A NEW MODELING PARADIGM FOR COMPUTER-BASED CONSTRUCTION PROJECT PLANNING

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ABSTRACT

This paper reports on an on-going project aimed at developing a planning tool that is universally applicable within construction, and integrates the best characteristics of existing planning tools, namely: ease of use, versatility, enhanced user insight into the functioning of a project, and effective project optimization. The paper reviews various features of existing computer-based planning tools, and proposes a synthesis of many of these ideas, along with some enhancements. The overall aim is to provide a single tool more suited to the demands of present-day construction project management. Specifically, the developments are concerned with: (i) simplifying model design and understanding through structuring; (ii) moving beyond a schedule-centric perspective with discrete points of interaction by allowing for continuous interactions between any project variable; (iii) facilitating a more realistic representation of resource usage and dependencies (such as flexible crews) by using a structured form of resource definition; and (iv) enhancing visualization by using a graphical format that integrates both the model structure and work progress into a single view. The principles of the existing and proposed new approach to project planning are discussed and rationalized, and application of the new approach is compared to existing planning methodologies for example construction processes.

KEY WORDS

project planning, project optimization, Critical Path Method, linear scheduling, construction simulation, hybrid continuous-discrete simulation.

INTRODUCTION

Figure 1 show a genealogy and timeline for the development of the most familiar planning tools for construction. An open circle in this figure represents the emergence of a planning tool that is either in itself new or at least introduces a new modeling concept (such as Gantt Charts, or 4D CAD (see for example Koo & Fischer(2000)). The solid lines show the ancestries of the different tools, while the dashed lines with dots show where new modeling features are introduced to an existing planning tool (these features are often ideas taken from other planning tools). The figure shows clearly that there has been a fairly consistent

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expansion in the number of tools over the last 100 years, and that while there has been some cross-fertilization of modeling concepts, there is no single tool that fully integrates ideas from across the spectrum.

To the left of Figure 1 are two dichotomies, represented by split arrows. The first of these divides the tools into those used to model repetitive construction work and those used to model non-repetitive work. The second dichotomy divides the tools into those that are dynamic (which is predominantly simulation methods (Halpin & Woodhead,1976), (Sawhney et al., 1998), (Hajjar & AbouRizk, 2002)) and those that are static (such as the critical path-based methods - CPM).

Linear scheduling methods (see for example Matilla and Abraham (1998)), are an example of static modeling tools used for planning work that is repetitive or that can be reduced to a set of repetitive tasks. It has long been noted that the tools classified in this diagram as static and targeted at non-repetitive construction work (such as the CPM-based tools) are not very effective at modeling construction work that is highly repetitive (such as tunneling or high-rise construction) (Harris & Ioannou, 1998). In this context, the tools generate models that are unduly complicated and provide little understanding of the interactions between repetitive construction tasks. Likewise, while the dynamic models are very versatile at representing repetitive work, they are not particularly easy to use, and are unnecessarily complicated and not very insightful when it comes to modeling non-repetitive work. The static modeling techniques targeted at repetitive work (such as linear scheduling) are very easy to understand and provide great insight into the behavior of a construction system, but they cannot be used at all to model non-repetitive work and are not very versatile when it comes to modeling repetitive work. Linear scheduling methods, for example, cannot easily represent operations that use flexible crews, that is, crews that may be split-up occasionally to work temporarily on several tasks and then regrouped later (which is often the way they are utilized in repetitive working environments).

Unfortunately, there is no single tool well suited to modeling the broad spectrum of repetitive and non-repetitive construction work in terms of versatility, insight, and ease of use. Consequently, planners are left with two choices: (i) to use a selection of planning tools or; (ii) to use a single tool for planning all types of work even though it will not always be the most appropriate. The first choice is rarely adopted since it requires the planner, and all other involved parties, to be proficient in the use of several software packages some of which they may only use on rare occasions. Most often, a critical path-based method is adopted (typically within a Gantt chart format) and applied to all situations. The problem is exacerbated by the fact that frequently a given construction project will include both repetitive and non-repetitive components, and so cannot be modeled satisfactorily by any planning tool.

This paper reports on on-going work that attempts to synthesize the best features from the wide range of existing planning tools (and to enhance those features where possible), with the objective of providing a powerful and simple-to-use framework, applicable to all construction projects.

