A KNOWLEDGE BASED SYSTEM FOR LINKING INFORMATION TO SUPPORT DECISION MAKING IN CONSTRUCTION

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SUMMARY: *This work describes the development of a project model centred on the information and knowledge generated and used by managers. It describes a knowledge-based system designed for this purpose.*
A knowledge acquisition exercise was undertaken to determine the tasks of project managers and the information necessary for and used by these tasks. This information was organised into a knowledge base for use by an expert system. The form of the knowledge lent itself to organisation into a link network. The structure of the knowledge-based system, which was developed, is outlined and its use described.
Conclusions are drawn as to the applicability of the model and the final system. The work undertaken shows that it is feasible to benefit from the field of artificial intelligence to develop a project manager assistant computer program that utilises the benefit of information and its links.

KEYWORDS: *Knowledge acquisition, Knowledge structuring, Information link, Project Control, Knowledge-Based System, Project Managers, Decision Support Systems*

1. INTRODUCTION

Managing construction projects is a complex task and the role of a project manager lies at the heart of any project. On many, if not most projects, all parties find this difficult and turn to 'techniques' and technical experts for assistance. Artificial Intelligence is a field that potentially offers great benefits for project tasks and some of the earliest research work on the use of artificial intelligence in construction was designed to assist in this area, see for example (O'Conner et al, 1986), (Ibbs, 1988) and (Levitt and Kunz, 1988). However any attempt aimed at aiding a project manager must start by analysing the project manager's task and the project management techniques employed to help managers carry out these tasks. This is perhaps particularly important when considering AI applications, because many construction project managers do not understand the technology to be employed and consequently distrust it. Such detailed analysis enables the most important tasks to be recognised and tackled first.

A literature review revealed that there does not seem to be general agreement regarding the tasks of a project manager and so direct comparison between researchers' beliefs of what the project manager's tasks are is very difficult, see (Riggs, 1988), (RIBA, 1996) and (Tenah, 1977). However, In order to assist project managers and to assess how AI can be utilised, it is necessary to identify and define the project manager's task.
A task can be defined as the smallest measurable activity within a process, see (Pall, 1987). Others view tasks as comprising of input and an output, see (Sayle, 1991). These ideas can be extended and represented as shown in Figure 1. It can be seen that a task or tasks do not stand independently but form an integral part of a process. A process can be defined as the logical organisation of people, materials, energy, equipment and procedures into work activities designed to produce a specified end result. A process must have inputs and outputs the linkage between the process and tasks is illustrated in Figure 2.

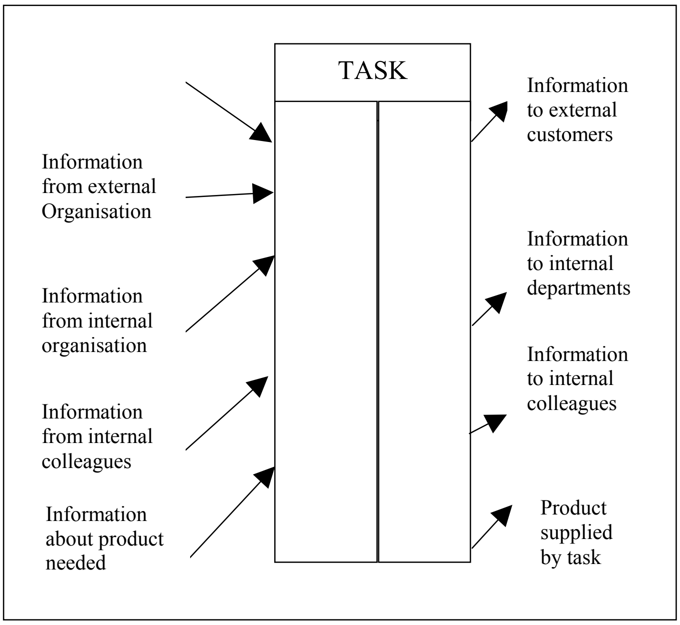

FIG.1: Input and output of a task (Adopted and modified from Sayle, 1991)

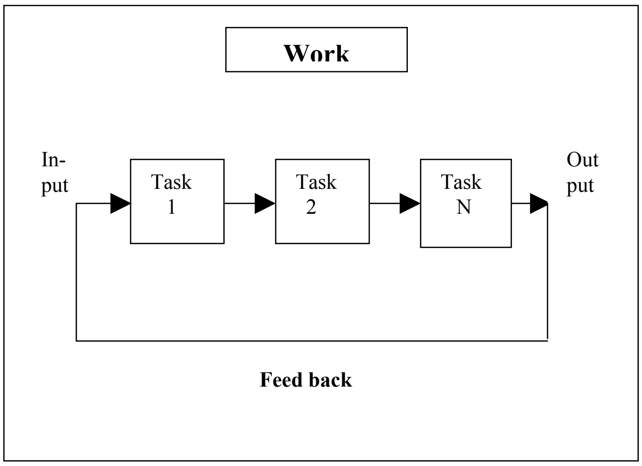

FIG.2: Linkage between process and tasks (Adopted from Pall, 1987)

Although (Pall, 1987) describes the work processes to be sequential, in reality tasks interact and can go in parallel as well as sequentially. Figure 3 illustrates a more suitable linkage between tasks in a process.

For example, in planning, it is important to know the dependency between the information and how the information flows towards the final objectives. Once the information flows are understood, monitoring and controlling the flow of information assures that the right people receive the right information at the right time. Furthermore, when a task is experiencing difficulties, or when changes are made, the root of the difficulty can be more easily identified. Thus, an understanding of any of process must be preceded by diagnosis and prescription of the elements of the process.

This concept relies on defining tasks and their requirements in order to improve process control, see (Pall, 1987) and (Drukker, 1991).

The paper described here reports on the development of a model centred on the information and knowledge generated and used by the managers. It relies on the recognition of the interdependence of the information and analyses it to generate tasks tailored to specific stages of a project. A knowledge-based system is developed to identify the interrelationship between tasks, to analyse the interdependency, to generate the tasks and to recommend corrective actions. This was then used as the basis for an intelligent decision-support system for project managers.

2. BASIC MODEL AND METHODOLOGY EMPLOYED

An initial information link model has been developed which establishes the linkage between project manager's tasks. The links between the tasks were established based on literature review and also by interviewing a small number of experts. Further, this initial link model was taken as a tool to facilitate a structured interview with experts from the construction industry. These interviews were aimed at defining tasks in terms of the information they require and the information they produce, a task being the a main building block in the basic information link model. All tasks were mapped out to define their interaction based on their information requirement. In the second phase of this research, the initial link model was then extended into a basic information link model. The process representing the development of the basic link model can be seen in figure 3. The following sections contain brief descriptions of the steps constituting this process.

