Construction Planning and Manageability Prediction

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ABSTRACT

The Construction Planning and Manageability Prediction (CM) System builds a master plan and schedule that explicitly represents planned construction methods and resource utilization. The system simulates the schedule and identifies potential risks causing difficulties during construction. An automated diagnosis procedure analyzes the simulation results to identify potential risk factors in the plan and schedule in order to help a project manager assess project manageability. This paper also discusses the knowledge structure for construction planning and manageability design in the knowledge-based computer tool.

1. INTRODUCTION

1.1 BACKGROUND

Careful pre-construction master planning and scheduling is a prerequisite to later success in the construction phase. In practice, designs and plans rarely include explicit assessments of how easy or difficult they will be to perform, i.e., their manageability. A good project manager can identify potential risk factors of a plan and schedule: conditions that might go wrong or cause problems with a successful project execution, and create successful construction master plans and schedules that are both feasible and reliable. Feasibility is largely a technical issue: given a building plan and a set of construction methods and resources. Reliability, on the other hand, is largely a managerial issue, describing the predictability of a plan. Therefore, this is the basic issue of our research on manageability.

While we do not have quantitative survey evidence, it is our experience and impression that most projects have relatively large numbers of unanticipated problems concerning timely availability of resources, ability to manage resources safely, quickly and effectively while finding workarounds for incomplete, erroneous or suboptimal designs. Project managers seem to spend large amounts of time "fighting fires" while rather less time administering a planned routine. Therefore, reliability is the basic issue of our research on manageability.

This research project demonstrates the potential of using computer tools to build construction plans and schedules automatically, and to assess the manageability of a planned project, given its design, construction plan and schedule. This manageability assessment can be done during the pre-construction phase, so the design, plan or schedule can be changed to improve manageability. For contractors, quick planning and early analysis of manageability should lead to better anticipation and management of construction problems. (Better management anticipation should in turn lead to a higher likelihood that projects are completed on-time, on-budget, with higher quality for users, and higher profits for all involved.)

1.2 OBJECTIVE

This project started due to the current lack of planning and operational theories and proven standard practice for assessing construction risks. In addition, there is a lack of effective tools to make feasible construction plans and schedules automatically and to assess risks in construction plans and schedules for manageability. The difficulty of building feasible and reliable plans led us to the following two major objectives:

- *Help automate the master planning and scheduling processes.* Our conjecture is that computer tools can help human planners to produce feasible plans and schedules much faster and more accurately.
- *Improve master planning and scheduling reliability.* Carefully conceived computer tools can aid human planners to produce plans and schedules more accurately while considering such issues as constructability, safety, effective resource movement, and impact of construction on surrounding areas. The three main features in attaining this objective are as follows:
  1. identify specific risk factors,
  2. identify their causes and potential effects on activities,
  3. identify particularly risky activities that could occur during construction time.

  The theory should produce a formalized procedure to assess plan feasibility and reliability and to identify specific issues that may make plans unreliable.

This project will lead to definitions of risk factors that affect project reliability and theories of how to assess their presence. These definitions and theories can then lead ultimately to procedures and tools that will help project managers operate their construction projects more successfully.

To meet these objectives, we (1) formulated a theory of master planning and scheduling in enough detail that it can be implemented into a computer; (2) implemented the theory into a computer; (3) tested the theory using realistic test cases.

1.3 SCOPE

Figure 1 shows a schematic representation of the process of pre-construction master planning. Using project and design information, project planners use engineering knowledge to plan construction methods, create a construction plan, and build a schedule. They then attempt to predict potential problems and assess project manageability.

Normally, busy engineers use corporate experience and standard methods such as CPM to do method and construction planning and scheduling. Manageability assessment, if done at all, is informal. Thus, the assessment made during planning will include implicit assumptions.

Project information used for setting objectives include:

- Financial, physical, regional, social and other environmental conditions and objectives that characterize the local building environment.

Design information used in planing and scheduling include:

- 3D CAD design or, more typically, 2D plans, elevation and section drawings.

