Information link model for construction using artificial intelligence

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ABSTRACT | This paper reports on a novel project model developed to help clients plan, monitor and control their construction projects. It describes a knowledge-based system designed for this purpose. The paper initially concentrates on the practical aspect of knowledge acquisition indicating problems that were faced and solutions employed. Following this, 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 | construction, information model, project control, knowledge-based system, artificial intelligence

1 Introduction

In construction, all parties are required to plan a project and control its operation. 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 these 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 [1, 2 and 3]. All of these reported on construction project planning of some form using artificial intelligence techniques. Some authors [4, 5] also reported in the early years of AI work other planning type applications.

This initial work was mainly concerned with the scheduling of the actual construction phase and as such was mainly of help to contractors. Much work has been done in this area since these early papers and is reported in the literature for example [6, 7].

The requirements of the other parties to a project have received much less attention. Indeed, control from the client's perspective has been almost neglected in the AI literature. This is despite their decisions being based on large amounts of information and requiring considerable knowledge. These decisions are made at time of sanction for the project is therefore potentially much more expensive if wrong. These properties make them apparently ideal for AI solutions.

There is a need to provide improved support to the project manager especially in the area of project control.

This paper describes a practical application, which is the result of a research project, aimed at helping construction clients and their project managers to improve their control of projects from the initial concept through to the final completion. 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 organ-

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ised into a knowledge base for use by an expert system. The form of the knowledge lent itself to organisation into a link network. This was then used as the basis for an intelligent assistant for a project manager.

2 Project manager's tasks and their interdependencies

The term Project manager is used to represent different people, a project manager is found in a contractor's organisation in a consultant's organisation, in an Architectural / Engineering's organisation and in a client organisation. Ideally the objectives of a project are the same as the objectives of the client [8], therefore the term Project Manager is used in this paper to mean the project manager in a client organisation.

Managing construction projects is a complex task and the role of a project manager lies at the heart of any project. 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 [9, 10, 11]. 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.

The idea of a Tasks Matrix (TM) was developed to help in the identification of the project manager's tasks. The

Table 1. List of tasks in the conceptual stage of a construction project

No	Task Title
1	Interpreting of client's requirements
2	Obtaining client's expectation of project time
3	Obtaining client's expectation of the cost of the project
4	Obtaining client's expectation of project quality
5	Identifying work required
6	Ensuring preparation of budget cost estimate
7	Qualifying Existing Procedures
8	Selecting project site
9	Preparing project brief
10	Suggesting and define roles of parties involved
11	Identifying special studies required
12	Assessing capabilities of firms
13	Identifying training required
14	Preparing of special studies
15	Setting up control procedures
16	Assuring provision of information required to obtain approvals (time, scope, quality)
17	Assuring provision of information required to obtain approvals (cost)
18	Setting up key dates/milestones
19	Preparing project organisation charts
20	Obtaining approvals/scope
21	Obtaining approvals/cost
22	Preparing outline proposal
23	Selecting team members
24	Formalising client's requirements
25	Preparing project breakdown structure
26	Preparing material take-off/concept
27	Preparing concept drawing
28	Preparing cost estimate/concept
29	Preparing master program
30	Preparing outline specification
31	Preparing value engineering reports and reviewing
32	Obtaining client's approval/concept

	Cost	Time	Quality
Planning			
Organising			
Staffing			
Controlling			
Monitoring			
Co-ordinating & Communicating			

Figure 1. A template for project manager's tasks matrix

idea depends on defining the project management functions and the project management objectives.

Figure 1 shows the template for the project manager's task matrix. The initial assumptions considered when constructing the TM are as follows:

1. The project management function can be said to include planning, organising, staffing, controlling, monitoring, co-ordinating and communicating [12].
2. The client's main objective is to complete the project within an agreed cost and time, and within certain specifications (quality).
3. The main goal of the project management function is to achieve the project objectives.
4. Any tasks that a project manager does or efforts he/she makes are directed towards achieving one or more of the client's main objectives.

Based on the initial assumptions, it can be deduced that any project manager's tasks during the life cycle of a project are guided by a project management function. These tasks are completed in order to achieve a client's objective, or, in other words:

P.M. task = F (project management process; client's objectives)

Table 1 shows the result of using the TM, project manager's tasks for the conceptual design stage of a project. This was developed through interviews with 25 senior project managers in a middle eastern defence force. As for example [planning x quality] result in many tasks of which is a task called: 'Interpreting client's requirements'. Tasks, which resulted from the TM were verified by interviews with the experts (This is explained in the knowledge acquisition section) and was found to be very satisfactory in establishing the project manager's tasks. In fact the TM can be utilised and extended not only to establish the project manager's tasks in the construction industry, but in any business.