2.1 The process of knowledge acquisition

The process of eliciting knowledge for this research took place in Saudi Arabia and utilised a structure interview method. The process of knowledge acquisition followed in this research comprised several steps that are described briefly in the following sections.

2.1.1 Preparatory work

This step started with a literature review and ended with a first proposal of the interrelation of the project manager's tasks (initial link information model) along with the proposed definition of the project manager's tasks.

A project is an information flow over time, though projects can be seen as one complete system that has as its input a client's request and as its output the physical project (building) as shown in figure 4. It is composed of many subsystems (tasks). These tasks are interrelated. The interrelation between tasks is a factor in the dependency of information required by a task from other tasks. In other words, each task to be performed requires information. This information forms the 'input'. When the task is performed, it produces information 'output'. The output becomes an input to a subsequent task or tasks.

The proposed interrelation of the project manager's tasks served as a basis for interviewing experts and had two main purposes: firstly, to gain experts' views about the proposed relationship of tasks, their comments on the relationship and the content of the whole structure, and secondly, to elicit the information required and produced by each task.

A three-section form was prepared. The first section 'The heading', is the title of the task. This title is made up of two further sections: the first is concerned with the project manager's function toward the task and the second is the name of the task. The second part is the information required for the task, is entitled 'Input', the third part is the 'Output' generated by the task.

A form on A4 size paper was prepared for each task. An example of a reduced size of knowledge acquisition form is shown in figure 5.

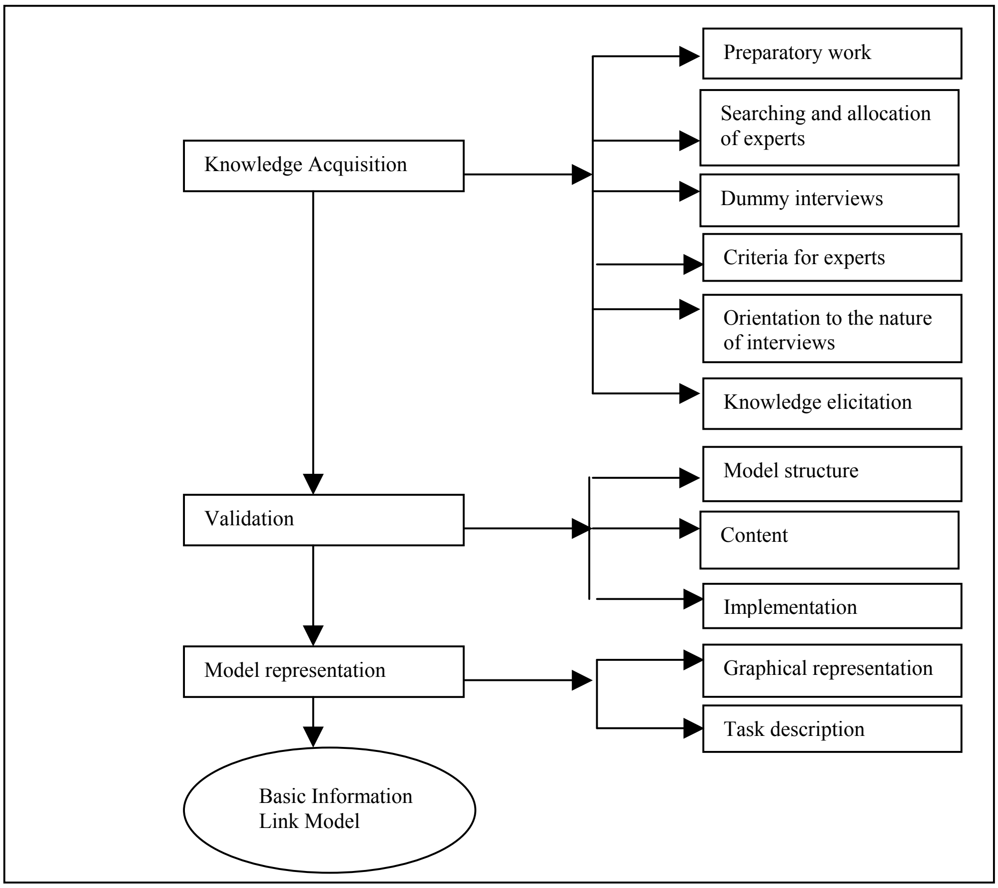

FIG.3: The development of the basic model

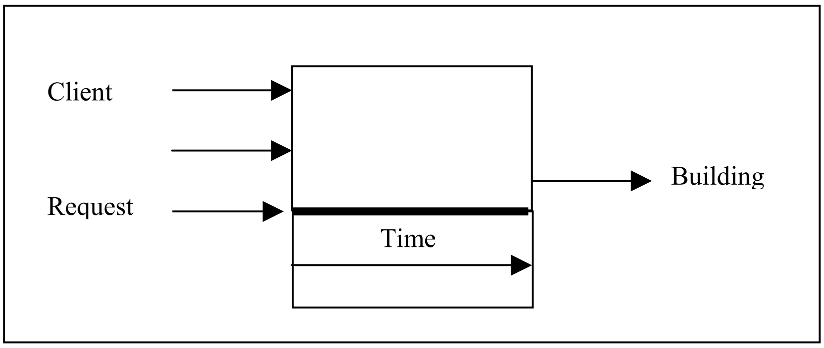

FIG.4: Information versus time

Title: Define roles of parties involved	
Input	Output
- Need for specialised expertise - Current staffing - Government regulation	- Responsibility for design - Responsibility to admit design - Responsibility to carry out special studies

FIG.5: An example of a reduced size of the knowledge acquisition form

2.1.2 Searching for and allocating experts

It is difficult to locate project mangers who have experience of all stages of a project and who have extensive experience in representing various parties within a project. It is more usual, especially in large organisations, to find managers who are proficient in certain stages or in specific disciplines within a project.

The difficulty of locating experts willing to volunteer and share their knowledge was recognised at an early stage. Using previous established contacts and sources of expertise, possible experts were searched out prior to the actual visits. A report was sent to project directors to be circulated in order to seek out proficient parties who might be interested in participating and who would be willing to be interviewed. The report consisted of the objectives of the research, the expected basic capabilities of the expert system to be developed, a suggested process for acquiring the knowledge, an explanation of how to fill in knowledge acquisition form, a list of project manager's tasks and a brief definition of the project manager's tasks.