Problem simulation and manageability analysis are normally implicit in the minds of project managers, but rarely performed explicitly due to a lack of time, tools and theories. If performed, it considers information including project information, design information, methods, plans and schedules.

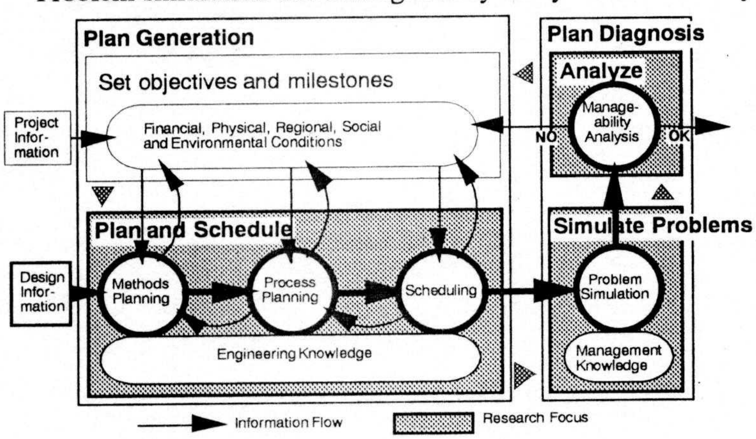

Figure 1: Master planning and scheduling process

The Construction Planning and Manageability Prediction (CM) System builds a master plan and schedule that explicitly represents planned construction methods and resource utilization.

Figure 2 shows the CM system logic flow indicated in six steps as follows:

- Build symbolic model: given a 3D CAD model, the CM system builds a symbolic conceptual building model that describes the features of the facility.
- Methods Planning: infers activities and resources needed for construction of the designed building.
- Process Planning: infers precedence of inferred activities.
- Scheduling: builds a scheduling chart based on the results of planning phases.
- Problem Simulation: simulates problem occurrence in the planned project.
- Manageability Analysis: analyzes each activity and identifies conditions that will make the activity easy or difficult to perform.

The CM system used AutoCAD as a 3D CAD modeling package and ProKappa as a symbolic Object-Oriented modeling tool. We built AutoCAD routines to recognize features in the graphic model and to send those features to the Kappa application.

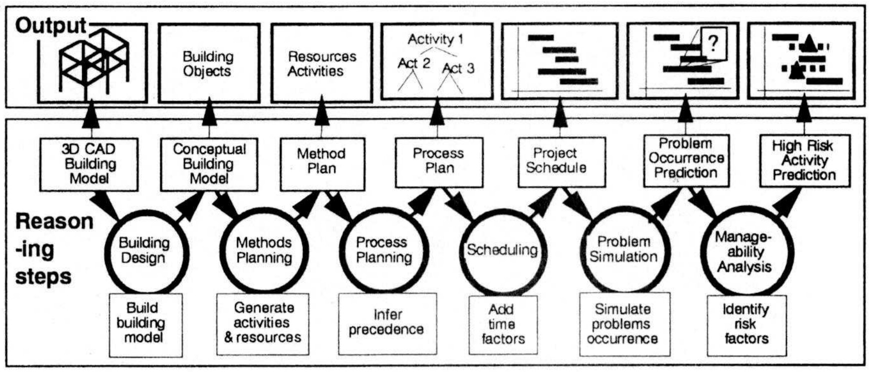

Figure 2: CM system information flow

2. MODEL FOR REASONING

The CM system includes symbolic models of both a building to be built, and the process of master planning and manageability analysis. These symbolic models have explicit representations of form, function and behavior, based on the approach to symbolic modeling described by [Kunz].

Form describes the basic conceptual elements of a model. The form of the master planning and manageability analysis includes conceptual entities in project management, such as activities and risk factors. Activities have standard CPM predecessor/successor relationships. In addition, they have a *SupportingActivity* relationship to identify necessary support activities. For instance, "Erect framing steel activity" has "Maintain cranes activity" as a *SupportingActivity*.

