ESTIMATING ACTIVITY DURATIONS BY EXPERT SYSTEMS

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ABSTRACT

The identification and specification of construction operations and the selection of construction methods, including equipment and labour resources, are central activities in the production planning of construction projects. The decisions taken are complex and the choice of construction method and estimate of production output have serious consequences for the effectiveness of programming in achieving the most economic, practicable solution. Improving construction productivity by detailed and accurate planning is critically important in the increasingly competitive environment of the construction industry. Mathematical or statistical models of factors affecting production output together with knowledge based expert systems, available to the planner through the medium of the micro-computer, could be valuable tools by which to improve planning and productivity and hence minimize the costs of construction.

This paper describes a pilot study of a system designed to provide such a tool for all the activities associated with concrete frame construction. This prototype expert system consists of a rule-frame-classes-based knowledge base which can be used to simulate a consultation between an expert in construction methods, a domain expert in productivity analysis and a construction planner, the system user.

2. INTRODUCTION

Most aspects of construction activity duration estimating involve judgement into which an element of subjective bias is likely to creep. In addition, estimating activity durations is typically developed from engineering judgement and part experience of similar or near-similar situations. One of the major tasks faced by construction planners in attempting such estimates is to improve construction efficiency through accurate forecasting of resource productivity and hence reduce construction costs through efficient and reliable resource scheduling. A wide variety of construction methods is available and reliable knowledge as to the potential performance of each of these methods, in the conditions of the construction project to be planned, would be of great value to the construction planner. The development of such methods for estimating productivity and activity durations is necessary for the preparation of improved construction plans and in the more effective application of formal project scheduling methods such as CPM and PERT.

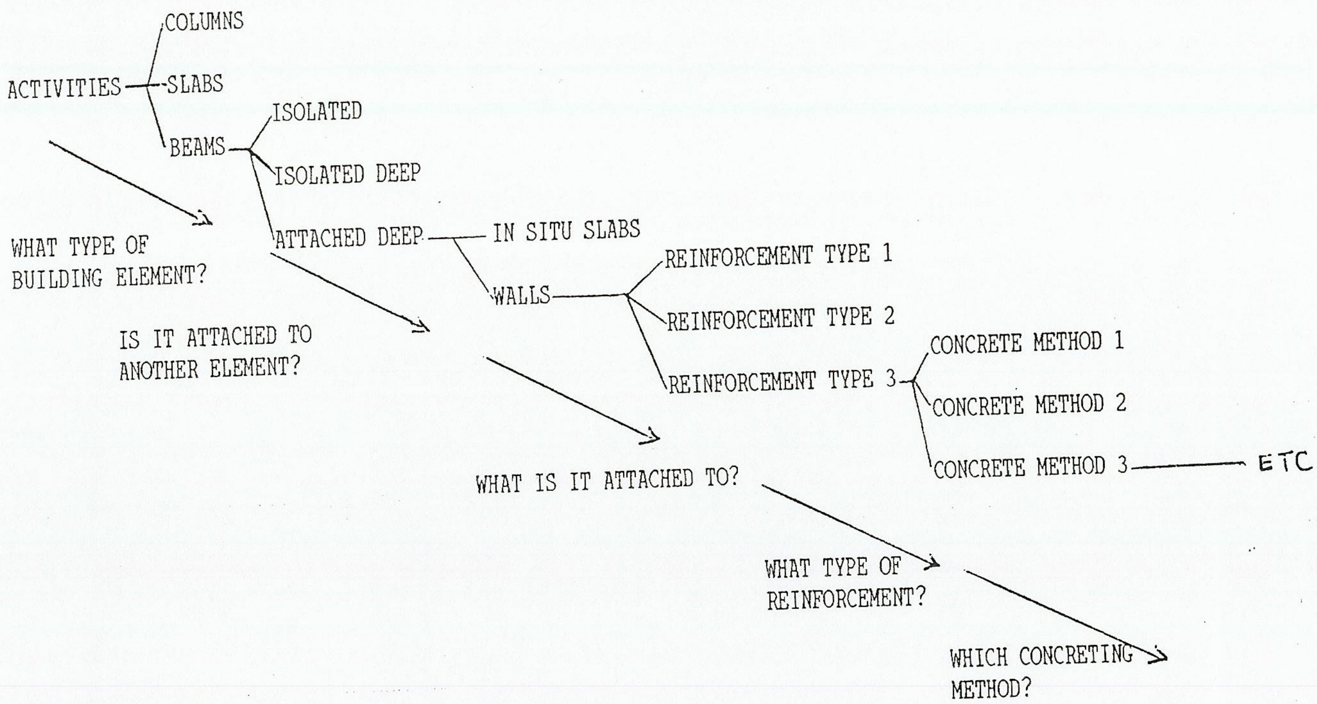
The identification of activities, the definition of relationships between these activities, the determination of resources required by the activities and the calculation of activity durations are standard tasks at the planning stage of any construction project (4,5). Although mathematical models have been used as tools to improve the accuracy and optimise activity durations, the application of knowledge based systems in the field of construction planning is just beginning (1). To demonstrate this concept this paper describes a prototype model for the estimation of activity duration. The prototype knowledge base simulation model represents an example of a new type of computer aid that can provide assistance in the construction planning process. The purpose of the research is to investigate the feasibility of an expert system of the process followed by a planner, to allow explicit analysis and a systematic representation of the estimation method. For this purpose, decision tree representation of the definition of activities and estimating durations is employed. This representation is implemented as a knowledge-based simulation system with domain knowledge expressed as production or "if-then" rules in addition to frame and classes representation of objects (2). The prototype model defines activities, estimates their times and provides a variety of explanation and advisory facilities. The prototype is limited to the construction of concrete frames though the principle may be applied to any type of activity.