2.1.3 Dummy interviews

In his research, Ignizio (1991) emphasises the importance in initial meetings with experts and highlights the potential gains to the knowledge engineer. He advises the following as part of a dummy interview:

- Prior to the meeting, the knowledge engineer should make an all-out effort to familiarise himself with the problem, the domain, and the terminology used within the domain.
- Locate the meeting in comfortable surroundings. Limit the duration of the meeting (such a meeting should last less than 2 hours).
- The meeting should be conducted in an informal, relaxed manner.
- Tell the expert what your plans and goals are, and explain the purpose of the system and what it can do (and cannot do) for the expert as well as the organisation.
- Explain the evolution of the expert system (in particular discuss how initial decisions, developed by early prototypes, are likely to appear).

Before the actual interviews, dummy interviews were carried out in order to assess the efficacy of the method. Two interviews were conducted unofficially and without record, for the purpose of assessing how other experts might be interviewed. Each of the dummy interviews took approximately four hours and covered only eight tasks. The following points were noted:

- The project manager's tasks totalled 55 and it was noted that each task would take in excess of 20 minutes. Therefore to interview one expert and to record the input and output of all tasks would be an extremely lengthy process.

- Interviewees were occasionally diverted from or expanded on a task under discussion. This made the process even lengthier.
- The first trials of the interviews showed that all the tasks might be more appropriate for managers and specialists who were directly involved with such tasks in their day-to-day work to be interviewed. For example, specialist managers from the 'contracting section 'should be interviewed about tasks related to the tendering process.

Based on the findings from the dummy interviews, a decision was made that it would be more appropriate to interview specialists in addition to project managers who have many years of construction experience. Specialists and managers include:

- A project manager who have many years of experience in construction projects.
- A design manager who have many years experience in managing a design department or sections.
- Senior architects, senior civil engineers, senior electrical engineers, senior mechanical engineers and senior specification writers.
- Senior cost engineers and engineers in charge of material take-off.
- Senior engineers who have experience in contracting and budget departments.
- Project planners who have long experience in planning construction projects.
- A manger with many years experience in charge of quality control/quality system.

Setting up the above criteria for experts allowed an approach to be made to the relevant departments in the organisation chosen for the interview. Experts who met the criteria were approached to obtain their willingness to participate. The agreement of individuals was obtained while orientating them to the nature of the interview.

2.1.4 Orientation to the nature of the interview

Kvale (1996), when discussing steps to qualitative interviewing advises that subjects should be briefed before the actual interview. He indicated that proper briefing is essential and is part of the validation process. This was thought to be important for this research.

Before the interviews were conducted, three days were spent in order to familiarise the experts with the nature of the interview, as well as to arrange suitable times. In total, 18 interviewees were presented with a coloured chart showing the relationship of the project manager's tasks drawn on CAD onto A2 paper. Each expert, with the exception of four senior engineers and an architect who was working at an engineering section, was given a graphical representation of the interrelationship of the tasks, and was oriented individually. The four who were working together were oriented as a group. Each orientation took approximately 45 minutes to one hour.

Following the briefing, the experts were then asked if they would participate and were willing to be interviewed. Those who responded positively were scheduled and were given a free choice of a task or tasks in which they considered themselves to be experts. Six stated that they would find it difficult to state the entire input and output of the tasks they had selected in one simple session. It was decided that the form should be completed without time restrictions and should be collected at a later date.

2.1.5 Interviewing

The orientation of the experts proved useful. Ten experts were interviewed. Other experts who preferred to complete the forms at their own pace were visited at the time they specified. The interview started immediately when the experts met for the second time. Experts were mentally prepared but all preferred their comments to be noted as they talked.

The interviews were carried out on the basis of an example of a school project to ease and aid knowledge acquisition. The content of the form was scrutinised and clarification was sought where necessary. Three experts misunderstood the intention of the form, which was designed to have two columns: an input column and an output column. These experts wrote the relevant information as the input, but missed in the second column what was intended to be generated as the output of a task, recording instead an output for a piece of information. For example, for input "interview clients" the recorded output was "for better understanding of the requirements".

2.2 Knowledge elicitation

Interpreting knowledge gained from experts is termed knowledge elicitation; see (Elizabeth, 1989). The interview described in the previous section resulted in describing each task in terms of inputs and outputs. Mapping out the tasks was done on the basis that a task generates an output, and if this output is required by another task or tasks, then the tasks are said to be interrelated. This allows all tasks to be linked by this information into a network.

The resulting model produced a chart which, when drawn out, is physically very long. (3 metres long) Although such a chart might seem a disadvantage, there are many benefits to be gained from a graphical representation on one sheet. This allows the actual user of the chart to grasp the entirety of the project with ease.

The production of the information link network was an iterative process. It includes validation of the initial information link model through experts' interviews. This resulted in some refinements and suggestions concerning the initial information link model.

The final interview took the form of a workshop and aimed to validate the basic information link model and discuss its generality. It is noted that to maintain the generic nature of the model a learning facility is included by which particular information can be specified in more detail (if necessary) by the user organisation to meet their specific practice. For example, in tasks related to the authorisation of permits and approvals each organisation has to deal with specific government authorities (regarding the fund approvals). The nature and location of the project dictate what permits would have to be obtained and from what authorities. Another example related to the tasks involved in organising the project.

Information, which defined the roles of parties, such as learning government regulations regarding Architectural Engineering (A/E), was kept very general.
Tasks fall into ten types based on their interdependency.

2.3 Validation of the model structure

The final validation of the tasks' interrelationship was performed in two workshops of three hours each. This workshop brought together six experts from the General Directorate of Military Work –Ministry of Defence – Saudi Arabia who were engaged at that time in the design of numerous projects of various types. These experts were as follows:

An architectural section head, mechanical section head, electrical section head, and structural section head, a design manager and a planning manager.

In the first workshop experts were oriented and provided with the graphical diagram of the interrelationship of the project manager's tasks.

The workshop started with an orientation to the diagram of the interrelationship, followed by a brief of what was required. The group generated written comments about the diagram. Following the receipt of the comments, an open discussion was held with the same group in order to clarify some issues.

The comments prepared by the experts stated that the structure of the model reflects the existing practice in managing projects.

It was predicted that an individual expert could not remember all the detailed characteristics of all tasks (e.g. input, output), though it was planned to elicit the knowledge at a second stage by interviewing more experts, to produce one form for each task. The form produced listed more than what one expert thought of as input and output. The method adopted has a good deal in common with Delphi technique as it is based on eliciting and refining knowledge in different locations in a repetitive manner and has the advantage of acquiring knowledge in a repetitive manner for validation purposes. Two high-grade experts made themselves available for consultations. One of them had 44 years of experience and worked with the American Corps of Engineers on Saudi projects. At this time he was working as one of the senior staff to the project director. The other worked for more than 25 years, 15 years of which were with UK government construction projects. He is currently the senior engineer in a project director's office.

