GENERATION OF CONSTRUCTION SCHEDULES
A KNOWLEDGE BASED APPROACH

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ABSTRACT

The generation of construction schedules is a time consuming task that requires the participation of experienced personnel and is mostly unsupported by today's computer software. The objective of this research effort is to utilize a Knowledge Based approach to produce better tools for providing added support to the construction scheduler. Collaboration of several construction firms and their schedulers has been obtained for the knowledge acquisition process. Some of the main results of this acquisition are discussed here. The ongoing implementation effort is also briefly described.

1. INTRODUCTION.

The task of generating the schedule for the construction of a project demands a considerable amount of expertise. Since it is also a time consuming task, it implies the attention of experienced personnel during a substantial period of time.

Commercially available computerized tools for the support of the scheduling effort are limited in nature. They provide only the capability of producing and maintaining a network representation of the activities involved in the execution of a project. All the work of breaking down the construction process into activities, sequencing them and determining their durations is still manually performed.

It is the objective of this research effort to produce a computerized tool that is able to support not only the CPM calculations involved in scheduling, but the processes of identifying activities, defining their sequencing and their durations. The approach is to utilize Knowledge Based Systems technology to provide this kind of support. An essential part of this approach is to learn from the actual schedulers about their skill. Collaboration from the Industry has been obtained and has been successful in this respect.

The work is currently focused on the analysis of mid-rise building construction. The results are believed to be extendable to other types of construction with some effort.

2. KNOWLEDGE ACQUISITION PROCESS.

Four construction firms are participating in this research effort by providing the expertise of their schedulers. The experience in scheduling for the collaborating experts ranges from ten to twenty years. The acquisition of the knowledge they utilize to generate construction schedules is undoubtedly one of the most essential and critical tasks in this research effort. There are however some obstacles that had to be overcome in order to perform a complete and accurate knowledge elicitation process.

The major obstacle encountered is the reduced interest in some sectors of the Construction Industry to actively participate in research efforts. Most of the schedulers contacted are aware of the potential benefits that better tools created through research efforts might bring. However, it is difficult for most of them to see an immediate or short term payoff that unfortunately is often required to obtain top management level support for research activities. It was decided to deal with this limitation here by designing a methodology for knowledge acquisition that would reduce the time spent by the experts while keeping the amount and quality of the acquired knowledge adequate.

Two main approaches are here used to acquire the knowledge. One is the direct observation of the experts while in the process of producing the schedule of a mid-rise building new for all the participating experts. The other is the discussion based on the examination of schedules created by the schedulers for real projects constructed by their respective firms.

Because of the experts' time limitations it is not feasible to observe a completely typical scheduling generation process. Actual observation of an expert in action is done by having the interviewer act as an assistant to the expert in a series of meetings. The objective of the meetings is to allow the expert to provide instructions to the interviewer for generating the schedule. In a typical meeting, the interviewer presents the progress performed on the schedule obtained by following the instructions provided in the previous meeting. The expert comments on the work done, approving it or recommending changes, and defines the instructions to continue the generation of the schedule.

This process of acquiring knowledge through the generation of a schedule for a mid-rise building was performed only at two of the four construction firms that collaborated in this work. Five meetings of approximately two hours were held with each expert, with an average period of two weeks in between one meeting and the next.

The other approach for acquiring knowledge consists of discussions based on the analysis of schedules generated for previous construction projects. This approach was performed at all four participating firms. The major results of both knowledge acquisition processes are described in the following section.

3. SCHEDULING OF MID-RISE BUILDING CONSTRUCTION.

3.1. GENERAL APPROACH.

The schedule generation process is composed of two major steps (refer to Figure 1.). The first step consists of the understanding of relevant project information. The scheduler is given drawings and specifications for the project for which a schedule has to be produced. The approach followed by the scheduler in this first step is to learn about the project by identifying typical and non-typical features.

Most of the effort of the scheduler in this first step is used in identifying the scope of the project (type of project, location, size and main systems) and in understanding the non-typical features belonging to the different systems (Structural System, Mechanical System, etc.). Since he/she has dealt with typical features extensively in the past (prior experience), there is no need to use considerable effort to understand them.

The second step of the schedule generation process consists of the actual production of the schedule. It is important to mention that there is an overlap and iteration between these two steps; that is, the production of the schedule starts before all the relevant information from the project has been identified and digested by the scheduler. But there is a clear difference between the first phase when the effort is mostly dedicated to understanding and the second phase when the effort is focused to produce a schedule.

