (5.17)
Time Vs Distance
(Empty scraper operations)



Equations for the curves

$y = -20.8965 + 331.6054x$ Grade = 2%

$y = -15.434 + 289.2369x$ Grade = 4%

$y = -11.9911 + 241.7644x$ Grade = 6%

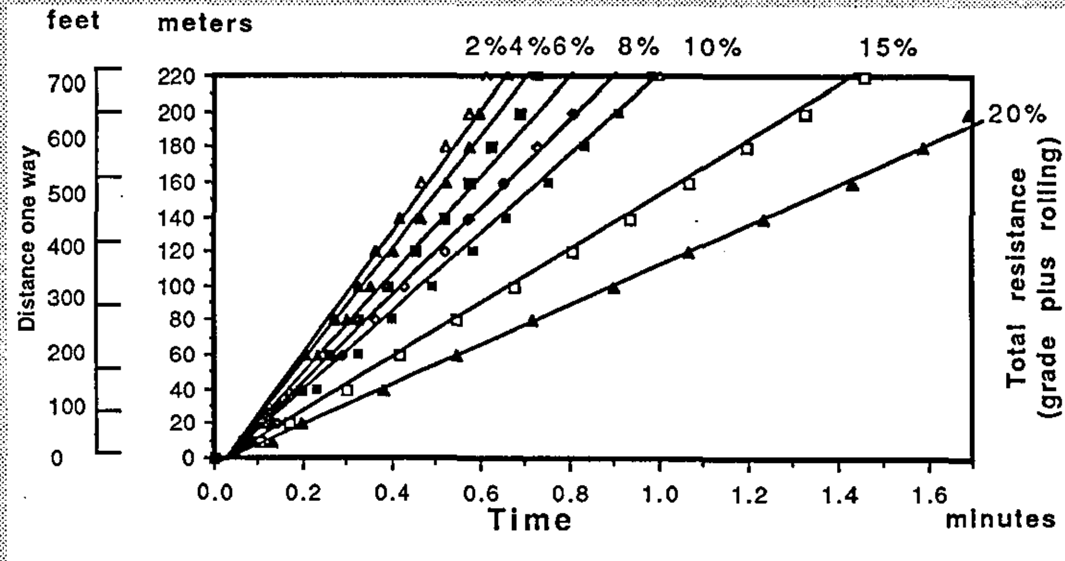
$y = -8.0308 + 195.529x$ Grade = 8%

$y = -4.4106 + 158.807x$ Grade = 10%

$y = -0.3883 + 83.4717x$ Grade = 15%

$y = -0.3494 + 104.7745x$ Grade = 20%

Fig (5.18)
Time Vs Distance
(loaded loader operation)



Equations for the curves

$y = -15.7408 + 343.1641x$	Grade = 2%
$y = -15.3934 + 373.6542x$	Grade = 4%
$y = -14.8924 + 307.6119x$	Grade = 6%
$y = -9.886 + 227.5734x$	Grade = 8%
$y = -5.3993 + 243.1309x$	Grade = 10%
$y = -4.2131 + 153.9318x$	Grade = 15%
$y = -3.3917 + 116.6211x$	Grade = 20%

Fig (5.19)
Time Vs Distance
(Empty Loader operations)

5.4.4 **Final selection** (fig 5.20):

At this stage, the system has already calculated the amount of material to be hauled in the time period for the completion of the earthwork operations, hence the required rate of earthmoving is also known.

The system however, provides the user with the opportunity to input machine availability and capacity to achieve the required rate of production, together with the cost incurred for each group of selected machines. The user has the option of selecting from owned, hired equipment or a combination of both.

The system calculates the cost per unit volume of material hauled, and advises on the lowest cost and most economical fleet configuration.

However the final selection may not always rest with the solution producing the lowest finishing time and cost.

Other considerations such equipment penalty clauses, liquidated damages, etc. notable when the project program exceeds the client's specified finishing date may be of overriding importance. The model assists the user to deal with these situations by allowing solutions based on a lowest finishing time only. The user also has control on the portfolio of equipment to include in the data files. For example in practice company fleets do not often contain all varieties of machine. Finally items might need to be changed after the project has commenced. Observed performance data can be fed into ESEMPS and fresh advise given on the type of action to take. An example for the scraper might

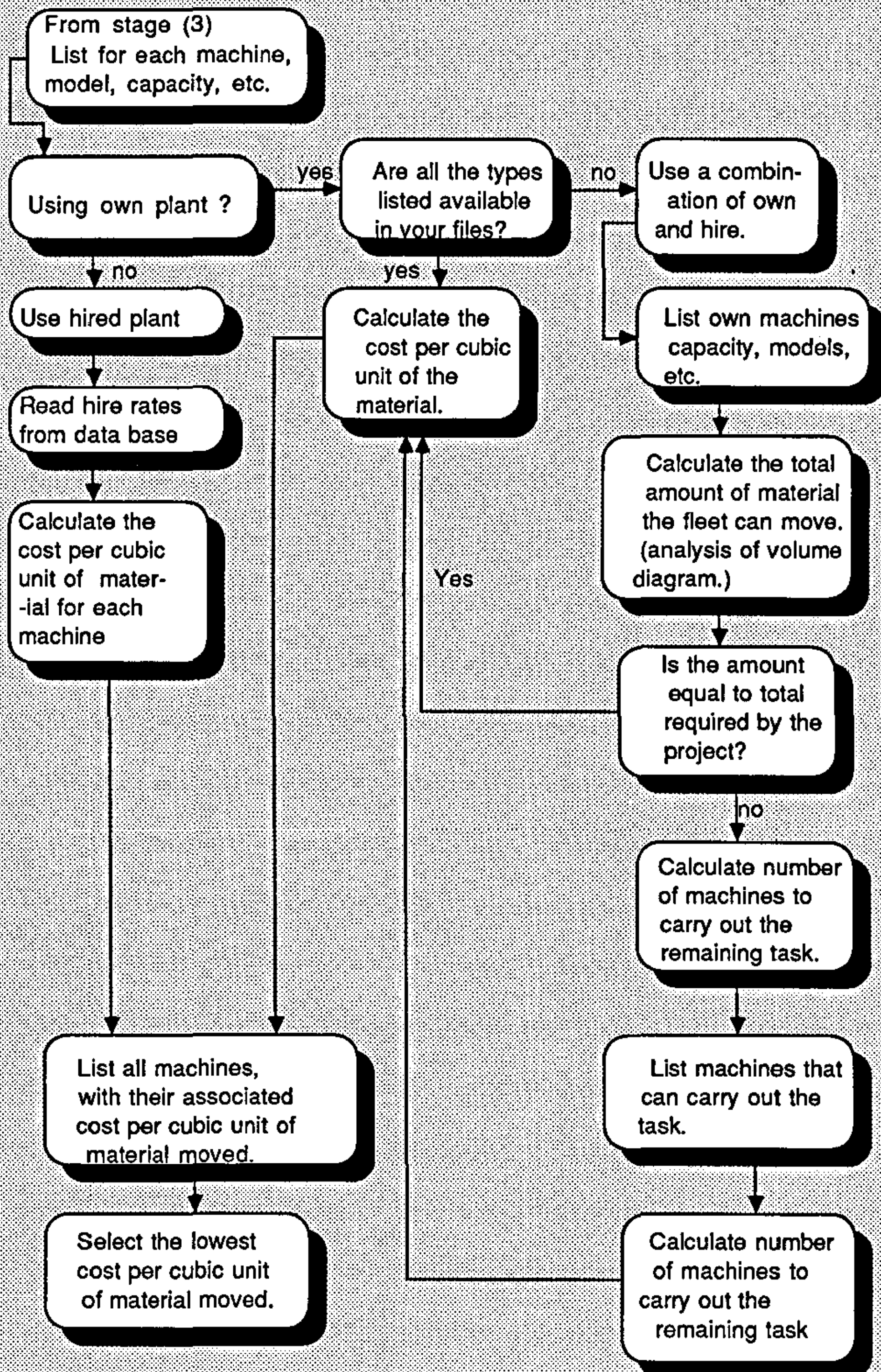


Fig. 5.20
Machine matching

be:

IF the pusher idle time is greater than zero.
AND the scrapers idle time is zero.
AND there is no scraper break down.
THEN increase the number of scrapers by one.

Having done that , if the idle time of the pusher is still greater than zero, then add other scraper and so on until all the machines are busy.

5.4.5 Simulating the earthmoving operation:

Simulation involves initiating event-by-event behavior of the modelled system, to capture the random nature of changing conditions, breaks, delays, etc. often found on construction sites[171].

Such a model could be of help after the equipment fleet has been selected from ESEMPS by controlling the subsequent efficient use of the available resources regarding time and cost on the actual site. For example responses to change may result in resources increasing costs but not necessarily higher production rate.

ESEMPS deals with by advising the user to look for the key machines, e.g. a breakdown of a loader stops the whole operation although enough trucks might be available.

The rules are formulated as follows:

a) In order to have the optimal productivity, the earthmoving equipment should always be busy.

b) In order to keep the cost down, idleness of equipment has to be avoided.

These heuristic rules, although based on common sense, were best explained using productivity and cost curves for a loader/trucks operation as illustrated in Fig(5.21).

By increasing the number of utilised trucks, productivity increases until the balance point where the loader productivity equals the truck productivity reached. The unit cost of moving material correspondingly decreases.

For example using the combination shown in figure (5.22) an analysis of the optimal fleet combination on site could be developed as follows:

a) **IF** IDELNESS OF LOADER > 0%
AND IDLENESS OF TRUCKS = 0%
THEN DOUBLE NUMBER OF TRUCKS

b) **IF** IDLENESS OF LOADER = 0%
AND IDLENESS OF TRUCKS > 0%
THEN REDUCE THE TRUCKS BY ONE.

c) **IF** IDLENESS OF LOADER = 0%
AND IDLENESS OF TRUCKS = 0%
THEN STOP

Other computerised simulation programmes such as CYCLONE (Cyclic Operations Network) [175], calculate the productivity of the process and idle time of each resources, and the associated algorithm could be linked to the system ESEMPS.

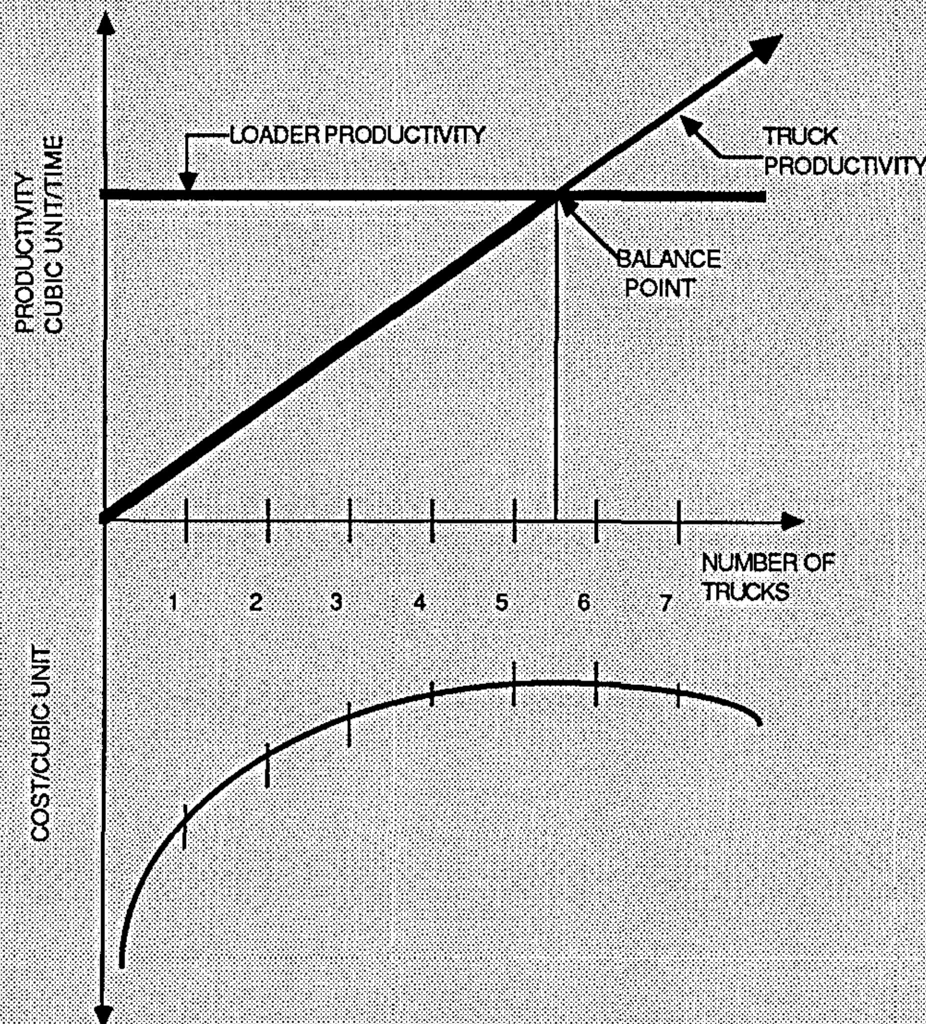


fig 5.21
PRODUCTIVITY AND COST CURVES

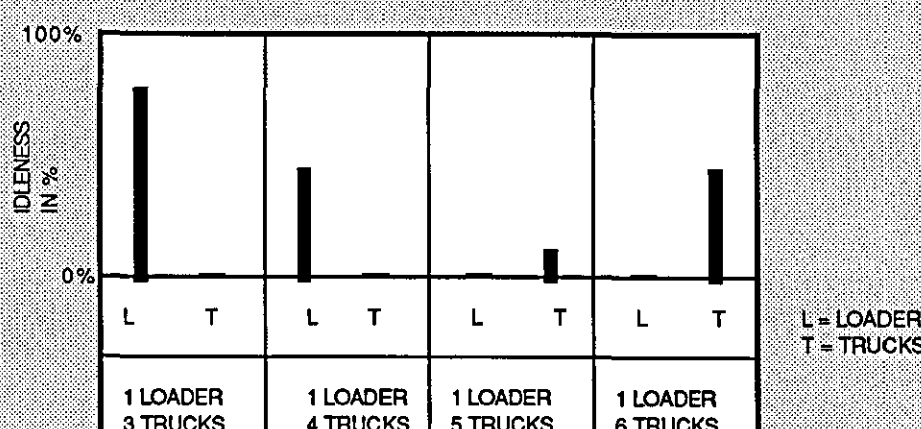


fig 5.22
LOADER/TRUCK IDLENESS

According to the hierarchy of the heuristic rules the optimisation procedure tries first to eliminate the idleness of the loader, the contraining factor. The second objective is minimise the idleness for the trucks, reached in **(c)**.

5.5 Knowledge acquisition for ESEMPS:

The stages in the design of expert systems are generally stated as:[176]

- **i)** Task(s) identifications,
- **ii)** Knowledge acquisition,
- **iii)** System design,
- **iv)** System development,
- **v)** System initial use and evaluation.

The most important stage is the accumulation and codification of knowledge. This being the heart of the expert system, [100].

It is advisable that the expert system designer should not be the domain expert. "Do not be your own expert" [100]. The expert system designer nevertheless needs to be fully educated about knowledge acquisition techniques and must be especially aware of the potential problems associated with it. Particular attention should be given to answering questions concerning the adequacy of the knowledge base, reasoning differences of opinion among experts, and structuring interviews sessions and so on.

5.5.1 Knowledge acquisition in general:

Knowledge for any domain is normally held by the experts in the specific domain.

This knowledge typically consists of two types: **public** and **private** [177]. Public knowledge is quantified to the extent that it may be considered static, and is found in textbooks, journals, and other written references sources. Human experts, on the other hand, usually possess the "private" and kind has not been included in the published literature. This private knowledge includes rules of thumb that have become known as **heuristic rules**.[177].

A heuristic is a piece of knowledge capable of suggesting plausible courses of action to follow or avoid. This definition is not complete, because for a body of knowledge to be effective, each heuristic within it must also specify the situation in which actions are appropriate or inappropriate [177]. In other words, a heuristic must have both an "if part" and a " then part". A heuristic is thus defined as a collection of attributes and corresponding values that include various kinds of condition **(if part)** and actions **(then part)**.

Engineers often utilise a heuristic search [176] and set approximate goals to begin a design without fully knowing what is possible. Heuristic reasoning is thus used to compensate for the lack of complete theory, or to enable the human expert to make educated guesses when necessary. Defining, extracting, and encoding these heuristics are the primary tasks in knowledge-base development and thus expert systems construction [164].

There are several reasons for emphasising knowledge rather than formal reasoning mechanisms when discussing the construction of expert systems. Perhaps the most important one is the recognition of knowledge as a scarce resource. Traditionally, the process of transforming a trainee into expert is a long process of extensive education and experience. Thus the potential benefits of extracting knowledge from experts and encoding it in a computer programme may produce a significant reduction in the amount of time required to develop expertise in a given domain.

Another reason for emphasizing knowledge over formal reasoning mechanisms is that many work place problems do not have algorithmic solutions. Planning, diagnosis, equipment selection, and many design processes often rely on heuristic knowledge rather than on well-defined mathematical relationship.

5.5.2 The knowledge acquisition process

Knowledge for the system was derived from self experience, experts in the domain of road construction, planning engineers, equipment specialists [172, 179, 180, 181, 182, 183, 184], published literature and field trials.

The concept of building the knowledge-base by first extracting the expert's knowledge and then organising it in an efficient manner is referred to as knowledge engineering. During the knowledge engineering for ESEMPS the following factors were considered:

i) The design and organisation of the system must be able to reflect the complexity of the plant selection problem and the heuristic knowledge available.

ii) The system must be able to convert the common sense into appropriate rules.

Data relevant to road construction was classified into three basic types: **i)** facts, **ii)** beliefs, and **iii)** heuristics, arranged for making good judgment in situations where valid algorithms do not exist.

Expert systems like practitioners, are distinguished by the quality of knowledge they possess. Thus the great challenge was to acquire the proper quantity and quality of knowledge for incoding in the knowledge-base.

Even though a number of programing shells are available to assist in constructing a complex knowledge base, there are no universally accepted rules for selecting appropriate experts, formulating appropriate questions, or initiating the construction of the knowledge base. For these reasons the following steps were followed while developing the knowledge for the system ESEMPS:

a) **Identifying all relevant sources of knowledge:** A thorough review of the literature related to road construction and earthmoving equipment selection was completed in order to gather the sum of the static knowledge appropriate for inclusion in the rule base. Concurrently, a group of experts in the domain of road construction and equipment specialists were identified and contacted in order to build a pool of expertise from which to extract heuristics later in the process.

   At this stage the knowledge gained from literature was used to build a prototype model. The group of experts reviewed the model, progressively determining it's development.

b) **Extract knowledge from sources:** Interviews and written communication with selected experts were conducted to assemble the heuristic knowledge were completed. The knowledge was codified and stored in the knowledge base. Demonstrations also proved successful, and hand-written notes were taken, later transcribed in detail. Although these provided a fairly complete record of the interview sessions, tape recording subsequently proved more reliable. Transcription of the detailed record of the knowledge acquired, whether from rough notes or from a tape recording, was always a very time-consuming process.

The domain experts were all experienced engineers from different construction firms and training institutions. In the early stages of the knowledge elicitation, up to five were approached for general sessions.

However, as interviews became more focused only a couple of the more co-operative participants proved practicable. Longer than two hours a secession, concentration on both sides waned.

The interview techniques compromised:

a) **Unstructured interviews**- experts were asked to describe all their knowledge of equipment selection. The emphasis was on getting an overview of the whole domain in the early stages of the interview.

b) **Structured interviews**- experts were asked to describe all their knowledge of small preselected areas, forexample, procedures for selecting different types of loaders etc. operating in given specific conditions. The emphasis was on trying to achieve complete knowledge of that area.

c) Prototyping- this involved the development of a knowledge base at an early stage during knowledge elecitation. The prototype was offered for criticism and gradually improved by allowing the experts to comment. Also the demonstration of the prototype proved very valuable in revealing new knowledge. The procedure was repeated until the final stage of the system was approved by the experts, roughly eighteen months.

iii)Evaluate quality of the knowledge base: The facts and heuristics recommended for inclusion in the final knowledge base were thoroughly evaluated by the domain experts after reaching the final decision on disagreements regarding rules.

5.6 Using the shell and external programmes

The "SAVOIR" [194] knowledge based system shell was chosen after a comprehensive evaluation of expert system shells for the construction industry [79] based on facilities avaliable for a price we could afford. The specific features that influenced the choice included use with a personal computer, interfacing with procedures written in the Pascal programing language and ability to accept uncertain replies to questions.

Notes on Knowledge Acquisition for ESEMPS

The knowledge for the system was acquired using the following techniques:

1) Questionnaire forms were sent to twenty five construction companies and organisations in the UK, demanding information on plant selection and earthmoving processes.
2) The results of the questionnaire were encouraging to the extent that some organisations were approached to extract information by interviewing their experts.
3) The response was not very encouraging, only six organisations responded and appointments were made for the interviews. Finally 12 practitioners were interviewed at different stages of the system and a total of 60 hours of knowledge acquisition was carried out in thirty sessions over a period of 20 months of the research time.
4) Initially two experts provided the first knowledge, together with that gathered in literature and text books. This knowledge was arranged in a prototype system and demonstrated back for criticism and building more knowledge. Eight sessions were achieved with them.
5) The prototype was then offered for criticisim by other experts, hence more knowledge was added until the final stage was achieved.
6) The system then was tested on site against a case study in the presence of the experts interviewed in the early stages of the model.
7) The system is comprehensive and contains a vast amount of knowledge in particular (365 questions), (725 variables) and (1250 actions). It was difficult to handle all this knowledge in the capacity of the RT program of Savoir. Hence it was separated in to two linked models.