A brief meeting was arranged between these two experts for them to add all their thoughts to the forms produced. Both preferred to take the same document and record their thoughts. Finally, a workshop enabled the two experts to match up their comments, including minor observations. These were then incorporated into the information link model.

3. DEVELOPING THE INTELLIGENT SYSTEM

The basic information model described above has been extended to produce a practical intelligent decision support system that would be able to support the decision making of a project manager.

The developed information model relies on defining and understanding the links between the information and the interdependencies of the tasks. It provides a good supporting management tool to a manager as it provides the logical links between the information and the ordering of how this information is exchanged and developed.

Logical links and the ordering of information are the main two ingredients for any project planning, monitoring and controlling. It is very important for any management to know the dependency of information. One of objectives of this research is to explore the feasibility of developing a decision support system, which will furnish pertinent information to the project manager. It is aimed to enhance the effectiveness of the project manger's decision-making abilities. This is possible if, as a result of the proposed system, a better understanding of the tasks, their relationships and requirements can be achieved.

Project managers utilise their knowledge to define the tasks that have to be carried out. One of the system's objectives is to assist the project manager in generating the tasks that need to be carried out. The other objective is to help the project manger to manage a project and to assist in project planning, monitoring and controlling. Decision support systems, in broad terms are computer-based systems that aid the process of decision-making and also designed to support decision-makers. Emphasis is placed on helping the decision-makers make decisions rather than actually making decisions for them.

The computer system developed in this research can be classified to share the characteristics of a knowledge-based system and a decision support system.

3.1 Knowledge Structuring

Describing how the basic information link model is interpreted manually will help in understanding knowledge structuring. The basic information link model shows the linkages between tasks based on what information is required. For the model to be used manually, the user starts at the beginning of the model at the start task. The first question he asks is if the initial or the start task has been completed? This can be answered in yes/no format. If the answer is yes, the user moves to the next linked task or tasks in the case that the task is linked to more than one other task. Every time the user answers that a task is being done, he will investigate other parallel tasks. When they all are completed, the user investigates the sequential task and the tasks, which are parallel to it.

Utilising the benefits of the model however, requires intelligence. In cases where the answer is that the task is not done, the user will investigate why. Carrying out this investigation requires investigating the output of the task (the information the task generates). In cases where there is more than one piece of information required, all pieces of information will have to be investigated. This leads to three possibilities:

- All the information is presented but there is a hold on the task. Here the user can conclude that the information required is another task, which is available.
- No information has been gathered

- Some pieces of information are complete and others are not.

In the third possibility, the user will highlight what pieces of information have been gathered, trace their flow to other tasks and investigate if other information, dependent on the completed information, has also been collected.

In order to explain the interpretation of the information links and how Artificial intelligence is applied to extend the capability of the basic information link model, it is convenient to use the analogy of a postman. This analogy can be used to explain how the basic information model is interpreted as a search space. The basic information link model is like a city map that is given to a postman. This postman's job is quite different from that of an ordinary postman; he is given a start point and his success is accomplished when he delivers the mail to every unit in the town (that is when he reaches his objectives). However, the mail (the sub-objective and objective) he delivers is not given to him in advance but rather he has to collect it from units in the town and deliver it to other units, in that he is directed to an initial starting location. The map he is given shows every unit and how it is linked to other units; these units are grouped into clusters and each cluster consists of two parts. The postman delivers mail to one part in a cluster and he has to wait and collect other mail from the second part of the cluster. The mail he collects and delivers from a cluster can all be given to him at once or at different times. However, the movement between clusters is restricted, in that he cannot use the same road back and forth. The map also shows the major road between clusters and the secondary road between units. In order to move from one location, a cluster or a unit to another the postman has to assess the status of the move. Each time the status changes, (for example there is mail ready to be delivered) the postman has to decide what road to take in each situation, although for him to perform efficiently, he has to decide in a advance the rules he will adopt in delivering mail under different situations.

Similarly, the city may represent the information link model in that:

The clusters of units represent the task
The units represent the pieces of information
The major roads represent the task-to-task links
The secondary roads represent information-to-information links
The two parts of the cluster represent the input and the output of a task

Searching the basic information link model requires the setting up of rules. Rules that guide the search problem are shown in Figure 6.

3.1.1 Simplified decision trees

Decision trees are a graphical representation of a decision process that attempts to mimic the knowledge domain of experts. When decision trees are used the inference strategy involves no search, unlike the rule-based system. However, the inference when using decision trees is achieved by following a tree from the root to a leaf (node). The basic elements of a tree are attributes and outcomes. The outcome on the leaf of the tree is reached based on the value of the attribute.

More interestingly, one characteristic of trees is that a tree can represent an attribute itself. For example, a tree that has attributes and outcomes can represent attribute 2 in Figure 7. In this case, when an attribute is encountered in a tree, if a tree represents the attribute, then the inference will move to executing this tree before returning to the original tree. This process is referred to as the backward chaining of trees and can be linked to many levels below. If an attribute does not have a corresponding tree, then the inference engine prompts for its value. When a leaf outcome is reached and this leaf is pointing to another tree, then execution moves to the new tree. This process is referred to as the forward chaining of trees.

General rules for the tasks connection

Rule No. 1

Each task has a status, which relates to its output.

Rule No. 2

IF the condition of a task is done
(this implies that the condition of all the input and output is positive)

THEN the output is already generated

IF the condition of a task is negative (not done)
(this implies one of the following) :

THEN

Rule No. 2A:

Some or all of the output is not done and /or

Rule No. 2B:

Some or all of the input is not done.