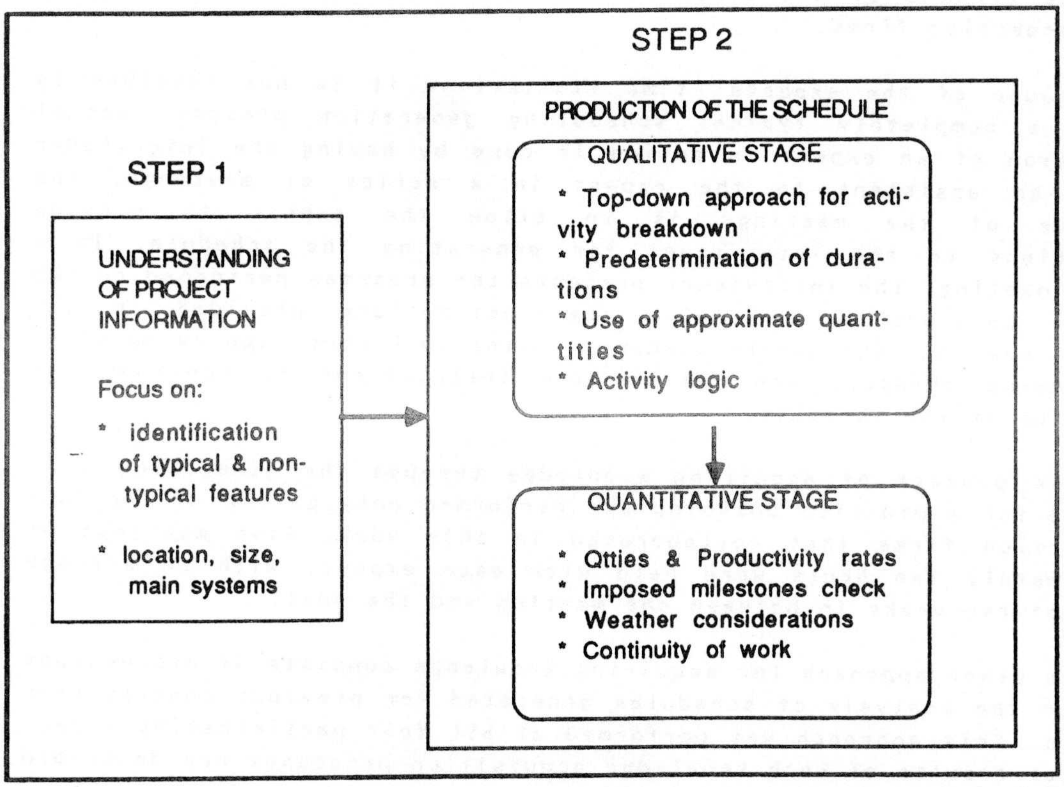

Figure 1. Overview of the Schedule Generation Process

3.2. PRODUCTION OF THE SCHEDULE.

The production of the schedule (second step) is executed in two stages. What is here defined as a qualitative stage comes first where the scheduler follows a top-down approach to break down the construction of the project into activities. A preliminary sequencing of the activities is also performed. Section 3.3. provides a detailed description of how the scheduling logic is determined. Activity durations are then preliminarily determined in this qualitative stage with the objective of producing an adequate pace of construction for the overall construction process.

A major role is played by some of the activities in this predetermination of the pace and duration of the construction process. The excavation and foundation, the frame erection, the enclosure installation, the mechanical and electrical finishes, and the elevator installation are very likely to be part of the critical path. The of the construction process pace is largely dependent on these dominant activities.

The concept of work area definition is employed here by the scheduler for performing the breakdown of the construction project into activities. Typically a work area is associated with a story (floor) and a system (rough electrical second floor). Under certain circumstances the floors may be subdivided further, into smaller work areas. For instance, if the size of the floor slab or concrete deck is larger than the amount of area that a concreting crew can handle comfortably in a day, the floor slab or concrete deck is cast in two or more operations, implying the existence of two work areas for this particular floor.

The second stage of the production of the schedule is defined here as the quantitative stage. Here quantities of work are associated with crew (labor) productivity rates to verify the durations predetermined in the qualitative first stage. The schedule is checked against imposed milestones (e.g. project construction completion) and weather constraints (e.g. no concreting activities in cold weather).

A very important goal of the scheduler in this second stage is to maintain the flow of the work of the different trades. The intention is to avoid interruptions in the work of crews performing repetitive activities, since these interruptions negatively affect the performance. By improving the continuity of work the learning curve effect is maximized, and delays and extra effort (set-up time, temporary storage of tools/materials, etc.) associated with work interruptions are minimized.