5.6.1 Savoir method of operation:

i) Create a knowledge base source file written in the Savoir knowledge representation language, using an editor e.g. Wordstar, (The latest version of Savoir has it's own editor).
ii) The source file should be compiled by running "SCOMP". This checks for syntex errors and produces an object code knowledge file.
iii) Variables should be initialised by running "PV" which checks for logical errors.
iv) Consultation starts by running "RT" and follows the instructions.

5.6.2 Savoir knowledge representation:

Savoir adopted a production rule representation method to represent the knowledge in three main language components as follows:

i) Questions referred to as "QUESTION".
ii) Rules, referred to as "VARIABLE".
iii) Demons, referred to as "ACTIONS".

Savoir allows the knowledge engineer to write a procedural programme that sits on top of the inference network and instructs the system to investigate different goals at different times. This is done through "ACTION" command which is either "INVESTIGATE" which puts the goals on the investigation list, or "STOP" which takes them off. Both types are fired as soon as some appropriate conditions have been satisfied. There are also some types of ACTION which allow the knowledge engineer to change variable values, and call external functions.

Savoir also enables the knowledge engineer to group more than one goal to be investigated as soon as one of them is investigated. This avoids having to list them all in the INVESTIGATION action, and shows that there is some logical connection between them.

Savoir, also contains an attractive user interface (a colour window display format) and a variety of user options during the consultation, such as "AMPLIFICATION", "BACKUP", 'DISPLAY", "HELP", and "VOLUNTARY ANSWER". The amplification option assists in choosing a route through the questions and answers routines which proved particularly helpful. The explanation facility however was somewhat disappointing for it had to be written by the knowledge engineer, and an automated display of the text of rules within the system would be preferable.

5.6.3 Savoir inference logic:

Savoir is equipped to deal with both classical logic and uncertain reasoning. It provides the standard propositional logic connectives, AND, OR, NOT. All variables and questions including probability types have flags indicating if their values are KNOWN and if they have been ANSWERED. This means that the condition variables in Savoir employ extended boolean logic i.e. it can be established that the variable has been evaluated to "UNKNOWN".

Savoir provides the facility to compare the values of numeric, probability and string variables and return a truth value for the proposition.

The main probability operator provided is the Baysian inference rule. Savoir also provides the fuzzy logic operators OPPOSITE, MAX, CAP, and CUP, which correspond to the classical logic operators NOT, AND, OR. it also allows the option to turn numbers into probabilities, so that adhoc methods can be used to calculate probabilities if desired. Also simple mathematical operations are available in Savoir.

5.6.4 Limitations of SAVOIR:

Although SAVOIR provides the knowledge engineer with a variety of general-purpose programing capabilities, there are limitations. many of which result directly from the desire to be as general as possible. Furthermore SAVOIR lacks the ability to directly access its own rules and control mechanisms. Due to this inability there is no means by which a system built in SAVOIR can add to or modify its own structure directly. Therefore, one can not construct a system capable of learning new rules or monitoring changes to its own logic. This ability also creates problems when the system is required to explain its line of reasoning, which forces the knowledge engineer to write this line of reasoning and thereby spend more time than should be necessary using better shells. More information on other shells, is given in Appendix[D].

Although SAVOIR provides an easy to use "trap handler" which allows the knowledge engineer to access external functions included in the system, it cannot access an existing external programme or data base, unless these are written in Pro-Pascal and included in the "trap handler". This means that the knowledge engineer must have a good programing knowledge in Pascal to be able to write any external programme to perform complex calculations, data bases, and graphics, in comparision to currently available software packages.

Another limitation is that the user can only communicate with SAVOIR by answering questions in the appropriate format, or by using one of the systems "options". It does not attempt to provide a natural language interface that will accept English-like input, and parse it to identify the user's wishes.

Lastly SAVOIR is quite complex and novice users will find many baffling problems when creating the expert system, but conversely the package is very flexible and knowledge engineers will find ways round these problems when familiar with the shell.

5.6.5 Control strategy of ESEMPS:

The first issue to be addressed in the construction of this expert system was that of building an agenda or control strategy that would execute the required rules or other functions at the right time.

There is no default control strategy. The system does not automatically plough through a static list of goals. Instead the inference engine will sit and do nothing unless it is instructed to do so by an action in the knowledge base. However, in a way this is the system's strength, since the knowledge engineer has the option to build the control procedures to meet the specific requirements of the domain, thus making the system apparantly intelligent to the user.

The control logic of ESEMPS is divided into four stages, the first deals with the job conditions, the second eliminates the inappropriate machine from the list, third stage deals with material volume calculations and advice on the amount moved between cuts and fills, with the final advices on the final plant selection and their numbers, types and capacities.

The first task gives the user a choice of options handled through the use of a menu. The input function in SAVOIR allows the knowledge engineer to construct a menu of options from which the user has only to type in a number.

This menu allows the option of altering the consultation, access the knowledge base, ask for help and information about ESEMPS, or exit the system, as shown in fig(5.23). If the user chooses to access the knowledge base i.e. to add, delete, or otherwise modify the rules, then ESEMPS must be exitted into DOS system to open the knowledge base file and carryout the modification. However using other shells this would have been performed directly through direct access to the knowledge base.

Once the user chooses to start the consultation option, ESEMPS fires questions that need to be answered and so on until the end of the consultation, progress went giving advice on the appropriate earthmoving equipment. This is achieved through different actions built into the inference engine which controls the knowledge base.

ACTIONS control the line of reasoning through the knowledge base, and the output of the messages and calculations. Typically a consultation will be started by ACTION which puts a particular goal on the INVESTIGATION list. In ESEMPS goals can be rules or questions, so it is possible to start the consultation by asking keyquestions which will determine which branch of the inference network should be investigated next. This ability to use FORWARD CHAINING when desired gives the knowledge engineer great control.

When a question is put on the INVESTIGATE list it will simply be asked as soon as it comes to the head of the list. When a VARIABLE comes to the head of the list, the system employs backward chaining to find the rule's ultimate antecedent questions and poses them.

Goals can also be taken off the INVESTIGATE list, using the "STOP" ACTION. This is useful in curtailing needless questioning if an answer has already been found, or if it seems unlikely that an answer will be found in the present part of the inference network.

5.6.6 The components of the system (ESEMPS):

The system is stored as sequences of statements held in a text file. There are three basic components used to construct the system, these are QUESTIONS, VARIABLES and ACTIONS.

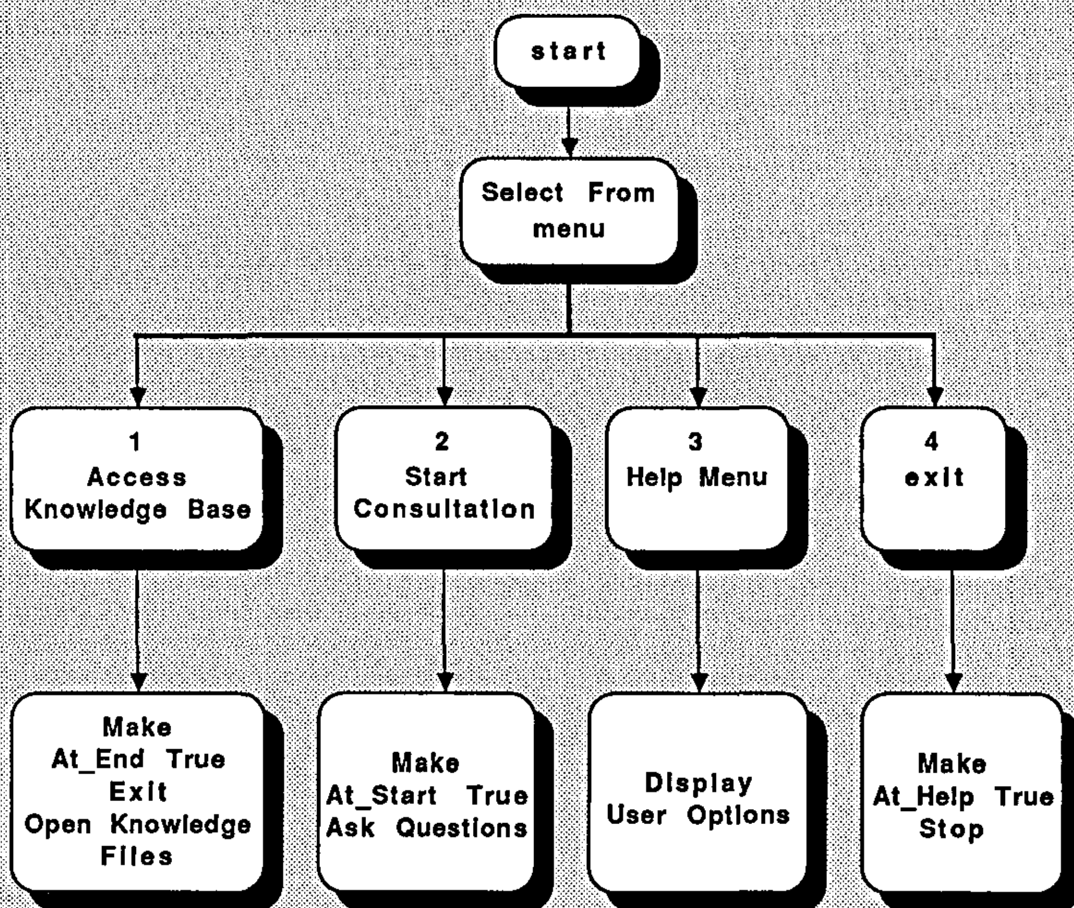


Fig 5.23
ESEMPS options menu

5.6.6.1 <u>Questions</u>

Questions are employed to elicit information from the user. Within the model structure, questions are positioned at the leaves of the system knowledge tree, antecedent to the consequent variables to whose values they contribute. There are different types of questions which can be asked by ESEMPS to gather pertinent information, these are:

a) Conditional questions- These questions are quite simple and are phrased so that the user can answer either "YES", "NO" , or "!" if the answer to the question is unknown, as illustrated in the following example of conditional questions.

```
QUESTION ask_road '£13££13££13££sq£
         Is the task road construction?£eq£'
YESNO

QUESTION validate_ask_road'£sq£You have replied
         UNKNOWN. Are you sure that you dont know
         if the task is road construction or not?£eq£'
AMPLIFY '£sa£If you reply with YES I will assume
         it is not road construction and will give
         a chance to re-start or stop this
         consultation, otherwise I will re-ask the
         question again.£ea£'
YESNO
```

An alternative form of the conditional question allows the user only to respond with "YES", confirming that some instructions have been carried out, as shown in the following example.

```
QUESTION help_sub_2  '£tab3£- -
        GENERAL INFORMATION ABOUT ESEMPS - -
£tab0£ESEMPS is used to assest in plant selection
and  to  advise  on procedures. It is a small
demonstration  system intended to illustrate the
essential features of a diagnostic/advice expert
system written  in the SAVOIR language and users
should be aware that its reasoning is fairly simple.
£13££tab0£
ESEMPS contains questions which ask directly about
      ground conditions,obstructions, quantity, and
      plant availability'
CONFIRM
```

b) **Numeric**- This is another type of question which ESEMPS is capable of asking the user, a real number or integer response is expected as shown in the following examples:

```
QUESTION menu_1_a '£13££sq£
     Shall I:£13£
     £tab1£1) re-ask those questions to which you
              replied UNKNOWN,
     £tab1£2) continue with questions about more
              detailed information ignoring the
              assessment of general information,or
     £tab1£3) finish this ESEMPS session ?£eq£'
AMPLIFY '£sa£ You have one last opportunity to answer
        those questions for which ESEMPS does not have
        sufficient information (reply 1). If you reply
        2, however, ESEMPS accepts that it cannot
        know the general information and will try to
        get a more accurate estimate of the project's
        conditions  by asking more detailed questions.
   You may wish simply to leave the consultation at
   this point. Alternatively you may wish to see the
   questions anyway and give some guessed answers.£ea£'
NUMERIC 1 3
```

In these examples an answer from the user of a real number outside the range(100) , or of an integer outside (1&3), will cause the system to display the message "Invalid answer" and to repeat the question. In both cases the user may alternatively reply "!" indicating "don't know".

c) Probability - for this type of question ESEMPS will expect as a response from the user a number ranging between 5 (i.e. the user definitely agrees with the proposition), through 0 (the user doesn't have any information related to the proposition), to -5 (the user definitely disagrees with the proposition), as illustrated in the following example:

```
QUESTION  type_of_soil
     '£sq£ESEMPS  IS  now starting to  consider  the
       type  of soil.
       In particular, what kind of soil the machines
       will  be dealing with on site.  Please choose
       one of the following: £cr£

             £TAB1£   5   for clay
             £TAB1£   3   for clay_and_gravel
             £TAB1£   2   for earth_natural
             £TAB1£   0   for mixed
             £TAB1£   -2  for sand
             £TAB1£   -3  for gravel
             £TAB1£   -5  for rock  £eq£'

CERT PRIOR 0.5

PROBABILITY obstructions 'the normal obstruction
            on site'
ANNOUNCE '£sann£ ESEMPS is
   now  starting  to consider if  there  are  any
   obstructions on site.£eann£'
TRACE  '...  in particular,  whether any obstructions
        on site.)£etr£'
ESSAY  '£sess£I use 3 measures to find out  if
        there are any obstructions :
£tab1£ - are there any trees or buildings,
£tab1£ - the surface moisture and water table, and
£tab1£ - if  the haul units will use or  cross
         public ways.£eess£'
         trees                       LS 4.0    LN 0.25
         prob_moisture               LS 4.0    LN 0.25
         ask_public_way              LS 4.0    LN 0.25
         prob_haul_distance          LS 4.0    LN 0.25
         prob_work_shop_distance     LS 4.0    LN 0.25
             prob_road_work          LS 4.0    LN 0.25
PRIOR 0.5
```

The prior value (in this case) is the value which will be assigned for a reply of zero ('don't know"). A reply of between 0 and 5 will be scaled linearly to reflect a probability between the prior and 1; a reply of between -5 to 0 will be similarly scaled to reflect a probability between prior and 0.

d) String questions- these expect as a response a string of characters. The basic syntex of a string question is shown in the following example:

```
QUESTION ask_rain_frequency'£13££13££sq£ Reply by
         choosing  ONE from the following,where the
         road will be constructed
         £13£ is it?
         £13£ -----£13£
         £tab1£  a) in the south, or
         £tab1£  b) in the middle,or
         £tab1£  c) in the north of the country ?£eq£'
AMPLIFY '£sa£''Rainfall could be known from past
                recordes or from past years.£ea£'
ALPHA 1 1
```

The user may also enter an empty string, this is just a carriage return, to indicate that the answer is not known.

All the above examples are concerned with eliciting the appropriate data from the user. Alternatively the data can be obtained directly from the external programme. This can be achieved by calling a suitable external function.

5.6.6.1.1 <u>Status of questions during consultation</u>

Before the question has been asked and the user (or the external function) has replied, the status of the question is defined as "unanswered". In this case the value the question contributes to the system can only be broadly known as lying within the full range of responses possible from the user.

Once the model user (or external function) has replied, the status of the question becomes "answered", and the value this question contributes to the system is then precisely defined by that answer. Having become "answered", a question normally retains this status throughout the consultation. However, questions may be reset to "unanswered" by means of a CLEAR command included in an action, as shown in following example:

```
CLEAR ALL
INVESTIGATE restart
ASSOONAS    NOT ask_road
            OR NOT ask_site_investigation
            OR     validate_ask_road
            OR NOT KNOWN validate_ask_road
            OR     validate_site_investigation
            OR NOT KNOWN validate_site_investigation

MAKE At_end TRUE
     ASSOONAS (restart = 1) OR NOT KNOWN restart



CLEAR ask_moisture INVESTIGATE ask_moisture
DISPLAY '£sd£Since you seem uncertain whether to let
         me know  the moisture content, I
         will re-ask you anyway.£ed£'
     ASSOONAS  ANSWERED validate_moisture AND
         NOT  KNOWN validate_moisture

CLEAR  validate_moisture
STOP validate_moisture
     ASSOONAS ANSWERED validate_moisture
```

The "RT" program asks those questions needed to decide the values of the goals it has been asked to investigate as shown in the following example:

```
INVESTIGATE used_before
     ASSOONAS AT_START

DISPLAY'£13££13££13££13£'
DISPLAY '£sd£   You seem uncertain whether you have
         used E_MOVE  before  so I will £sp4£assume
         that  you haven''t.  £ed£'
 ASSOONAS ANSWERED used_before
          AND NOT KNOWN used_before
INVESTIGATE new_user_info
ASSOONAS NOT used_before OR NOT KNOWN used_before
```

Where a question has been qualified by IF/ELSE condition, for example:

```
NUMBER working_week 'Number of working weeks'
((contract_time/7) * less_five)
IF wd
ELSE working_week_1

NUMBER working_week_1'number of working weeks'
(contract_time/7) * 5
IF wd1
ELSE
((contract_time/7) * more_five)
```

The system will first investigate the attached condition (if not already answered). If the condition evaluates to true the question will be asked. If the condition evaluates to false the question will not be asked and the answer will be found by investigating the alternative derivation.

In the example above when the system needs to know "working_week", it will first ask about "working_day". If the user replies "NO" it will not ask the question about "working_week" but will investigate "working_week_1" instead.

5.6.6.1.2 **Questions which are related:**

The order in which questions are asked is in general determined by the "RT" programme as it tries to decide the values of its goals. The questions which are antecedents to the current goal will cover the same area of the subject under consideration, and thus will in any case naturally be related, and the system will investigate all of them before reaching any decision.

In some cases a number of questions may be concerned with completely separate goals, then these questions are coupled together by the "LINK" statement with the list of the related question names, for example:

LINK *ask_road_construction* *ask_site_investigation*
ask_working_week *ask_productivity*

As soon as any one of these questions is asked, they will all be asked, in the order specified in the LINK statement.

5.6.6.2 **Variables:**

Variables are used to store values describing the state of the system as it progresses through the consultation by the user. The values of a variable are calculated from the values of other variables and from the replies to questions. Each time the user replies to a question, the RT programme automatically uses the value of the reply to recalculate the values of all consequent variables. This is a very valuable facility when calculating material volumes.

The value assigned to a variable is determined by the replies received to the antecedent questions on which it depends. Until these questions have been answered, the value of the variable is said to be "unanswered". The variable becomes "answered" as soon as its value is completely determined.

The following example illustrates the definition of a numeric variable:

```
QUESTION SECT_1_C'£13£ Answer please the amount of
     cut in cubic meters from section one.£13£'
 NUMERIC 0 1000000

QUESTION SECT_1_F'£13£ Answer please the amount of
     cut in cubic meters fill from section one.£13£'
 NUMERIC 0 1000000

QUESTION SECT_2_C'£13£ Answer please the amount of
     cut in cubic meters cut from section two.£13£'
 NUMERIC 0 1000000
```

Variables could be either a NUMBER, CONDITION or PROBABILITY.

5.6.6.3 **Actions:**

When the user has replied to a question, the RT programme uses the response to recalculate the values of all the variables for which it is an antecedent , and then goes on to see if any actions should be "fired". An action comprises a set of commands, together with a statement of the trigger condition which must be satisfied to have these commands "fired" as illustrated in the followig example:

```
DISPLAY'
  £13£------------------------------------------------
  £13£***Twin engine SCRAPER is recommended.
  £13£------------------------------------------------
  £13£------------------------------------------------
  £13£    Because the task is mass excavation, the
  £13£    material size is less than 12%, the soil
  £13£    moisture is between 20 and 30%, and the
  £13£    and job conditions were favourable.
  £13£    If any of these assumptions are incorrect
  £13£    please run the program again.
  £13£------------------------------------------£13£'
INVESTIGATE choose4
ASSOONAS  general_information_good AND X2 AND t11
          AND kb1 AND s1 AND scrapers
```

The commands available for use in action include those to control the display of information to the user and to control the subsequent investigation of variables and questions.

5.6.6.3.1 **Firing of Action:**

An action is fired (i.e. the commands which it contains are executed) when its qualifying trigger condition is first set TRUE. The commands of this action are then executed in the order in which they appear in the model definition. Many actions may be triggered by answering single questions. The precise order in which they will be fired then depends upon the state of the knowledge tree at the time of firing.

Action may take one of the following:

a) Investigating goals (investigate and stop)

The variables and questions which should be investigated are put on the "investigate list" by means of INVESTIGATE command, for example:

```
INVESTIGATE validate_haul_distance_k
     ASSOONAS (ask_haul_distance_k>=25)

DISPLAY  '£sd£You seem to be uncertain whether the
         haul distance is £ask_haul_distance_k£km,
         so I will re-ask the question£ed£'
     ASSOONAS ANSWERED validate_haul_distance_k
     AND NOT KNOWN validate_haul_distance_k

CLEAR ask_haul_distance_k
INVESTIGATE ask_haul_distance_k
     ASSOONAS NOT validate_haul_distance_k
     OR NOT KNOWN validate_haul_distance_k

STOP ask_haul_distance_k validate_haul_distance_k
     ASSOONAS validate_haul_distance_k
```

During the consultation the RT programme always starts its investigation of the goals from the head of the investigation list. An INVESTIGATE command adds new goals to the top of the list, the order of the list being such that the left hand item following the INVESTIGATE becomes the current goal at the head of the list.