3. STRUCTURE OF THE MODEL

The system is designed to analyse the construction operation hierachically, at different levels of analysis (see Figure 1). These levels are considered with respect to the way in which a construction planner structures his knowledge in the planning process. At the first level he generates construction activities relating to building components, e.g. construction of first floor columns, before moving down to the second level of detail which consists of the selection of the construction process, technology and associated resources.

The third level is the estimation of the output of the resources generated at the second level. This process consists of an analysis of productivity factors that affect each combination of resources and activity in the environment of the particular site. This analysis is achieved in the system by using an expert simulation method to quantify their effects, resulting in an adjusted productivity for each construction operation (see Figure 2). The final level is to simulate the progress of the construction operation under the forecast weather conditions in order to determine its estimated duration.

At any stage, the planner may return to a higher level and recycle through the steps in order to investigate answers to the 'what if' type of question. The system provides a list of construction activities, construction methods, resources, the expected productivity of each resource and activity durations, ready to be used by a network programme.



NOTE: An effective means of solving diagnostic tasks is to use a class-subclass frame taxonomy containing prototype description of class members as a discrimination net to successfully refine the classification of a given activity.

FIGURE 1: DEFINITION OF CONSTRUCTION PROCESS

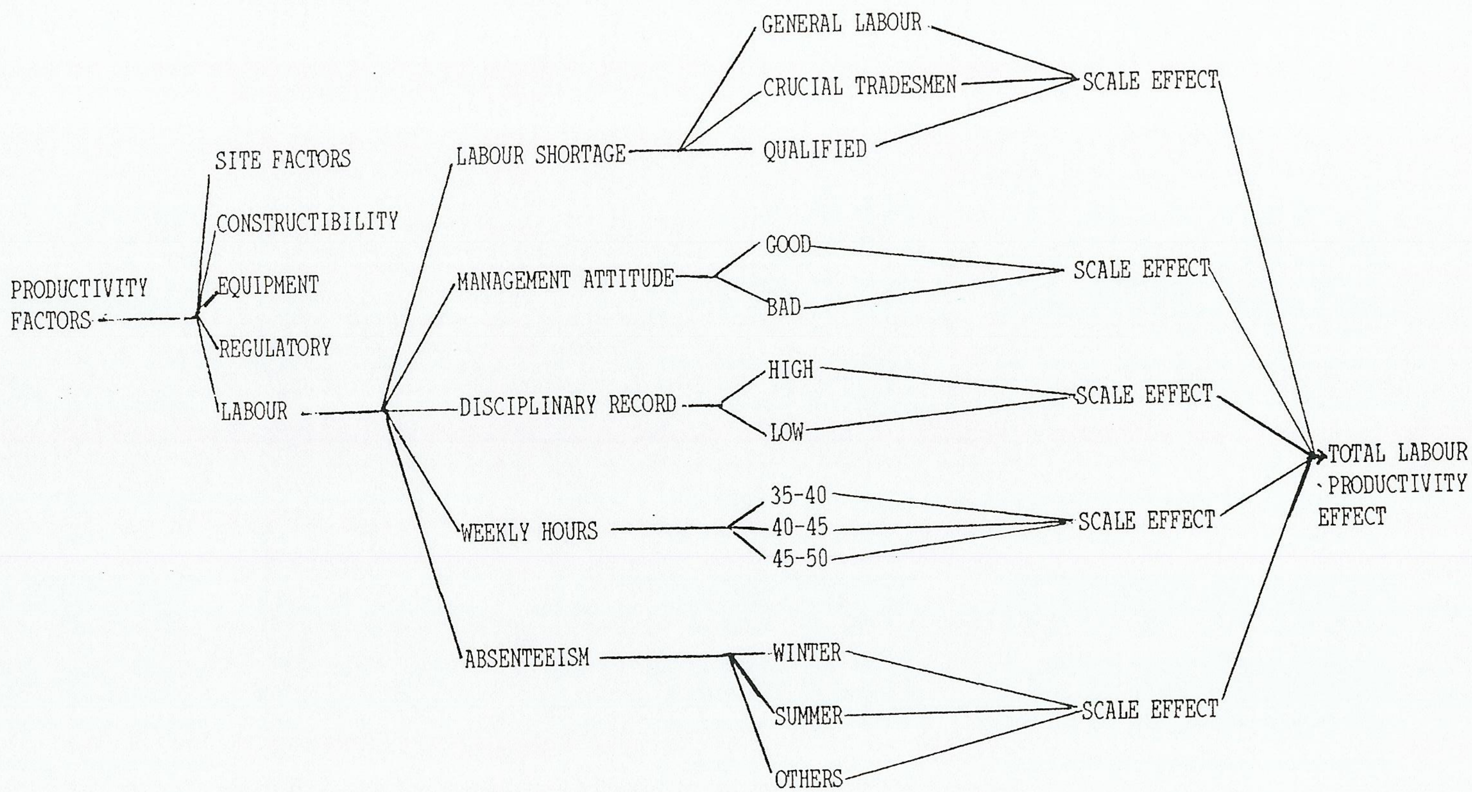


FIGURE 2: ANALYSIS OF PRODUCTIVITY FACTORS: An example of labour factor analysis

The knowledge base of the system is represented by a rule-frame sets process level. After the termination of the process analysis of the operation, the ruleset in the object-frame of this operation returns control to the higher level (main ruleset) and stores the expected productivity and activity durations.

4. KNOWLEDGE ACQUISITION FOR THE MODEL

Domain experts usually possess conceptual models which they use to represent, understand and solve problems in their respective domains. In these models there are concepts, rules and strategies for performing these tasks. The first problem in knowledge acquisition is understanding the differences and relations between the concepts and strategies used by the expert. In carrying out this task answers to the following questions are important (3).