Functions describe the intent of designers in using specific forms. In the case of the building, the function is simply to provide space. Other possible functions include maintaining a particular temperature and lighting levels, resisting lateral and gravity loads, and providing access to allow occupants to move from one space to another. In the case of master planning and scheduling, functions include various activities as summarized as follows:

- Construction Activities e.g., Erecting framing steel work, Placing form work.
- Supply Resource Activities e.g., Labor supply, Materials supply, Energy supply.
- Maintain Site Facility Activities e.g., Moving equipment maintenance.
- Plan, Schedule, Operation Activities e.g., Task scheduling, Site direction.
- External Coordination Activities e.g., Neighbors negotiation, Law requirement coordination.

In the CM system, resources have behavioral attributes, including descriptions of the way in which they may or may not perform intended activities as planned. Behavior normally includes the way in which form elements are intended to behave, given their functions, and it may include additional behaviors which might be benign, beneficial or undesirable.

3. CONSTRUCTION PLANNING AND SCHEDULING

This section describes the first four steps performed by the CM system.

3.1 BUILDING DESIGN

Construction planning requires understanding the building elements of a design. In addition, each of these elements have properties such as dimensions, features, materials, and construction methods. Finally, these elements have relationships with each other, such as "Supported by" and "Surrounded by." Typical CAD drawings are built using very simple graphic primitives (e.g., extruded rectangles), that identify the higher level elements to be constructed, such as walls and beams, and to identify the properties and relationships of each physical element. The first step in the CM system, as shown in Figure 2, is Building Design. It involves creating a 3D CAD drawing of a building and identifying the structural engineering and construction features in the drawing.

In addition to interpreting construction features in a graphic building model, the user also identifies the structural engineering features of the building model. Thus, a user might interpret a particular column as a steel (S), a reinforced concrete (RC), or as a steel and reinforced concrete (SRC) structure.

3.2 CONSTRUCTION METHOD PLANNING

The second step in the CM system involves selecting the methods to be used to construct each construction element and then identify the materials, resources and activities.

The CM system now considers three kinds of construction methods:

- Building Method e.g., steel or reinforced concrete structures.
- Process Method; Precedence of construction steps e.g., jointless or floor-by-floor steel construction.
- Production Method; Production of each building object or part e.g., prefabricated concrete or site-built methods.

The CM system infers applicable methods in each building feature to be constructed. When multiple methods are possible, the user selects a preferred method.

The CM system infers activities and resources in the following way, as shown in Figure 3.

- Identify building materials needed to construct each building object, given chosen construction methods.
- Identify subsidiary materials required by the main materials and methods.
- Identify activities required to place main materials.
- Identify activities required to place and remove subsidiary materials.
- Infer "works with" and its inverse, "works for", relationships among activities. For example, an activity to place elevated objects or resources also requires an activity to place scaffolding. The place-scaffold "works for" some associated place-objects activities, and they in turn "work with" the place-scaffold activity.

The CM system includes descriptions of building objects, any of which may require other building objects. Using these building object descriptions, resource and activity generation are performed recursively. For example, a building requires a column that requires concrete that requires a form and form erection. Eventually, CM generates all activities and resources needed for construction of a designed building. The CM system calculates activity durations based on unit times and the volume of each building object being processed by an activity.

In the CM system, construction planning activities include providing resources, site maintenance, placing and removing temporary resources such as scaffolding, external coordination, and actual construction activity.

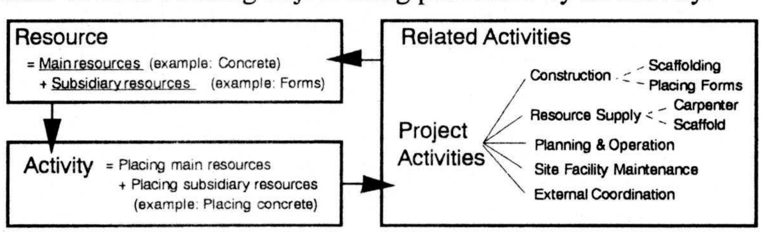

Figure 3: Activity and Resources Reasoning

3.3 PROCESS PLANNING

The third step in the CM involves creating the precedence relationships among the activities to be performed in construction. The CM system uses the OARPLAN planner [Darwiche] with further enhancement made for this research. OARPLAN uses two basic intuitions:

- Actions build Objects using Resources.
- The planner uses basic structural engineering relationships to sequence activities.