Projects are executed to overcome an existing problem. The solution is accomplished by a collaboration of efforts of different participants (under the direct or indirect control of a project manager) bringing together their various capabilities to achieve the specific objectives. In order to achieve these specific objectives, a number of tasks have to be performed. These tasks interact in a complex manner but specifically each task requires information before it can be performed and produces information as it is performed. The information moves towards the objective in a timely manner through the organisation of the project. Understanding the links between the information is a key factor, as it will provide the basis for planning monitoring and controlling.

The significance of timely and accurate information and decision making in construction projects has been addressed by many researchers see [11, 13, 14]. All project participants acquire and transfer information. Delaying the process of transferring and receiving this information is one of the most important causes for project delays.

The management process of a project is information driven. Most difficulties which occur during the process of the management of a project are those that relate to information. Hence the management of projects can be viewed as the management of the information that is produced, evaluated and transferred. Therefore, an effective project management system must have a feature of maintaining the linkages between the information to a significant degree.

This paper describes 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. AI techniques are used to identify the interrelationship between tasks, to analyse the interdependency, to generate the tasks and to recommend corrective actions.

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 [15, 16].

A task can be defined as the smallest measurable activity within a process [15]. Others view tasks as comprising of input and an output [17]. These ideas can be extended and represented as shown in Figure 2. 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 3 [15].

Although Pall [15] describes the work processes to be sequential, in reality tasks interact and can go in parallel as well as sequentially. Figure 4 illustrates a more suitable linkage between tasks in a process.

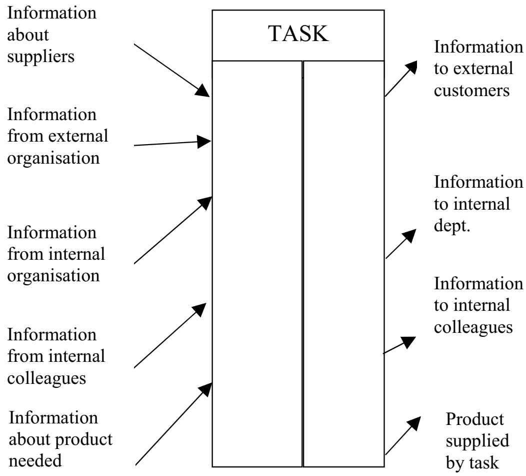

Figure 2. Input and output of a task (Adopted and modified from [17])

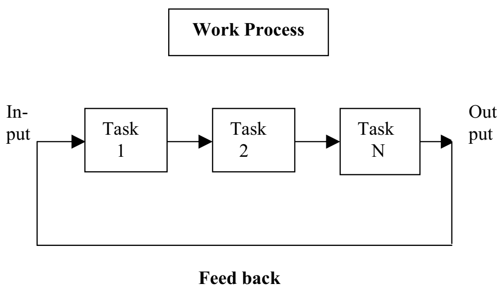

Figure 3. Linkage between process and tasks. (Adopted from [15])

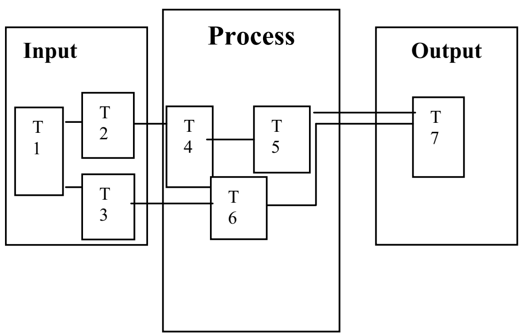

Figure 4. A modified linkage between process and tasks

3 Knowledge acquisition

In order to identify how tasks interact; there is a need for the identification of task requirements (for example the input required to each task and the output generated by each). This requires a knowledge acquisition exercise. The main goal of knowledge acquisition for a knowledge-based system is to ensure that the system is "effective". Knowledge acquisition is not a simple matter but is recognised as the most difficult task in the system life-cycle [18, 19]. Its difficulty stems from many sources that have been addressed by numerous researchers. As a result of these difficulties, tools, aids and techniques have been developed especially to overcome knowledge acquisition problems. The tools and techniques that are used for knowledge acquisition vary in their sophistication [20]. They range from manual tools to automated tools [21, 22, 23], but whatever tool or technique is used it must always be kept in mind that knowledge acquisition is an art as much as a science and that it depends not only on the tools and techniques but also on personal ability, judgement and initiative [20].