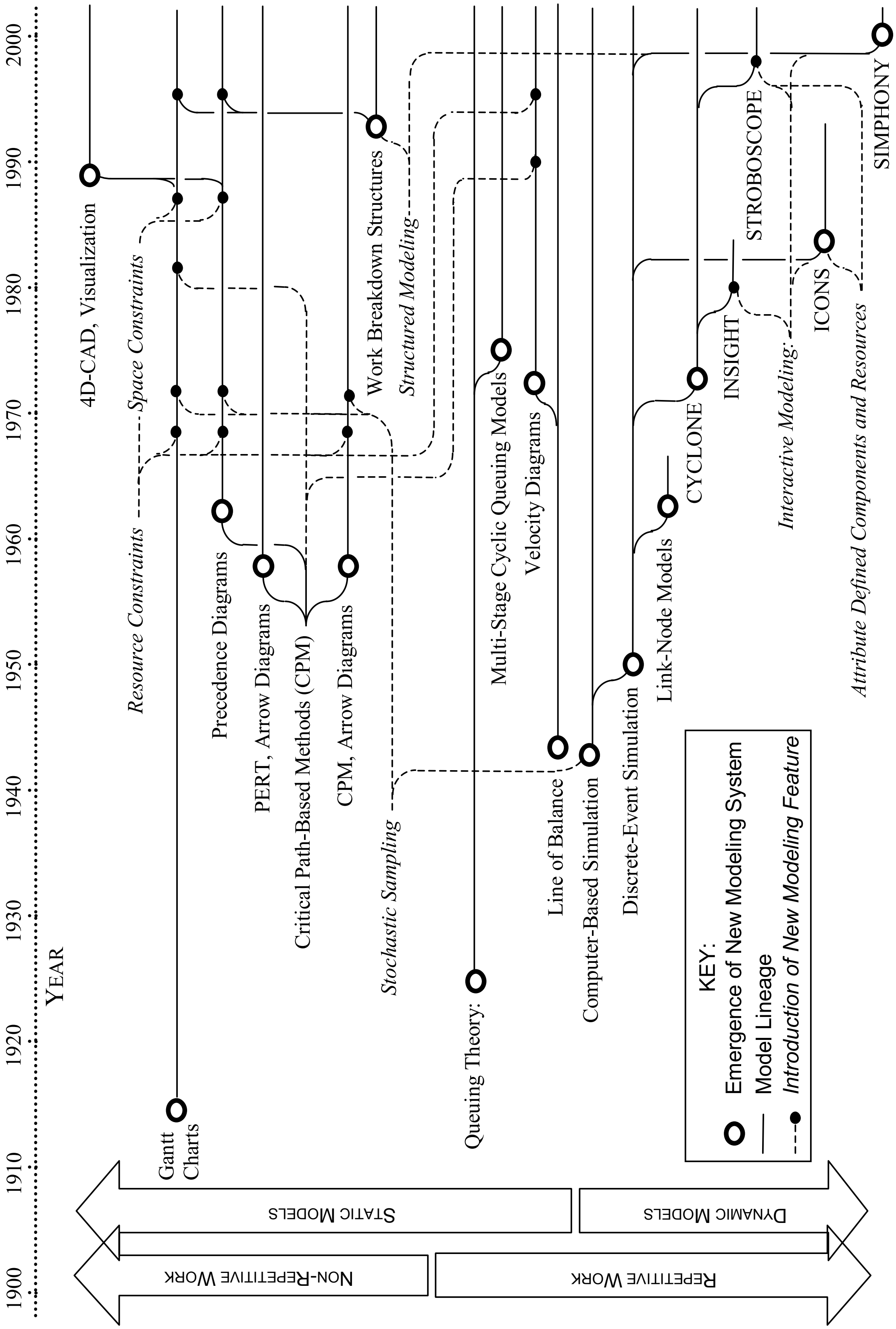


Figure 1: Genealogy and Timeline of Development of Construction Planning Tools

HIERARCHICAL (STRUCTURED) MODELING

A hierarchical approach to modeling has long been recognized in systems science as a powerful way of developing and defining representations of very large and complex systems. In essence, a hierarchical approach forms a representation of a system by decomposing it into categories of tasks and subtasks, in a top-down manner. For construction, the decomposition into tasks should be building-component oriented (as opposed to say material-type, trade, or division oriented) since this reflects the way in which buildings are assembled. The main advantages of a hierarchical approach to modeling are simplified model development and revision, fewer errors in the model design, and better insight into the system being modeled (since the model provides understanding at different levels of abstraction) (AbouRizk and Hajjar (1998), Huber et al. (1990), Ceric (1995)).