It is also possible to remove variables, questions and groups from the investigate list, using the STOP command, for example:

```
DISPLAY REPORTLIST
STOP general_information
INVESTIGATE menu_1
     ASSOONAS  ANSWERED ask_work_shop_distance
     AND ( general_information_poor OR
           general_information_fair OR
           general_information_good )


DISPLAY REPORTLIST
STOP general_ground_conditions_x
INVESTIGATE menu_1
             ASSOONAS
             ( general_information_poor_X OR
               general_information_fair_X OR
               general_information_good_X )
```

b) messages to the user (DISPLAY, PRINT, REPORT):

Messages to the user can either be collected into a single report and displayed together, or can be displayed individually as soon as an action fires. The former is used to report the overall results of a consultation, while the latter might be used for warning messages or to guide the user during the consultation.

The DISPLAY command can be used to display information immediately on the user's terminal, as shown in above mentioned examples.

The REPORT command will add a text string to the collected report, for example:

```
DISPLAY '£13££13££13££13£'
REPORT 100 '£13£ESEMPS has now completed the
    assessment of the GENERAL JOB CONDITIONS and '
        ASSOONAS general_information_poor OR
                 general_information_fair OR
                 general_information_good OR
                 general_information_uncertain OR
                 general_information_poor_X     OR
                 general_information_fair_X     OR
                 general_information_good_X     OR
                 general_information_uncertain_X

REPORT 99 'Unfortunately it is UNFAVOURABLE, Which
       means the task is dificult and will be rather
       costly, for you need CRAWLER type of machines
       and more bad news, scrapers can't be used.'
     ASSOONAS general_information_poor OR
              general_information_poor_x
REPORT 99 'I assess it to be FAIR.
      £13£  In   general it means that  you  can  use
            shovels,  bulldozers,  and scrapers.  We
            are going to find out the best one later
            on  when  we  are going to  discuss  the
            project in more detail.'
       ASSOONAS general_information_fair OR
                general_information_fair_x
REPORT 99 'I am pleased to tell you it is FAVOURABLE.
      £13£In   general  that  means   you   can   use
      shovels, buldozers, and scrapers. We are going
      to  find out the best one later on  discussing
      the project in more details. '
     ASSOONAS general_information_good OR
              general_information_good_x
```

The user can at any time call up a display of the report accumulated sofar, by calling on reply option "r" in the response to any question. Alternatively the system forces the display of the report, by including within an action the command:

DISPLAY REPORTLIST or PRINT REPORTLIST (in order to print the report).

c) Clearing the answer to a question:

Generally a question which has been answered retains the value of the reply from the user, and is never asked again. Sometimes however it may be desirable to repeat a question. The reason is that the users may want to change their replies and should be given the chance to change the observations.

The status of a question or list of questions can be reset to "unanswered" and "unknown" with the CLEAR command, for example:

```
CLEAR ask_grade INVESTIGATE ask_grade
DISPLAY   ' £sd£Since you seem uncertain whether you
            are able to tell me what the grade is,
          I will re-ask that question anyway. £ed£ '
     ASSOONAS NOT KNOWN validate_grade

CLEAR  validate_grade
STOP validate_grade
     ASSOONAS ANSWERED validate_grade
```

5.6.7 The dialogue between the system and the user:

The user **consults** the compiled system by running a programme called **RT.** This programme decides which goal needs **investigation**, searches the system's **knowledge base** to find the appropriate **antecedent question** and presents this to the user. If the user gives a direct reply then this value is **propagated through all nodes** in the knowledge base for which the question was an antecedent. The change of the values in the system may then cause **actions to fire.**

Instead of a direct reply to a question the user may enter a **single letter**, select an **option** to **interrogate** the state of the system or to **volunteer** an answer to a question not yet asked.

As far as the user is concerned, this process proceeds as a dialogue, in responding to the questions of the system, and from time to time also receives advice. As described before there are four types of question each needing an appropriate type of answer:

Number question - a number within the range specified or "!" (don't know unless qualified only).

Condition question- "Yes", "No", or "!"(don't know unless qualified only).

Probability question- A number between 5 (definite agreement) and -5 (definite disagreement), this is converted into a probability).

String question - A string of characters whose length is defined by the system.

However, the initiative of the dialogue does not lie solely with the system. The user may reply to any question with an "**option**", which takes the form of a single letter, denoting some action to be carried out. This option may interrogate or alter the state of the model (e.g. to print out the goals currently being investigated, or volunteer an answer to a question which has not been yet asked).

5.6.7.1 <u>User's reply options:</u>

Instead of making a direct reply to a question, the model user may call on an **"option"** to control the system in some other way. Each option is identified by entering a single letter from the options described below:

a- Display an amplification of the current question. This is helpful for users not experienced in plant selection where they may not understand all the implementations of tersley worded questions. An uncertain user may call on a reply option "a" to ask for amplification, attached with the each question in the system.

b- Step back to the previous question in order to supply a different answer. This previous question will revert to "unanswered" and "unknown". It may be possible to "unwind" the previous part of the consultation by the stepping back through several questions, however, it is not permitted to step back beyond a point where an action was fired. An example of this option is shown below:

c- Display chain of reasoning being followed, i.e. the name of the goal being investigated, and the names of intermediate nodes on the knowledge tree down to the current question at a terminal leaf.

d- Display details of the internal questions, variables and actions used in the system. The user will be asked to specify whether a display is required of the whole model, of a selected group of items, or of just a single item.

e- Display an "essay" for each item on the chain of the reasoning currently investigated. In most cases "e" will be used to provide an explanation to the model user of why a question is being asked.

h- This is used to trigger "help" facilities included in the system.

i- Display a list of all those items currently appearing on the investigate list, together with an indication as to which related to a current goal.

q- This option gives the user a chance to end the session. The session will then terminate and no further questions will be asked.

r- Display the built in report.

s- Display a summary of the questions which have been answered so far.

v- Display all list of the questions which have not been answered so far. The users will then be asked if they wish to "volunteer" the answer to one of these questions. This allows direct control over the conduct of the advice session.

?- Display a summary of this table to remind the model user of the purpose of every option.

5.6.8 External programmes:

While Savior enabled the building of the knowledge base using heuristic knowledge, ie. rules of thumb, *external programmes* could not be avoided in dealing with algorithms, for example calculation of the cycle times and numbers of equipments. Also a data base containing information about each particular machine such as make, model, capacity, engine size, etc. could only be handled using Pascal code as Savoir is unable provide a direct link to existing procedural routines. A sample of such external porgrammes is shown in apendix [E].

5.6.9 Summary

This chapter described an expert system, ESEMPS (Expert System for Earth_Moving Plant Selection), capable of advising on earthmoving equipment selection in road construction consistent with that of an expert.

The knowledge base used in this expert system was obtained from self experience, published literature, planning engineers, plant hirer professionals, and practitioners in the field of road construction.

The author acted as the knowledge engineer to acquire knowledge from the experts to build the knowledge base and apply it in SAVOIR.

Knowledge acquisition techniques for ESEMPS were also explained. Fig (5.24) illustrates diagramatically the structure of ESEMPS.

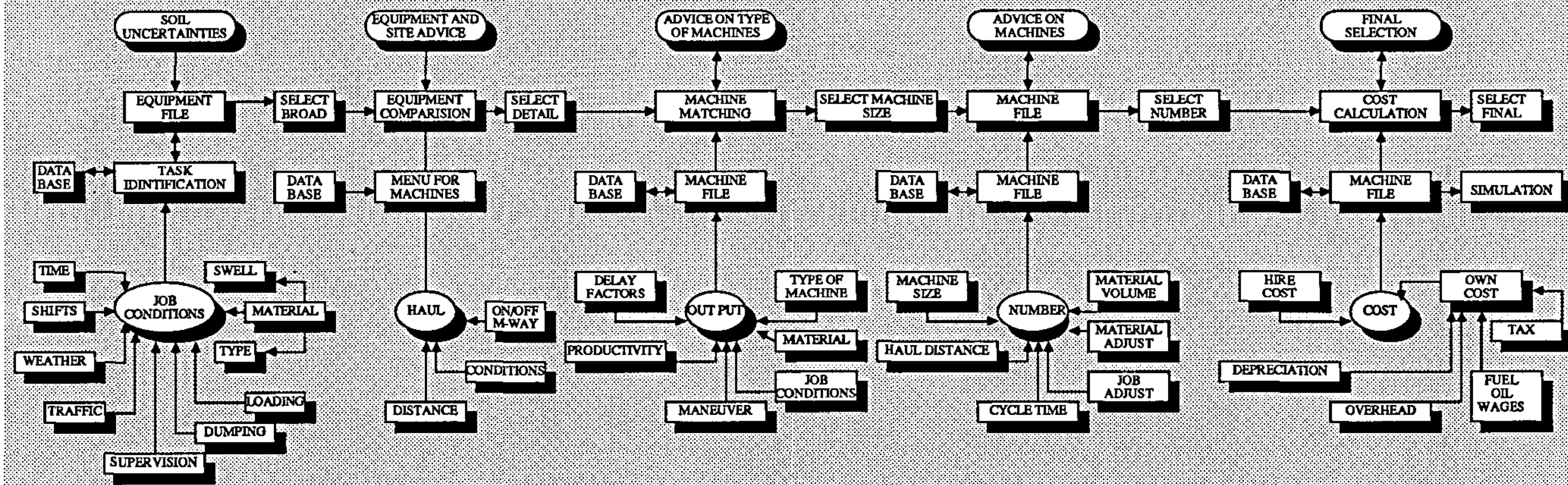


Fig 5.24
A Flow-Chart for ESEMPS

CHAPTER SIX

EVALUATION OF ESEMPS

6.1 Evaluation considerations.

6.2 Evaluation of ESEMPS.

6.3 Evaluation of ESEMPS by users.

6.4 Feedback from demonstrations.

6.1 Evaluation considerations:

Expert Systems would generally be developed in response to some human need. This obvious means of evaluating a system's performance is to judge how well it responds to that need. This observation has led to the conclusion by some that the primary focus in evaluating an expert system should be on how well it performs the task for which it was designed [176]. However, because of the evolutionary nature of expert systems, this approach does not always hold true. In fact, continuous evaluation by the system builder is typical, rather than an exception [176]. Every time the system builder adds a rule, or in some other way modifies the programme, the resulting performance is evaluated, whether formally or informally.

Since expert systems are, by nature, associated with computer science, the use of the word evaluation should be clarified. Evaluation, for the purpose of this research shall be associated with the expert systems performance of the task it was designed to address, which is a difficult task. One reason for this difficulty is that human experts these systems are designed to emulate are seldom evaluated on an objective basis[176]. Unlike their human counterparts, expert systems are not required to pass certain tests to become licensed or certified. Neither do humans use a numerical rating scheme when selecting a doctor or some other professional service.

There is currently no consensus on how to evaluate the performance of an expert system [164], and much of the early work in this area has been informal and subjective. Even today the more formal evaluations still have not defined precisely what characteristics an expert system are appropriate or proper to evaluate. But one thing is clear. If the users of the system are not convinced that the decisions it makes are reliable and accurate, then the system will not be used.

Expert systems are constructed for use in domains where the advice from human experts is usually based on their judgement. Because of this, it is not easy to show that a system's answer to a problem is the "correct" one.

In recognition and response to these problems, there have been a number of key issues proposed as pertinent to the evaluation of any expert system [164]. These include:

i) an objective standard.

ii) elimination of irrelevant variables.

iii) realistic standards of performance.

iv) reasonable time span for evaluation.

An objective standard, or a generally accepted "correct" answer in the case of a particular machine, is very elusive. As pointed out in the problem definition and supported in the literature review, there are generally many factors that will provide the equipment selection goals for a given situation in earthmoving operations. Therefore, in this respect, a reasonable approach is to compare the equipment recommended by ESEMPS to that suggested by the expert for the same situation. The standard in this case will be if ESEMPS was able to obtain the same equipment fleet as the expert and at approximately the same cost.

The idea behind eliminating variables in the evaluation of an expert system is to ensure that the decision-making performance of the system is consistent and satisfactory. In this way if the system is not accepted by its intended users, then something other than the correctness of its answers would be the cause.

The standard of performance of an expert system must be set in accordance with the standards used to evaluate human experts in the particular domain. In this respect, the standard of performance of the ESEMPS system in providing earthmoving plant selection was judged as "acceptable" by the members of the an earthmoving company [172], who are well respected and have completed many highway projects in the U.K.

The construction of an expert system is an iterative process that involves continual modification and revision of the knowledge base. It is important that precise accounts be maintained of a system's performance throughout it's development. In this way, when new knowledge is added performance can be checked against previously addressed situations to determine if any inconsistencies have developed. In this respect detailed files are continuing to maintained on each problem analysed by ESEMPS, these will be utilised as the system continues to grow and develop.

Finally, there is the issue of adequate time for evaluation by experts. On this point ESEMPS was thoroughly evaluated throughout the development stage by experts [172,179,182], and tested with a case study for a road construction site [A42 Bypass in Meacham England].

6.2 Evaluation of ESEMPS:

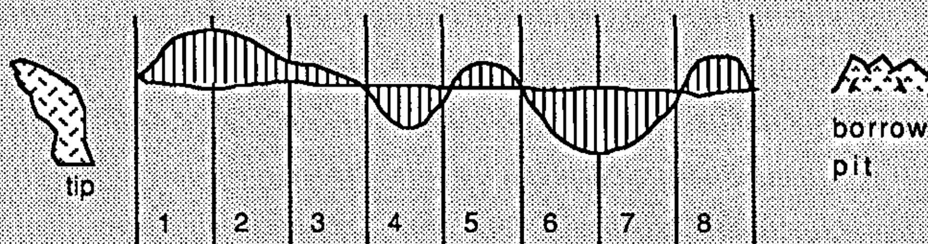
The evaluation of ESEMPS, for the purpose of this thesis, was undertaken in two parts, one being a comparitive selection of earthmoving plant from completed projects using the linear programing technique, and two, a case study based on real data obtained from a road construction project still under construction, already analysed and the earthmoving plant selected by experts using the arrow diagram method of planning. Also the system was tried and criticised by different users from novice users and to practitioners.

6.2.1 Example one: a comparsion of ESEMPS with Linear programming

The first evaluation centred on the example problem presented in chapter (5), as described below:

"A roadway contractor is planning a grading operation of the terrain shown in fig.(6.1). The cut and fill quantities have been estimated for each of the eight 1000 ft sections of roadway. An acceptable borrow pit located near the north end of the roadway. A tip located 2000 ft, from the south end of the roadway can be used for the waste material. The material characteristics for the various sections of cut and borrow and the cut and fill quantities are shown in the table included in fig(6.1)."

EXAMPLE



Road way profile

Road Sections	Estimated quatities (in cubic yards)		Type of soil	Swell factor	Shrinkage factor
	Cut	Fill			
1	30000		Common	1.3	0.8
2	25000		Common	1.3	0.8
3	10000		Rock	1.5	1.0
4		35000			
5	20000		Common	1.3	0.8
6		25000			
7		25000			
8	15000		Common	1.4	0.75
Borrow	available		Common	1.2	0.9
Tip	available				

Fig (6.1)
Soil characteristics
[source of information (ref.25)]

i) **Linear programing solution:**

The contractor responsible for this project [30] used a linear programing method for earth allocation between the sections. with results as shown below:

$X(1,4) = 6250\ yd^3$ $X(2,4) = 25000\ yd^3$ $X(3,4) = 10000\ yd^3$
$X(5,6) = 20000\ yd^3$ $X(8,7) = 15000\ yd^3$ $X_B(N,6) = 10000\ yd^3$
$X_B(N,7) = 15280\ yd^3$ $X_D(1,s) = 23750\ yd^3$

Where:

$X(1,4)$ = The amount of material transported from section 1 to section 4.

$X(2,4)$ = The amount of material transported from section 2 to section 4.

$X(3,4)$ = The amount of material transported from section 3 to section 4.

$X(5,6)$ = The amount of material transported from section 5 to section 6.

$X(8,7)$ = The amount of material transported from section 8 to section 7.

$X_B(N,6)$ = The amount of material transported from a borrow tip to section 6.

$X_B(N,7)$ = The amount of material transported from a borrow tip to section 7.

$X_D(1,S)$ = The amount of material transported from section 1 to a tip.

These results where obtained using forty five equations [30, 32] using a large memory computer.

Applying these equations however, requires the user to know the cost of transporting a unit of material between cut and fill sections which by implication necessities the equipment to have been decided in advance and would thus probably need the availability of an expert.

ii) <u>ESEMPS solution:</u>

ESEMPS was applied using the same data to calculate the material allocation between the sections, as shown in figures (6.2 and 6.2.1).

In this part ESEMPS calculated the amount of material needed to be transported between the sections using a combination of human judgement and simple calculation to arrive at similar results as to the linear programing approach. ESEMPS guides the user through a step by step process by asking for an input and explaining the reasons behind every question asked.

Furthermore, ESEMPS advises the user on the type and number of machines to be used to carryout the earthwork allocation as shown in fig (6.3). During trials this part of the system, as far as the novices and experienced users were concerned was observed to be very important, for to arrive at an appropriate equipment selection generally demands the heuristic knowledge of an experienced practitioner in road and equipment domains, i.e. there must be an expert avaliable when such decisions have to be made. In contrast a linear programming approach can't be applied unless the appropriate equipment has first been selected.

How many sections are there along the road?
(1 To 40, ! if not known or an option) 8

Is section one :
1- Cut
2- Fill
(1..2, ! if not known or an option) 1

Tell me please the amount of cut in cubic yards from section one.
(0 To 1000000, ! if not known or an option) 30000

Is the soil:
1-Rock or,
2-Common.
(1..2, ! if not known or an option) 2

Is section two :
1- Cut
2- Fill
(1..2, ! if not known or an option) 1

Tell me please the amount of cut in cubic yards from section two.
(0 To 1000000, ! if not known or an option) 25000

Is section eight:
1- Cut
2- Fill
(1..2, ! if not known or an option) 1

Tell me please the amount of cut in cubic yards from section eight.
(0 To 1000000, ! if not known or an option) 15000

Is the soil:
1-Rock or,
2-Common.
(1..2, ! if not known or an option) 2

SECTION	CUT C. yard	FILL C. yard	SWELL
1	30000	0	1.30
2	25000	0	1.30
3	10000	0	1.50
4	0	35000	0.00
5	20000	0	1.30
6	0	25000	0.00
7	0	25000	0.00
8	15000	0	1.30
TOTAL	100000	85000	

Do you want to repeat or change your answers?
(Y..!..N or an option) N

Fig (6.2)
ESEMPS output for example one

ESEMPS output continued

Alright here are the final quantities:

SECTION	CUT C. yards	FILL C. yards
1	30000	0
2	25000	0
3	10000	0
4	0	35000
5	20000	0
6	0	25000
7	0	25000
8	15000	0
TOTAL	100000	85000

The Report is:-

As you can see the the amount of cut material is greater than the amount of fill material, that means you may not need to borrow any material from a borrow pit.

I am going to calculate the amount of material to be cut or filled for each section.

Please type in -Y- to continue
(Type Y only or an option) Y

You need to transport the amount of material between the sections as shown below:

amount C.Yard	from section	to section
10000	3	4
25000	2	4
6250	1	4
23750	1	TIP
20000	5	6
15000	8	7
10000	BORROW	6
15278	BORROW	7

The system has no question to ask at present(Only options are allowed)Q
Finish this advice session [Y,N] ? Y

Fig (6.2.1)
part two of
ESEMPS output for example one

You need to transport the amount of material between the sections as shown bellow:

LINEAR PROGRAMMING SOLUTION

amount cubic yard	from section	to section	equipment
10000	3	4	Not available
25000	2	4	Not available
6250	1	4	Not available
23750	1	TIP	Not available
20000	5	6	Not available
15000	8	7	Not available
10000	BORROW	6	Not available
15278	BORROW	7	Not available

ESEMPS SOLUTION

amount cubic yard	from section	to section	equipment required
10000	3	4	Single engined scrapers
25000	2	4	Single engined scrapers
6250	1	4	Hydraulic excavator and dump trucks.
23750	1	TIP	Hydraulic excavator and dump trucks.
20000	5	6	Single engined scrapers
15000	8	7	Single engined scrapers
10000	BORROW	6	Hydraulic excavator and dump trucks.
15278	BORROW	7	Hydraulic excavator and dump trucks.

Fig 6.3
Material allocation and equipment selection for example one (Linear programming Vs ESEMPS)

6.2.2. **Example two- a case study:**

This test of validation applied the ESEMPS system to an actual highway project under construction. It begins by describing the £30 million project and then proceeds to show how the earthwork was carried out on site, and then illustrates how ESEMPS would advise on the same tasks and select the types of machines to be used. Finally, the results proposed by ESEMPS are compared with those actually used on site.

6.2.2.1. **Project description (A42 bypass):**

The project under study was located in the Midlands area of the U.K. It consisted of constructing a three lane concrete highway approximately 10 kilometers in length connecting the M1 motorway with M42 motorway. The earthwork volume involved consisted of almost 5 million cubic meters of common soil and rock, a large volume by almost any standard.

6.2.2.1.1. **Methods applied by the contractor:**

The contractor adopted an **arrow diagram** approach in planning the earthwork allocation and plant selection. The reader is advised to return to chapter four for a detailed explanation of this approach. Fig (6.4) shows the road profile of the project and table (6.1) illustrates the amount of material available in each cut section and the amount needed for each fill section. Fig (6.5) illustrates the the arrow diagram plan.