CM infers predecessor activities of generated activities using structural constraints such as the *"SupportedBy"* structural relationship and physical constraints such as the *"SurroundedBy"* physical relationship. For instance:

- Activities that place objects on the first floor are predecessors of the second floor's activities.
- Column placement activities are predecessors of beam placement activities.
- For a SRC structure, activities that erect framing steel have precedence over activities that place reinforcing bars, and over activities that pour concrete.

CM infers a precedence for some activities by considering their role as placing a subsidiary material or providing a supporting activity, using "Work For" relationship as shown in Figure 4. For instance:

- Placing forms is a predecessor of placing concrete because forms are subsidiary materials required by concrete.
- Removing forms is a successor of placing concrete.
- Placing scaffold is a predecessor of placing reinforcing bars because the activity placing reinforcing bars works with a supporting activity managing scaffold.

3.4 SCHEDULING

The fourth step in the CM uses the CPM algorithm to create a schedule for the construction activities. A Gantt chart displays the schedule. Users can change activity durations interactively on the schedule chart, such as the one to be illustrated in Figure 8, and it automatically updates dependent activity start and end times.

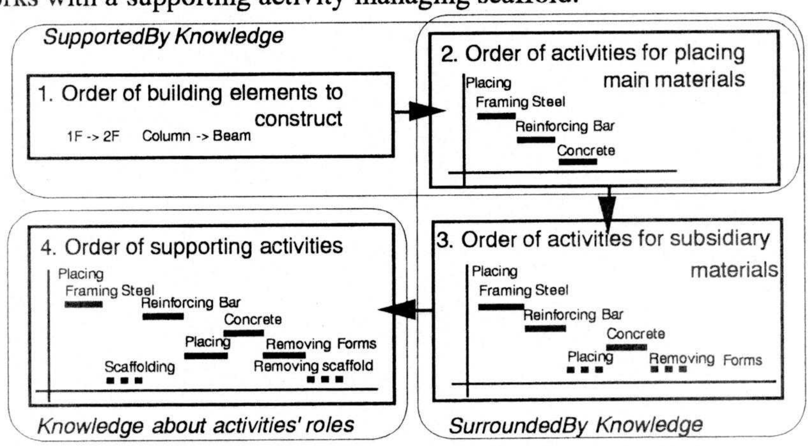

Figure 4: Process Planning

4. MANAGEABILITY DIAGNOSIS

Section 1 dealt with the necessity of manageability diagnosis for successful construction management, and section 3 discussed the steps performed by the CM system that set up the input to the manageability analysis. This section therefore talks about the mechanism by which risks become management problems, and develops a theory to predict the manageability of a planned construction project, given its design, plans and schedule.

4.1 A FORCE FIELD METAPHOR

A force field is a suggestive metaphor for the process of project management. Managers and engineers exert a control force to push a project along a planned trajectory towards it's goal. There is always an opposing problem force (sometimes named "Murphy") that pushes against the control force. The balance of the control and problem forces will determine the construction's progress. The assumption behind our work therefore is that a control force is more likely to be effective when it can predict an opposing problem force.

It's common occurrence that many problems during construction, even given a feasible plan, for instance, workers may not come on time because of poor cooperation or reluctance to work with an unfamiliar subcontractor, or more particularly during severe weather condition.

In this research, manageability describes the ease of executing a project plan. Manageability describes how easy or hard it will be for the project team to follow a feasible plan.

4.2 GENERIC CAUSES OF RISKS

Inexperienced construction engineers often have not developed the skills to anticipate and manage these risks consistently and effectively. Highly skilled managers and engineers, on the other hand, seem to formalize their specific experiences into more general categories of knowledge, and eventually, anticipate potential problems in projects, making plans to avoid them.

The CM system uses basic intuitions:

- Resources have essential attributes.
- Activity components get sick when resources' essential attributes activate.
- Sick activity components, eventually, make a whole project down.