This process of producing the schedule is iterative in nature. The scheduler incorporates any desired changes in the schedule and then assesses it again until it meets the criteria described above.

3.3. SCHEDULING LOGIC.

An important part of the definition of activities for accomplishing the construction of a building is the determination of the activity logic. Relevant contributions to the understanding of activity logic exist in the literature. The results presented here build on the work of others [Gray 86], [Levitt 88], [Navinchandra 88], [Zozaya 88].

Four major factors that determine activity logic are identified: (1)functional relationships among building components; (2)interactions among different trades involved in the construction process; (3)limited resources; and (4)code regulations and standards. There is a summary of the effects on scheduling logic of these factors in Figure 2. They are also described in more detail in the paragraphs below.

Functional Relationships Among Building Components.

Activities that consist of the installation of building components (e.g. columns 1st floor, paint 5th floor walls) have precedence relationships affected by the relationships of the components they install with other building components. This is very much in agreement with the work described in the references mentioned above. The main relationships considered here are as follows:

- <building component 1> supported-by <building component 2>
- <building component 1> covered-by <building component 2>
- <building component 1> weather-protected-by <building component 2>
- <building component 1> embedded-in <building component 2>

If an activity consists of the installation of a door that is supported by a door frame, then the activity of installing the door frame should precede the former. Similarly, the other three relationships among building components (covered-by, weather-protected-by and embedded-in) imply precedence relationships between their associated activities

Trade Interaction.

The construction of a project involves the participation of numerous trades working in the same location, and for quite a few of them, operating simultaneously on site. This interaction of trades affects the scheduling logic when crews and their equipment affect the performance other crews. The interaction of crews and equipment can be described by the following cases:

- <crew or equipment 1> occupies-same-space-as <crew or equipment 2>
- <crew or equipment 1> provides-service-to <crew or equipment 2>
- <crew or equipment 1> may-damage <component installed-by crew 2>
- <crew or equipment 1> affects-environment-of <crew 2>

If a crew is competing for space with another crew or a piece of equipment (e.g. rough-in plumbing and formwork) a sequence has to be established. Similarly, if a crew is providing a service to another crew (e.g. rough-in electrical is providing the power to install and test the elevator platforms) the latter has to follow the one providing the service. In the case in which the installation of a building component damages another component (e.g. wall painting may damage the carpet), a precedence relationship has to exist. A clear sequence has to be established as well if the installation of a component affects negatively the environment; e.g. spraying of fire proofing for a steel frame affects the quality of the air.

Resource Limitations.

Competition for resources necessarily forces non-parallelism in the execution of the competing tasks.

Code Regulations.

The final factor identified here that affects the sequencing of activities originates in regulations imposed on the construction process dictated mainly by safety standards. This is the case of the regulation enforced by OSHA that requires a horizontal diaphragm following not more than two stories behind the steel erection crew in steel framed structures. In practice this results in the installation of the metal deck staggered two stories behind the erection of the frame. It can be argued that this situation can be represented as the metal deck crew providing a service (safety) to the steel erection crew. However, it is classified separately because regulations and standards are subject to change.