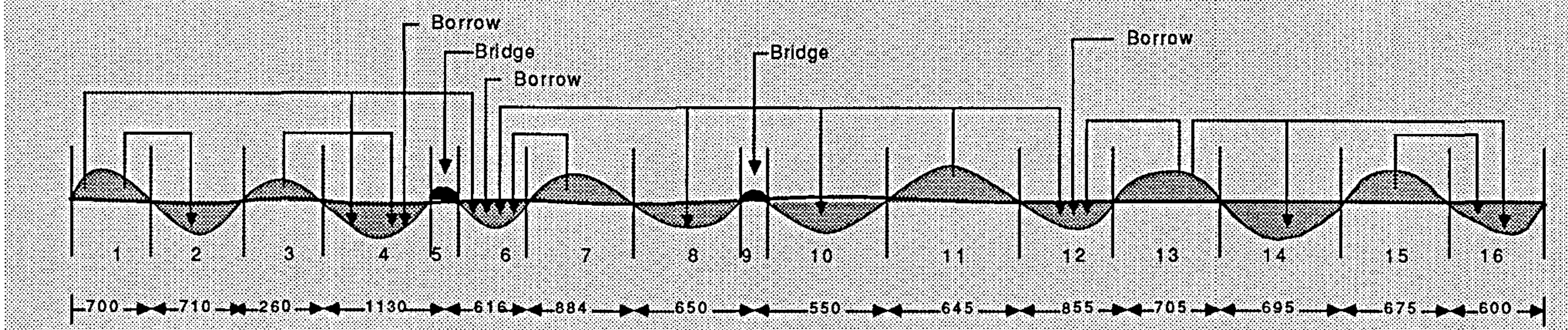


Fig (6.4)
Road profile (A42) Contractor's method

SECTION	CUT cubic metres	FILL cubic metres
1	139066	--
2	--	21579
3	8111	--
4	--	143698
5	0	--
6	--	256283
7	136552	--
8	--	56422
9	0	--
10	--	61421
11	161385	--
12	--	282834
13	315103	--
14	--	21295
15	608	--
16	--	148732

Table 6.1
Quantities of material for example two

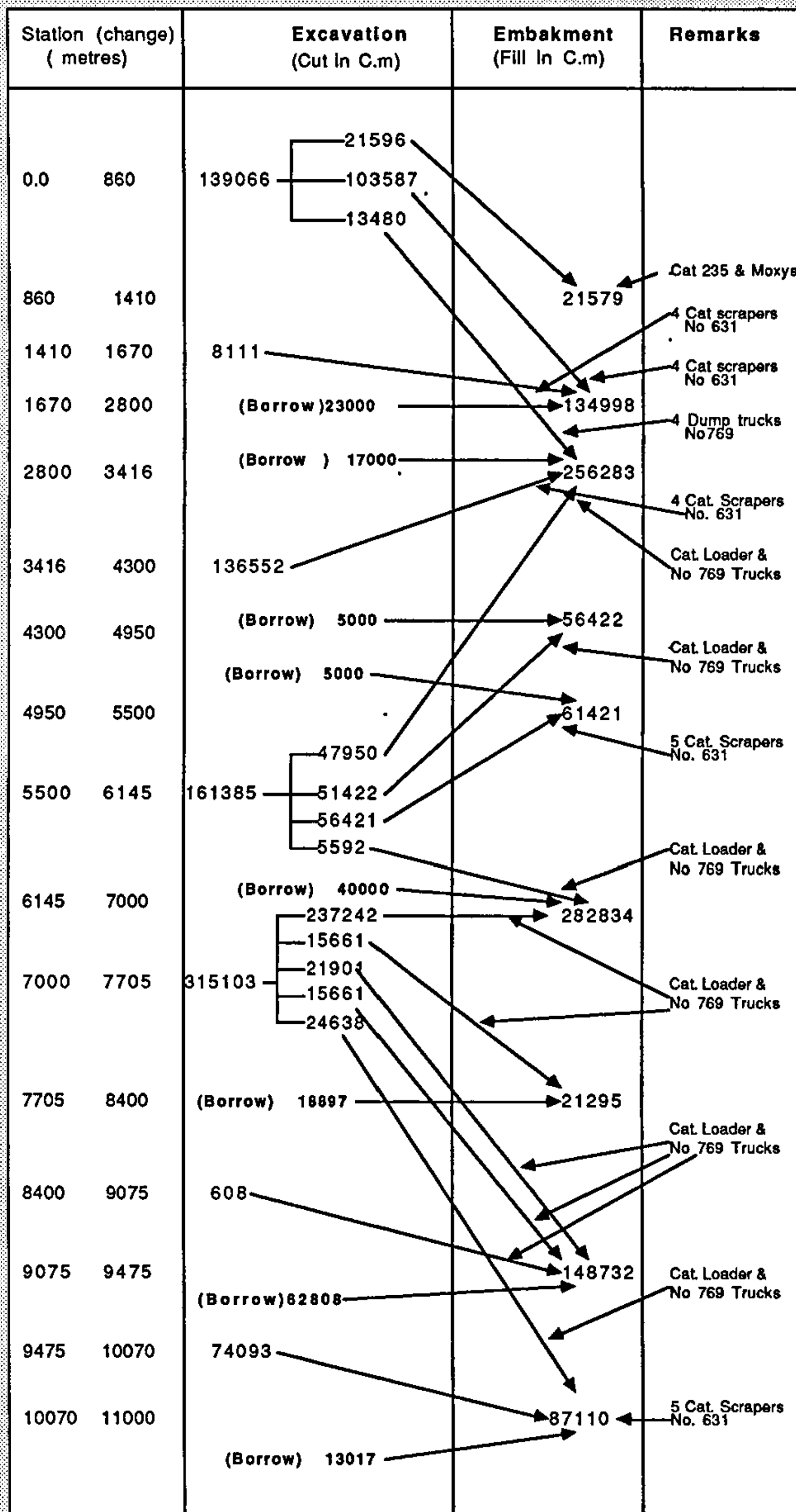


Fig (6.5)
An arrow diagram approach applied by the contractor on the A42-Midlands, England

6.2.2.1.2 **Applying ESEMPS to the case study:**

As was explained in detail in chapter (5), ESEMPS was designed in a way that calculates and advises on earthmoving sequences using heuristics and mathematical techniques. Only then are the appropriate equipment selections made.

The system begins by inquiring about road conditions such as gradients, soil types, weather conditions, time for the job, etc., thereafter the job conditions are determined and suitable major categories of equipment selected as shown in the following sample of printout from the system.

The quantities of material from each cut section and the amount needed in each fill section are derived from the drawings and site survey. These quantities are used as input to the ESEMPS as illustrated in the sample run of the system shown in figures(6.6, 6.6.1, and 6.6.2,). The amounts of material from or for each section are shown in the programme output fig (6.6.3). Depending on the combination of the rules in the knowledge base and mathematical techniques, ESEMPS suggests material allocations between the sections as shown in the system's output figures (6.7, 6.7.1, 6.7.2, 6.7.3, 6.7.4, and 6.7.5).

Having decided on the earthwork allocation, the system gives advice on the appropriate equipment in broad catagories to carry out material transportation as shown in figure(6.8), and calls from the database different types and makes of the machines in the same catagory to help the user in decision making as shown in fig(6.8.1). It then calculates the cycle time by applying the distance/time curve equations. The number of each particular machine is subsequently derived as shown in fig (6.9). Fig (6.10) illustrates a comparision between the equipment used by the contractor and those suggested by ESEMPS.

```
>> Is the task road construction?
(Y..!..N or an option)  Y


>> Do you have a site investigation report  ?
(Y..!..N or an option)  Y


>> I shall later ask you some questions relating
   to distance.
   Would you prefer to use:

   1) Customary measures (i.e. miles, inches),
   or
   2) Metric measures (i.e. kilometres,
      centimetres) ?
      For any enquires please type A.
    ( 1 To  2, ! if not known  or an option)  2

>> Do you want to use

   1-Factual (Yes, No, Numbers) answers?
   2-Probabile (-5 to +5) answers?
   3-Mix answers?
 (1..3, ! if not known  or an option)  1


>> I am now starting to consider the type of
   soil, in particular, the kind of soil the
   machines will be dealing with on site. Please
   choose one of the  following:
   For any enquiry please type (A)


   1-  Top soil, dry clay, or loam earth.
   2-  Pit run gravel, sand, soft shale,
       damp clay.
   3-  Heavy clay, single size aggregate,
       rock.
    (1..3, ! if not known  or an option)  1
```

Fig 6.6
Sample of ESEMPS consultation for example two
(part 1)

```
>> I would like you to tell me if you are planning
   to work night shifts. Please choose one of the
   following:

 1- none,
 2- some, or
 3- regular.
(1..3, ! if not known  or an option)  1


>> Are there any obstructions (ie. trees, buildings,
   or others) on the site?
 (Y..!..N or an option)  n


>> Please inform me of the haul gradient and
   rolling resistance by selecting one of the
   following: For any inquiry please type (A)

       1-  Less than 2%,
       2-  2%  to 4% ,
       3-  4%  to 8%, or
       4-  More than 8%.
       (1..4, ! if not known  or an option)  1

=====================================================
The Report is:-

I have now completed my assessment of the  GENERAL
JOB CONDITIONS and I am pleased to tell you it  is
FAVOURABLE. In general  that  means  you  can use
shovels, bulldozers, and scrapers. We are going to
find out the best one later on when discussing the
project in more details.
=====================================================

 >> That concludes my investigation in general .
    Shall I:

             1) investigate in more detail, or
             2) finish this ESEMPS session ?
    ( 1 To  2, ! if not known  or an option)  1



        ***** DETAIL INFORMATION  *****

I  am  now  starting to consider the project  in
more detail. I will do this by asking  questions
concerned with MACHINE PERFORMANCE, and CONDITIONS.
```

Fig 6.6.1
Sample of ESEMPS consultation for example two
(part 2)

```
How many sections are there along the road?
( 1 To  40, ! if not known  or an option)  16


Is section 1 :

1- Cut
2- Fill
3- Neither

If you need any help in answering the
 question type in -A-.
(1..3, ! if not known  or an option)  1

Answer please the amount of cut in cubic metres
from section one.
( 0 To  1000000, ! if not known  or an option)  139066


Is the soil:

1-Rock or,
2-Common.
(1..2, ! if not known  or an option)  2

Answer please the CHAINAGE in metres  of section 1.
( 0 To  100000, ! if not known  or an option)  860

Is section 2 :

1- Cut
2- Fill
3- Neither

If you need any help in answering the
 question type in -A-.
(1..3, ! if not known  or an option)  2


Answer please the amount of fill in cubic metres
from section two.
( 0 To  1000000, ! if not known  or an option)  21579


Answer please the CHAINAGE in metres  of section 2.
( 0 To  100000, ! if not known  or an option)  1410
```

Fig 6.6.2

Sample of ESEMPS printout for example two (part 1)

```
> Do you want to see a table of QUANTITIES?
  (Y..!..N or an option)   Y

================================================
 Alright here are the final quantities:
```

SECTION	CHAINAGE metres	CUT C. metres	FILL C. metres
1	860	139066	--
2	1410	--	21579
3	1870	8111	--
4	2800	--	143698
5	2800	0	--
6	3416	--	256283
7	4300	136552	--
8	4950	--	56422
9	4950	0	--
10	5500	--	61421
11	6145	161385	--
12	7000	--	282834
13	7705	315103	--
14	8200	--	21295
15	8400	608	--
16	9475	--	148732

```
================================================
```

Fig 6.6.3

Sample of ESEMPS printout for example two
(part 2)

```
> Do you want to view the material ALLOCATIONS
  between CUT and FILL sections:

1- All in a one TABLE form.
2- Each section individualy.

(1..2, ! if not known  or an option)2

=====================================================
You need to transfer the amount of material FROM
SECTION (1) as shown below:
---------------------------

Section    amount          amount          to
  no.      cubic        transported      section
           metres
------     --------     -----------      -------
  1        139066
                           21579             2
                           117487            4
=====================================================


I am going to advise on the amount of material to
be transported from section (3).

   Please type in -Y- to continue
  (Type Y only or an option)  Y

=====================================================
 You need to transfer the amount of material from
 section (3) as shown below:
 ---------------------------

 Section    amount          amount          to
   no.      cubic        transported      section
            metres
 ------     --------     -----------      -------

   3        8111
                            8111             4
=====================================================
```

Fig 6.7

Sample of ESEMPS printout for material allocation for example two (part 1)

```
I am going to advise on the amount of material to
be transported from section (5).

   Please type in -Y- to continue
   (Type Y only or an option)  Y

=================================================
 You need to transfer the amount of material from
 section (5) as shown below:
 ---------------------------

 Section    amount          amount         to
   no.      cubic         transported    section
            metres
 ------    --------       -----------    -------

   5        0
=================================================

I am going to advise on the amount of material to
be transported from section (7).

   Please type in -Y- to continue
  (Type Y only or an option)  Y

=================================================
 You need to transfer the amount of material from
 section (7) as shown below:
 ---------------------------

 Section    amount          amount         to
   no.      cubic         transported    section
            metres
 ------    --------       -----------    -------

   7        136552
                             136552         6
=================================================
```

Fig 6.7.1

Sample of ESEMPS printout for material allocation for example two (part 2)

I am going to advise on the amount of material to be transported from section (9).

Please type in -Y- to continue
(Type Y only or an option) Y

==

You need to transfer the amount of material from section (9) as shown below:

Section no.	amount cubic metres	amount transported	to section
9	0		

==

I am going to advise on the amount of material to be transported from section (11).

Please type in -Y- to continue
(Type Y only or an option) Y

==

You need to transfer the amount of material from section (11) as shown below:

Section no.	amount cubic metres	amount transported	to section
11	161385		
		61421	10
		56422	8
		43542	6

==

Fig 6.7.2

Sample of ESEMPS printout for material allocation for example two (part 3)

I am going to advise on the amount of material to be transported from section (13).

Please type in -Y- to continue
(Type Y only or an option) Y

You need to transfer the amount of material from section (13) as shown below:

Section no.	amount cubic metres	amount transported	to section
13	315103		
		21295	14
		282834	12
		10974	16

I am going to advise on the amount of material to be transported from section (15).

Please type in -Y- to continue
(Type Y only or an option) Y

You need to transfer the amount of material from section (15) as shown below:

Section no.	amount cubic metres	amount transported	to section
15	608		
		608	16

Fig 6.7.3

Sample of ESEMPS printout for material allocation for example two (part 4)

```
Do you want to view the material ALLOCATION
between CUT and FILL sections in :

1) All in a TABLE form?
2) Each section individually?
   (1..2, ! if not known or an option) 1


===================================================
 You need to transfer the amount of material
 from CUT SECTIONS to FILL SECTIONS as shown below:
---------------------------------------------------

 Section     amount        amount          to
   no.       cubic       transported     section
             metres
 ------     --------     -----------     --------
    1       139066
                             21579           2
                             117487          4
---------------------------------------------------

    3       8111
                             8111            4
---------------------------------------------------
    5       0
---------------------------------------------------

    7       136552
                             136552          6
---------------------------------------------------

    9       0
---------------------------------------------------
    11      161385
                             61421           10
                             56422           8
                             43542           6
---------------------------------------------------

    13      315103
                              21295          14
                              282834         12
                              10974          16
---------------------------------------------------

   15      608
                              608            16
===================================================
```

Fig 6.7.4

Sample of ESEMPS printout for material allocation for example two (part 5)

```
Do you wish to view the amount of material
 needed in each FILL SECTION?
(Y..!..N or an option)Y


=====================================================
 You need to transfer the amount of material
 from CUT SECTIONS to FILL SECTIONS as shown below:
-----------------------------------------------------

 Section     amount needed      amount        from
   no.       cubic metres     transported    section
 -------     ------------     -----------    -------

   2         21579
                                21579          1
-----------------------------------------------------

   4         143698
                                117487         1
                                8111           3
-----------------------------------------------------

   6         256283
                                136552         7
                                43542          11
                                76189          BORROW
-----------------------------------------------------

   8         56422
                                56422          11
-----------------------------------------------------

   10         61421
                                61421          11
-----------------------------------------------------

   12        282834
                                282834         13
-----------------------------------------------------

   14        21295
                                21295          13
-----------------------------------------------------

  16        148732
                                10974          13
                                608            15
                                137150         BORROW
=====================================================
```

Fig 6.7.5

Sample of ESEMPS printout for material allocation for example two (part 6)

```
==========================================================
To transport material from:
---------------------------

SECTION 1  to SECTION 2
SECTION 3  to SECTION 4
SECTION 7  to SECTION 6
SECTION 11 to SECTION 10
SECTION 13 to SECTION 14
SECTION 13 to SECTION 12
SECTION 13 to SECTION 16
SECTION 15 to SECTION 16

----------------------------------------------------------
*** Single engine conventional SCRAPER, is
    recommended.
----------------------------------------------------------

   Because the task is mass excavation, material
   size is between 12 and 18 inches,the soil
   moisture was less than 30%, THE HAUL DISTANCE
   IS LESS THAN ONE KILOMETER, the grade when empty
   was less than 12%, and job conditions are good.
   If any of these assumptions are wrong please run
   the program again.
==========================================================


==========================================================
To transport material from:
---------------------------

SECTION 1  to SECTION 4:
SECTION 11 to SECTION 8
SECTION 11 to SECTION 6

----------------------------------------------------------
*** Hydraulic excavator and dump trucks are
    recommended.
----------------------------------------------------------
   Because the task is mass excavation, material
   size is between 12 and 18 inches,the soil
   moisture was less than 30%, the HAUL DISTANCE
   IS MORE THAN ONE KILOMETER, the grade when empty
   was less than 12%, and job conditions are good.
   If any of these assumptions are wrong please run
   the program again.
==========================================================
```

Fig 6.8

Types of equipment suggested by ESEMPS for example two

Do you want to view the different types of SINGLE ENGINED ELEVATED SCRAPERS which will carry out the task?(Y..!..N or an option) Y

Single Engined Scrapers

manufacturer	model	kw	capacity struck cubic metre	capacity heap cubic metre
Caterpillar				
	613B	112	----	15.30
	623B	246	----	16.80
	633D	336	----	33.60
	613	112	----	8.40
	633C	309	----	24.50
Fiat Allis				
	161	171	-----	11.60
	261B	242	-----	17.50
Terex				
	S11E	107	-----	8.40
	S35E	341	-----	26.80
International				
	412B	51	-----	8.40
	442B	243	-----	16.80
JHON DEER				
	JD862	186	------	12.23
	JD762	142	------	8.40
	JD860A	170	------	11.50

Do you want me to continue advising on selecting the machines?(Y..!..N or an option)Y

*** Having decided on TYPE OF MACHINE we are going to choose the suitable MAKE and number of MACHINES and HAUL UNITS to carry on the task.

Fig 6.8.1
Sample of types of equipment included in the data base linked to ESEMPS

Section no.	Amount cubic metres	Amount transported C. metres	to section	Haul distance metres	Equipment type	Number	Time days
1	139066	21579	2	705	a)Single engined scraper 16 Cm.	4	50
					b)Single engined scraper 24 Cm.	2	50
		117487	4	1905	Hydraulic excavator 2 Cm bucket.	2	
					and 24 Cm trucks.	13	50
3	8111	8111	4	695	a)Single engined scraper,16 Cm.	4	10
					b)Single engined scraper 24 Cm.	2	10
5	0						
7	136552	136552	6	750	a)Single engined scraper 16 Cm.	10	50
					b)Single engined scraper 24 Cm.	6	50
9	0						
11	161385	61421	10	598	a)Single engined scraper 16 Cm.	4	14
					b)Single engined scraper 24 Cm.	2	14
		56422	8	1198	Hydraulic excavator. 2 Cm bucket.	1	14
					Dump trucks 20 Cm.	4	14
		43542	6	2714	Hydraulic excavator. 2 Cm bucket.	1	14
					Dump trucks 20 Cm.	8	14
13	315103	21295	14	600	a)Single engined scraper 16Cm.	5	14
					b)Single engined scraper 24 Cm.	3	14
		282834	12	780	a)Single engined scraper 16 Cm.	6	120
					b)Single engined scraper 16 Cm.	10	90
					c)Single engined scraper 24 Cm.	10	70
		10974	16	1585	a)Single engined scraper 16 Cm.	6	10
					b)Single engined scraper 24Cm.	4	10
15	608	608	16	638	Single engined scraper 16 Cm.	3	3

Fig 6.9
Material allocation and equipment selection for example two suggested by ESEMPS

Section no.	Amount transported cubic metres	to section	Equipment types (ESEMPS)	Number	Equipment types (contractor)	Nnumber
1	21579	2	a)Single engined scraper 16 Cm.	4	a)Loader 2Cm	1
					trucks 16Cm	5
			b)Single engined scraper 24 Cm.	2		
	117487	4	Hydraulic excavator 2 Cm bucket.	2	Hydraulic excavator 2.2 Cm bucket.	2
			and 24 Cm trucks.	13	and 24 Cm trucks.	14
3	8111	4	a)Single engined scraper,16 Cm.	4	a)Single engined scraper,16 Cm.	4
			b)Single engined scraper 24 Cm.	2		
5	0					
7	136552	6	a)Single engined scraper 16 Cm.	10	a)Single engined scraper 16 Cm.	8
			b)Single engined scraper 24 Cm.	6		
9	0					
11	61421	10	a)Single engined scraper 16 Cm.	4	a)Single engined scraper 16 Cm.	5
			b)Single engined scraper 24 Cm.	2		
	56422	8	Hydraulic excavator. 2 Cm bucket.	1	Hydraulic excavator. 2.4 Cm bucket.	1
			Dump trucks 20 Cm.	4	Dump trucks 20 Cm.	4
	43542	6	Hydraulic excavator. 2 Cm bucket.	1	Hydraulic excavator. 2.4 Cm bucket.	1
			Dump trucks 20 Cm.	8	Dump trucks 20 Cm.	9
13	21295	14	a)Single engined scraper 16Cm.	5	a)Single engined scraper 16Cm.	5
			b)Single engined scraper 24 Cm.	3		
	282834	12	a)Single engined scraper 16 Cm.	6	a)Single engined scraper 16 Cm.	5
			b)Single engined scraper 16 Cm.	10		
			c)Single engined scraper 24 Cm.	10		
	10974	16	a)Hydraulic excavator 2 Cm bucket.	1	a)Loader and 2.5 Cm bucket.	1
			trucks 16 Cm.	6	trucks 16 Cm.	5
			b)Single engined scraper 24Cm.	4		
15	608	16	Single engined scraper 16 Cm.	3	Single engined scraper 16 Cm.	4

Fig 6.10
A comparision between the equipment used by the contractor and those suggested by ESEMPS for example two

Depending on this information a road profile and material allocation between cut and fill sections was drawn as illustrated diagramatecally in fig(6.11). Excavation starts at the far left hand i.e. section1(cut), with material hauled to the adjacent fill areas ie. sections 2, 4 (fill). Any remaining material is then discharged to tip. Also material is borrowed from elsewhere when needed. In cases where there are obstructions in the roadway such as bridges, a dummy cut is implemented as typified in sections 5 and 9 from the road profile.