The CM model activates essential attributes when a resource attempts to work against some inevitable physical or organizational force. For example, a framing steel column, even one that is long and heavy, will not fall if it is not erected. To erect a steel column is an action against the law of gravity. To erect a long and heavy steel column with a careless worker is dangerous.

If workers must place many similar framing steel pieces in exactly correct positions, the "difficulty of performing accurate work repeatedly" essential attribute will cause a generic hazard to the success of the framing activity and thus to the overall construction project. The latent hazard becomes an actual risk factor that may lead to a problem if specific management influence does not provide adequate worker training, strong motivation, and careful measurement with review of the work's accuracy.

The problem cascade shows the potential effects of management influence in blocking the cascade of effects from hazards to problems. The CM system simulates the sequence of activity completion. The manageability analysis shows each place in the activity schedule there is an opportunity to exert management control force to reduce the likelihood of hazards becoming problems.

At those times when the need for management attention is greatest, are times when the project is most likely to go out of control: without management attention, generic hazards quickly become real problems.

As an example, Figure 5 shows the problem cascade for one potential problem for an activity that involves placement of framing steel. Resources and actions have essential attributes (note that the site is a resource in most activities); resources have generic hazards and risk factors; activities have problems.

- Essential Attributes are basic properties of resources and actions.
- Generic Hazards are specific risks of an activity that involves use of a resource to perform a specific action.
- Risk factors are specific situations concerning supporting activities that, if unchecked, will lead to project problems.
- Problems are situations concerning construction activities that delay project progress.

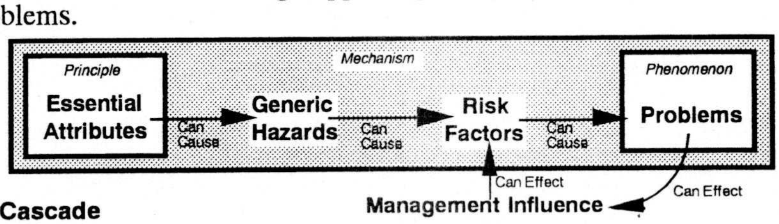

Figure 5: Activity Problem Cascade

4.3 PROBLEM SIMULATION

Simulation, the fifth step in the CM involves considering each activity in the construction schedule, identifying risk factors that may be present with the activity, and describing the causes and possible effects of those risks.

The CM system simulates possible activity behavior to identify the problems that activities can encounter and to identify the associated need for management attention to minimize problem likelihood and severity. The simulator uses heuristics to identify problems that might occur with each activity. Heuristics consider the following issues essential attributes of resources and activities, size of each activity component, worker's skill, familiarity of workers and problem difficulties.

The user runs the simulation interactively, like a computer game. The user asks the computer to simulate problems during a chosen period, e.g., one day or one week. The system identifies potential problems with sick activities being performed during that period. The user selects activities; treat "sick activities", to receive discretionary problem-management attention. If available management influence doesn't exceed the management effort required for the problems of the selected activities, the system can't remove all of the problems and they then affect future periods. Activities simulated in future time periods will then have fewer problems when the user chooses to give attention to problems of their preceding support activities.

Figure 6 shows the user interface of the CM system after it analyzed two time periods in the simple test case schedule and as the user selected two activities to receive management attention.

