AN EXPERT SYSTEM FOR CRANE SELECTION AND LOCATION

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1. Introduction

Typical construction planning decisions take place within complex real life situations which involve a great number of factors associated with the project to be executed, its site, the labor and equipment used for this purpose, the market, the environmental conditions, etc. Many of these factors can be assessed in quantitative terms only with a limited degree of certainty; some of them can be defined only in a most general non-quantitative manner. The planning, in such a situation, must rely, to a large extent, on the judgement and experience of the decision maker. The latter may be assisted by an Expert System which will guide him to a good "working solution", although not necessarily the best in terms of efficiency or effects.

The collection, storage and rational use of knowledge within the various classes of Expert Systems have been explained in [1],[2],[3] and other sources. Their advantages and limitations, when applied to construction problems, were discussed in [4]. One of the construction planning problems, which certainly justifies application of an expert system, is the selection and location of cranes on a building site.

The problems of crane location have been described in several publications. The algorithmic approaches to their solution were presented in [5],[6]. A set of rules for their selection was described extensively in [7]. The following paper describes the methodology of the development of an expert system for the crane location problem in view of its applicability to other construction planning tasks.

2. The General Principles

The specific tasks assigned to the expert system to be developed were defined as follows:

a. To extract from the planner all information pertinent to the decision about his particular application case.

b. To assist the planner in the above task by explaining to him, if needed, the purpose of the information, and the manner in which it can be obtained.

c. To present the planner with a set of feasible alternatives to his problem.

d. To guide the planner towards the selection of the most desirable alternative based on economic considerations.

e. To supplement the planner with "default" economic data which is unavailable otherwise.

The construction of an expert system with these objectives consists of the following main tasks:

- A precise definition of the problem, i.e. who is the user, what is the system within which he operates, what are specifically the questions the proposed tool is to answer, and what are the limitations on its applicability.

- Preparation of the knowledge base, which has to include all the factual information pertaining to the problem, the normative procedures, and the heuristic rules which allow to formulate and evaluate solution alternatives.

- Construction of a system "shell" which will contain a storage facility for the accumulated knowledge, a querying mechanizm for the extraction of the context data from the user, and an "inference engine" for its evaluation in view of the knowledge base rules. In the particular case described here, it was decided to adopt an available "shell" which will perform these tasks, rather than construct a new one.

- Construction of the expert system and experimentation with it.

These steps will now be illustrated within the context of the expert system for cranes' selection and location.

3. The construction of the system

The problem

The purpose of the system described here was to assist the construction planner, as noted earlier, in the selection and location of a crane on a given building site. The applicability was limited to the following cases:

a. The crane was selected as the appropriate materials' handling device for the buildings under consideration.

b. A single crane was not to serve more than two buildings at the same construction stage.

c. The planning is based on a representative layout of the building floor, assuming implicitly that the shape of the work area, or the work content do not change over the employment time of the crane on site, to an extent which will justify a modification of the design.

d. The timing of the equipment employment over the working day could be scheduled in such manner that it would not be needed at the same instant in different work locations - buildings or floors.

e. Some decision rules and all default values were applicable to the particular situation in Israel at the time of the expert system construction.

Limitations a,d could have been easily relaxed with a non-excessive amount of adaptation work, mainly in terms of additional querying. Limitations b,c would have required a considerable modification of the knowledge base in order to produce realistic solutions to problems. In any case, the methodology of the expert system construction would have remained the same.

The base for the case examined here consisted of the following types of knowledge:

a. The basic data about various building materials and components.

b. General information about the different cranes available for the material handling function on site. Five types of cranes were identified as appropriate for the handling tasks examined here:
   - rail mounted tower crane
   - fixed tower crane
   - climbing tower crane
   - movable crane on wheels
   - movable crane on tracks

   The information about the equipment types - their dimensions, performance capacity and prices, was obtained from books, trade literature, and manufacturers' brochures. The most important features of the examined cranes are summarized in Table 1.

Table 1 - The main features of the examined cranes

Crane type	Code	Manufac.	Effective radius	Building height	Lift.cap. at jib end	Max.lift. cap.	Typical price(*)	Default price	Technical limitations
			[m]	[m]	[ton]	[ton]	[1000$]	[1000$]	
Wheels mounted telescopic tower crane	W	Potain	25-30	10 >	0.75-1	2-3	65	65	• Cannot move with load. • Needs roads with less than 2% slopes.
Tracks mounted tower crane	R	Potain & Liebherr	25-45 45-75	36 >	1-2 1.5-5	2.5-8 5-20	70-150 140-500	110 250	• Max. slope along track 1%. • Needs careful installation of tracks.
Static tower crane (internal) => (external) =>	 I T	Potain & Liebherr	25-45 45-75	unlimited	1-2 1.5-5	2.5-8 5-20	55-140 120-400	90 200	• Needs to be tied in when height exceeds ~25m. • Needs appropriate foundations.
Climbing tower crane	C	Potain & Liebherr	25-45 45-60	unlimited	1-2 1.5-4	2.5-8 5-8	65-140 130-265	100 180	• Problems in dismantling. • 'Dead zone' near tower. • Stops work for climbing. • May delay finish works.
Crawler or wheels mounted mobile crane	M	P&H	12-20	10 >	3-10	20-110	120-350	240	• Needs space for maneuvering around building. • Operated from ground level