- How is the domain mapped out in terms of significant concepts and how are these related?

- What basic strategies does the expert use in performing his tasks and how does he break them down into sub-tasks?

- What influences his strategy?

However, since the subject domain models as possessed by experts are representative of the real world problem they are trying to solve, some differences might exist between their models and the real world. No single technique is regarded as sufficient for the task of knowledge acquisition. The more types of technique adopted the richer will be the knowledge obtained. Furthermore, the selection and application of appropriate acquisition techniques is not yet fully developed.

The initial phase of knowledge acquisition for the model, from the construction literature soon made it clear that structuring and representation of the knowledge would be a major problem, if not properly managed. Concrete frame construction for a multi-storey building was therefore chosen in order to provide a more limited domain in which to concentrate initial development.

The initial phase of knowledge acquisition was carried out by literature review and iterative prototyping as explained below. The second phase, to be carried out next, will be validating and expanding this knowledge by using interviews of planning experts and iterative prototyping. The general purpose of the literature review was to define the knowledge domain using the following steps:

1) Concept testing: listing of all concepts relevant to the problem being studied i.e. to list the proposed domain, titles, subtitles and any attributes
2) Step listing: Listing of all the steps that are relevant to solve the problem under study.

Iterative prototyping involves the development of a knowledge-base at an early stage during knowledge elicitation and the demonstration of this to the domain experts. At this early stage the system was limited by a lack of production information appertaining to productivity factors on construction sites. Inevitably there will be expert criticism of the prototype which will lead to it being improved or rewritten in a different form. The basic philosophy of this technique is that it is easier for a domain expert to say how the approach of an existing system is incorrect than to state what the correct approach should be. The prototype also served to correct misconceptions about the nature of the system being developed, particularly on the part of the domain experts.