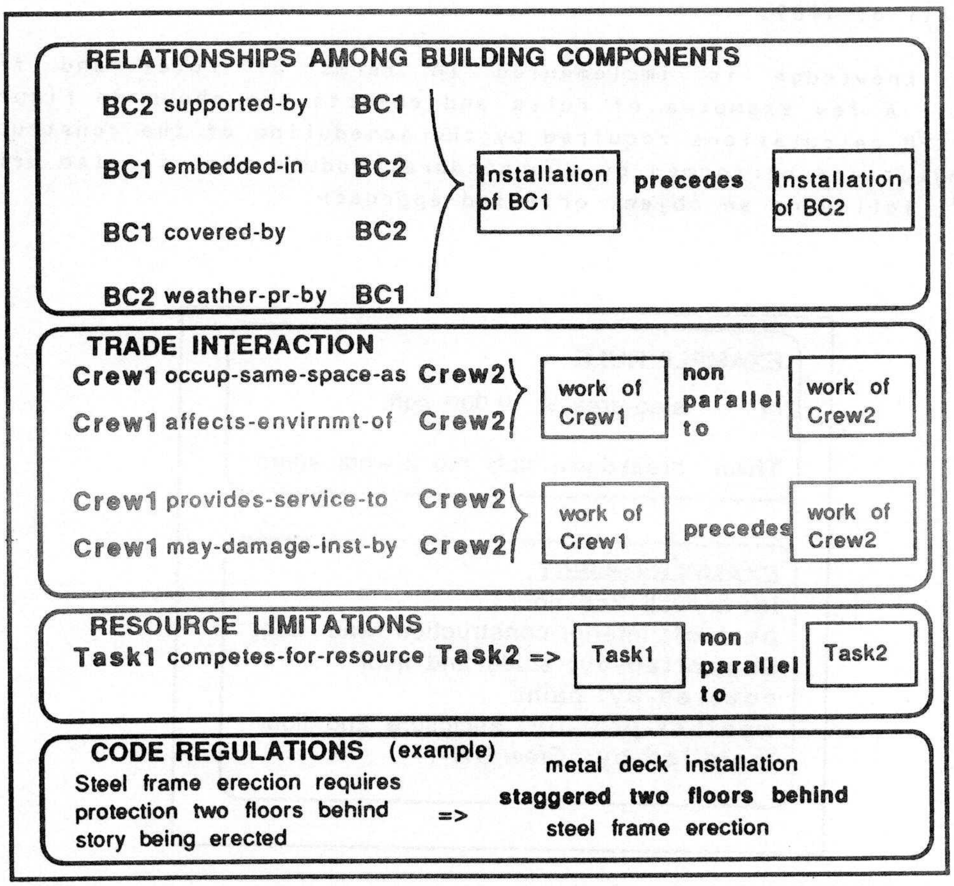

Figure 2. Factors that Influence Scheduling Logic.

4. PROTOTYPE IMPLEMENTATION.

A prototype Knowledge Based system is being implemented that incorporates part of the acquired knowledge. It is not intended to be a replacement for the scheduler but rather an intelligent assistant for him/her. In order to make it more useful to the scheduler it is being conceived to require reduced user input. The intention is to avoid the scheduler spending enormous amounts of time feeding information into the computer.

The knowledge base of this prototype system consists of several modules that interact following a blackboard architecture. One module consists of a hierarchical breakdown of the different building systems into building components. This module is in charge of providing the knowledge for the system to understand project information. Another module supports a hierarchical breakdown of the construction of the building into activities. A third module contains the knowledge to determine activity logic. The knowledge to perform allocation of crews and that checks the preliminary schedule against different criteria (see section 3.2.) is contained in another module.

The prototype system is being developed using KEE™. The implementation is currently in progress and is expected to be completed in the Fall of 1989.

The knowledge is implemented in terms of rules and frames (objects). A few examples of rules and objects are shown in Figure 3. All the CPM calculations required by the scheduling of the construction of a project are performed by a procedural module that is also written in KEE™, following an object-oriented approach.

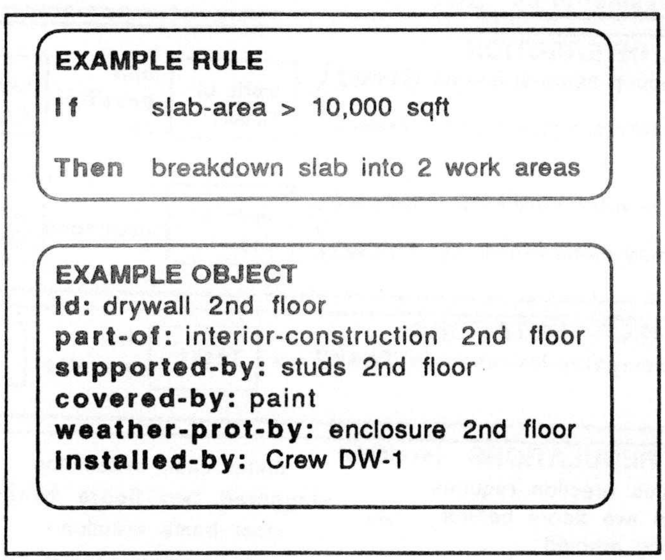

Figure 3. Example of a Rule and an Object.

5. CONCLUSIONS.

The collaboration of Construction Industry schedulers has been highly successful. A good body of knowledge has been acquired for the scheduling of mid-rise building construction.

Part of this knowledge is in the process of being implemented in a prototype Knowledge Based system. This effort is beneficial in terms of added support for construction schedulers. It is also contributing by providing a formalized description of the knowledge utilized by expert schedulers to create construction schedules.

6. ACKNOWLEDGMENTS.

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