FIG.6: Rules for searching the problem space

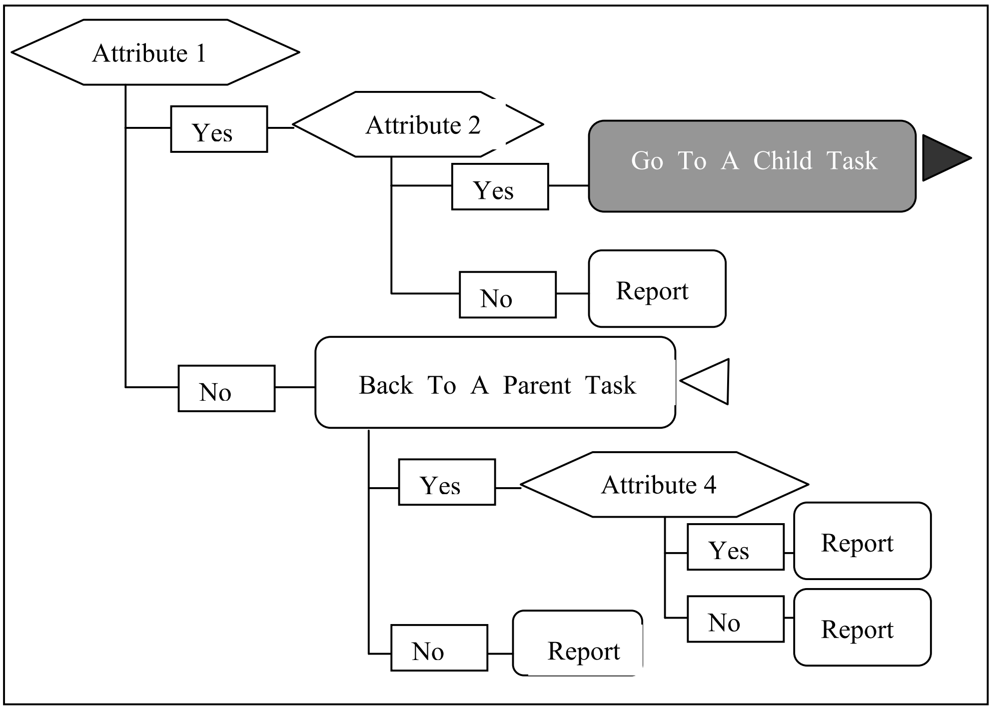

FIG.7: Decision tree

Representation using decision trees has the following features:

- It is more understandable than production rules, because of the graphical nature of its syntax and chaining strategy.
- Inference from trees can be a few orders of magnitude faster than inference using other representation. For example, it eliminates the need to search rule bases.

The main disadvantage of decision trees is that the decision tree expands exponentially. For example, when representing a task that has only four attributes, the tree will have 16 outcomes.

Some of the tasks in the basic information-linked model have more than 10 attributes as their input. The problem of the expansion of trees has been overcome by using a simplified decision tree.

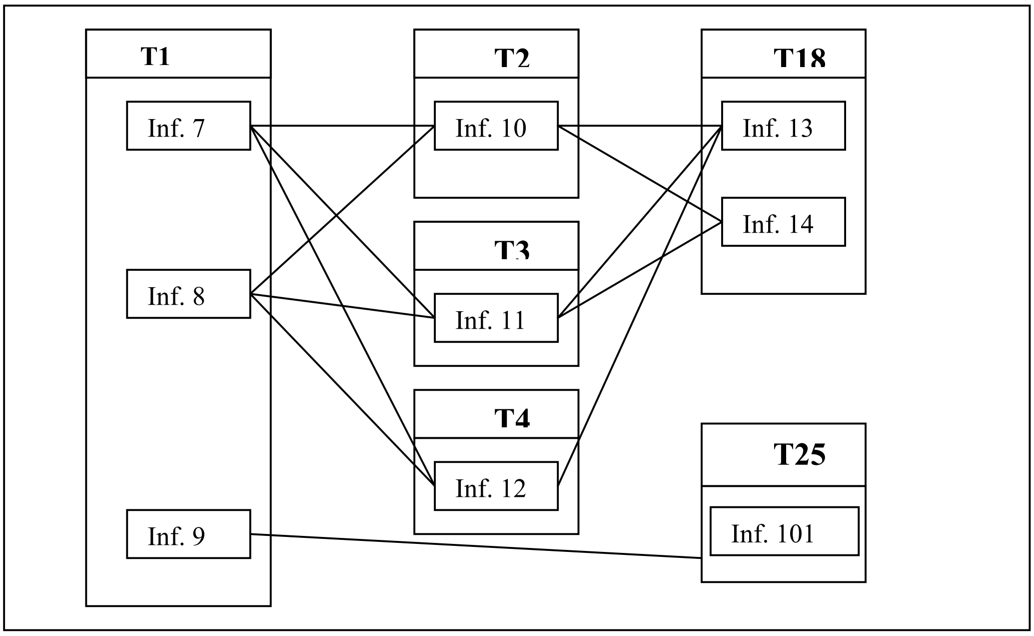

FIG:8: Types of connectors

To overcome the problem of using decision trees in relation to the expansion and use of trees, two main functions are used in this research. First, to capture the factual knowledge (facts) that is provided by the user of the system regarding the status of the tasks in the project and to discover whether or not these have been done and gathered by the system during consultation sessions. Based on the factual knowledge gathered, the second function of the decision trees is to find the most appropriate connection. At any stage of a task there are five possible connections. These connections are shown in Figure 8 and can be defined as follows:

- Type (1): Task (X) is connected to another task (Y); this only applies if the state of the task under investigation (X) shows that the task (X) has been completed.
- Type (2): Task (X) is connected to its output; this only applies if the state of the task under investigation (X) shows that the task (X) has not been completed.
- Type (3): The task is connected to its input; this only applies if the task output has not been generated (completed).
- Type (4): This connects the available output of an unfinished task to a related task or subtask.
- Type (5): This connection is activated in all cases, whenever there are no more information links to investigate. The connection leads to the generation of a report (generation).

The main advantage of the basic information links model lays in the features it offers regarding the relation of information-to-information links rather than tasks to task links. In cases where a task has not been performed, two possibilities occur: either part or all of the output generated by the task is not done or the input required by a task is not provided. However, when part of the output of a task is already done, this leads to situations where time can be saved and other possible tasks or subtasks can be completed. This is the role of the Type (4) connection. The Type (4) connector is activated only when there are finished subtasks that are required by either a task or another subtask. Grouping related information makes the Type (4) connector more effective. A simple example of how the grouping of related information is done might help clarify the need for the grouping. In this example, numbers will be used rather than tasks or subtask names to make the example simple, see figure 9**.**