Comparing the results of ESEMPS to techniques used by the contractor, it was found that similar advice was obtained, although there were some differences in earthwork allocation for example, the contractor suggested transporting material from section 1 to sections 2, 4, and 6, and borrowing for sections 4 and 6. ESEMPS suggested transporting all the material needed for sections 2 and 4, from section 1, and borrowing a larger amount for section 6. On discussing this with the practitioners on site the ESEMPS recommedation was indeed considered more practical and cheaper. In other aspects ESEMPS offered identical results on the plant selection to that of the contractor.

Importantly ESEMPS simplified the whole process of equipment selection in the sense that the user even a novice, is only required to follow the system's instructions and to input data on the project and material quantities. The system thereafter supplies output tables of the quantities, allocation, and the type and number of machines required to carry out the task. During the process the user can interrupt the system and ask for explanations on each question as including the reasons behind decisions.

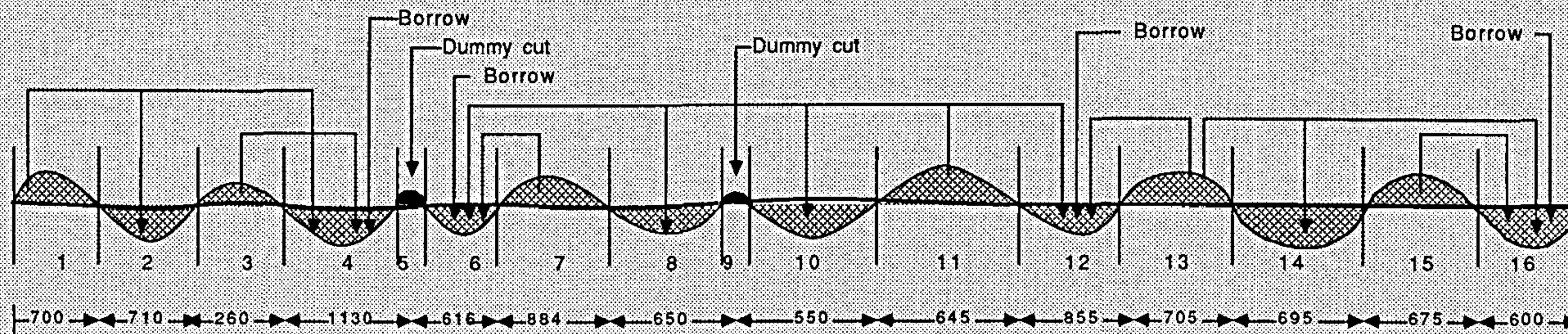


Fig (6.11)
Road profile A42 Project suggested by ESEMPS

6.3 Evaluation of ESEMPS by users:

The system was offered for criticism and gradually improved from the prototype, by allowing the experts to comment. This proved valuable in revealing new knowledge. The procedure was repeated until the final stage of the system was approved by the experts. Thereafter ESEMPS was reviewed by the experts on A42 road project during the case study and it was found to be a good technique in assisting the engineers on site when deciding on succeding sections for detailed planning.

The system was also tested by a sample of 16 novices from under_graduate, post_graduated students, and engineeres on construction sites who were unfamiliar with both ESEMPS internal logic structure and plant selection processes in general. Using this method in particular assisted in refining ESEMPS overall logic structure, and improving the wording of questions.

The demonstrations provoked numerous comments, criticisms and suggestions. Where the suggestions were preceived to be useful these were incorporated.

Inexperienced users were generally satisfied when using ESEMPS as a learning tool, especially in understanding the step by step process of plant selection for road construction, which otherwise would demand site experience. The explanation facility within the system clarifying the reasons behind actions and decisions was also helpful. ESEMPS clearly demonstrated a disciplined method of transferring knowledge and expertise to young engineers.

Some of the more obvious suggestions for improving ESEMPS both from practitioners and the inexperienced included enhansing the explanation facility i.e. automatically allow the user to explore the logic behind specific questions or fire an action. At present this is done by rewriting a summery of the rules into "Display or Amplify" action to call up option commands. The other suggestion was to improve the capabilty of the system for learning from experienced users by allowing the new rules to be absorbed easily into the knowledge base. At present to do so the user has to exit ESEMPS into DOS and open a knowledge file to edit the knowledge. Lastly, enhancing the system by graphics now available in modern CAD systems would clearly be of considerable advantage in illustrating the job situation, equipment configrations etc.

Many of these suggestions could be achieved by restucturing ESEMPS using more uptodate shells which facilitate easy access to external programs, graphics routines and direct access to the knowledge base. Unfortunately Savior was not capable of doing these.

6.4 Feedback from demonstrations:

The strong points of ESEMPS as indicated by feedback from demonstrations include the following:

i) Freedom from computer science jargon.

ii) The dialogue employed by the system is one that its intended users can immediately understand without the need for extensive user support.

iii) Most of the methods and rules of thumb used by the practitioners interviewed during the research could be included.

iv) The structure of the system was perceived to permit the user to carryout the earth allocation separately to the plant selection as well as both together.

v) After the various parties involved in earthworks operations are convinced of the satisfactory performance of the system the need to crosscheck calculations is largely eliminated. Although this was not completly achieved with ESEMPS. This should result in saving of time for site management especially if the system is built by its own personnel.

vi) The explanation facility of the system proved valuable in guiding the user step by step throughout the consultation.

The aspect of ESEMPS perceived as weaknesses include the following:

i) No contractor could be located who had used an expert system model in a real project situation. This view is a typical conservative attitude in the construction industry. The solution to this might be to convince established and respected contractors to use the system in parallel with their own techniques and then compare results.

ii) Transferring knowledge from the experts to less experienced people, requires thorough Expert Systems, which might be too expensive for most contractors to develop. A way out of this could be provided by encouraging contractors to pool their systems via a computer library using telecommunication links.

iii) Presently the reports on computer screen and printouts are the only means of explaining the decisions. A graphic facility would almost certainly improve understanding such a feature is needed even though reports are quite comprehensive. In the meantime graphic routines written in Pascal computer language can be accessed by the shell (SAVOIR), but this process is relatively unsophisticated.

iv) Details of the road profile and the material quantities have to be typed into the system for processing, thus only the time needed to carry out the calculations might be reduced. Since these are usually delegated to junior engineers on site the system may result in only reduction of their work. Nevertheless an examination of such criticism shows this is not a serious detraction as indicated by Cook and Jepson [186] who observed that the first reaction of a manager when receiving an adverse report is to review the source of data and calculations involved. The system indicates such time need not be wasted.

From the author's experience with British contractors [187] foreign contractors overseas, discussions with U.K. postgradate students with the appropriate industrial experience, and the contrary views raised the level of delegation to junoirs is, in the majority of cases, much less than expected. Even if the situation is accurate the system can atleast help avoid calculation errors.

v) Some participants were concerned that the price of a commercially available system might be uneconomical for small firms, when compared to seeking for advice from expert practitioners. Indeed Keen and Woodman [188] admit the difficulty of determining a realistic price for information and suggested that simply listing the potential benefits may be a useful alternative.

6.4.1 **General benefits which could arise from the system include:**

* Providing expert knowledge on earthwork allocation and earthmoving plant selection for road construction, for the inexperienced, especially where experts are not available or very expensive to employ i.e. in developing countries.
* Costs of consultation with experts can be limited.
* Time could be saved in waiting for the expert to arrive on site.
* The system could be used as an educational aid.
* Using computers on site enhances the image of the contontractor.

CHAPTER SEVEN

CONCLUSIONS, CONTRIBUTION TO THE FIELD AND RECOMMENDATIONS

7.1 Conclusions:

The preparation of plans and estimates for earthmoving operations depends greatly on skilled judgement in taking account of all the likely variables to be expected. Much information is available to assist the process and exists in the form of work study data, manufacturers machine performance specifications, guidelines on methods of calculating production output, labour resources and equipment requirements, etc. Unfortunately even the best of these sources generally involve the user in making bold decisions on the jobs conditions and categories of equipment for particular situations. ESEMPS is an attempt to overcome this defect by levening the conventional calculation processes with dialogue and advice. The implementation of ESEMPS on a real project has shown that it is possible to apply Expert Systems or Knowledge Based Systems to construction projects by assisting the project staff in planning the project by making the expert knowledge available in a logical and easy to understand way.

The research has also resulted in the following specific conclusions relating to both earthwork planning and Expert System technicalities:

1) The results of a test-case study were very encouraging with the equipment recommendation proving fairly accurate, the machine types in particular being correctly determined. Some refinement in output estimates and machine matching however is still needed as it appears that the data bank of adjustment controls do not fully reflect with working practice.

2) The potential of the system for plant selection are clearly manyfold, but most importantly results of trials with users indicate that the concept provides a disciplined method of transferring knowledge and expertise to young and untrained construction engineers.

3) Two experts sometimes have different ideas but both could be applicable. To overcome such problems the system could have more than one knowledge base, but it must be emphasised that expert systems are strictly limited by the knowledge stored and are therefore only applicable to the specific domain, whereas the expert is normally much more versatile.

4) Expert knowledge at present has to be laboriously acquired and stored in the knowledge base, in a manner that reflects practical decision making.

5) ESEMPS can already be classified as "expert" in that it has knowledge better than that of novices, practicing in the domain.

6) The system can be used as a tool in selecting the most appropriate fleet of earthmoving equipment for earthwork operations for road construction by those with little knowledge in the domain and even no knowledge in computers. Even for experts themselves, the system could be used as a datum in obtaining quick selections to achieve an estimate and arrive at reasonable resources allocation.

7) Work on Expert Systems is moving away from research and is concentrating on producing systems for commercial use. There is, therefore, much development work going on at present, and this is as active in the construction industry as any where else[189], such as MYCIN and PROSPECTOR. Each of these two systems claim to have achieved expert levels of performance.

8) There are now, very many Expert System shells or system building tools, commercially available. Each has its own set of advantages and drawbacks (as explained in Appendix E). It is the responsibility of the knowledge engineer to select an appropriate shell, suited to the problem domain. The price of the shells are reducing which ought to encourage continued interest in the field.

9) Because so many problems construction professionals face require specialized knowledge, skill, experiences and judgement for determination of solution strategies, the potential appears high for expert systems to become useful aids for practicing construction engineers.

10) Most systems are built around a particular shell whether this is appropriate to the solution or not. The development of more commercial shells and the natural maturing of the technology will reduce the magnitude of the problem. The current approach of using the shell most readily available has led many systems including ESEMPS to size and complexity limitations, inadequate user interfaces and slow systems response times.

11) The plant selection process seems ideally suited to an Expert System, perhaps this due to the uncertain nature of the information available to the end user, the rules of thumb applied, and the large amount of data required, especially that relating to soil types, cycle time and machine performances.

12) Expert Systems must contain expertise. While textbooks can provide an important and valuable source of information which should be incorporated into the system, text books

are insufficient by themselves, heuristic knowledge (rarely contained in books). Experts must be consulted at the creation and testing. Otherwise the system will not reflect the real world, and thus, will not perform well in the real world.

13) Different methods of knowledge elicitation are suitable for different purposes and several may be used at different stages in expert systems development. A review of the present knowledge elicitation techniques both manual and machine (chapter 3), indicates that, for the near future at least, knowledge engineers will still be needed to advise, direct and build expert systems. However, as machine aids and other techniques become more widely used they may be obliged to redefine their role in the expert system development process. As expert systems become more widely understood and applied, it is likely that the knowledge engineers will be working as part of a team rather than on their own.

14) The extensive preliminary work from the literature review prior to interviewing proved to be very useful. It helped put myself as the knowledge engineer in a good position for understanding the expert, especially in regard to technical terms.
An appropriate method of interviewing must be selected and, in particular, a method of recording the interview. Making notes during the interview was found to be unsatisfactory, as when it comes to writing the rules, they tend to be based on an immediate interpretation of what had been said. Usually there is no facility to go back to the expert's original words, as there would be with an audio or video recording. Building a good relationship with the expert was found helpful.

15) The difficulties in designing an Expert System are not simply those of selecting an appropriate shell and writing a set of logically accurate rules. The system designer must also consider how to obtain the information from the expert and more important, to configurate it.

16) The current complicated techniques applied to the earth work allocations such as linear programing and arrow diagram may be supplemented by adopting a combination of heuristics and simple mathematical algorithms via an Expert System such as ESEMPS.

17) In earthmoving operations scraper delays can be mainly categorised into three categories; firstly, major delays (weather, breakdowns, management policy changes), secondly, minor delays (operational delays, maintenance, personal delays), and finally, wait delays (interference of equipment).

18) The delays encountered in excavator-truck operations can be categorised as; a) truck delays (during hauling and returning), b) excavator caused delays (excavator break downs, waiting for other operations), and c) equipment wait delays(balancing delays).

19) Application of complex mathematical models for material allocation between cut and fill sections such as linear programing, are of little use to an experienced earthmoving practitioner, an estimator for example.

20) The most important production variables irrespective of the type of equipment used in a road project are planning and supervision i.e. management efficiency and quality.

21) The important factors which affect equipment cycle times on an earthmoving operations are fig (5.14):

a) Loading method.
b) Type of soil.
c) Job conditions.
d) Haul distance.
e) Haul road conditions.
f) Operator efficiency.
g) Supervision.

7.1.1 Practical limitations of the expert systems:

Expert System technology is still new and there is a great deal of work to be done in the developing, validations, and refining before the techniques becomes widely acceptable. The following are some practical limitations:

i) Knowledge elicitation: Whatever the effort applied by the knowledge engineer in eliciting knowledge there will be still gaps. At present the only way round this is that construction firms should aim to motivate their experts to co-operate with knowledge engineers to develop expert systems to suit the firm's own specific needs.

Indeed Neale [190] and Thompson [191] in two different studies on computerised project management systems have concluded that firms should build their own systems to suit their specific needs. This very much could be the case for developing expert systems

ii) Consistency of rules: There are problems associated with testing the consistency of rules, particularly as the knowledge base gets larger and rules becomes inextricably inter-connected. The problem is exacerbated if the knowledge base is to be extended and updated by someone other than the original contributor to the system. It is very difficult to prevent contradictory items being put into the knowledge base.

iii) Judging machine output: Experts, like all humans, seem subject to the vagaries of fashion and changes of mind.

As explained in chapter (3) this aspect could be reduced by asking experts to check and prove the system,then be validated against real data from site, and thereafter updated with new knowledge.

iv) Legal liability: What can be done to ensure that an Expert System acts responsibly, and what sanctions can be taken if mistakes are made? and who is responsible if the decision is wrong?......The system designer? The user? The system vendor? Or the expert who supplied the original knowledge? This is an issue which has not yet been decided.

7.2 Future of Expert Systems:

Despite these considerations it is possible that computers in general and expert systems in particular will become effective mediums of communication. It is essential therefore that construction industry professionals learn how to use and exploit them. As a new technology it seems worthwhile testing these systems side by side with expert practitioners in order to gauge their merits. Indeed indications are that the expert systems area is expanding, both through government and industry [189].

Finally, I am optimistic about the future of Expert Systems. This is not because I have created one, but because they will solve problems that could not be handled before without the assistance of an expert practitioner. As the technology becomes more mundane and commonplace, it will become a technique for solving problems instead of as at present a technology seeking a problem.

7.3 Contributions of ESEMPS to construction planning:

What began a simple demonstration programme quickly became quite detailed, primarily due to the underestimation of the complexities involved in planning earthworks for road construction. The process led me to a better understanding of the way practitioners make decisions.

7.3.1 Educational value of ESEMPS:

The educational value for such systems is significant. First, in using any kind of expert system the student gains some familiarity with an important and rapidly growing computer application. Second, the system will help students to understand the logic and technical background to the construction process. In this case earthmoving plant selection by guiding them step by step through the knowledge base and decision making process using the explanation options of the system. This itself is highly beneficial in learning. Finally, having became familiar with the system, students have the opportunity to examine case studies. While these are not not intended to replace field experience, such preparation can make subsequent field experience all the more valuable as training tool.

7.3.2 Contribution of ESEMPS to the industry:

If the system can assist in the training of young professionals, that in itself must be seen as a real benefit to the industry. However, foremost ESEMPS technology can successfully integrate engineering expertise with many algorithmic analysis programs. This concept is valuable, because often experts are not available on site that will give the state-of-the-art analytical advice. Expert systems thus allow for the convenient transfer of expert knowledge to the less experienced engineer. This could be achieved as suggested by Thompson [191] for project management systems, by motivating young engineers to use the systems by introducing money and time relationships at the same time as stress/strain relationships. Training in this area at this stage will be essential to make the best use of the available systems.

In a more practical sense, ESEMPS has brought together in an easily accessible form the expert knowledge required in effectively advising on material allocation and plant selection for road construction project all too often a mammoth task of knowledge acquisition and rule formulation.

7.4 Recommendations for future research:

i) As pointed out in the literature review, the power of an expert system is related to the size and completeness of its knowledge base. Although incomplete in this respect, ESEMPS can continue to be used as a tool for material allocation and plant selection, thus freeing the expert for other important tasks.

ii) Other enhancements could include the addition of graphics capabilities to the system, thereby automatically presenting the profile view of final material allocation between cut and fill sections and show the maneuvering space of the plant. This feature would not only allow the experienced user to quickly accept or reject ESEMPS's recommendations, but could also provide a novice with valuable graphical information and thereby greatly enhance the learning process.

iii) Other modifications could include linking ESEMPS to other research work [192, 193]. Also it could be linked to existing well established estimating packages to help the estimator in deciding on earthmoving equipment while also estimating the cost of a road project.

CHAPTER EIGHT

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APPENDICES

A. Survey of Expert System Models in Construction Management

B. Example of Linear Programming

C. Sample of ESEMPS Consultation

D. Survey of Expert Eystem Shells

E. Sample of External Programs Linked to ESEMPS

APPENDIX (A)

Survey of Expert System Models in Construction and Construction Management areas.

Expert Systems Applications in Construction and Construction Management.

Expert systems applications in the areas of construction and construction management have been presented by Levitt and Adeli [37, 79]. My survey on these systems have found that their applications ranging from systems which are in use by persons other than their developers to those which are in a prototype phase.

The followings are different Expert Systems applied to the field of construction management.

1) **KNOW-HOW** Transfer method.

   Developed at the advanced research Laboratory, Hitachi. Ltd., Japan.

   The primary feature of this expert system has been the development of the "Know-how" transfer method of acquiring knowledge needed by the project manager in the different areas of the managerial, technical, economic, financial, social, and legal/political skills. The system stores the risk know-how onto a standard work package matrix. Know-how then becomes a function of the construction activity, and the object involved in the construction.

   The system can provide information in several different ways. For example, the input data may be a work package and the output data could risk reducing strategies that should be followed for that activity. Another example would be to input a risk and receive as output thé risk factors involved, as will as other possible risks resulting from the original risk factors.

2- **SAFEQUAL:** Evaluating a contractor's Expected safety performance.

Developed at the Civil Engineering Department, Stanford University, California, USA.
SAFEQUAL was developed as a decision model to evaluate a contractor's safety performance.

3- **CLAIM EXPERT:** Expert System for Claim Analysis.
Developed at the Civil Engineering Department, University of Technology, Loughborough, England.
The system is capable of identifying various potential entitlement issues from giving facts, and provides guidelines for preparing the documentation and procedures necessary to persue the case.

4- **CRANS:** Selection of Tower Cranes fore Multi-Storey Construction Site.
Developed at the Civil Engineering Department, University of Technology, Loughborough, England.
The system is designed to check that the crane requirements determined from the site coverage criteria are compatible with those determined from crane productivity criteria. for example the user might have selected two cranes to cover the site whereas only one would be sufficient to move the necessary materials within the construction period.

5- **CONPLAT:** Plant Selection for Material Handling for the Construction of Concrete Frames.
Developed at the Civil Engineering Department, University of Technology, Loughborough, England.

The system advised on the selection of items of plant for handling materials during the construction of the concrete framed buildings.

6- **CAS:** Knowledge Base System for Decision Making on Construction Method.

Developed at the Department of Civil Engineering, Coventry Polytechnic, England.

The system was designed to aid the construction planner with the evaluation of potentially suitable methods of construction i.e to select, quantify and evaluate the suitability of alternative methods of construction.