A structured interview method is one of a set of techniques that researchers in AI usually consider in building systems that require capturing knowledge. In this work it was chosen as a technique to acquire the knowledge because it was suitable for the problem (see below) and all other sophisticated techniques were considered impractical. The use of interviews is a common technique in qualitative-based research and according to Kvale [24] most appropriate in a situation:

1. Where a process is to be studied.
2. Where exploratory work is required.
3. Where factual information is to be collected and the researcher knows in advance the type of information that the participants will be able to provide.

Knowledge Acquisition can be divided into three stages: The initial stage concerns obtaining knowledge from experts, the second stage concerns knowledge elicitation and the third stage concerns knowledge representation and writing the knowledge in a computer system [25]. Part one of the process of Knowledge Acquisition for this project took place in Saudi Arabia and utilised a structured interview method.

1. The preparatory work:
2. Searching for and allocating experts
3. Orientation to the nature of the interview
4. Interviewing

The other two stages of knowledge acquisition are described later in the interviewing section and in the development of the intelligent ProMaAss section.

3.1 Preparatory Work

It is necessary before developing any AI application to carry out some preparation work. In this project the preparatory work resulted in developing an initial information link model, the purposes of the model at this stage were as follows:

1. To be used as the basis to interview experts.
2. To propose the project manager's task to experts.
3. To gain experts' views about the proposed relationship of tasks, their comments on the relationship and the content of the whole structure.
4. To define the information required and produced by each task.

The preparatory work ended with a first proposal for the interrelation of the project manager's tasks along with the proposed definition of the project manager's tasks.

The list of the project manager's tasks that was produced using the Task Matrix (TM) described earlier and shown in table 1 were used to develop the initial information link model.

Each task was typed on to a separate label (these labels resemble mailing labels but are two centimetre square stickers and were placed on tracing paper for ease of

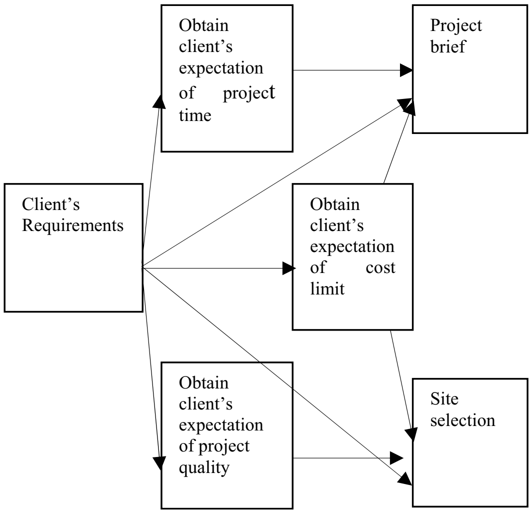

Figure 5. Part of the initial information link model

removal and replacement). Tasks were presented to experts to define their relationships.

The initial information link model is intended to show the relationship between the tasks see figure 5.
Developing this relationship between tasks was an iterative process where continuous advice and suggestions were sought through discussions with a small number of experts. This step took a considerable time and required more than 40 consultation sessions with experts. Based on the result of a consultation session a refinement may be required. The result of this step is a preliminary/ initial definition of the interrelationship between the tasks.

The main format of the initial information link model is a square, which holds the title of the task and an arrow to show the linkage between the tasks, it is an extension to a traditional project network but the earlier represent information flow rather than technical constraints. In this it is rather more like a system design produced through a procedure such as Structure System Analysis and Design Methodology (SSADM).

The benefits gained from the initial information link model are as follows:

1. It provides, in pictorial form, an outline of the interrelationship of tasks.
2. It shows the general relationship between tasks and simplifies their presentation making it easier for experts to understand.
3. It allows the tasks of the project to be traced, validated and investigated
4. It eases the difficulties and obstacles that are usually associated with knowledge acquisition. (This step is explained further in the next Section).
5. It provides a basis from which to select the method for acquiring knowledge

3.2 Searching and Allocating Experts

It is difficult to locate project managers 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 even within an organisation were recognised at an early stage. The client for this work was the General Directorate of Military Work (GDMW), a department that belongs to the Saudi Arabia Ministry of Defence. Using previously established contacts and sources of expertise, possible experts were sought 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 system, a suggested process for acquiring the knowledge, an explanation of how to fill in the knowledge acquisition form, a list of the project manager's tasks and a brief definition of the project manager's tasks.

3.3 Orientation to the Nature of the Interview

A knowledge acquisition form was designed to be suitable to interview both project managers and experts on specific disciplines see Figure 6. For example, a task

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

Figure 6. An example of a reduced size of the knowledge acquisition form

entitled "Preparation of proper cost estimate" is a subject on which to interview either project managers or expert cost estimators. 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. Eighteen interviewees in total were presented with a coloured chart (drawn with CAD onto A2 paper) showing the relationship of the project manager's tasks. Each expert was given a graphical representation of the interrelationship of the tasks, a list of the project manager's tasks, and was oriented individually. 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.