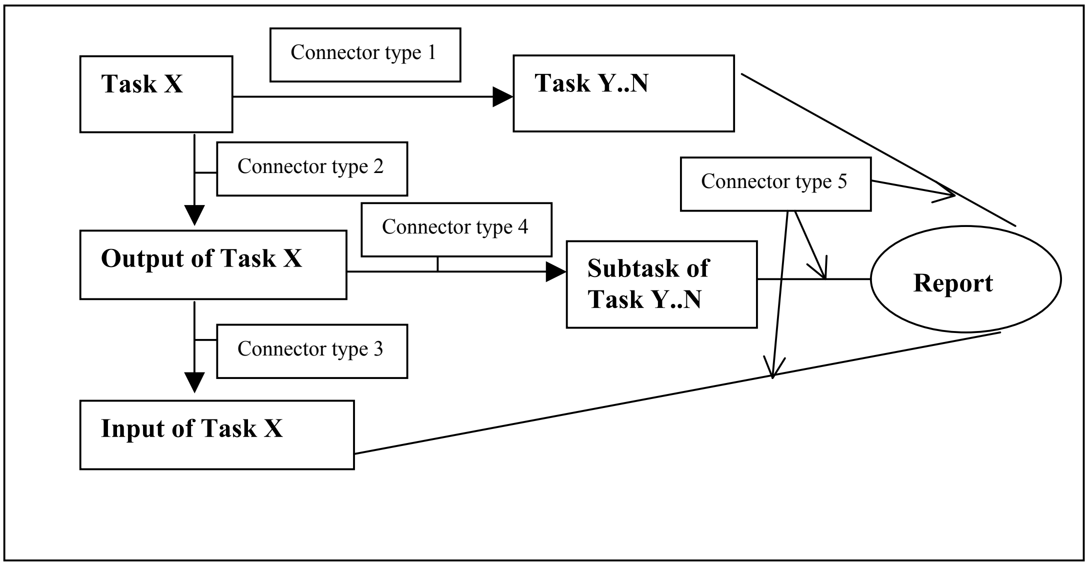

FIG.9: Grouping related information

Task 1 generates information 7, 8 and 9. Information 7 and 8 are required as an input to information 10, 11 and 12. Information 9 is required as an input to Task 25 information 101. In this situation, Task 1 is said to have a set of information [(7, 8), (9)].

Typifying the connectors and grouping the information permits the design of a simple version of decision trees that can capture the facts from the user and activate the proper connector type.

This simplified tree is composed of two parts. The above is responsible for capturing and recording the facts provided by the user. The second part of the tree is written in the form of a simple procedure that activates the proper connector based on the provided facts. Figure 10 shows a simplified decision tree.

3.1.2 Summary of knowledge structuring

The lack of a modelling methodology for decomposing a large application into a hierarchical structure represents a major difficulty in building knowledge base systems. Within the method used, the difficulty of structuring the knowledge has been overcome by the following.

1. The information-link model provides a structure of allowing each related piece of information to be in one unit, called a project manager task
2. An individual tree represents each task. A tree representing a task has two outcomes based on the state of the task, that is, whether the task has been performed or not. Thus, the tree will correspond to two trees. These are:

    a) A tree corresponds to the next task tree only if the state of the predecessor task has been performed: As for example, if Task 1 and Task 2 are done, the next task to be investigated is Task 3.

b) A tree corresponds to a tree that investigates the root of a difficulty by capturing the status of whether information has not been generated. If not, the tree is linked to its parent tree and then:

3. Trees are linked to parallel task's trees. A parallel task tree is a tree that shares as input the output of a predecessor task.

In exploring the state of the information in any unfinished task, if part of the information is generated, and this part provides an input to a subsequent task, the state of the subsequent task is investigated.

3.2 Expert system shell for the proposed system

An expert system shell was used for the development of the proposed system. The shell chosen was XpertRule. This choice was made for the following reasons:

- It is relatively cheap.
- It has its own procedural programming language for computations.
- It provides a wide range of facilities for the users as menus and explanation facilities.
- It can run on personal computers in a Window 98 environment.
- It utilises production rules and decision trees. Each decision tree can consist of (16000 tasks) that can be built individually tested and debugged.
- The knowledge base can be constructed in a similar way to that in which experts structure their decisions, by allowing direct editing of decisions trees.
- More advantages can be seen in the flexibility of maintenance in terms of time and lower cost. End users can easily modify decision trees whenever they are constructed and a change of rules is required.
- It is easy to learn and its end product can be used without the need for computer training.
- The supplier is consciously targeting decision-making theories as was noticed from the manuals of the shell. (It was felt that this is a good indication of effective support.)
- It provides links with Microsoft Office.

4. OVERVIEW AND USE OF THE INTELLIGENT SYSTEM

The Intelligent System is composed of two main subsystems: the knowledge-based system, and the database subsystem. The knowledge-based subsystem component constitutes the information link model, which is built using decision trees. A report generator and explanatory text are also provided within the knowledge-based subsystem. The knowledge-based subsystem is integrated into the database subsystem component, which is built using Microsoft Access and Microsoft Excel. Figure 11 shows the architecture of the prototype.

4.1 Knowledge-based system component – The Task Generator

The basic information link model is extended to a knowledge-based system that utilises the simplified decision trees discussed above. As mentioned earlier the strength of the model rests in its ability to show the links between the information.

The current state of a project is the main issue that the project manager assesses before deciding on what tasks need to be undertaken. In planning, one if the roles of the project manger is to identify the tasks that will need to be done. Controlling and monitoring are through continuous assessment of what tasks have been performed, and what tasks and subtasks are ready to be performed but have not yet been carried out.

The objectives of the *Task Generator* component are as follows:

- To capture the status of the project by investigating what tasks have been done
- To identify tasks and subtasks that are ready to be performed
- To identify tasks that will have to be performed