7- **BERT:** Brickwork Expert.

Developed at the Department of Computer Science and Construction Management, University of Reading, England.

The system was designed in order to standardise design advice to architects. It also aid in evaluating proposed designs for brickwork cladding of buildings. BERT examines a submitted design from an AUTOCAD system, comments on the quality of the design, and suggests improvements.

8- **MASON:** An Expert System for Masonry construction Duration Estimation.
Developed at the Department of Civil Engineering, Carnegie-Mellon University, USA.

MASON is a prototype system which provides facilities for estimating masonry construction durations, explaining the calculations involved in the conclusions and making recommendations for crew coposion and technologies.

9- **CRANES:** Crane Resource and Evaluation System.
Developed at the Department of Civil Engineering, University of Reading, England.

The system is designed in order to use graphics to help the user locate loads, sizes, and possible crane locations on a site plan. After that the lifting problem is evaluated through an expert system. Once the full specifications of the crane have been established, CRANES refers to an integral data base of available cranes to pattern-match the specifications from the expert system.

10- **HOWSAFE:** Evaluation of the Safety of a Construction Firm.
Developed at the Department of the Civil Engineering, Stanford University, California, USA.

The system is intended as a diagnostic tool to assist a construction manager in determining the "helth" of his construction company's safety programs.

11- **PROPICK:** Selection of contract Type.
Developed at the Civil Engineering Department, Stanford University, California, USA.

The system attempts to determine whether traditional contract management, design/construct, or construction management is the correct basic contract type. It will point out to a client who wants lowest cost, shortest schedule and freedom to make changes that no form of contract will satisfy all of these objectives, the client is forced to decide which objective is important for the given project.

12- **DECAS**: Determining Entitlement under a Differing Site Conditions Clause.
Developed by the Construction Engineering and Management Program at the University of Colorado.

The system is designed to investigate the differing site conditions clauses under the standard fedral contract. DECAS advises the user for the "Entitlement or NO Entitlement" of the claim.

13- **PLATFORM**: Hybrid Decision Support Tool for Project Management.
Developed at the Civil Engineering Department, Stanford University, California, USA.

The system was developed as an attempt to show that Artificial Intelligence environment can represent and use construction task knowledge and hence leverage the capabilities of network-based project management systems as real time control tool.

14- **SOILCON**: Soil Exploration Consultant.
Developed at the Department of Civil Engineering, University of Texas, USA.

The system is designed to recommend site exploration techniques. If there is very little known about the site then SOILCON may recommend preliminary testing techniques and vice versa. Output consists of list of recommended investigation methods ranked by certainty, displayed description of those methods, and displayed cost estimates for the methods.

APPENDIX (B)

Example of Linear Programming

Linear Optimisation Formulation (Linear programming)

Obtaining quantity estimates is a first task in planning an earthwork operation. These cut and fill volumes are usually calculated from field cross-sectional data and approximated by any of several methods for each section of the road as was explained in (Chapter 4).

Let:

C_{ij} = the cost of moving a unit volume from **i** to **j**.

T_{ij} = the time to move a unit volume from **i** to **j**.

V_{ij} = the volume moved from **i** to **j**.

where:

i, is a supply point, in our case a cut zone or borrow area.
j, is a demand point, in our case a fill zone or dump area.

The total cost of moving the earth = **Z**

$$Z = \sum_{i} \sum_{J} C(i,J) \;\; V(i,J)$$

The total time for moving the earth = **T**

$$T = \sum_{i} \sum_{J} C(i,J) \;\; V(i,J)$$

With the summations over all values of **i** to **j**.
The optimum cost solution is that set of values of V_{ij} which gives the least total cost. Similarly for the optimum time solution.

However, the V_{ij} must satisfy the following constraints.

i) Each V_{ij} must be grater or equal to zero.

ii) The total volume of earth in each cut zone must be removed.

Thus for each cut zone there will be an equation of the following form:

$$V_{n1} + V_{n2} + V_{n3} + \text{------} V_{ns} = CV_n$$

where **s** is the total number of demand points, i.e. the sum of the number of the fill and dump areas, and CV_n is the volume of earth to be removed from the cut zone **n**.

iii) Similarly for each fill zone an equation of the following form will apply:

$$V_{1m} + V_{2m} + V_{3m} + \text{-------} + V_{rm} = FV_m$$

where **r** is the total number of supply points.

FV_m is the volume of fill required at fill zone m.

iv) For each borrow area an inequality of the following form will apply:

$$V_{p1} + V_{p2} + V_{p3} + \text{-------------} + V_{ps} <= BV_p$$

Where BV_p is the maximum volume of earth that can be removed from borrow area **p**.

v) For each dump area an inequality of the following for will apply:

$$V_{1q} + V_{2q} + V_{3q} + \text{------------} + V_{rq} <= DV_q$$

Where $\mathbf{DV_q}$ is the maximum volume of earth that can be deposited at the dump area **q**.

Because the volumes need to be in the same form in the above expressions, the excavation volumes are converted to their equivalent fill volumes, and the unit costs and times are for unit volumes of fill.

The objective of applying the linear equation is to minimise the total cost of earthmoving. The total cost is the sum of the cost of moving earth among sections, from cut sections or borrow pits to fill sections or disposal tips. In symbols, the objectives can be written:

$$\min\ Z = \sum_i \sum_J C(i,J)\,V(i,J) + \sum_i \sum_q C_q(i,q)\,V_q(i,q) + \sum_p \sum_J C_p(p,J)\,V_p(p,J)$$

<u>**EXAMPLE**</u>

"A roadway contractor is planning a grading operation of the terrain shown in fig.(6.1). The cut and fill quantities have been estimated for each the eight 1000 ft sections of roadway. An acceptable borrow pit located near the north end of the roadway. A tip is located 2000 ft, from the south end of the roadway can be used for the waste material. The material characteristics for the various sections of cut and borrow and the cut and fill quantities are shown in the table included in fig(6.1)."

Using the data in table included in fig (6.1), the constraint for cut required in section 1, is:

$$X\,(1,4) + X\,(1,6) + X\,(1,7) + X_d\,(1,S) + X_d\,(1,N) = 30$$

and for sections 2, 3, 5, 8, are:

$$X\,(2,4) + X\,(2,6) + X\,(2,7) + X_d\,(2,S) + X_d\,(2,N) = 30$$

$$X\,(3,4) + X\,(3,6) + X\,(3,7) + X_d\,(3,S) + X_d\,(3,N) = 30$$

$$X\,(5,4) + X\,(5,6) + X\,(5,7) + X_d\,(5,S) + X_d\,(5,N) = 30$$

$$X\,(8,4) + X\,(8,6) + X\,(8,7) + X_d\,(8,S) + X_d\,(8,N) = 30$$

Shrinkage factor of the table in (fig 6.1), the constraints for sections 4, 6, 7, are:

$$0.8\,(1,4) + 0.8\,X(2,4) + 1\,X(3,4) + 0.8\,X\,(5,4) + 0.75\,X\,(8,4) + 0.9X_b\,(N,4) = 35$$

$$0.8\,(1,6) + 0.8\,X(2,6) + 1\,X(3,6) + 0.8\,X\,(5,6) + 0.75\,X\,(8,6) + 0.9X_b\,(N,6) = 25$$

$$0.8\,(1,7) + 0.8\,X(2,7) + 1\,X(3,7) + 0.8\,X\,(5,7) + 0.75\,X\,(8,7) + 0.9X_b\,(N,7) = 25$$

The solution of the above equations for Minimum Unit Cost (Z) is:

The amount of material transported from section 1 to section 4, (1, 4) = 6250 Cubic Yards.

The amount of material transported from section 2 to section 4, (2, 4) = 25000 Cubic Yards.

The amount of material transported from section 3 to section 4, (3, 4) = 10000 Cubic Yards.

The amount of material transported from section 5 to section 6, (5, 6) =20000 Cubic Yards.

The amount of material transported from section 8 to section 7, (8, 7) = 15000 Cubic Yards.

The amount of material borrowed from borrow pit to section 6, (N,6) = 10000 Cubic Yards.

The amount of material borrowed from borrow pit to section 7, (N,7) = 15280 Cubic Yards.

The amount of material transported from section 1 to the tip, (1,S) =23750 Cubic Yards.

Note: All other variables equal zero.

For minimising the total cost of **Z** = £469894.

APPENDIX (C)

Sample of ESEMPS Consultation

```
                W e l c o m e   t o   ESEMPS ....


      .... a demonstration Expert System
knowledgeable about the selection of earthmoving
equipment.

             Have you used ESEMPS before ?
(Y..!..N or an option)  N


 >> ESEMPS will advise you on earth moving plant
selection by asking you questions. There are two
sections to the consultation:

             - questions about the site,  intended  to
derive general information  about the project  to help
on primary  selection and
             - more  detailed questions,concerning the
performance of selected plant to more detailed  advise
on plant selection.

The  first section will be automatically started but I
will later give you the option to ignore the second.

When I have assessed the information, either in general
general  or in detail,  I will give you the option  of
seeing  the  results before giving you some advice  on
the selection of the plant.

HELP  is provided in ESEMPS.  When a  question  states
that  an  option is available,  the response 'h'  will
invoke the help system.

(Type Y only or an option)  y


 >> Is the task road construction?
(Y..!..N or an option)  y
```

Sample of ESEMPS Consultation

```
>> Do you have a site investigation report  ?
  (Y..!..N or an option)  y


>> I shall later ask you some questions relating
   to distance.
    Would you prefer to use:

     1) Customary measures (i.e. miles, inches),
   or
     2) Metric measures (i.e. kilometres,
        centimetres) ?
     For any inquiries please type A.
  ( 1 To  2, ! if not known  or an option)  2


>> Do you want to use

 1-Factual (Yes, No, Numbers) answers?  or
 2-Probable (-5 to +5) answers?
 3-Mix answers?
(1..3, ! if not known  or an option)  1

 >> I am now starting to consider the type of soil, in
    particular,  the kind of soil the machines will be
    dealing  with on site.  Please choose one  of  the
    following: For any inquiry please type (A)

         1-  Top soil, dry clay, or loam earth.
         2-  Pit  run gravel,  sand,  soft  shale,damp
             clay.
         3-  Heavy clay, single size aggregate, rock.
        (1..3, ! if not known  or an option)  1
```

```
>> Does the material contain one of the following
   rock or gravel sizes in diameter:-
 --------------------------------
 1- Less than 5 centimetres.                type  1.

 2- Between 5 and 15 centimetres.           type  2.

 3- Some between 15 and 30 centimetres.     type  3.

 4- Some between 30 and 45 centimetres.     type  4.

 5- Some greater than 45 centimetres.       type  5.

 6- Contains none of above.                 type  6.

---------------------------------------------------

If  you want to view an example of the  effect  of
the  SIZE  of  the material on the output  of  the
machine, please type in       A.

(1..6, ! if not known  or an option)  a

i--------------------------------------------------------i
i      Effect of material SIZE on loader out-put         i
i----------------i---------i----------i--------i--------i
i material        iout put  i No.cycle i Av.loadi %fill i
i                 iper hour i          i per cy iweight i
i----------------i---------i----------i--------i--------i
i3/16cm Gritsand i  575     i       139  i   4.2  i  100% i
i   1cm Limestone i  565     i       138  i   4.1  i   98% i
i   4cm Limestone i  462     i       134  i   3.5  i   83% i
i 12cm Greywacki i  408     i       132  i   3.1  i   74% i
i 24cm Blackstonei  367     i       133  i   2.8  i   67% i
i________________i_________i__________i________i________i

(1..6, ! if not known  or an option)1

>> I would like you to tell me which one of the
following apply to the dumping area?

 1-  Maintained by dozer and is an unrestricted
     area.
 2-  Some restrictions or soft ground.
 3-  Restricted or very soft ground.
 (1..3, ! if not known  or an option)  1
```

ESEMPS Consultation, Continued

```
>> Will the supervision on the site be:

 1-  Adequate in all areas.
 2-  Intermittent.
 3-  Little or no continuous supervision.
     (1..3, ! if not known  or an option)  1

>> Now I wish to know whether haul units will be
   involved with public traffic. Will you please
   choose one the following cases :

 1- No involvement with public roads or railways.
 2- Road crossing.
 3- Haul always in city streets.
  (1..3, ! if not known  or an option)  1

 I would like you to tell me if in general the
 weather is:

 a- dry,
 b- fair, or
 c- wet
(Enter 1 Characters or an option)  a

>> I would like you to tell me if you are planning
   to work night shifts. Please choose one of the
   following:

 1- none,
 2- some, or
 3- regular.
(1..3, ! if not known  or an option)  1


>> Are there any obstructions (ie. trees, buildings,
   or others) on the site?
 (Y..!..N or an option)  n


>> Please inform me of the haul gradient and
   rolling resistance by selecting one of the
   following: For any inquiry please type (A)

      1-  Less than 2%,
      2-  2%  to 4% ,
      3-  4%  to 8%, or
      4-  More than 8%.
      (1..4, ! if not known  or an option)  1
```

```
The Report is:-

I have now completed my assessment of the  GENERAL JOB
CONDITIONS  and  I  am  pleased  to  tell  you  it  is
FAVOURABLE. In general that means  you can use shovels,
bulldozers, and scrapers. We are going to find out the
best  one  later  on discussing the  project  in  more
details.



 >> That concludes my investigation in general .
    Shall I:

              1) investigate in more detail, or
              2) finish this ESEMPS session ?
       ( 1 To  2, ! if not known  or an option)  1


                   ***** DETAIL INFORMATION  *****

I  am  now  starting to consider the project  in  more
detail. I will do this by asking  questions  concerned
with MACHINE PERFORMANCE, and CONDITIONS.


I am going to find out whether SCRAPERS
are appropriate.


>> Is the TASK :-

   1- Stripping Top Soil. type   1.
   2- Mass Excavation.    type   2.

  (1..2 or an option)  2
```

```
>> This question is about the maneuvering  space
   of the machine.

   Please tell me can the machine maneuver
   easily?

  (Y..!..N or an option)  y


I am going to calculate the amount of material to
be moved between cut and fill areas along the
haul route. Please type in        Y.

(Type Y only or an option)  y


 How many sections are there along the road?
( 1 To  40, ! if not known  or an option)  16


 Is section 1 :

 1- Cut
 2- Fill
 3- Neither

 If you need any help in answering the
  question type in -A-.
(1..3, ! if not known  or an option)  1

 Answer please the amount of cut in cubic metres
 from section one.
( 0 To  1000000, ! if not known  or an option)  139066


 Is the soil:

 1-Rock or,
 2-Common.
(1..2, ! if not known  or an option)  2
```

```
 Answer please the CHAINAGE in metres  of section 1.
( 0 To  100000, ! if not known  or an option)  860

 Is section 2 :

 1- Cut
 2- Fill
 3- Neither

 If you need any help in answering the
  question type in -A-.
 (1..3, ! if not known  or an option)  2


 Answer please the amount of fill in cubic metres
 from section two.
( 0 To  1000000, ! if not known  or an option)  21579


 Answer please the CHAINAGE in metres  of section 2.
( 0 To  100000, ! if not known  or an option)  1410


 Is section 3 :

 1- Cut
 2- Fill
 3- Neither

 If you need any help in answering the
 question type in -A-.
 (1..3, ! if not known  or an option)  1

 Answer please the amount of cut in cubic metres
 from section three.
( 0 To  1000000, ! if not known  or an option)  8111


 Is the soil:

 1-Rock or,
 2-Common.
(1..2, ! if not known  or an option)  2

 Answer please the CHAINAGE in metres  of section 3.
( 0 To  100000, ! if not known  or an option)  1870
```

```
 Is section 4 :

 1- Cut
 2- Fill
 3- Neither

 If you need any help in answering the
  question type in -A-.
(1..3, ! if not known  or an option)  2

 Answer please the amount of fill in cubic metres
 from section four.
( 0 To  1000000, ! if not known  or an option)  143698

 Answer please the CHAINAGE in metres of section 4.
( 0 To  100000, ! if not known  or an option)  2800


 Is section 5 :

 1- Cut
 2- Fill
 3- Neither


 If you need any help in answering the
  question type in -A-.
(1..3, ! if not known  or an option)  1


 Answer please the amount of cut in cubic metres
 from section five.
( 0 To  1000000, ! if not known  or an option)  0


 Is the soil:

 1-Rock or,
 2-Common.
(1..2, ! if not known  or an option)  2


 Answer please the CHAINAGE in metres  of section 5.
( 0 To  100000, ! if not known  or an option)  2800
```

```
 Is section 6 :

 1- Cut
 2- Fill
 3- Neither

 If you need any help in answering the
 question type in -A-.
(1..3, ! if not known  or an option)  2

 Answer please the amount of fill in cubic metres
 from section six.
( 0 To  1000000, ! if not known  or an option)  256283


 Answer please the CHAINAGE in metres  of section 6.
( 0 To  100000, ! if not known  or an option)  3416


 Is section 7 :

 1- Cut
 2- Fill
 3- Neither

 If you need any help in answering the
  question type in -A-.
(1..3, ! if not known  or an option)  1

 Answer please the amount of cut in cubic metres
 from section seven.
( 0 To  1000000, ! if not known  or an option)  136552


 Is the soil:

 1-Rock or,
 2-Common.
(1..2, ! if not known  or an option)  2

 Answer please the CHAINAGE in metres  of section 7.
( 0 To  100000, ! if not known  or an option)  4300
```

```
 Is section 8 :

 1- Cut
 2- Fill
 3- Neither

 If you need any help in answering the
  question type in -A-.
(1..3, ! if not known  or an option)  2

 Answer please the amount of fill in cubic metres
 from section eight.
( 0 To  1000000, ! if not known  or an option)  56422

 Answer please the CHAINAGE in metres  of section 8.
( 0 To  100000, ! if not known  or an option)  4950

 Is section 9 :

 1- Cut
 2- Fill
 3- Neither

 If you need any help in answering the
  question type in -A-.
(1..3, ! if not known  or an option)  1

 Answer please the amount of cut in cubic metres
 from section 9.
( 0 To  1000000, ! if not known  or an option)  0


 Is the soil:

 1-Rock or,
 2-Common.
(1..2, ! if not known  or an option)  2

 Answer please the CHAINAGE in metres  of section 9.
( 0 To  100000, ! if not known  or an option)  4950
```

```
 Is section 10 :

 1- Cut
 2- Fill
 3- Neither

 If you need any help in answering the
  question type in -A-.
(1..3, ! if not known  or an option)  2

 Answer please the amount of fill in cubic metres
 from section 10.
( 0 To  1000000, ! if not known  or an option)  61421

 Answer please the CHAINAGE in metres  of section 10.
( 0 To  100000, ! if not known  or an option)  5500

 Is section 11 :

 1- Cut
 2- Fill
 3- Neither

 If you need any help in answering the
  question type in -A-.
(1..3, ! if not known  or an option)  1

 Answer please the amount of cut in cubic metres
 from section 11.
( 0 To  1000000, ! if not known  or an option)  161385


 Is the soil:

 1-Rock or,
 2-Common.
(1..2, ! if not known  or an option)  2

 Answer please the CHAINAGE in metres  of section 11.
( 0 To  100000, ! if not known  or an option)  6145
```

```
 Is section 12 :

 1- Cut
 2- Fill
 3- Neither

 If you need any help in answering the
  question type in -A-.
(1..3, ! if not known  or an option)  2

 Answer please the amount of fill in cubic metres
 from section 12.
( 0 To  1000000, ! if not known  or an option)  282834

 Answer please the CHAINAGE in metres  of section 12.
( 0 To  100000, ! if not known  or an option)  7000

 Is section 13 :

 1- Cut
 2- Fill
 3- Neither

 If you need any help in answering the
  question type in -A-.
(1..3, ! if not known  or an option)  1

 Answer please the amount of cut in cubic metres
 from section 13.
( 0 To  1000000, ! if not known  or an option)  315103


 Is the soil:

 1-Rock or,
 2-Common.
(1..2, ! if not known  or an option)  2

 Answer please the CHAINAGE in metres  of section 13.
( 0 To  100000, ! if not known  or an option)  7705
```

```
 Is section 14 :

 1- Cut
 2- Fill
 3- Neither

 If you need any help in answering the
  question type in -A-.
(1..3, ! if not known  or an option)  2

 Answer please the amount of fill in cubic metres
 from section 14.
( 0 To  1000000, ! if not known  or an option)  21295

 Answer please the CHAINAGE in metres  of section 14.
( 0 To  100000, ! if not known  or an option)  8200

 Is section 15 :

 1- Cut
 2- Fill
 3- Neither

 If you need any help in answering the
  question type in -A-.
(1..3, ! if not known  or an option)  1

 Answer please the amount of cut in cubic metres
 from section 15.
( 0 To  1000000, ! if not known  or an option)  608


 Is the soil:

 1-Rock or,
 2-Common.
(1..2, ! if not known  or an option)  2

 Answer please the CHAINAGE in metres  of section 15.
( 0 To  100000, ! if not known  or an option)  8400


 Is section 16 :

 1- Cut
 2- Fill
 3- Neither

 If you need any help in answering the
  question type in -A-.
(1..3, ! if not known  or an option)  2
```

```
 Answer please the amount of fill in cubic metres
 from section 16.
( 0 To  1000000, ! if not known  or an option)  148732

 > Do you want to see a table of QUANTITIES?
(Y..!..N or an option)
That was not a valid reply
(Y..!..N or an option)  Y

=================================================
 Alright here are the final quantities:
```

SECTION	CHAINAGE metres	CUT C. metres	FILL C. metres
1	860	139066	--
2	1410	--	21579
3	1870	8111	--
4	2800	--	143698
5	2800	0	--
6	3416	--	256283
7	4300	136552	--
8	4950	--	56422
9	4950	0	--
10	5500	--	61421
11	6145	161385	--
12	7000	--	282834
13	7705	315103	--
14	8200	--	21295
15	8400	608	--
16	9475	--	148732

```
=================================================
```

I am going to calculate the amount of material to be cut or filled for each section.