To an extent, the concept of hierarchical modeling is already adopted in construction project planning in the form of Work Breakdown Structures (WBS's) and is even implemented in some project planning software packages. WBS's are, however, simply a classification or grouping of work tasks (to make the model more readable) and are not an integral part of the structure and operation of the model, that is, they do not help define the logic of the model or its constraints.

Consider for example, the sample project plan shown in Figure 2. The left side of the figure shows the project organized within a conventional WBS format, while the right side shows the equivalent project organized using a fully hierarchical approach. For both approaches, each block represents a task (or sub-task) and each link represents a dependency (timing for most planning models) between tasks. A fundamental difference, however, is that the hierarchical approach allows the dependencies to be defined between tasks at any level in the network (the scope of dependency of a link being all sub-tasks within the task to which it is connected) whereas the WBS approach requires all logic to be defined at the lowest level tasks. In this example, the Tasks 1.3.1 and 1.3.2 require Tasks 1.1.2 and 1.1.3 to be completed, and Task 1.3.2 requires additionally Task 1.2.2 to be completed. Clearly, the hierarchical approach reduces the total number of links required to define the logic, thus making the plan easier to read and modify. Also, more subtly, the hierarchical approach provides a better insight into the logic of the project by indicating generalized relationships (those at higher levels of abstraction). For example, it is clear from the hierarchical format that the high-level component represented by Task 1.3 is fully dependent on the completion of the high-level component represented by Tasks 1.1, and partially dependent on completion of Task 1.2.

Interestingly, a computer-based implementation of this approach could readily determine the simplest set of hierarchical links that would achieve a given logic. Thus, a planner may input links at an unnecessarily low level in the structure (in an extreme case, this would be to input all links at the lowest level tasks) and the software would reduce these to the minimum set of higher-order links. Moreover, the computer implementation could be readily programmed to identify and suggest new groupings of tasks that would further reduce the number of links (such as illustrated by the dashed boxes in Figure 3) – such groupings may have some physical meaning and value in the organization of the project that the planner had not previously identified, in addition to enhancing the readability of the model's logic.