3.4 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".

3.5 Knowledge Elicitation

Interpreting knowledge gained from experts is termed knowledge elicitation [25]. 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. Figure 7 presents a simplified part of the information link network; it shows how the tasks were mapped.

The resulting model produced a chart which, when drawn out, is physically very long. (3 metres long)

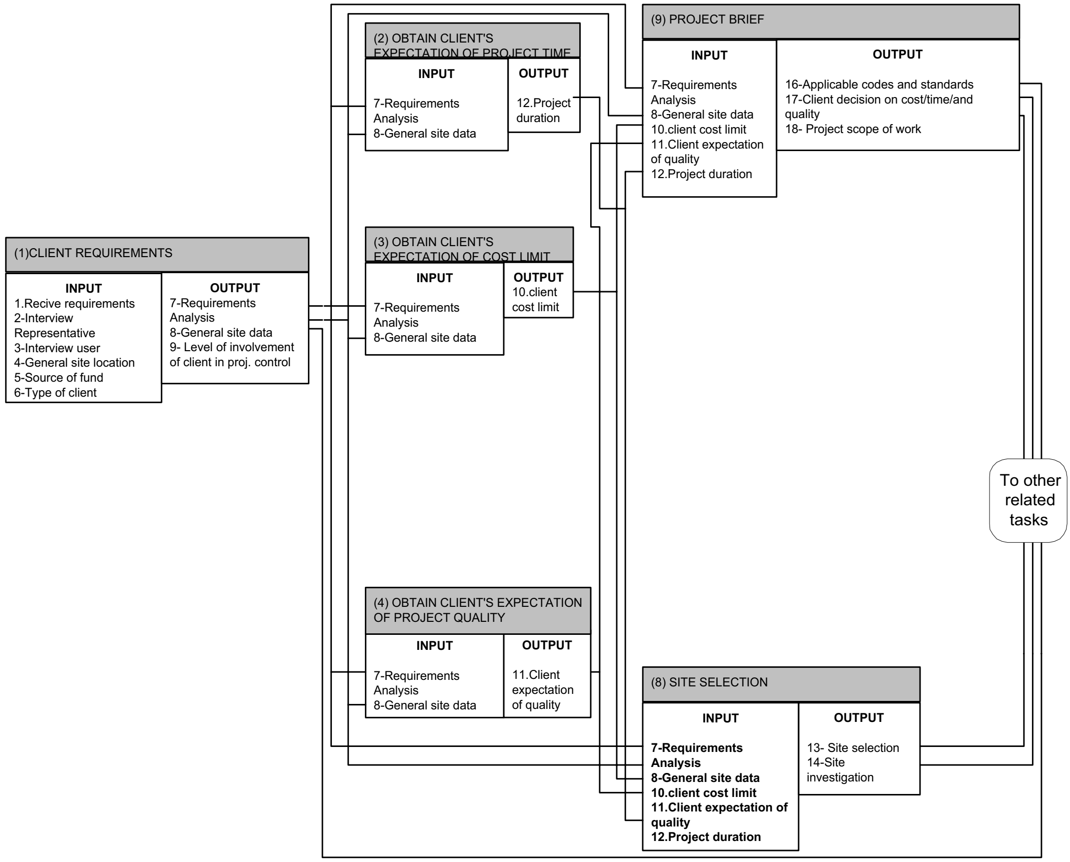

Figure 7. Simplified part of the information link model

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.

Table 2 shows the tasks are classified based on their input and output.

Table 2. Type of task connections

Type	Description
I	Input: One single input from one single task Output: One single output goes to one single task
II	Input: One single input from one single task Output: Any number of outputs going to one single task
III	Input: One single input from one single task Output: Any number of outputs. Each output goes to one task
IV	Input: One single input from one single task Output: Any number of outputs. Each output going to any number of tasks
V	Input: Many inputs from one single task Output: One single output goes to one single task
VI	Input: Many inputs from one single task Output: Any number of outputs going to one single task
VII	Input: Many inputs from one single task Output: Any number of outputs. Each output goes to one task
VIII	Input: Many inputs from one single task Output: Any number of outputs. Each output going to any number of tasks
IX	Input: Many inputs from many tasks Output: One single output goes to one single task
X	Input: Many inputs from many tasks Output: Any number of outputs going to one single task
XI	Input: Many inputs from many tasks Output: Any number of outputs. Each output goes to one task
XII	Input: Many inputs from many tasks Output: Any number of outputs. Each output going to any number of tasks

For example, Type II, where the input to the task is one single piece of information from one single task, but the output involves many pieces of information going to one single task.