Please type in -Y- to continue
(Type Y only or an option)Y

You need to transfer the amount of material FROM SECTION (1) as shown below:

Section no.	amount C.metres	amount transported	to section
1	139066		
		21579	2
		117487	4

I am going to advise on the amount of material to be transported from section (3).

Please type in -Y- to continue
(Type Y only or an option) Y

You need to transfer the amount of material from section (3) as shown below:

Section no.	amount C.Yard	amount transported	to section
3	8111		
		8111	4

I am going to advise on the amount of material to be transported from section (5).

Please type in -Y- to continue
(Type Y only or an option) Y

You need to transfer the amount of material from section (5) as shown below:

Section no.	amount C. metres	amount transported	to section
5	0		

I am going to advise on the amount of material to be transported from section (7).

Please type in -Y- to continue
(Type Y only or an option) Y

You need to transfer the amount of material from section (7) as shown below:

Section no.	amount C. metres	amount transported	to section
7	136552		
		136552	6

I am going to advise on the amount of material to be transported from section (9).

Please type in -Y- to continue
(Type Y only or an option) Y

You need to transfer the amount of material from section (9) as shown below:

Section no.	amount C. metres	amount transported	to section
9	0		

I am going to advise on the amount of material to be transported from section (11).

Please type in -Y- to continue
(Type Y only or an option) Y

You need to transfer the amount of material from section (11) as shown below:

Section no.	amount C. metres	amount transported	to section
11	161385		
		61421	10
		56422	8
		43542	6

I am going to advise on the amount of material to be transported from section (13).

Please type in -Y- to continue
(Type Y only or an option) Y

You need to transfer the amount of material from section (13) as shown below:

Section no.	amount C. metres	amount transported	to section
13	315103		
		21295	14
		282834	12
		10974	16

I am going to advise on the amount of material to be transported from section (15).

Please type in -Y- to continue
(Type Y only or an option) Y

You need to transfer the amount of material from section (15) as shown below:

Section no.	amount C. metres	amount transported	to section
15	608		

Answer please the CHAINAGE of section 16.
(0 To 100000, ! if not known or an option) 9475

Do you want to view the material allocation in a table form?
(Y..!..N or an option) Y

You need to transfer the amount of material from CUT SECTIONS to FILL SECTIONS as shown below:

Section no.	Amount C. metres	Amount transported	to section	Haul distance
1	139066			
		21579	2	705
		117487	4	1905
3	8111			
		8111	4	695
5	0			
7	136552			
		136552	6	750
9	0			
11	161385			
		61421	10	598
		56422	8	1198
		43542	6	2714
13	315103			
		21295	14	600
		282834	12	780
		10974	16	1585
15	608			
		608	16	638

```
Do you want to view the amount of material
needed in each FILL SECTION?
(Y..!..N or an option)Y

=====================================================
You need to transfer the amount of material
from CUT SECTIONS to FILL SECTIONS as shown below:
```

Section no.	amount needed C. metres	amount transported	from section
2	21579		
		21579	1
4	143698		
		117487	1
		8111	3
6	256283		
		136552	7
		43542	11
		76189	BORROW
8	56422		
		56422	11
10	61421		
		61421	11
12	282834		
		282834	13
14	21295		
		21295	13
16	148732		
		10974	13
		608	15

```
How many DAYS is the contract time?
(0..10000, ! if not known  or an option)  20


 How many days each week do you work?
Is it:
------
       1) Less than five days.
       2) Five days.
       3) more than five days.
      (1..3, ! if not known  or an option)  2


How many hours per day do you work?
Is it:
-----
     1) Less than eight hours.
     2) Eight hours.
     3) More than eight hours.
     (1..3, ! if not known  or an option)  2

 >> From the site tests.

    Can you tell me whether the soil moisture
    content is:

            1) less than  30 percent,
            2) 30 to  35 percent, or
            3) more than  35 percent ?
        (1..3, ! if not known  or an option)  1

 >> This question is about the ROCK SIZE and you
    will find it easier if you go back to the site
    test report.
    Are you able to tell me whether the size of
    the rock is:

            1) less than  6 Centemetres,
            2) between  6 and  12 Centemetres, or
            3) more than  12 Centemetres
         (1..3, ! if not known  or an option)  1


 >> This question is aimed to find  out whether
    it is possible to hire plant. Please tell me if
    you can hire a plant?
    (Y..!..N or an option)  y
```

```
 >> This question is about whether you have got
    your own plant and if you intend to use them?
   (Give a reply of ! if you do not know)

    Please tell me if you own your plant?
   (Y..!..N or an option)  y

=======================================================
REPORT:
------
To transport material from section 1 to section 2.

***Single engine conventional scraper, is recommended.

   Because the task is mass excavation, material size
   is  less  than 30 centimetres,the soil moisture  is
   less  than 20%,  the gradient is less than 12%  and
   the haul distance is less than (1.6) kilometre.
   If  any of these assumptions are wrong  please  run
   the program again.
========================================================

========================================================
REPORT:
------
To transport material from section 3 to section 4.

***Single engine conventional scraper, is recommended.

   Because the task is mass excavation, material size
   is  less  than 30 centimetres,the soil moisture  is
   less  than 20%,  the gradient is less than 12%  and
   the haul distance is less than (1.6) kilometre.
   If  any of these assumptions are wrong  please  run
   the program again.
========================================================

========================================================
REPORT:
------
To transport material from section 7 to section 6.

***Single engine alleviating scraper, is recommended.

   Because the task is mass excavation, material size
   is  less  than 30 centimetres,the soil moisture  is
   less  than 20%,  the gradient is less than 12%  and
   the haul distance is less than (1.6) kilometre.
   If  any of these assumptions are wrong  please  run
   the program again.
========================================================
```

```
===========================================================
REPORT:
------
To transport material from section 11 to section 10.

***Single engine conventional scraper, is recommended.

   Because the task is mass excavation, material size
   is  less  than 30 centimetres,the soil moisture  is
   less  than 20%,  the gradient is less than 12%  and
   the haul distance is less than (1.6) kilometre.
   If  any of these assumptions are wrong  please  run
   the program again.
===========================================================

===========================================================
REPORT:
------
To transport material from section 13 to section 14.

***Single engine conventional scraper, is recommended.

   Because the task is mass excavation, material size
   is  less  than 30 centimetres,the soil moisture  is
   less  than 20%,  the gradient is less than 12%  and
   the haul distance is less than (1.6) kilometre.
   If  any of these assumptions are wrong  please  run
   the  program again.
===========================================================

===========================================================
REPORT:
------
To transport material from section 13 to section 12.

***Single engine conventional scraper, is recommended.

   Because the task is mass excavation, material size
   is  less  than 30 centimetres,the soil moisture  is
   less  than 20%,  the gradient is less than 12%  and
   the haul distance is less than (1.6) kilometre.
   If  any of these assumptions are wrong  please  run
   the program again.
===========================================================
```

```
============================================================
REPORT:
------
To transport material from section 13 to section 16.

***Single engine conventional scraper, is recommended.

   Because the task is mass excavation, material size
   is  less  than 30 centimetres,the soil moisture  is
   less  than 20%,  the gradient is less than 12%  and
   the haul distance is less than (1.6) kilometre.
   If  any of these assumptions are wrong  please  run
   the program again.
============================================================

============================================================
REPORT:
------
To transport material from section 15 to section 16.

***Single engine conventional scraper, is recommended.

   Because the task is mass excavation, material size
   is  less  than 30 centimetres,the soil moisture  is
   less  than 20%,  the gradient is less than 12%  and
   the haul distance is less than (1.6) kilometre.
   If  any of these assumptions are wrong  please  run
   the program again.
============================================================



 Do you want to view the different types of
SINGLE ENGINED SCRAPERS which will carry
out the task?(Y..!..N or an option)  y
```

SINGLE ENGINED SCRAPERS

manufacturer	model	kw	capacity struck cubic metre	capacity heap C. metre
Caterpillar				
	613B	112	----	15.30
	623B	246	----	16.80
	633D	336	----	33.60
	613	112	----	8.40
	633C	309	----	24.50
Fiat Allis				
	161	171	-----	11.60
	261B	242	-----	17.50
Terex	S11E	107	-----	8.40
	S35E	341	-----	26.80
International	412B	51	-----	8.40
	442B	243	-----	16.80
JHON DEER	JD862	186	------	12.23
	JD762	142	------	8.40
	JD860A	170	------	11.50

REPORT:

To transport material from section 1 to section 4.

**hydraulic excavator and trucks are recommended.
Because the task is mass excavation, material size is less than 30 centimetres,the soil moisture is less than 30%, the gradient is less than 12% and the haul distance is greater than (1.6) kilometre.
If any of these assumptions are wrong please run the program again.

```
==========================================================
REPORT:
------
To transport material from section 11 to section 8.

**hydraulic excavator and trucks are recommended.

   Because the task is mass excavation, material size
   is  less  than 30 centimetres,the soil moisture  is
   less  than 30%,  the gradient is less than 12%  and
   the haul distance is greater than (1.6) kilometre.
   If  any of these assumptions are wrong  please  run
   the program again.
==========================================================

==========================================================
REPORT:
------
To transport material from section 11 to section 6.

**hydraulic excavator and trucks are recommended.

   Because the task is mass excavation, material size
   is  less  than 30 centimetres,the soil moisture  is
   less  than 30%,  the gradient is less than 12%  and
   the haul distance is greater than (1.6) kilometre.
   If  any of these assumptions are wrong  please  run
   the  program again.
==========================================================


Do you want me to continue on advising on
selecting the machines?(Y..!..N or an option)y


*** Having decided on TYPE OF MACHINE we are going to
    choose the suitable MAKE and number of
    MACHINES and HAUL UNITS to carry on the task.


How many DAYS is the contract time?
(0..10000, ! if not known  or an option)  20


 How many days each week do you work?
Is it:
------
       1) Less than five days.
       2) Five days.
       3) more than five days.
    (1..3, ! if not known  or an option)  2
```

```
How many hours per day do you work?
Is it:
-----
     1) Less than eight hours.
     2) Eight hours.
     3) More than eight hours.
(1..3, ! if not known  or an option)  2


 Do you want to view the number of machines that
can carry out the task?(Y..!..N or an option)  y

 The  following  table shows the different  types  and
 number of machines will carry on the task within the
 time avaialble to the project:
```

Section no.	Amount cubic metres	Amount transported C. metres	to section	Haul distance metres	Equipment type	Number	Time days
1	139066	21579	2	705	a)Single engined scraper 16 Cm.	4	50
					b)Single engined scraper 24 Cm.	2	50
		117487	4	1905	Hydraulic excavator 2 Cm bucket.	2	
					and 24 Cm trucks.	13	50
3	8111	8111	4	695	a)Single engined scraper,16 Cm.	4	10
					b)Single engined scraper 24 Cm.	2	10
5	0						
7	136552	136552	6	750	a)Single engined scraper 16 Cm.	10	50
					b)Single engined scraper 24 Cm.	6	50
9	0						
11	161385	61421	10	598	a)Single engined scraper 16 Cm.	4	14
					b)Single engined scraper 24 Cm.	2	14
		56422	8	1198	Hydraulic excavator. 2 Cm bucket.	1	14
					Dump trucks 20 Cm.	4	14
		43542	6	2714	Hydraulic excavator. 2 Cm bucket.	1	14
					Dump trucks 20 Cm.	8	14
13	315103	21295	14	600	a)Single engined scraper 16Cm.	5	14
					b)Single engined scraper 24 Cm.	3	14
		282834	12	780	a)Single engined scraper 16 Cm.	6	120
					b)Single engined scraper 16 Cm.	10	90
					c)Single engined scraper 24 Cm.	10	70
		10974	16	1585	a)Single engined scraper 16 Cm.	6	10
					b)Single engined scraper 24Cm.	4	10
15	608	608	16	638	Single engined scraper 16 Cm.	3	3

```
That is the END OF THE EXPERT SYSTEM
Do you want to:
      1- Restart the consultation,
                                         or
      2- End this consultation ?
(1..2, ! if not known  or an option)2


 OK THAT IS THE END OF THIS CONSULTATION,
                HAVE A GOOD DAY.
```

APPENDIX (D)

Survey of Expert Systems Building Tools (Shells)

EXPERT SYSTEM BUILDING TOOLS (SHELLS)

Expert Systems are primarily aimed at symbolic processing and many of the development tools do not provide sufficient computational capabilities to satisfy the requirements of a particular application. Interfaces to data bases and external programs, as well as features to facilitate the development of a good end-user interface are also required in systems design. The majority of available tools do not provide all above capabilities. Software reviews on various knowledge-based system development tools for their suitability to develop Civil Engineering applications have been presented in the literature [78,79, 195]. Even though some of the tools claim to have all the desired features, they often turn out to be seriously limited. This is why the suitability of each tool has to be evaluated on the basis of experience gained in developing prototype applications. In this section 14 Expert Systems Building Tools (Shells) are evaluated.

1- **SAVOIR**

Developed by ISI Ltd., UK: it is a flexible Rule-based (IF THEN) expert system building tool written in Pro-Pascal programing language.

SAVOIR, creates a knowledge base source file written in it's knowledge representation language, using an editor e.g WordStar, the recent version has it's own build in editor.

The source file is compiled by running the compiler " SCOMP" which checks for syntex errors, produces an object code knowledge file and a compilation listing.

Variables in the knowledge base are checked by running the programme "PV", which initialise the Prior Value of the variables and check for logical errors.

The consultation starts by running the Run-Time programme "RT" using forward and backward chaining to search through the knowledge base.

SAVOIR is equipped to deal with both classical logic and uncertain reasoning. It also handle simple calculations, and can access an external programs provided they are written in Pro-Pascal and included in it's "Trap Handler".

The rules, questions and actions are easy to code and enter, once the knowledge engineering process of formulating the rules has been completed. Some times the knowledge representation can be lengthy.

2- EXPERTECH "Xi"

Developed by Expertech Ltd. Uk: it is a rule based expert system building tool based on a backward chaining strategy.

The knowledge base can be prepared as a text file using a text editor and read into Xi. Alternatively, knowledge can be input interactively within the Toolkit. The knowledge base can be saved in its parsed and its text form, there is no compiler and the text format source knowledge is converted on entry to another indexed form for use and storage.

Rules in Xi can very easily be entered in the interactive "toolkit" mode, which checks each statement's syntax before adding it to the knowledge base. Rules are easy to write .

3- **ESP/ADVISOR**

Developed by Expert Systems International, UK.: it is a rule based expert system building tool, based on a backward chaining strategy.

The knowledge engineer creates a knowledge base source file using an editor. This file contains the relevant domain knowledge written in the ESP/ADVISOR knowledge representation language.

The knowledge source is compiled by running the "KRL" programme, then the consultation is started by running the "ESP" programme.

The knowledge base is quite easy to put together. Additions to the knowledge can be easily inserted wherever required.

4- **APES**

Developed by Logic Based Systems Ltd., UK: it is a rule based expert system building tool written in Micro-Prolog, based on the matching search strategy of top to bottom through the knowledge base.

Once the APES environment has been entered, the user can load previously created knowledge bases, further APES models or create a new knowledge base using the APES "add" and "edit" utilities. The process of adding knowledge , editing it and querying it are all carried out interactively by the Micro-Prolog interpreter.

Prolog is extremely flexible and powerful, but arguably difficult to use. The facilities provided by APES are sufficient to create an expert system, but the utilities provided to create and arrange the knowledge base are complex, and slow.

The knowledge base is interpreted not compiled. All knowledge base models are stored in Micro-Prolog and interpreted into sentence format when output either as questions or listings. Validity checks on the knowledge syntax are made as the statements are entered.

5- **TESS**

Developed by Helix Expert System, UK: it a Rule-Based expert system building tool, based on Backward chaining strategy.

A knowledge base is created as a source file written in the TESS knowledge representation language using an editor, e.g. WordStar.

The knowledge representation is essentially a Baysian inference network, but the goals, rules, facts and questions are stored in a predicate format, and predicate argument values can be returned to make true solution statement.

The consultation can be started with "menu rule" which allows the user to select which main portion of the inference network should be investigated. once the main line of enquiry has been chosen the system tries to establish the validity of the top level "enquiry rule". As it does so "answer rules" will be proved or disproved and their associate answer text will be output as appropriate.

6- **EX-TRAN 7**

Developed by Intelligent Terminals Ltd., UK: it is a rule based expert system building tool, based on forward chaining strategy written in FORTRAN77.

There are two main components; the "Driver" which is the inference engine, and the "Acl-Tran" which is a rule induction system.

Acl-Tran is an interactive tool for entering examples of decisions from the domain, and inducing rules from them, which can be output in Fortran code. Rules can also be entered directly if desired.

The Driver runs the expert system consultation session. It uses an overall controlling script, the "Problem Text File", to determine the organisation of the compete knowledge base, and supply natural language text for the questions and answers.

The ability to induce rules from a set of examples makes creating knowledge bases in suitable domains extremely easy. A lot of care will still need to be exercised when using the rule induction system to ensure that example tests and hence the rules are complete and accurate.

7- **KESS " Knowledge Engineering System"**

Developed by Software Architecture and Engineering Inc., USA: it is a rule based expert system building tool based on backward chaining strategy.

A knowledge base source file is created using standard text editor, then the KES environment is entered, invoking the appropriate logic subsystem for the named knowledge base source file. KES checks for syntax error, and performs a consultation session if none are found.

Kes BAYS is a very pure implementation of Bay's theorem. It ensures that the user remains faithful to the central assumptions that the set of possible results, or hypotheses, is exhaustive and mutually exclusive.

There is no separate compiler for the system, the knowledge base is parsed and checked every time the KES system is entered.

The creation and editing of the knowledge base is quite easy as it is done using standard text editors. The main problem encountered when trying to develop a knowledge base for the first time was debugging the language syntax.

The system can be linked to any software through KBA. A special communications file allows parameters to be passed between KES and an external programme. Data can be read from and written to the external file.

8- **ENVISAGE**

developed by Systems Designers Plc., UK: It is a rule based shell based on the forward chaining strategy.

The knowledge source file can be created using the Vax editor, then the knowledge source file is compiled.

The main components of the shell network are goals, rules and questions. The rules are evaluated their associated rules. The rules are evaluated using using values passed from their antecedent rules and questions.

It is quite easy to code and enter most of the facts, rules and procedures There is enough flexibility in the shell to tacle any given problem in a number of ways.

External functions can be written. They have to be declared in the Model Area at the head of the knowledge base.Any variable type can be passed to and from the external function, which should be written in Pascal.

9- **KEE (Knowledge Engineering Environment)**

Developed by IntelliCorp, USA: it is a rule and frame based shell based on forward and backward chaining written in LISP.

KEE is a large, flexible, and powerful expert system building tool. It has many features and can be extended by the user.

Procedural knowledge written in LISP can be attached to the slots in the frame representation. It is interfaced to the user through graphics, and its line of reasoning for reaching a conclusion can be displayed graphically.

KEE can be used effectively only by experienced knowledge engineer.

10- **ART, (Automated Reasoning Tool)**

Developed by Inference Corporation, USA: It is a rule based expert system building tool based on both forward and backward chaining , written in LISP.

It is consist of four parts: a knowledge language, a compiler for transforming the knowledge into LISP, an inference mechanism and a development environment.

ART can be used effectively only by an experienced knowledge engineer.

11- **EXPERT-EASE**

Developed by expert Software International, USA: it is a rule based expert system building tool based on both forward and backward chaining written in PASCAL.

The knowledge is created by inputing examples through a matrix of attributes and generic recommendations for a decision-making problem. It generates a procedure for solving the problem and a decision tree representing the procedure.

EXPERT-EASE cannot handle complex mathematical operations, and cannot be linked to external programs.

12- **M.1**

Developed by Teknowledge Inc. USA: it is a rule-based expert system building tool based on both forward and backward chaining strategy, written in PROLOG.

The knowledge base can be created using an editor such as a

WordStar. It cannot handle complex mathematical operations, and cannot be linked to external programs.

13- **RULEMASTER**

Developed by Radian Corporation, USA: it is a rule-based and induction (from examples) expert system building tool, based on both forward and backward chaining strategy written in C language.

The knowledge source file can be compiled into C.

14- **INSIGHT 2+**

Developed by Level Five Research USA: it is a rule-based expert system building tool based on both forward and backward chaining, written in PASCAL.

Knowledge bases can be created using a provided text editor, these are compiled before execution. This means high speed of execution which is important for the problem solution. The compiler checks the syntax of the source code.

The shell is easy to use and allows easy integration with algorithmic programs written in PASCAL, also it can access data bases.

SUMMARY

Some of the software tools currently availabile in the market to assist expert systems development are evaluated for the possibility of building models applicable to construction industry. Rule-based shells have limitations in knowledge representation and for large scale developments. The combination of frames and rules is desirable for construction engineering applications. Access to external programs and data bases was found to be necessary in designing expert systems.

In the future expert systems shells will perhaps be developed for a class of problems, e.g. diagnosis, interpretation, etc. It is important to note that the shells developed so far are most suitable for the solution of diagnosis problems. They cannot be used directly for the solution of planning or design problems. Shells can be appropriately developed only for a particular class of design problems.