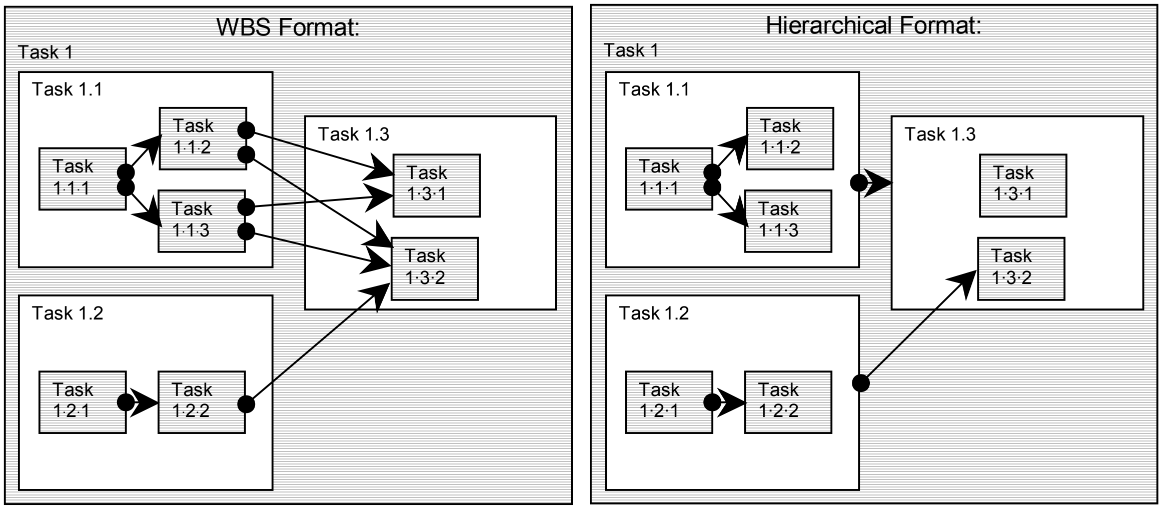


Figure 2: Comparison of WBS and Hierarchical Approaches to Structuring a Network

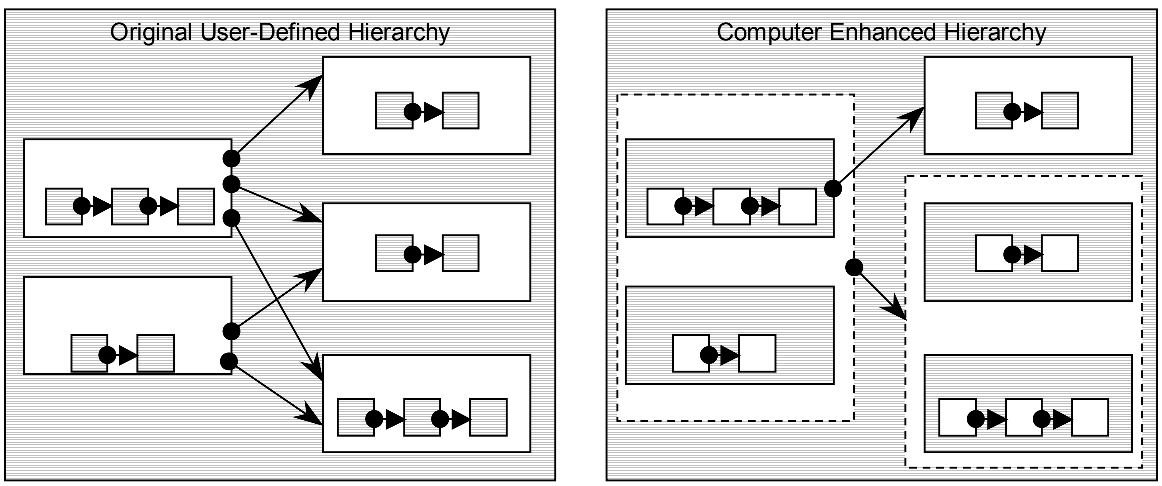


Figure 3: Computer-Based Optimization of Project Hierarchy

FREEDOMS AND CONSTRAINTS

The progress of work on a project is partially determined by constraints on the system. The constraints are any logical requirements that must be satisfied, and range from limitations on the availability of resources (equipment, money, space, etc) through to a requirement for one task to maintain a minimum amount of work in advance of another task (a distance or time buffer for example). Any planning methodology must allow all significant constraints to be taken into account.

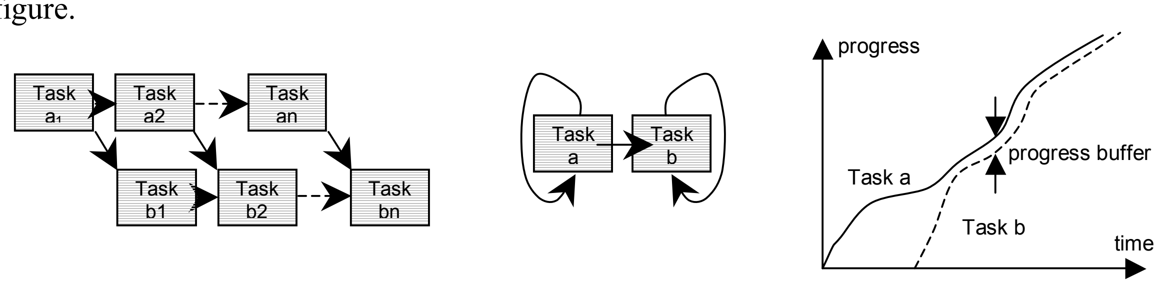
In contrast, all projects have a number of freedoms in the way in which work may be executed. For example, some tasks may not be able to occur at the same time but might have the freedom to be executed in any sequence. Other tasks may have some leeway in terms of the numbers of resources they need to perform the work, such as flexible crews where all members may work together on a single task for a while and then later split to perform concurrent tasks. The freedoms in a project create the need for optimization, that is, determining the choice from within the freedoms that will satisfy the project objectives most effectively. For the proposed system, optimization of a project plan would make use of Genetic Algorithms, due to the ability of these techniques to handle problems that comprise both discrete and continuous parameters and complicated system structures and dependencies.

DEPENDENCIES BETWEEN TASKS

Task dependence (that is, where the progress of a task(s) is limited in some way by the progress of another task(s)) is the most common form of constraint considered in planning. Figure 4 illustrates the different methods used for defining task dependency between two continuous processes using: (a) precedence networks; (b) simulation diagrams; and (c) velocity diagrams. In the precedence network approach (see Figure 4(a)), the arrows indicate event dependencies between tasks, typically used to indicate that the preceding task must finish before the successor task can start. Less commonly, the dependencies may be between the start events of both tasks, the finish events of both tasks, or even the start event of the preceding task and the finish event of its successor. Also, in a precedence network, each task is executed just once.