(*) including freight costs and local taxes.

c. Algorithms for calculation of an optimal crane location with respect to a given building and its required reach, developed for this purpose.

d. Procedures for a comparison of the crane alternatives, based on an accepted engineering economics knowledge.

e. Heuristic selection and location rules obtained from experts. The rules were formulated on the basis of a thorough study of the factual material described in a,b above, and interviews with experts from the following occupations:

- project managers/construction planners.
- officers of large construction companies in charge of equipment acquisition, and allocation to building projects.
- dealers and rental companies of construction equipment.

The interviews with the persons in each group included specific questions about each type of cranes and its applicability to different classes of building projects.

f. Default values for various economic parameters essential for the comparison of feasible crane alternatives, and which could not be supplied by the user.

Items a-b could be considered as generally available factual knowledge which requires, however, some judgement and general experience in its compilation and use. Items c-d represent a more thorough knowledge in application of general quantitative tools of managerial analysis. Items e,f represent a specific expertise in the domain of cranes selection and usage.

The "shell"

The system "shell" for the storage and manipulation of the domain knowledge was selected, based on the following criteria:

- A sufficient capacity to contain all the necessary decision rules in the problem domain.

- An explanatory facility enabling an optional guidance of the user in his answers to the system queries.

- An interface with quantitative formulas and algorithms.

- Operational capacity on a regular personal computer (IBM PC with a memory of 512K).

The shell, which was eventually selected for this purpose, was the SAVOIR - Expert System Package, described in [8]. It was written in PASCAL and therefore could handle external functions written in that language, and with the required computer configuration it could contain up to 1,000 decision rules arranged in a semantic network form.