Tables (D1 and D2) shows a list of the evaluated shells.

Name of the Shell	Knowledge Representation	Inference Mechanism	Computational Capabilities	Access External Programs and Data Bases	Type Of Computer Required
Ops5	Production Rules	Forward Chaining	Simple Arithmetics	Not available	Micro
Guru	Production Rules	Forward Chaining Backward Chaining	Simple Arithmetics	Integrated	Micro
Pc Plus	Production Rules	Backward Chaining	Simple Arithmetics	Data Base	Micro
Goldworks	Frames and Production Rules	Forward Chaining Backward Chaining	Simple Arithmetics	Data Base and Lotus-123	Micro With Minimum 5mb Ram
M.1	Production Rules	Backward Chaining	Simple Arithmetics	Not available	Micro
Savoir	Production Rules	Forward Chaining Backward Chaining	Simple Arithmetics	Available in Pro-pascal	Micro
Xi	Production Rules	Forward Chaining	Simple Arithmetics	Not available	Micro
Esp	Production Rules	Forward Chaining	Simple Arithmetics	Available in Prlog	Micro
Apes	Production Rules	Forward Chaining Backward Chaining	Simple Arithmetics	Available in Prlog	Micro
Vp	Production Rules	Forward Chaining Backward Chaining	Simple Arithmetics	Available	Micro
Leonardo	Frames and Production Rules	Backward Chaining	Simple Arithmetics	Available	Micro

Table D1
Expert Systems Building Tools (Shells)
(part one)

Name of the Shell	Knowledge Representation	Inference Mechanism	Computational Capabilities	Access External Programs and Data Bases	Type of Computer required
Tess	Production Rules	Backward Chaining	Simple Arithmetics	Not available	Micro
Ex-tran 7	Production Rules	Forward Chaining	Simple Arithmetics	Available in Fortran	Micro
Kes	Production Rules	Backward Chaining	Simple Arithmetics	Link to any Software	Micro
Sage	Production Rules	Backward Chaining	Simple Arithmetics	Not available	Micro
Expert	Production Rules	Backward Chaining	Simple Arithmetics	Not available	Main Frames
S.1	Production Rules and Objects	Forward Chaining Backward Chaining	Simple Arithmetics	Data Base in Lisp	Main Frames
Kee	Production Rules and Frames	Forward Chaining Backward Chaining	Simple Arithmetics	Available in Lisp	Main Frames
Expert-Ease	Examples	Forward Chaining Backward Chaining	Simple Arithmetics	Not available	Micro
Rulemaster	Production Rules	Backward Chaining	Simple Arithmetics	Not available	Micro
Insight 2+	Production Rules and Objects	Forward Chaining Backward Chaining	Simple Arithmetics	Available in Pascal	Micro

Table D2
Expert Systems Building Tools (Shells)
(part two)

APPENDIX (E)

Sample of External Programs Linked to ESEMPS

External Programs Linked to ESEMPS:

One of the important features of an Expert System is the ability to access external programs, in order to perform complex calculations.

ESEMPS, is linked to external programs included in the "Trap Handler" provided by "Savoir". These are called external functions, for example, one function converts numbers to probabilities, so that numerical methods can be used to calculate probabilities. Another can be used to define simple fuzzy logic mapping function.

Other different programs written in Pascal code are written to perform calculations, search data-bases, and return values to ESEMPS as answer to particular questions.

```
(*-----------------------------------------------------------------*)
(*------------------------ External Programs ---------------------*)
(*-------------------------- Included in the ---------------------*)
(*----------------------- Trap Handle Unit -----------------------*)
(*------------------------ Within Savoir Package -----------------*)
(*    This unit must implement the functions definition given in
       the head of any model which uses it

Functions
    CertFun(Prob):Num
    Cond_Prob(Cond,Num):Prob                    [ Second Param is Prior ]
    NumProb(Num,Num):Prob                       [ Second Param is Prior ]
    ProbNum(Prob):Num
    Member(Num, Num, Num, Num, Num, Num):Prob   [ Second Param is Prior ]
    Votes(Any):Cond                             [ First Param is Numeric ]
    Cat(String, String):String
    DefineWindow(Num,Num,Num,Num,Num,Cond,Num,Num,Num,Num,Num,Cond):Null
    Del_file(String):Null
    Int_Part(Num):Num
    Round_up(Num):Num
    Gmod(String):Null
    Retrieve_num(String,Num):Num
    Retrieve_string(String,Num):String
    Store_cycle_time(String,Num):Null
    Retrieve_cycle_time(String,Num,Num,Num):Num
*)

SEGMENT Trap;

        (*$I USERDEFS.PAS *)

        Var TrapState: I_Possibility;
                (* Local To Trap but always Available *)
                (* Set immediately before TrapHandle Call *)

        (*$I STACK.EXP *)
procedure makewindow(index,w,h,x,y : integer;border,paging : Boolean;
 bordcol,bordlinecol,backcol,forecol,protcnt : integer); external;

(* NOTE: The first 3 procedures - OBTAINPRIOR, OBTAINPARAMCOUNT and
ISUNKNOWN are utilites that might be useful for writing other external
functions for SAVOIR *)

Function ObtainPrior: Real;   (* Pops a passed prior probability *)
Var PriorProb: NumPair;
                 Function AdjustPrior(P:Real):Real;
                 Begin
                       If (P = UnknownReal) Or
                          (P < 0.0) Then AdjustPrior:= 0.0
                  Else If (P > 1.0) Then AdjustPrior:= 1.0
                      Else              AdjustPrior:= P;
                 End;
```

Sample of External programme Linked to ESEMPS

```
Begin
    PopNum(PriorProb);
    With PriorProb Do
      Begin
          LowValue:= AdjustPrior(LowValue);
          HighValue:= AdjustPrior(HighValue);
          ObtainPrior:= (HighValue + LowValue)/2;
      End;
End;

Function ObtainParamCount: Integer;  (* Pops param count for Any *)
Var ParamCount: NumPair;
Begin
    PopNum(ParamCount);
    ObtainParamCount:= Trunc(ParamCount.HighValue);
End;

Function Is_Unknown(Var Np: NumPair): Boolean;
Begin
    Is_Unknown:= (Np.LowValue = UnknownReal) Or
                 (Np.HighValue = UnknownReal);
End;

Procedure CertFun;   (* CERTFUN (PROB) : NUM *)
Var Prob_Param: ProbTriple;
    Result:Num_Pair;
         Function HalfCertFun(Actual, Pr_Prob:Real):Real;
        Begin
            If Actual > Pr_Prob Then
            HalfCertFun:= ((Actual - Pr_Prob)/(1.0 - Pr_Prob)) * 5.0
            Else HalfCertFun:= ((Actual - Pr_Prob)/(Pr_Prob)) * 5.0;
          End;   (* Half Cert Fun *)
Begin (* CertFun *)
      PopProb(Prob_Param);
      With Prob_Param Do
          Begin
              Result.Low_Value:= HalfCertFun(Min_Prob, PriorProb);
              Result.High_Value:= HalfCertFun(Max_Prob, PriorProb);
          End;
      PushNum(Result);
End;    (* Cert Fun *)

Procedure Cond_Prob;  (* Cond_Prob(Cond, Num) : Prob *)
Var Cond_Param:Cond;
    Result:Prob_Triple;
Begin
    Result.PriorProb:= ObtainPrior;
    PopCond(Cond_Param);
    With Result Do
```

```
        Begin
             Case Cond_Param Of
                 True_Value: Max_Prob:= 1.0;
                False_Value: Max_Prob:= 0.0;
                 Unknown   : Max_Prob:= Prior_Prob;
              End;
             Min_Prob:= Max_Prob;
        End;
    PushProb(Result);
End;

Procedure NumProb;   (* NumProb(Num, Num): Prob *)
Var Result: ProbTriple;
    InputNumber: NumPair;

    Function Adjust(N:Real):Real;    (* Ensures that N is in [0..1] *)
    Begin
        If N > 1.0 Then Adjust:= 1.0
   Else If N < 0.0 Then Adjust:= 0.0
      Else              Adjust:= N;
    End;

Begin
    Result.PriorProb:= ObtainPrior;
    PopNum(InputNumber);

    With Result, InputNumber Do
       Begin
           If Is_Unknown(InputNumber) Then
                Begin
                    MaxProb:= PriorProb;
                    MinProb:= PriorProb;
                End
         Else   Begin
                    MaxProb:= Adjust(HighValue);
                    MinProb:= Adjust(LowValue);
                End;
       End;

    PushProb(Result);
End;

Procedure ProbNum; (* ProbNum(Prob):Num *)
Var InputProb: ProbTriple;
    OutputNum: NumPair;
Begin
    PopProb(InputProb);
    With InputProb, OutputNum Do
      Begin
          HighValue:= MaxProb;
          LowValue:=  MinProb;
      End;
    PushNum(OutputNum);
End;
```

```
Procedure Member;
Var X1, X2, X3, X4, V, InputPrior,
                      FirstResult, SecondResult: NumPair;
   ResultProb:Probtriple;

   Procedure Ramp(LeftParam, RightParam, V:NumPair; Var Res:NumPair);

       Function HalfRamp(LeftHalf, RightHalf, V:Real):Real;
       Begin
             If V <= LeftHalf then HalfRamp:= 0.0
        Else If V >= RightHalf Then HalfRamp:= 1.0
           Else      HalfRamp:= (V - LeftHalf)/(RightHalf - LeftHalf);
       End;      (* HalfRamp *)

   Begin      (* Ramp *)
      If LeftParam.HighValue > RightParam.HighValue
                       Then LeftParam.HighValue:= RightParam.HighValue
      Res.LowValue:= HalfRamp(LeftParam.HighValue,
                             RightParam.HighValue, V.LowValue);

      If RightParam.LowValue < LeftParam.LowValue
                         Then RightParam.LowValue:= LeftParam.LowValue
      Res.HighValue:= HalfRamp(LeftParam.LowValue,
                              RightParam.LowValue, V.HighValue);
    End;       (* Ramp *)

Begin     (* Member *)
    PopNum(X4);
    PopNum(X3);
    PopNum(X2);
    PopNum(X1);
    ResultProb.PriorProb:= ObtainPrior;
    PopNum(V);

    If Is_Unknown(V) Or
         Is_Unknown(X1) Or
         Is_Unknown(X2) Or
         Is_Unknown(X3) Or
         Is_Unknown(X4) Then
      Begin
          ResultProb.MaxProb:= ResultProb.PriorProb;
          ResultProb.MinProb:= ResultProb.PriorProb;
      End
 Else
      Begin
          Ramp(X1, X2, V, FirstResult);
          Ramp(X3, X4, V, SecondResult);

          With ResultProb Do
            Begin
               MaxProb:= 1.0 - SecondResult.LowValue;
               MinProb:= 1.0 - SecondResult.HighValue;
               If MinProb > FirstResult.LowValue
                                Then MinProb:= FirstResult.LowValue;
               If MaxProb > FirstResult.HighValue
                                Then MaxProb:=FirstResult.HighValue;
              End;
```

```
     End;
    PushProb(ResultProb);
End;                    (* Member *)

Procedure Votes;    (* Votes(Any):Cond     First param is Numeric   *)
Var I,
     ParamCount,
      TrueCount,
         FalseCount,
           IntCritical: Integer;
    Critical: NumPair;
    Result, ThisParam: Cond;

Begin   (* Votes *)
    ParamCount:= ObtainParamCount;
    TrueCount:= 0;              (* Zero counters  *)
    FalseCount:= 0;

    For I:= 1 to ParamCount - 1 Do  (* last param is critical number *
       Begin
           PopCond(ThisParam);
           If ThisParam = TrueValue Then TrueCount:= TrueCount + 1
      Else If ThisParam = FalseValue Then FalseCount:= FalseCount + 1;
       End;

     PopNum(Critical);
     If (Critical.HighValue = UnknownReal) Or
        (Critical.LowValue  = UnknownReal) Then Result:= Unknown
  Else
        Begin
            If TrueCount >= Critical.HighValue Then Result:= TrueValue
       Else If FalseCount > (ParamCount - 1 - Critical.LowValue)
                                        Then Result:= FalseValue
          Else Result:= Unknown;
        End;

      PushCond(Result);
End;    (* Votes *)

Procedure Cat;
Var S1, S2:E2String;
    I, L:Integer;


Begin
    PopString(S2);
    PopString(S1);
    If (S1.StringLength > StringMax) Or
       (S2.StringLength > StringMax) Then
                S1.StringLength:= StringMax + 1
```

```
 Else
     Begin
          L:= S2.StringLength;
          If L + S1.StringLength > StringMax Then
                L:= StringMax - S1.StringLength;
          For I:= 1 to L Do
             S1.StringChars[S1.StringLength + I]:= S2.StringChars[I];
          S1.StringLength:= S1.StringLength + L;
     End;
    PushString(S1);
End;

Procedure DefineWindow;
var index,w,h,x,y,bordcol,bordlinecol,backcol,forecol,protcnt : integer
    paging, border : Boolean;

function obtainparam(lo,hi : integer) : integer;
var n : numpair;
    temp : real;
begin
  popnum(n);
  if is_unknown(n) then obtainparam := hi
  else begin
    temp := (n.highvalue + n.lowvalue)/2;
    if temp > hi then obtainparam := hi
    else if temp < lo then obtainparam := lo
    else obtainparam := round(temp);
  end;
end;

function obtaincond(default : Boolean) : Boolean;
var c : cond;
begin
  popcond(c);
  case c of
    truevalue : obtaincond := true;
    falsevalue : obtaincond := false;
    unknown : obtaincond := default;
  end;
end;

begin
   paging := obtaincond(false);
   protcnt := obtainparam(0,25);
   forecol := obtainparam(0,15);
   backcol := obtainparam(0,7);
   bordlinecol := obtainparam(0,15);
   bordcol := obtainparam(0,7);
   border := obtaincond(false);
   Y := obtainparam(1,25);
   X := obtainparam(1,80);
   H := obtainparam(1,25);
   W := obtainparam(1,80);
   index := obtainparam(1,16);
   makewindow(index,w,h,x,y,border,paging,bordcol,
   bordlinecol,backcol,forecol,protcnt);
end;
```

```
{--------------------------------------------------------------}

{ Savoir external routine to erase a text file (if it exists)  }


Procedure Del_file;

VAR afile : text;
    filename : string[12];
    s1 : E2string;
    i : integer;

BEGIN

   popstring(s1);

   filename :=  '';

   FOR i := 1 TO 12 DO insert(s1.stringchars[i],filename,i);

   IF fstat(filename) = true  THEN    {pascal library routine
       returns false if filename invalid or file of that name
                 does not exist}

 BEGIN
      Assign(afile,filename);
      Erase(afile);
   END;     {if fstat....}

END;      {del_file}

{------------------------------------------------------------------}

{ Savoir external routine to obtain integer part of a real variable}


Procedure Int_Part;   {Int_Part(Num):Num }

   Var InputNum:NumPair;
       OutputNum:NumPair;

   Begin
      Popnum(InputNum);

      If Is_Unknown(InputNum) Then

         Begin

         OutputNum.HighValue := UnknownReal;
         OutputNum.LowValue  := UnknownReal;

         End
      Else Begin

         OutputNum.HighValue := Trunc(InputNum.HighValue);
         OutputNum.LowValue  := Trunc(InputNum.LowValue);

         End;
```

```
      PushNum(OutputNum);

   End;

{-----------------------------------------------------------------}

{ Savoir external routine to round a real variable up to the
                    nearest integer}

Procedure Round_up;    {Round_up(Num):Num }

   Var InputNum:NumPair;
       OutputNum:NumPair;

   Begin
      Popnum(InputNum);

      If Is_Unknown(InputNum) Then

         Begin

         OutputNum.HighValue := UnknownReal;
         OutputNum.LowValue  := UnknownReal;

         End

      Else Begin


         OutputNum.HighValue := Trunc(InputNum.HighValue) + 1;
         OutputNum.LowValue  := Trunc(InputNum.LowValue) + 1;

         End;

      PushNum(OutputNum);

   End;

{-----------------------------------------------------------------}

     {$I MTYD.PAS }

{------------------------------------------------------------------}
{Savoire external routine to read a number from a specified line
                                                   in a text file}
Procedure retrieve_num;

LABEL 99;

VAR  wfile : text;
     wfilename : string[12];
     s1 : e2string;
     number,counter : num_pair;
     stop,i : integer;
     dum : char;
```

```
BEGIN;      {main program}

popnum(counter);  {line number of required data item in text file}
popstring(s1);    {work file name supplied by call statement}

   IF trapstate IN [prior_call,backingup,clearing] THEN
      BEGIN
      number.high_value := 5;
      number.lowvalue := 0;
      GOTO 99;
   END;     {if trapstate}

wfilename := '';

FOR i := 1 TO 12 DO insert(s1.stringchars[i],wfilename,i);

assign(wfile,wfilename);
reset(wfile);              {prepare work file for reading from}

stop := trunc(counter.high_value + 0.1);

FOR i := 1 TO stop-1 DO readln(wfile,dum);
readln(wfile,number.high_value);

number.low_value := number.high_value;

close(wfile);

99:  pushnum(number);

END;     {retrieve_num}

{-----------------------------------------------------------------}

{Savoire external routine to read a character string from a specified
                                              line of a text file}

Procedure retrieve_string;

LABEL  99;

VAR  wfile : text;
     wfilename : string[12];
     field,s1 : e2string;
     matches,stop,i : integer;
     counter : num_pair;
     s : string[80];
     b : string[1];
```

```
BEGIN;     {main program}

popnum(counter);
popstring(s1);          {work file name supplied by call statement}

   IF trapstate IN [prior_call,backingup,clearing] THEN
      BEGIN
      field.stringlength := 7;
      field.stringchars[1] := 'U';
      field.stringchars[2] := 'n';
      field.stringchars[3] := 'k';
      field.stringchars[4] := 'n';
      field.stringchars[5] := 'o';
      field.stringchars[6] := 'w';
      field.stringchars[7] := 'n';
      GOTO 99;
   END;     {if trapstate}


wfilename := '';

FOR i := 1 TO 12 DO insert(s1.stringchars[i],wfilename,i);

assign(wfile,wfilename);
reset(wfile);             {prepare work file for reading from}

stop := trunc(counter.highvalue + 0.1);

FOR i := 1 TO stop DO readln(wfile,s);

field.stringlength := length(s);

   FOR i := 1 TO field.stringlength DO
      BEGIN
      b := copy(s,i,1);
      field.stringchars[i] := b[1];
   END;

close(wfile);

99: pushstring(field);

END;    {retrieve_string}

{-------------------------------------------------------------------}

{Savoire external routine to store details of cycle time calculation}

Procedure store_cycle_time;

TYPE values = (waiting_time,loading_time,hauling_time,damping_time,
               retairning_time,job_factor,work_time,day_hour,weather,
               efficiency;
```

```
VAR  wfile : text;
     s1 : e2string;
     wfilename : string[12];
     i : integer;
     data : ARRAY[values] OF num_pair;
     name : values;

BEGIN     {main program}

   popstring(s1);      {workfile name supplied by call statement}

   wfilename := '';

   FOR i := 1 TO 12 DO insert(s1.stringchars[i],wfilename,i);

   assign(wfile,wfilename);
   rewrite(wfile);            {prepare work file for writing to}

   FOR name := hauling_time TO efficiency DO
                                   writeln(wfile,data[name].high_value)

END;

{-------------------------------------------------------------------}

{Savoire external routine to retrieve details of a past cycle
                                   time calculation from file}


Procedure retrieve_cycle_time;

LABEL  99;

VAR  wfile : text;
     wfilename : string[12];
     s1 : e2string;
     counter,avalue,high_prior,low_prior : num_pair;
     stop,i : integer;

BEGIN     {main program}

   pop_num(low_prior); {lower prior value bound supplied in
                                   call statement}
   pop_num(high_prior);   {high prior value bound}
   pop_num(counter);     {line no of required value in file}
   popstring(s1);       {work file name supplied by call statement}

   IF trapstate = prior_call THEN
      BEGIN
      avalue.high_value := high_prior.high_value;
      avalue.low_value := low_prior.high_value;
      GOTO 99;
   END;     {if trapstate}
```

```
   wfilename := '';

   FOR i := 1 TO 12 DO insert(s1.stringchars[i],wfilename,i);

   assign(wfile,wfilename);
   reset(wfile);            {prepare work file for reading from}

   stop := trunc(counter.highvalue + 0.1);

   FOR i := 1 TO stop DO readln(wfile,avalue.high_value);

   avalue.low_value := avalue.high_value;

99:   push_num(avalue);

END;      {retrieve_cycle_time}

{-----------------------------------------------------------------}
Procedure TrapHandle(TrapNo:integer);
Begin
    If TrapNo In [1..16] Then
       Case TrapNo Of
      1: CertFun;
      2: Cond_Prob;
      3: Num_Prob;
      4: Prob_Num;
      5: Member;
      6: Votes;
      7: Cat;
      8: DefineWindow;
      9: Del_file;
     10: Int_Part;
     11: Round_up;
     12: Gmod;
     13: Retrieve_num;
     14: Retrieve_string;
     15: Store_cycle_time;
     16: Retrieve_cycle_time;
     End
 Else Writeln('An Illegal Trap No has Occurred ',TrapNo);
End;

(* Called just before a call on TrapHandle *)
Procedure TrapSet(Ts:I_Possibility);
Begin
    TrapState:= Ts;
End;

(* Called by PV and RT once, when they first start up *)
Procedure TrapInit;
begin
    Writeln(' Trap Handler - 2.12.86 version');
end;

BEGIN
END.
```