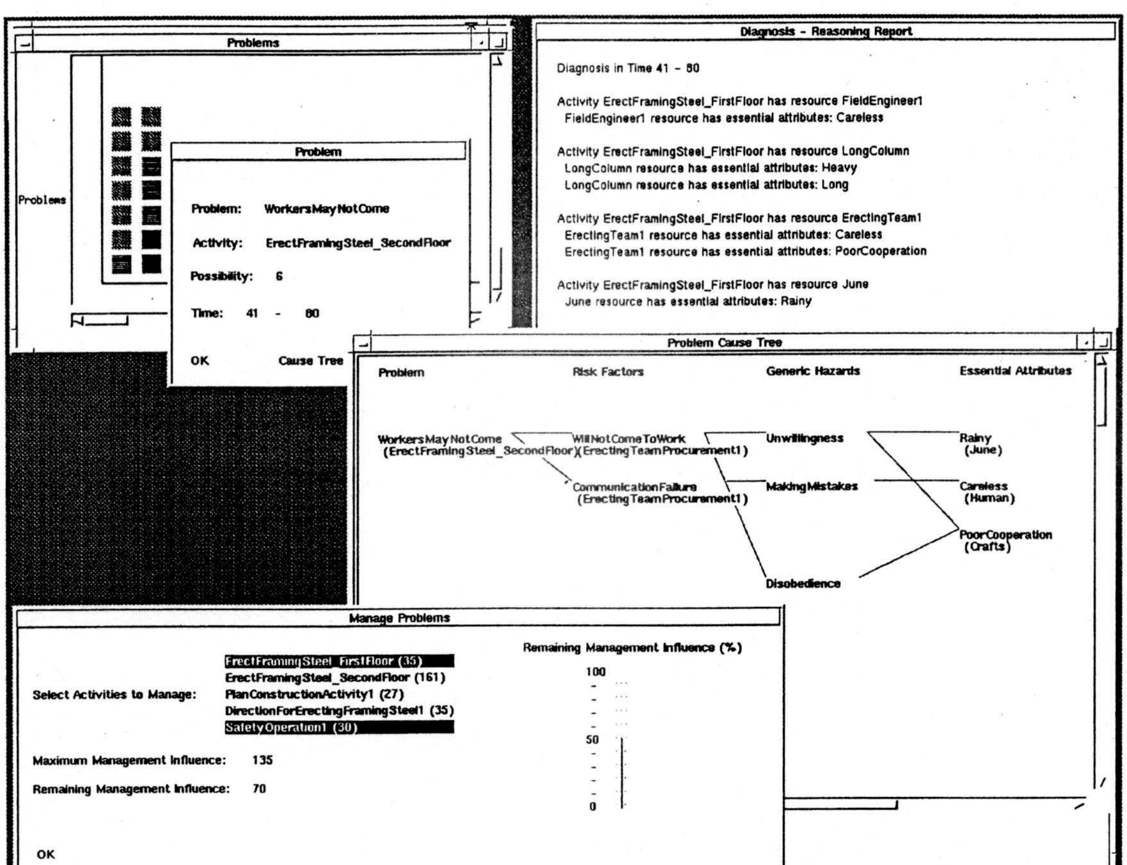

Figure 6: Example CM system detailed output

4.4 MANAGEABILITY ANALYSIS

As the result of manageability analysis, Figure 8 shows a complete Gantt chart for the simple case example (bottom window), maximum available management influence during each time period between vertical time lines in the Gantt chart (middle window), and problems during each time period (top window). The Gantt chart identifies activities with problems by assigning them a different color and, as shown in Figure 8, slightly larger bar height, during the time periods in which the system infers that problems may be active.

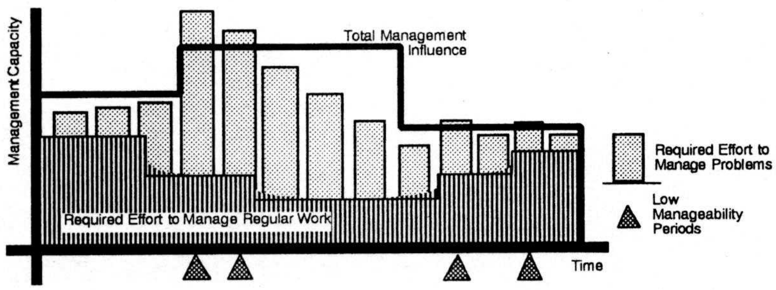

Figure 7: Manageability Analysis

Total management capacity during any time period, as shown in Figure 7, varies directly with the number of available managers, their skill and their roles in a management organization. Management influence varies inversely with increasing numbers of workers scheduled to work and the difficulty of planned activities.