For most simulation methodologies used in construction, the arrows in a diagram show the flow of resources between tasks, indicating that a task cannot start until some combination of resources are available at its input (typically with either an AND logic or an Exclusive-OR logic). Task ‘b’ in Figure 4(b), for example, requires some combination of resources from both tasks ‘a’ and ‘b’ in order to be functionally the same as the precedence network. In contrast to the precedence network, the simulation approach allows tasks to be repeated many times, possibly by different resources performing the task concurrently.

For a velocity diagram (such as that shown in Figure 4(c)), the dependence between tasks is imposed by a buffer between the respective progress curves. The buffer can be time oriented (giving a minimum advance in time that must be maintained by the preceding task over its successor), or it may be progress oriented (giving a minimum advance in quantity of work that must be maintained by the preceding task over its successor) as shown in this figure.



(a) Precedence Network (b) Simulation (c) Velocity Diagram

Figure 4: Alternative Types of Dependency for Three Common Planning Methods.

Each of the above three approaches has its own advantages. The precedence network approach is very simple to use, but is not well suited to projects where many of the tasks are repetitive in nature. Simulation is the most versatile allowing relatively complicated logical dependencies to be developed between tasks, but these dependencies are limited to discrete task events. The velocity diagram approach is simple to understand and allows continuous dependencies between the progress of tasks, but it lacks the versatility of the simulation approach and requires all tasks to operate along a single sequence.

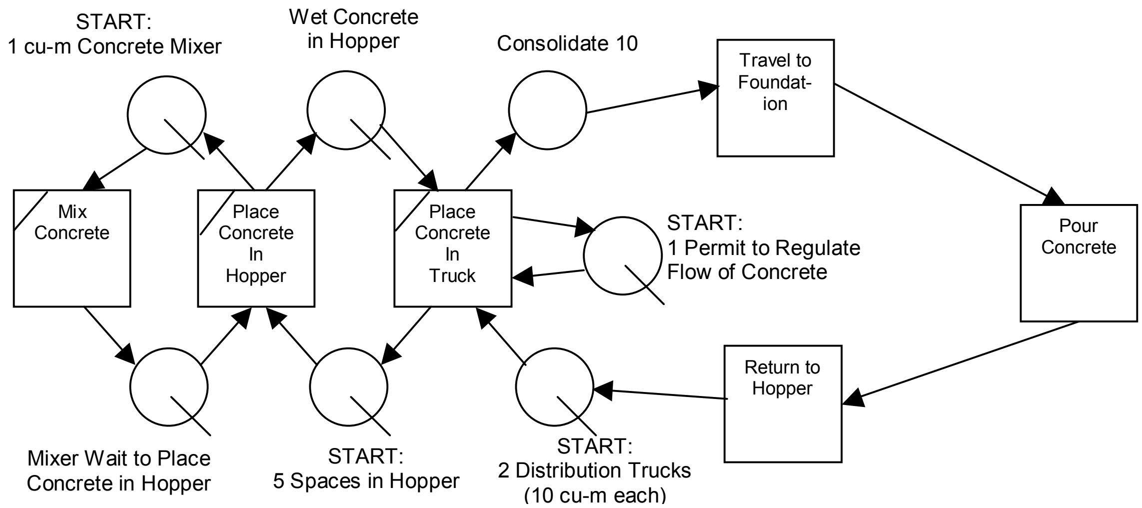
Simplicity in use yet versatility (and thus accuracy) in modeling are key attributes for any planning tool. In the case of task dependencies, this balance can best be achieved using an extension of the velocity diagram technique. For the proposed system, dependencies can be defined between any tasks (and at any level) that limit their relative progress, and for any measure of work (time, distance, units completed). The advance in progress may be specified to be above or below a given value, and their may be more than one such dependency between two tasks. Thus, it may be defined that task 'A' be at least 10 m behind task 'B' but no more than 25 m behind. Another variant would be for the progress of the tasks to flip-flop between the limits so, for example, task 'A' may operate until it is 25 m ahead of task 'B' but then wait until task 'B' catches up to 10 m distance. This approach has the versatility to model any dependency available in the precedence network, velocity diagram, and the commonly used simulation diagram approaches. Figure 5 compares the proposed representation with that of the CYCLONE system (Halpin and Woodhead (1976)) for a concrete production and distribution system. The system represented comprises a 1 cu-m concrete batching plant, a 5 cu-m hopper for storing wet-concrete, and two 10 cu-m distribution trucks. In the proposed new approach (part (b) of the Figure), most of the dependencies would simply specify that preceding tasks must be completed before their successors can start. However, the link between the middle-level tasks would specify that 'Concrete Production' must be between 0 and 5 cu-m of wet concrete ahead of 'Concrete Delivery'. This would impose the logic of a 5 cu-m wet-concrete hopper between these middle-level tasks, equivalent to that of the CYCLONE model.