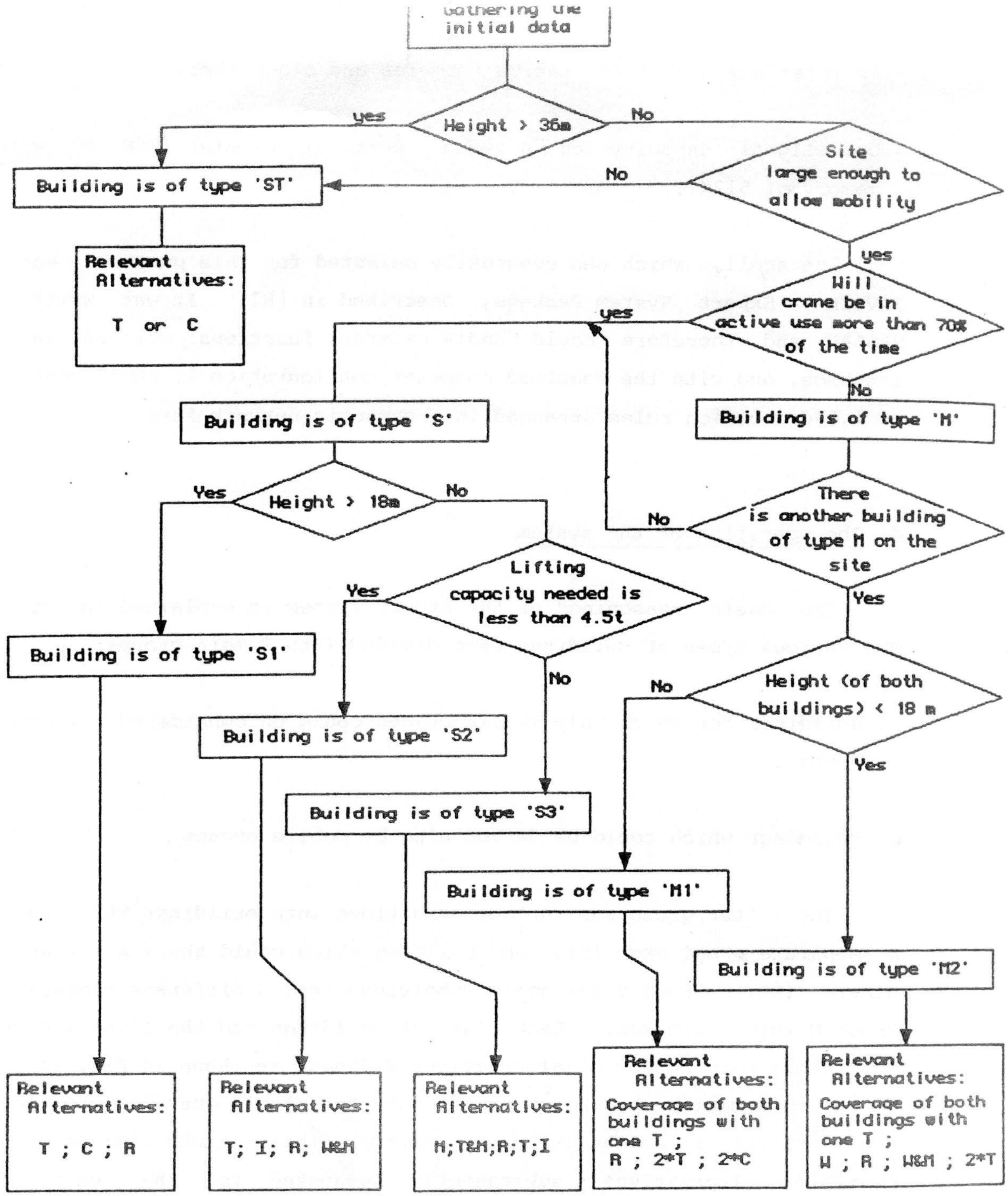
4. The operation of the system

The basic "reasoning" of the expert system is explained in Fig. 1. The various types of buildings were divided into 2 main groups:

a. Buildings for which only static cranes could be considered (climbing or fixed).

b. Buildings which could be served also by mobile cranes.

The latter group was further subdivided into buildings which required a separate crane each (S), and building which could share a crane with others (M). Group S was again subdivided into 3 different classes, and group M into 2 classes. Each class of buildings had the total set of its applicable main equipment alternatives defined, as shown in Fig. 1. Based on the information obtained from the user during his querying process, and the application of the system algorithms, this set was limited to the feasible alternatives subsequently suggested to the user, each characterized by the equiment type, its reach, payload and location.



Legend :

W - Wheels mounted telescopic tower crane.
R - Tracks mounted tower crane.
T - External static tower crane.
I - Internal static tower crane.
C - Climbing tower crane.
M - Crawler or wheels mounted mobile crane.

Fig. 1 - The reasoning scheme of the system

The selection of the most desirable alternative was left to the user, who could apply his own criteria with respect to the equipment availability at his disposal, its cost of use and his own personal preference. If the user was willing to base his selection solely on economic considerations, he could be guided towards this purpose by the system which was able to offer default values for the unknown cost parameters.

The querying of the user, by the system, is schematically depicted in Fig. 2. It is performed in three stages. In the first stage, the user is asked to supply all the pertinent information about the building geometry and the nature of the crane employment. The general classification of the buildings follows from this stage. In the second stage, the user is asked specific questions about possible applicability of each pertinent type of cranes to his particular case. As a result, the feasible alternatives of cranes are identified and defined in terms of their major features. In the last stage, the user is guided towards a rational selection of the most appropriate alternative from the set of equipment available to him.

An application case following those lines is illustrated in the Appendix.

5. Conclusions and recommendations

The general purpose of an expert system, in the construction planning, is to present the user with the feasible alternatives to his problem and to guide him in the selection of an optimal alternative. For this purpose the user is queried by the system for all information pertinent to the solution of his particular problem.

The development of the system consists of compilation of a knowledge base and a construction or a selection of an appropriate "shell" for knowledge manipulation. The knowledge base includes the factual information extracted from books, norms, trade literature, etc., various normative and theoretical evaluation procedures, and heuristic decision rules applicable to the problem. The rules are formulated following a systematic interviewing process of the various expert groups whose work is related to the problem domain.

Stage of consultation	Topics of inquiry
1. Gathering the initial data and characterization of the buildings	- Number of buildings. - Coordinates and height of each building. - Lifting capacity required for different works. - Duration of crane activity needed. - General information about the site.
2. Evaluating the alternative cranage systems	
• Climbing crane	- Possible locations within the building. - Problems which might arise with crane location.
• External static tower crane	- Possible locations on the perimeter. - Possibility of crane attachment to building.
• Tracks mounted crane	- Possibility of placing rails on site (free space, obstructions, slopes, ...). - Feasible location for rails (considering width needed, distance from building, slopes and radii allowed, coverage of building, accessibility to storage areas, dismantling crane ...).
• Wheels mounted tower crane	- Possibility of mobility on site (obstructions, slopes, roads,..) - Existence of suitable workstations around building.
• Crawler or wheels mounted	- Site conditions . - Possibility of mobility on site (obstructions, slopes, roads,..) - Existence of suitable workstations around building. - Possibility of incidental use.
3. Selection of most desirable alternative	- Availability of crane (in company, rented, new). - Costs of maintenance and operation. - Cost of transportation installation and dismantling. - Time related costs (insurance, taxes, periodic maintenance, ...) - Cost of purchasing a new crane, or renting rate. - Rate of interest or investment.