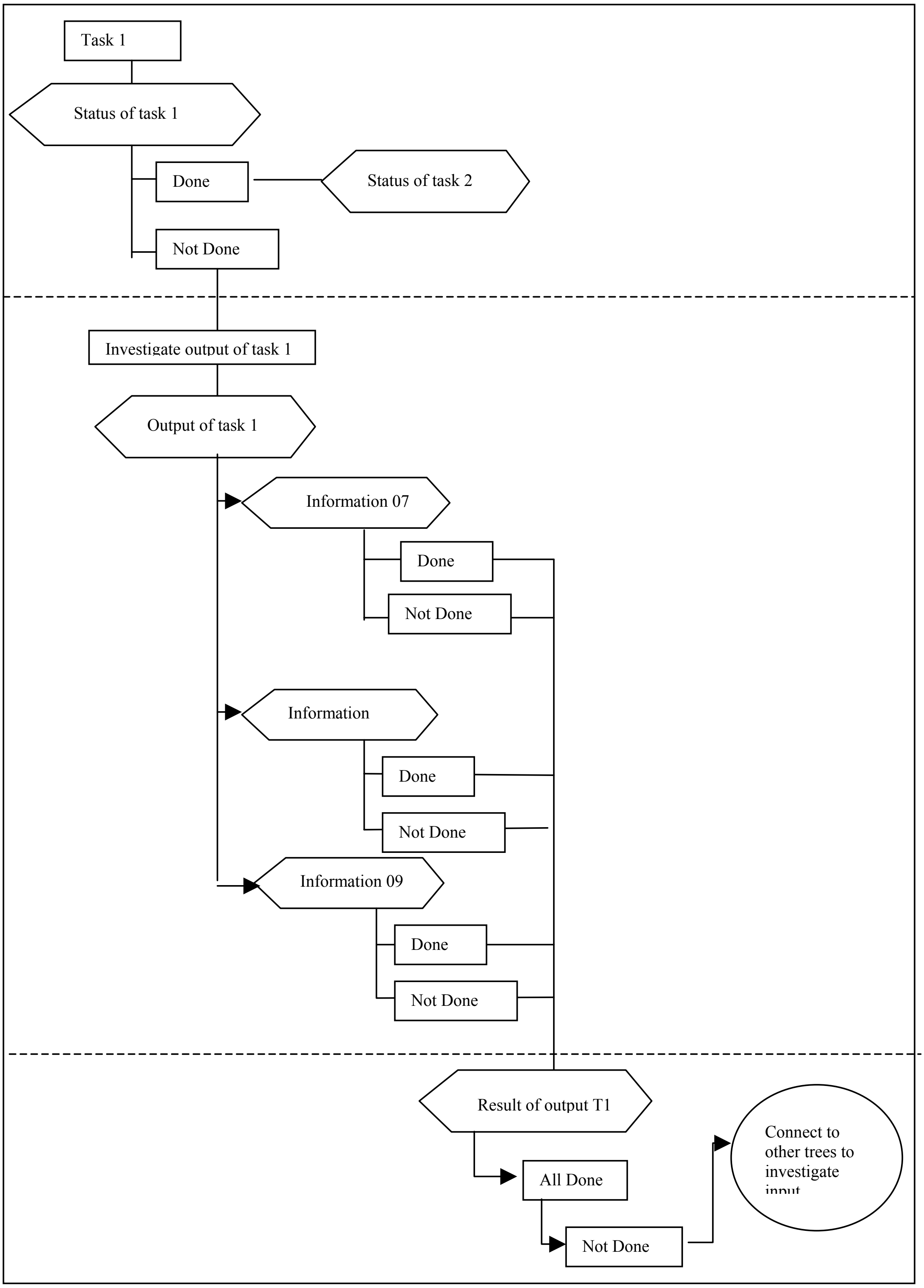

FIG.10: Example of a simplified decision tree

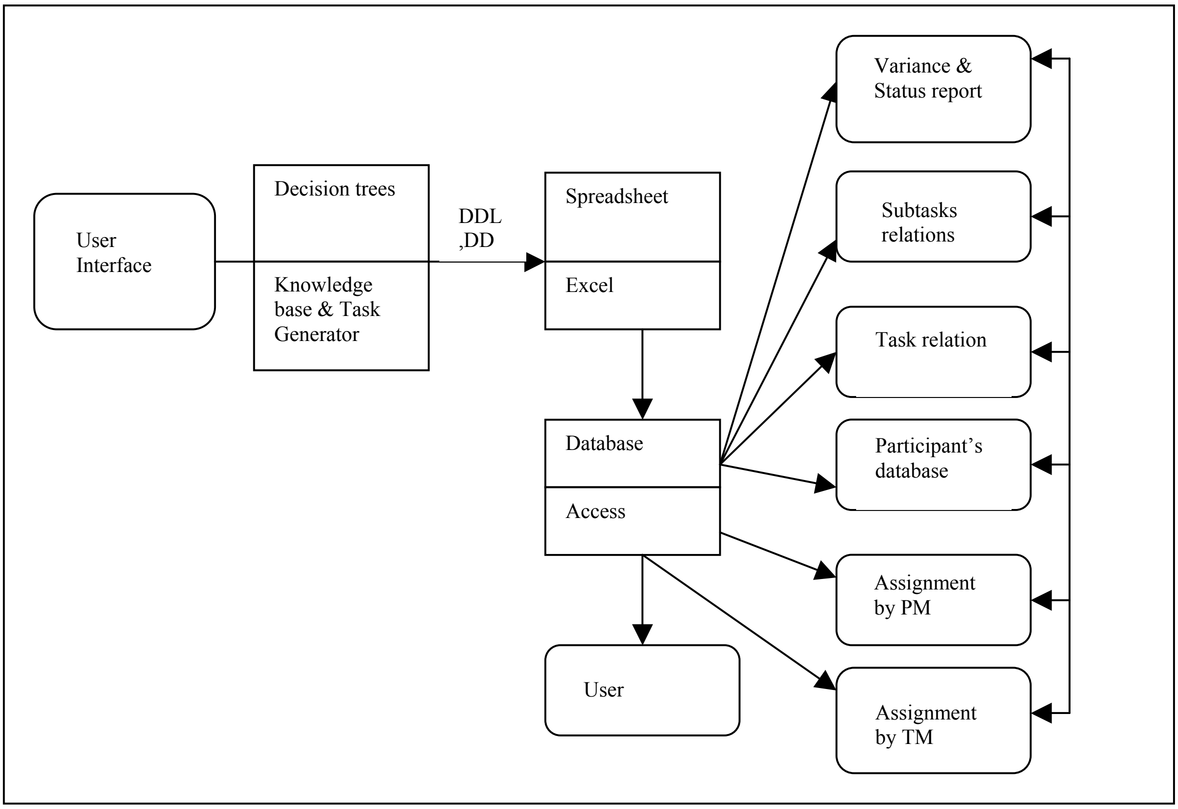

FIG.11: Intelligent system architecture

4.2 Database management subsystem -The Task Controller

The database management subsystem has been developed using Microsoft Access 97 and Excel 97. The knowledge-based subsystem interacts with Excel through what is called Dynamic Data Library (DDL) and Dynamic Data Exchange (DDE) techniques. Excel is used as a server for the knowledge base and as a client for the databases. The database subsystem is executed only through the knowledge-based subsystem. When first executed, the system asks the user if he wants to go to task generator or if he wants to go to task monitoring and controlling.

This part of the system is based on the output of the first component "The Task Generator" described in the previous section. It highlights the tasks and subtasks; it allows the user to investigate the dependency between tasks; it shows the requirements of each individual task that has to be performed; it also allows the user (the project manager or the task manager) to define the attributes of the subtasks (activities), their duration, start time, finish time, and as the project progresses, other information which is required, such as the actual start of a subtask. The objectives of the task controllers are as follows:

- To show the relationship between tasks
- To show the relationship between information
- To allow the project manager and task manager to define the attributes of subtasks (e.g. start times)
- To provide the user with a progress and status report.