4 Validation of the Structure of the Tasks

The final validation of the tasks' interrelationship was performed in two workshops of three hours each. This workshop brought together seven 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. A hypothetical project was assumed to be as shown in Table 3.

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. Comments considered less important were studied later and in general all participants in the workshop thought the structure suitable and a reflection of the current practice used at General Directorate of Military Work/Ministry of Defence (GDMW).

However, it was interesting that participants also perceived the applicability differently. While experts from

Table 3. Hypothetical project criteria

Hypothetical project criteria					
1	Project type	School project	5	Project status	Just initialised
2	Location	Anywhere in Saudi Arabia	6	Actual user	Unknown
3	Available fund	Unknown	7	Funding Agency	Unknown
4	Client	Ministry of Defence	8	Client's request	Unclear

the design department (the architect, the mechanical, electrical and the structural experts) viewed the model as a means to control the design of projects, the quality control manager viewed the model differently, stating that even the management system certified under ISO 9000 does not work effectively, as it does not tell or guide the members in the team in what to do. He stated that management systems should be studied and developed around the information required. The planning manager was planning a construction project in Riyadh and realised the same approach could be used. The planning manager explained the methods currently used in construction activities, the difficulties associated with these practices and the methods and benefits of the new approach. 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.

5 Development and Use of Intelligent ProMaAss

A prototype knowledge-based decision support system called Intelligent ProMaAss, using a commercial expert system shell 'XpertRule' and Microsoft Office, has been developed. It is composed of two main subsystems: the knowledge-based system, and the database subsystem. The knowledge-based subsystem constitutes the information link model which is built using decision trees. A report generator and explanatory text is also provided within the knowledge-based subsystem. The knowledge-based subsystem is integrated into the database subsystem, which is built using Microsoft Access and Microsoft Excel.

5.1 The Knowledge-based Subsystem

The basic information link model is extended to a knowledge-based system that uses decision trees as a knowledge representation method. The model strength is gained from its ability to show the links between the information. An important aspect to a project manager in planning projects is to define the tasks that have to be performed, task requirements in terms of their information need and what the task generates in terms of information. An important aspect in monitoring and controlling is the follow up of the transfer of information. Whenever a stoppage of the transferred information occurs, several steps are required.

Defining the tasks and their requirements (input and output) that need to be performed can be done by finding where the stoppage of the flow of information is occurring. This is done based on the following:

1. To find the causes of this stoppage manually by using the information link model requires a backward tracing of the path of the flow of the information until the root cause is identified.
2. A problem with the flow of the information does not mean a stoppage of work. In reality it opens up the opportunity to look forward and seek what information can be generated that is not constrained by the identified stoppage.

The function of the knowledge-based system component is to fulfil the two points above. Developing the KBS is done based on the following:

1. Grouping related information
2. Utilising decision trees

The system starts asking questions of the user, who has to give only one answer to each question being asked. However, it is possible to return to previous answers to modify them. The answers to the question relating to the information in the project follow a Yes/No format.

According to the first question answered, sequential questions are asked of the user automatically. The sequence of questions is based on the type of connection and the linkage between tasks. Once the entire question is answered a report is displayed to the user. The report is summarised in Figure 8 and consists of:

1. The question asked of the user
2. The tasks which are ready to be performed

The user can go back as many times as is desirable to change answers to questions. The knowledge-based subsystem is very easy to use, even for those who are not computer users. Furthermore, it does not require reference to comprehensive manuals.

5.2 The Database Management Subsystem

The knowledge-based subsystem interacts with Excel through 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. The system, when first executed, asks the user if he wants to go to the ‘task generator’ or if he wants to go to ‘task monitoring and controlling’. If the user chooses to go to ‘task generator’ by the end of the consultation session, the system will prompt the user if he wants to go to ‘task monitoring and control’. When the user chooses this option, a main switchboard that has several options will appear to the user. The user then chooses one of the options: task assignments by the project manager; task assignments by the task manager; variances; task links and exit. Depending on the option chosen, a database file will be opened. These options are further described in next section.

6 Features of ProMaAss Used for Project Control

ProMaAss provides users with many features that allow them to control a project. ProMaAss is designed currently to assist client’s project manager to control construction projects, it considers controlling the project through all stages from concept until completion. ProMaAss can be used at the beginning and during the project. It provides the user with many features, which have been tested by an experienced project manager and a system development expert. A description of the main features of the system and the test follows.