Fig. 2 - The system application process

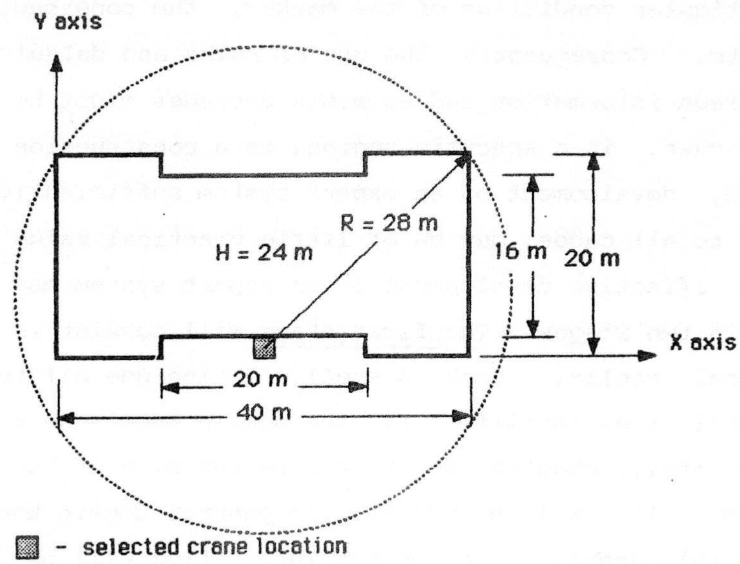
The context knowledge extraction process may be divided into several stages. In the first the user is asked about the general information about his case, in the second he is specifically queried with respect to the possible solution alternatives, and in the last he is guided towards selection of an optimal alternative.

The usefulness of the system, to the user, depends on its relevance to the particular conditions of the market, the construction methods, the prices, etc. Consequently, the use of rules and default values based on general trade information and economic averages might be misleading in a particular case, in a specific region, or a construction company. On the other hand, development of an expert system sufficiently general to be applicable to all cases, may be of little practical value to the immediate user. An effective development of an expert system may be, therefore, conducted in two stages. The first stage will consist in development of a "professional shell". Such a shell will include all the elements of a regular shell, i.e. facilities for the domain knowledge storage, querying, inference, etc., adapted to the nature and size of the problems to be encountered. It will include all the general domain knowledge pertinent to all possible users. The context information will be divided into two classes: one - general and common to a specific country, region or a construction company; the other - specific to a particular case to be solved. The general class will be fed into the"professional shell", in the second stage of development by an expert with sufficient knowledge of the local conditions and preferences, and prepare it in this manner for the immediate use by each particular user.

The crane selection problem examined here, for the illustration of the general approach to the treatment of the construction planning tasks, was very much restricted in nature by the various limitations enumerated in section 3. The scope of these limitations may give an insight on the amount of work to be expended for the development of an expert system which can be realistically used as a tool in managerial decision making. However, the methodology for the development of an expert system - without the restrictions, will remain largely the same, as described here. Still another remaining issue, which was not examined in this study, is to what extent the construction planning can be effectively performed by tools applied to particular tasks, such as equipment selection, without addressing the whole process as an integrated whole.

APPENDIX - Application case

Following is a brief description of an application case of the system. The project included one building with a configuration described below. The procedure, followed by the expert system, consisted of three stages as described in Fig. 2.



Stage 1 included the input of the geometrical data about the building, the maximum load to be lifted (3.5 ton) and special site conditions. Based on this information the building was classified by the system as S1.

In Stage 2 three crane choices were offered to the user: a climbing crane, a rail mounted crane and an external static crane. The climbing crane option was obviated by the user due to organizational considerations. A rail mounted crane with a 24m reach and 3.5 ton payload, and a fixed crane with 28m reach and 3.5 ton payload were found feasible considering the site conditions.

In Stage 3 the two remaining alternatives were evaluated based on the information supplied by the user, and the default values unknown to him (maintenance, operator, energy) supplied by the system.

The preferred alternative was the fixed crane with the total usage cost of $37,000. Its location, as determined by the system, was shown on the scheme.

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