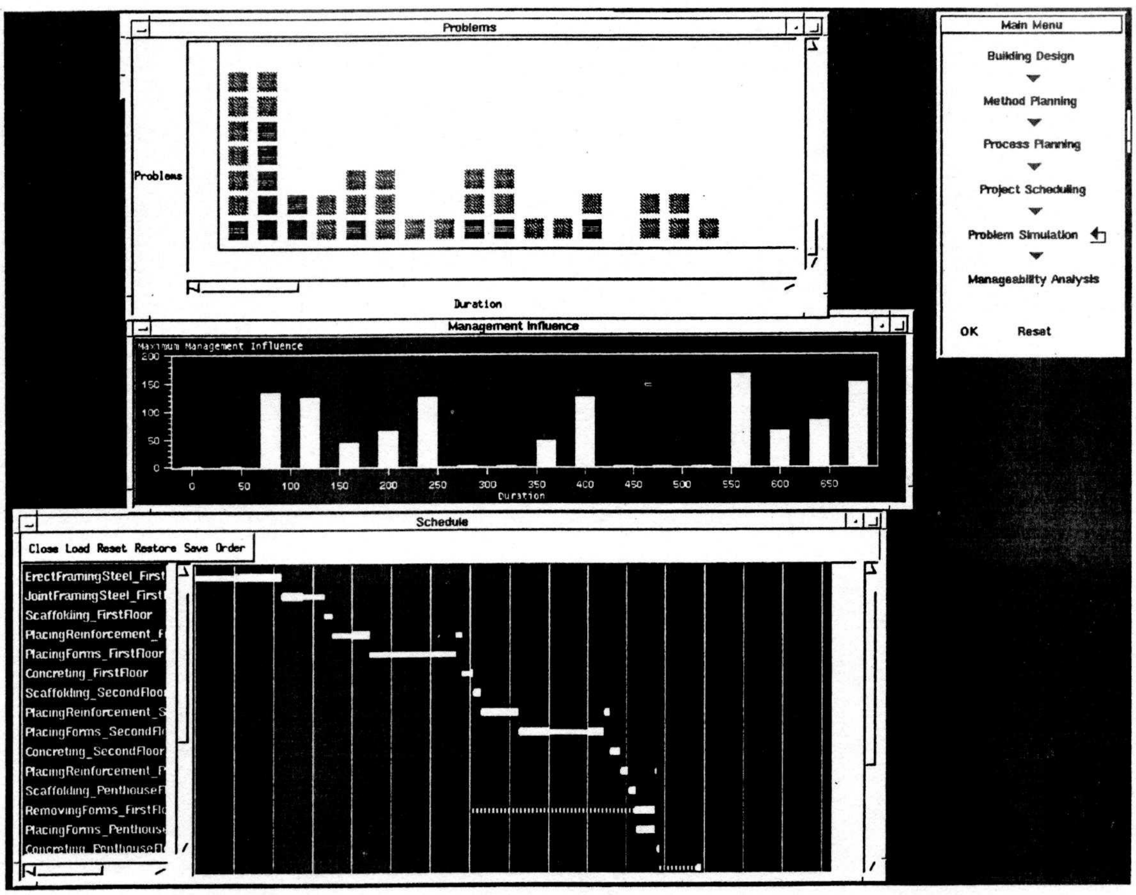

Figure 8: Example CM System output summary

5. CASE EXAMPLE

5.1 TEST CASE

We used the design of a small apartment house as a test case. We chose a Jointless method as a construction process with the plan and schedule to do all the framing steel work first, followed by a set of activities to place forms and concrete for each floor, as in Figure 8. The project finishes after removing all forms and scaffolds. The CM system built a feasible project plan and schedule as the result of a planning phase, according to the design of the building, and the users' choice for construction methods.

Figure 8 showed the results of manageability analysis. The upper window of the figure showed potential management problems with each period of the proposed schedule. Each box represents a problem. Each vertical column of boxes shows the problem with the activities within a set time period. Icons are color coded by severity of their associated problems. The center window of Figure 8 shows a summary of the available management influence on this project by each time period. During this period and then during the middle of the project, the project has no management slack. Thus, any problems that occur during these periods of low manageability are likely to have a serious impact on the projects completion time, cost, quality and/or safety.

Generally in Figure 8, low manageability periods occur during or just after periods of low management influence. Low management influence in a given time span appears to cause later low manageability. Furthermore, Figure 8 shows that the number of problems increases after periods of low management influence and decreases after periods of high management influence. This means the project status at any time depends on a balance between the severity of the problems and the influence of management.