Status of information

Y: The information is available **N**: The information is not available

INFO. NO	Information Description	
Info I13	A site been selected for the project	**Y**
Info I14	A site investigation has been made	**N**
Info I16	A decision has been made about the general codes and standards to be used	**N**
Info I17	Obtaining client's approval of the feasibility of the project in relation to time, cost & quality	**N**
Info I18	Preparing the project scope of work	**N**

Recommendation

In order to finish the following tasks :
Task 8 - Selecting and evaluating project site
Task 9 – Preparing and documenting the project brief
The above **unavailable** information (Info I14, Info I16, Info I17, Info I18) are required.

The following tasks are dependent on the above tasks being finished: -
Task 5- Identifying work required
Task 11-Identifying special studies required

Figure 8. Part of the output generated by intelligent ProMaAss

6.1 Task Recognition

This feature provides the user with the 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.

6.2 Sub-task Assignment by a Project Manager

This option will provide the project manager with the subtasks that have to be done in the project. It also asks the Project manager to assign responsibilities to subtasks by choosing the assignee from a predefined list of project participants, whether contractors or the project manager's own team members. A user could also add new name(s) to this list if required. A project manager will also be asked to provide the following information for each subtask: estimated duration, estimated start time and estimated finish time. Figure 9 shows a copy of the computer screen of the form "Sub task Assignments by a Project Manager". Each of the subtasks required within the project is displayed on a single computer screen.
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.

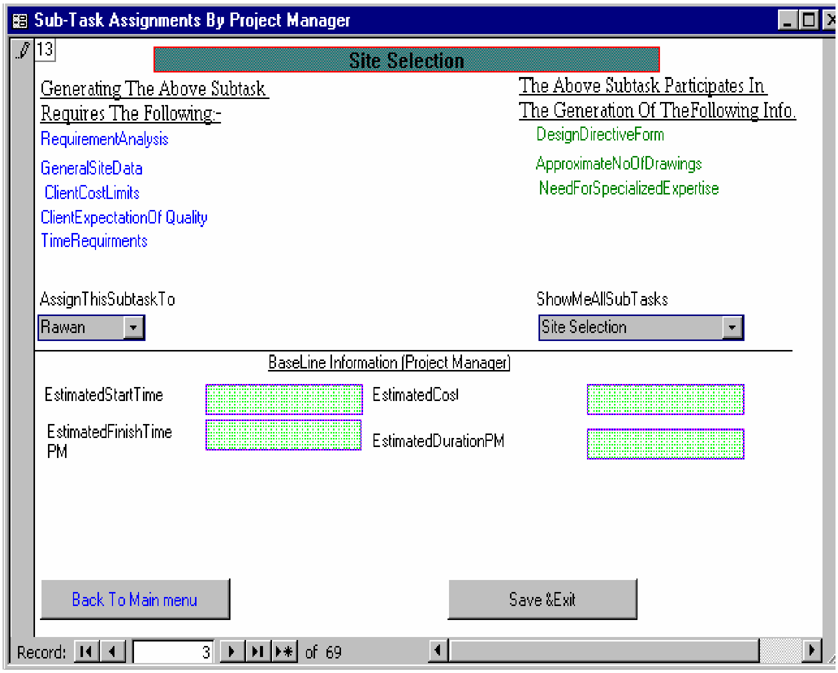

Figure 9. Copy of the screen Sub-task assignment by a project manager

6.3 Task Input-Output

In this option, 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. The assignee responsible for each piece of information, based on the assignment done by the project manager, is also presented to the user.

Figure 10 shows a copy of the computer screen of the option "Task input-output" ('Resp' here indicates the person responsible). This feature allows the user of the system to investigate all the tasks required for the project and the information required and generated by any task. This feature can be utilised as a checklist by a project manager and might help in recalling the tasks required together with the tasks' requirements.

6.4 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. Table 4 summarises the information required by both project and task managers.

6.5 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 made available when the user is investigating the status of tasks/subtasks. 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