4.3 Main features of the system

The main features provided by the system include:

- *Task recognition:* This feature provides the user with tasks that are ready to be performed. It provides the user with a report of what tasks are ready for execution. In the report, the questions asked to the user are listed and the rationale of how the tasks are chosen is detailed. In cases where the user provides the system with inconsistent information, special reports are provided stating any contradiction or inconsistency. The user can then go back, to change the answers.
- *Sub*-task *assignment:* This feature enables the project manager to assign responsibility to subtasks and provide information related to these sub-tasks such as estimated duration, estimated start and finish times. Figure 12 shows a copy of the computer screen of the form ' Sub task assignment by a project manager '. The screen also shows the subtasks that are required to finish or generate the tasks as well as those subtasks, which are dependent on other subtasks. The manager can also see the list of the subtasks required.
- *Task input-output:* In this feature, the user is provided with an option to choose a task. Once a task is chosen, the task requirements will be presented to the user together with the information that the task requires and those that the task generates. The user is provided with the option to see a list of the tasks and to go back and forth to check different tasks.
- Variance *Tracking:* The information provided by the project manager concerning the planned estimates and those that are provided and reported by the task manager are essential in order to report the status of the project and to calculate variances.
- *Responsibility Tracking:* In this option, the user is provided with a dialog box that allows him to enter a name or choose a name from a list to investigate what are the tasks/subtasks that an individual is responsible for. This feature is needed when a task or subtask is encountering difficulties and the user wants to find what other tasks/subtasks are the responsibility of the same manager. Other benefits of this feature are for each individual to list and report the tasks he is assigned to and also for the manager to check the workload of individual staff.

5. TESTING OF THE SYSTEM

Many dimensions exist in testing the effectiveness or utility of a decision support system. Testing normally relates to the performance of the system, its completeness and accuracy, the utility and benefits of the system, and the feedback to the knowledge engineer during development stages.

Since the purpose of the intelligent expert system developed here is to aid decision making, it was important that testing covers the following two major areas:

- The correctness of the Information within the knowledge-base
- The usability of the system

Experts from both academic and industrial sectors carried out informal test cases. The test cased resulted in certain suggestions for some additional work.

The testing of the system in both of the above areas has produced very satisfactory results in terms of the correctness of the information and the system's performance and usage. Also ideas for extending the system 's capabilities were suggested. The suggestions were not seen as limitations of the system but rather as improvements for future work. Improvements, such as for example adding an automated knowledge acquisition facility to the system, that will allow users to include new knowledge that is not currently in the system.

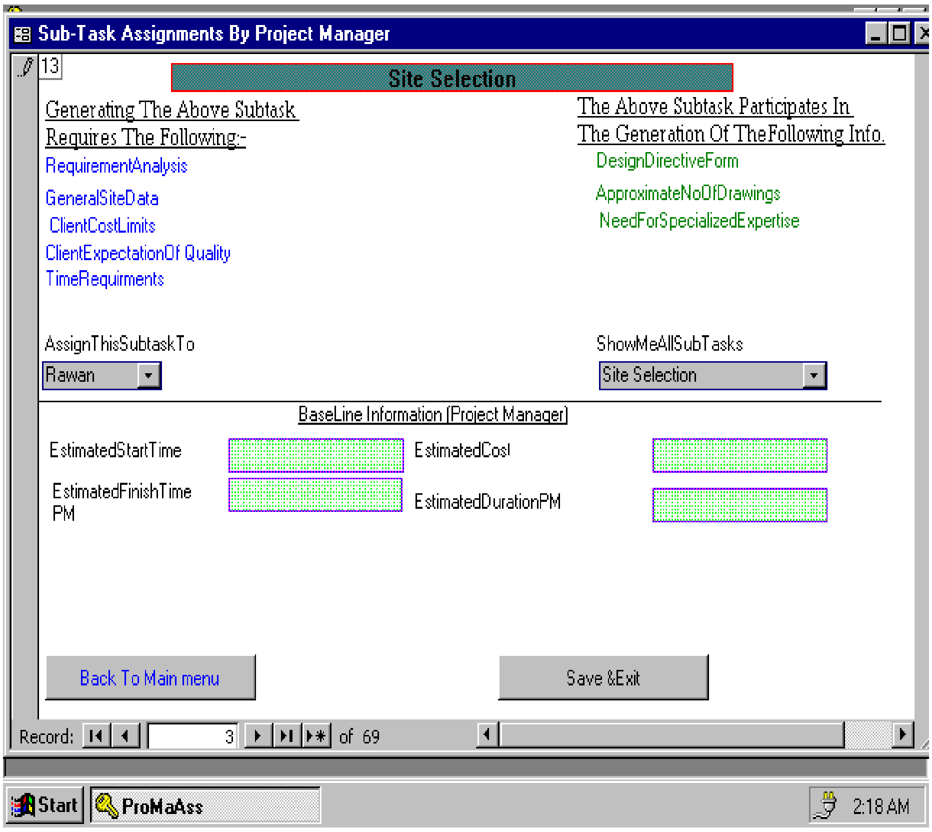

FIG. 12: Copy of the screen Sub-task assignment by a project manager

6. CONCLUSIONS

The knowledge acquisition undertaken in this research has shown that the difficulties usually associated with building knowledge-based systems due to knowledge acquisition can be minimised by following the steps adopted in the knowledge acquisition section. Decision trees if properly used can be used as a knowledge representation to overcome the problem that usually exist in using production rules such as modelling large application into a hierarchical structure.

Such structuring within the developed link model can also help in co-ordinating the efforts of the members of the project. By assigning responsibilities to information, each person responsible for generating information can assess the status of information, which is required, and all could be then notified if it is available. If that information is not available when it is needed, the path can be traced back in order to find the problem. When information is ready, the person responsible for the information knows to whom that information must be communicated.

The basic link information model is extended to an intelligent computer system that can take advantage of the usefulness of the model and be used as a control tool for the project manager. The intelligent system is used as a control tool that will assist project managers in planning, monitoring and control of their projects.

In planning, at any stage of the project, the tool can provide the manger with those tasks, which are current, ready to perform. It gives a list of tasks that have not been performed yet. The system also provides the ability to review the accuracy of the project schedule.

For the purpose of monitoring and control, the tool can also provide the manager with information such as the dependency of tasks and their information, when tasks are experiencing difficulties or changes are being made, so he can easily identify the root cause of the problem. In addition to that the system provides the ability to view the relationship between the participants once he assigns responsibilities to subtasks. This will allow him to control communication channels and the design of the organisation

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