5.2 EVALUATION

A test project for the evaluation of the diagnosis theory developed in this research project involved construction of an administration facility for the Port of Los Angels. For this example, the project organization included Client, Designers, Design consultant, Property owner, Construction management assistant to the owner, General contractor, Subcontractors to the general contractor.

We modeled each of these organizational participants as an instance of a generic resource, and each had specific skills, functions and coordination requirements. We modeled the activities and resources for this project at a high level. As organized, the system analysis showed that there was no available manageability until the very end of the project schedule: management was so busy managing regular work that there was no slack available to manage unanticipated problems until the very end of the project. More specifically, the CM system predicted that decision-making would be slow both at the project start and later in the project. The various period participants lacked well-developed practice in communicating with each other, causing slow decision-making. In the actual project, delay of decision-making in the design phase was one of the biggest problems that occurred early in the project. Slow decision-making caused other problems, such as the delay of the framing steel's supply.

As a "what-if" experiment, we changed the project organization to include only a client, general contractor with complete design and coordination responsibility, and subcontractors. This revised project still has little management slack, but it has slightly more and thus slightly better capacity to respond effectively to problems that otherwise could have a serious impact on the project completion time, cost, quality and/or safety.

6. CONCLUSION

The CM system uses an object hierarchy to present a symbolic building model. The user manually identifies symbolic features (e.g., walls, columns, beams) in the 3D CAD model and some feature relationships (e.g., Supports). Feature dimensions and the user-identified relationships are sent from the CAD model to the symbolic model. In simulation results, low management influence in a given time span appears to cause later low manageability.

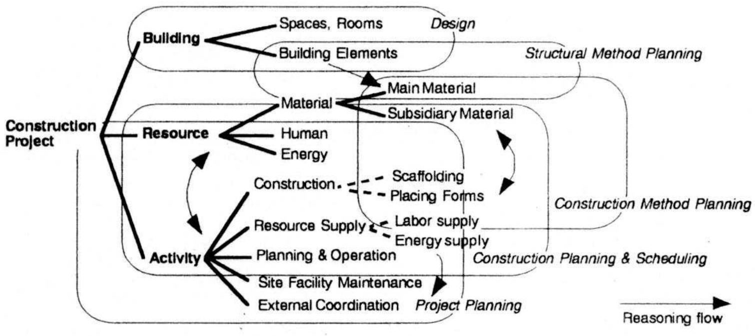

Figure 9: Knowledge Model for Construction Planning

Furthermore, simulation results show that the number of problems increases after periods of low management influence and decreases after periods of high management influence. We infer that the project status at any time depends on a balance between the severity of problems and the influence of management.

Figure 9 shows the principal components of the construction knowledge representation used in the symbolic model. The model application creates instances of those objects for individual project. As discussed in Section 3.2, the CM system infers activities and resources needed to construct the building elements. The planner creates each resource and activity as an "instance" of one of a set of generic resource and activity types, e.g., reinforcement and placing reinforcement, scaffold and removing scaffold, managers and arranging for building inspections. In the reasoning process, the CM system generates each instance using the recursive inference mechanism in the knowledge model in order to build an individual construction project model from a general construction model. In this research, we consider that the plan generation in Figure 1 is a phase to make an individual construction project model, and the plan diagnosis is a phase to simulate the model's behavior.

The current research suggests a number of extensions. The definitions of essential attributes and risk factors are now based only on personal experiences and judgment, and they could be refined. The CM model does not at the moment include potential learning effects. For example, the model takes a worker's skill and familiarity of workers with other workers as being constant. Clearly that can change, both through the normal activity of a project and as the result of management effort.

A long-term benefit of this research would be the development of theory and implementing tools that help project managers to review a plan and schedule and help them to identify construction-phase risk factors. If such a manageability analysis gives them a "heads-up" notice of the possible presence of risks, the forewarned project mangers can then attempt to modify methods, plans or schedules or to watch for and attempt to manage the predicted problems.

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