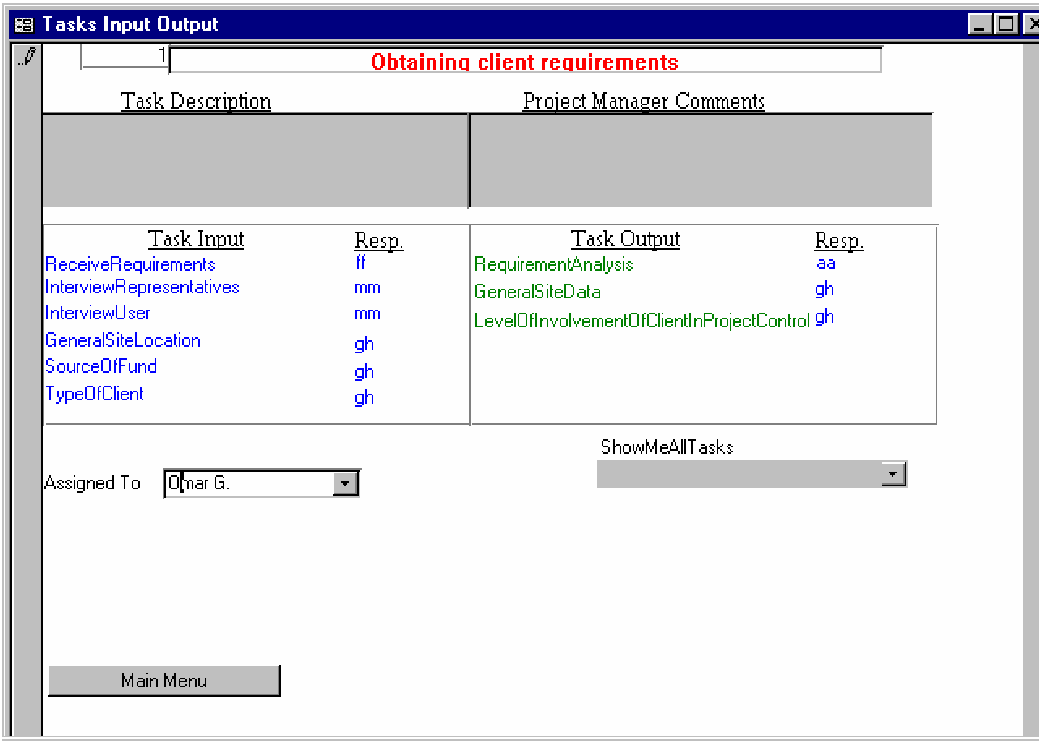

Figure 10. Copy of the screen Task input out put

Table 4. Summary of information required

	BASE LINE INFORMATION BY P.M.	
1	EST1	EXPECTED START TIME
2	EET1	EXPECTED FINISH TIME
3	ED1	EXPECTED DURATION
4	EC1	EXPECTED COST
	BASE LINE INFORMATION BY T.M.	
5	EST2	EXPECTED START TIME
6	EET2	EXPECTED FINISH TIME
7	ED2	EXPECTED DURATION
8	EC2	EXPECTED COST
	ON PROGRESS INFORMATION	
9	CEC	CURRENT ESTIMATED COST
10	AST	ACTUAL START TIME
11	CET	CURRENT EXPECTED DURATION
12	AC	ACTUAL COST

assigned to and also for the manager to check the workload of individual staff.

6.6 Summary of the Testing and Evaluation 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 and evaluation cover 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 and evaluation cases. These resulted in certain suggestions for some additional work.

The performance of an expert system is, to a large extent, dependent on the information or data it receives when the system is in use. This is equally true, and important, during the testing stage of the expert system. Test cases have been compared with the information acquired by the experts during knowledge acquisition to judge the validity Intelligent ProMaAss.

In addition to the evaluation of the system performance indicated above, consultation sessions with Intelligent ProMaAss have provided assessment of main features described in the previous sections, that is to say:

- Its ability to identify the ready to be performed tasks
- Its ability to provide the user with recommendations of tasks that have to be performed in a project
- Its ability to provide participants with a list of their assigned tasks
- Its ability to provide the user with progress report
- Its ability to allow reporting task status and progress

There is a need for such system to be developed and the goals that it covers; both the academic and industial experts mentioned this. The general impression of the usability of the system was very encouraging.

In fact, on the basis of the different test cases, the system 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.

7 Discussion

Literature reviews have revealed the importance of information issues as key factors for controlling projects. This research has therefore focused on defining project tasks and task requirements (input and output). Task input/output is used as a building block to form and define the linkage, dependency and interrelationship between tasks. An information link model is developed whereby tasks are connected to each other using different types of connections.

An important aspect in planning is the dependency of the tasks. The model can provide the planner with the basis to plan the project. It shows graphically when tasks can be done in parallel and what tasks must be done in sequence.

The model is extended further to an intelligent computer system that can take advantage of the usefulness of the model and be used as a control for the project manager. The other benefits that the information link network can be summarised to include:

1. The information link model will be used by the project manager throughout the project life-cycle as a monitoring and control tool to ensure the completion of the tasks required at different stages of the project.
2. The information link model will be used by the project manager throughout the project life cycle as a monitoring and control tool to ensure the completion of the task's requirements (task input and output).
3. The information link model will also assist the project manager to plan for the production of information and control projects by ensuring that the required information is included.
4. The Intelligent ProMaAss will present the task requirements to the project manager; the information that a task requires and that a task generates based on the state of the project.
5. The Intelligent ProMaAss will present to the manager the ready to be performed tasks.