5. KNOWLEDGE MODELLING USING A NETWORK APPROACH

A method introduced here is to represent knowledge in the context of network arcs in which it occurs. The purpose of this method is to interpret the knowledge in a logical pattern and to explain the reasoning behind decisions subsequently made by the system. The following demonstrates the procedures involved. For a given main construction activity of type K, it is possible to define a set of appropriate construction process sub-networks for a given building element (e.g. concrete slab) as: $n = (N_K, A_K)$. This approach to knowledge modelling is a direct general work break down structure graph (N,A) in which N represents the set of nodes and A is an ordered binary relation over N.

The most appropriate sub-network chosen be the system user from this set of relevant sub-networks, built into the expert system knowledge base, via a selection procedure using various sub-network attributes, corresponding to a vector knowledge, $X^{(K)}$, of inputs, conclusions and default values describing the building element construction operations. Because the number of possible sub-network configurations for any building element construction process is limited the concept of a set of appropriate construction network processes is theoretically possible. The exact network chosen as being representative of the building element under consideration is determined as a function of user inputs (by selecting from the knowledge base data).

The vector knowledge $X^{(K)}$, may be conceptualised as the physical and other parameters or attributes defining a particular construction process. For example, such a vector knowledge would include such information as construction technology, related costs and loss in productivity due to uncertainty factors. In the absence of quantified data for some of these factors it is very likely in the early use of the system, particularly by an inexperienced planner, that default data relating to some construction operations and productivity factors will be used. Such default data is built into the knowledge-base (vector $X^{(K)}$) The vector $X^{(K)}$ representing knowledge about a set of construction operations (a sub-network) could comprise any attributes relevant to that sub-network.

Furthermore, associated with the building element network (N_K, A_K) and the knowledge base attribute vector $X^{(K)}$ is the vector functions or sub-vectors describing the duration, productivity and resources of construction operations ($d^K(X^{(K)})$, $P^K(X^{(t)})$, $R^K(X^{(K)})$. Vector functions d^K, P^K and R^K are either functions of user inputs changing in a functional way as the values of X^1, X^2, ... X^n change or more specifically, attributes associated with it are of the network calculated by the expert simulations model depending on the vector $X^{(K)}$ inputs.

It follows from the above line of reasoning, that the parameters originally defining the relevant construction operation networks may now be extended to include any information or knowledge relevant to the durations, productivity and resources of each construction operation in the network. Consequently, a building element network is defined as:

1. $n = (N_K, A_K)$ predetermined function or functions of user inputs

2. $d^K(X^{(K)})$, $P^K(X^{(K)})$, $R^K(X^{(K)})$ output function which depend on vector $X^{(K)}$ inputs

3. $X^{(K)}$ knowledge vector considered as a state vector

Once a network and associated construction operations and their attributes relating to a relevant building element are completely defined, they are used to determine the network durations under the condition of state vector $X^{(K)}$. Furthermore, the state vector is enhanced by employing Monte Carlo simulation to add a probabilistic dimension to vector knowledge. By sampling from known or assumed distributions of the productivity factors involved in the construction process and with repeated iterations, it is possible to determine the expected value of the productivity factors under consideration, together with their associated probability distribution.

6. INTEGRATING THE COMPONENTS OF THE KNOWLEDGE-BASE

Following from the reasoning outlined above, it would seem feasible that identical logic is applicable to all the other elements of the construction process and their attributes. However, given that a choice of networks exists with its knowledge base of all relevant factors, from within a family of relevant building element networks and their associated attributes, it is evident that the problem of coupling chosen networks needs attention.

The Leonardo knowledge-base system shell was chosen for coupling components of the knowledge base. The facilities in the Leonardo shell provided an important means to integrate building element networks (N_K, A_K), knowledge base attributes vector $X^{(K)}$ and the output function $d^K(X^K)$, $P^K(X^K)$ and $R^K(X^K)$. The integration is achieved by using if-then rules. Frames and classes facilities in addition to procedures written in both Leonardo Code and Pascal Code.

CONCLUSION

The developments described in this paper have explored an area of research which requires much further investigation. The model although developed using past examples and data from literature, is still undergoing detailed evaluation with respect to its ability to correctly identify complex planning issues. The procedures for the estimation of activity durations however, seem satisfactory and provide a useful structure for most cases arising on construction projects. Initial trials indicate that the concept provides a disciplined method of transferring knowledge, especially to young and inexperienced planners. The next phase of development is to simulate the progress of construction opertions under any forecast weather conditions. The final phase of research will ascertain how well the model performs on carefully chosen samples of users with various levels of expertise of the subject.

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