6. The Intelligent ProMaAss will present to the manager the tasks required to finalise a project.
7. The Intelligent ProMaAss will allow the manager to assign tasks that are required to finalise a project.
8. The Intelligent ProMaAss will allow the task manager to assign tasks that are required to finalise a project and to report on the task's progress.
9. The Intelligent ProMaAss will allow its users to present the tasks that are assigned to them.

8 Conclusion

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.

The Information model and the system described in this paper have wide applicability. The information link model can 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 model also gives a broader picture when assigning team members as it shows the link and dependency of information that it will allow who depend on whom for the information required. Configuring the team members can be based on the information links rather than any other ad hoc method.

REFERENCES

[1] O'Connor M, De La Garza J and Ibbs C, (1986), *An expert system for construction schedule analysis*, in *Expert systems in civil engineering* edited by Kostem C and Mayer M, ASCE, New York.

[2] Ibbs C, (1988), *Knowledge engineering for a construction scheduling analysis system*, in *Expert systems in construction and structural engineering* edited by Adeli, Chapman and Hall Ltd., London.

[3] Levitt R and Kunz J, (1988), Artificial intelligence techniques for generating construction project plans, *Journal of Construction Engineering and Management*, vol. 114 no. 3, ASCE.

[4] Cohen P and Feigenbaum E, (1982), *Planning and problem solving*, Chapter XV in *The handbook of artificial intelligence,* volume 3, William Kaufmann Inc., Los Altos, California

[5] Tate A, (1977), *Generating project networks, international joint conference on artificial intelligence*, pp888-893, Boston, Massachusetts.

[6] Shaked O and Warszawski A, (1995), Knowledge-based system for construction planning of high-rise buildings, *Journal of Construction Engineering and Management*, *ASCE*, Vol 121 No 2, pp 172-182.

[7] Arditi D and Bentotage S N, (1996), System for scheduling highway construction projects, *Microcomputers in Civil Engineering,* Vol 11, No 2, pp 123-139.

[8] Walker, A. (*1996), Project Management in Construction, Granda Publishing Limited, London.*

[9] Riggs, L.S, (1988), Educating Construction Managers. *Journal of Construction Engineering and Management,* 114(2)**:** 279-285.

[10] Royal Institute of British Architects, (1996), *Plan of Works for Design Team Operation*. RIBA Publications.

[11] Tenah, K.A, (1986), Construction Personnel Role and Information Needs. *Journal of Construction Engineering and Management. Proceedings of the American Society of Civil Engineers,* 112(1).

[12] Mawdesley, M., Askew, W. and O'Reilly, M. (1997). *Planning and Controlling Construction Projects*. Addison Wesley Longman Ltd.

[13] Al-Hammad, A.M. and Al-Hammad, I., (1996), Interface Problems Between Building Owners and Designers. *Journal of Performance of Constructed Facilities,* 123-126.

[14] NEDC Report, (1994), *Information Quality on Building Site*s. Building and Economic Development Committee, Managers and Professionals.

[15] Pall, G.A, (1987), *Quality Process Management*. Prentice-Hall, Inc., USA.

[16] Druker, P, (1991), *New Templates for Today's Organisations*. Harvard Business Review, 55-63.

[17] Sayle, J.S, (1991), Meeting ISO9000 in a TQM World. *AJSL*, UK, 28-42.

[18] Giarratano, Riley, Expert *Systems Principles and Programming.* BWS Publishing Company, Boston.

[19] Jackson P, (1994), *Introduction to Expert Systems*, Second Edition. Addison-Wesley Publishing Company.

[20] Hart, A., (1989), *Knowledge Acquisition for Expert Systems.* Chapman and Hall, Hampshire.

[21] Budde, B., Kautz, K., Kuhlenkamp, K. and Zullighoven, H. (1991). *Prototyping: An Approach to Evolutionary System Development*. Springer-Verlag, New York, Berlin.

[22] Adelman, L. and Reidal, S, (1997), *Handbook for Evaluating Knowledge-based Systems*. Kluwer Academic Publishers, London.

[23] Ignizio, J.P, (1991), *Introduction to Expert Systems, the Development and Implementation of Rule Based Expert Systems*. McGraw-Hill.

[24] Kvale, S, (1996), *Interviews – An Introduction to Qualitative Research Interviewing*. Sage Publication, London.

[25] Elizabeth, S. , (1989), *Knowledge elicitation techniques for Knowledge-based systems*, in *Knowledge Elicitation principles, techniques and application*, Edited by Dan Diaper, Ellis Horwood limited.