HIERARCHICAL (STRUCTURED) RESOURCES

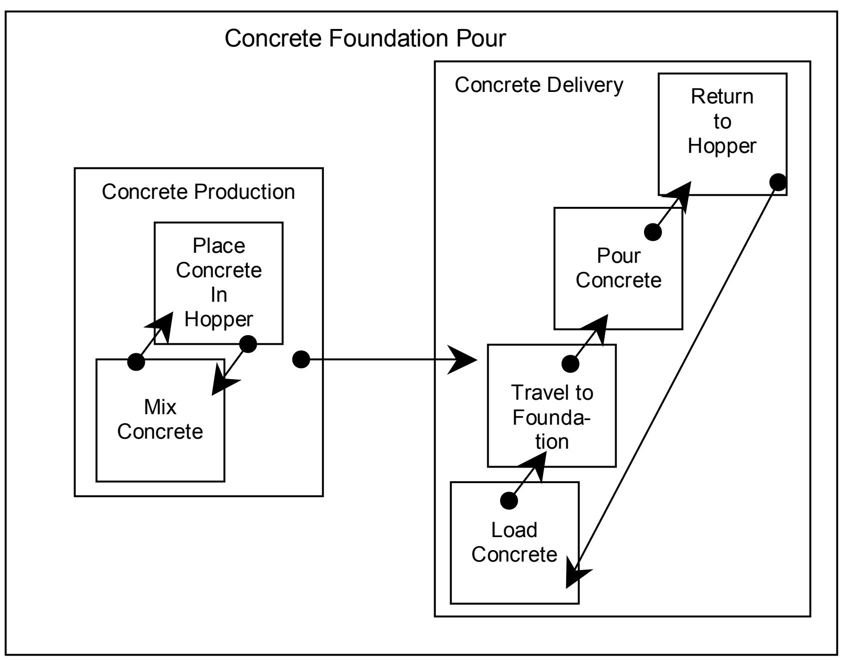
A second main class of constraint in a project (following task dependencies) is that of resource availability (equipment, labor, space, materials, work completed, money, etc). In the proposed system, a hierarchical approach to defining resources is adopted (similar to that for defining the tasks) in that a resource may comprise several sub-resources and sub-sub-resources. Each resource, or sub-resource, may be defined as an actual quantity required to complete the task or it may be defined as a range of values. The range of values provides a degree of freedom within the model creating an opportunity for project optimization, and facilitates consideration of factors such as flexible crews – for example, the number of general laborers in a crew may be allowed to vary within a specified range and thus crew members would be able to drift between tasks on an as-needs basis.

INTEGRATED VISUALIZATION OF PROJECT STRUCTURE AND PROGRESS

Visualization of progress in a project is key to understanding the effectiveness of a given plan, the actual performance on site, identifying possible problems, and proposing solutions to problems that will satisfy the project objectives. While precedence diagrams and simulation diagrams are useful for understanding the work involved in a project and the dependencies between tasks, the velocity diagram provides the most insight into the impact of task relationships on project progress. Velocity diagrams can, incidentally, be produced as output from simulation models. Precedence diagrams can (following a time analysis) be used to generate project progress curves, but these plots do not associate progress with the individual tasks, and thus provide limited visual insight into the impact of those tasks on the performance of the project.



(a) CYCLONE Diagram



(b) Proposed Representation

Figure 5. Concrete Production and Distribution System for Foundation

The hierarchical structure of a project plan in the proposed approach enables visualization of progress at many levels of detail and in a format similar to that of velocity diagrams. The project task structure can be graphed to scale with, for example, time shown in one direction and some measure of progress (such as cost or activity-days) plotted in the second direction. An example of this is provided in Figure 6 for part of a plan for an office complex. Progress is plotted in this scaled manner within each task box (cost versus time), and these task boxes can be peeled away to view progress at the higher levels in the project. This way, a user can, in an interactive environment, explore project progress at all required levels of detail. For sections of the project that are linear in nature (such as pipeline construction, tunneling, or highway construction) where several tasks follow each other on the same section of the project, the progress plots would result in something very similar to a velocity diagram.

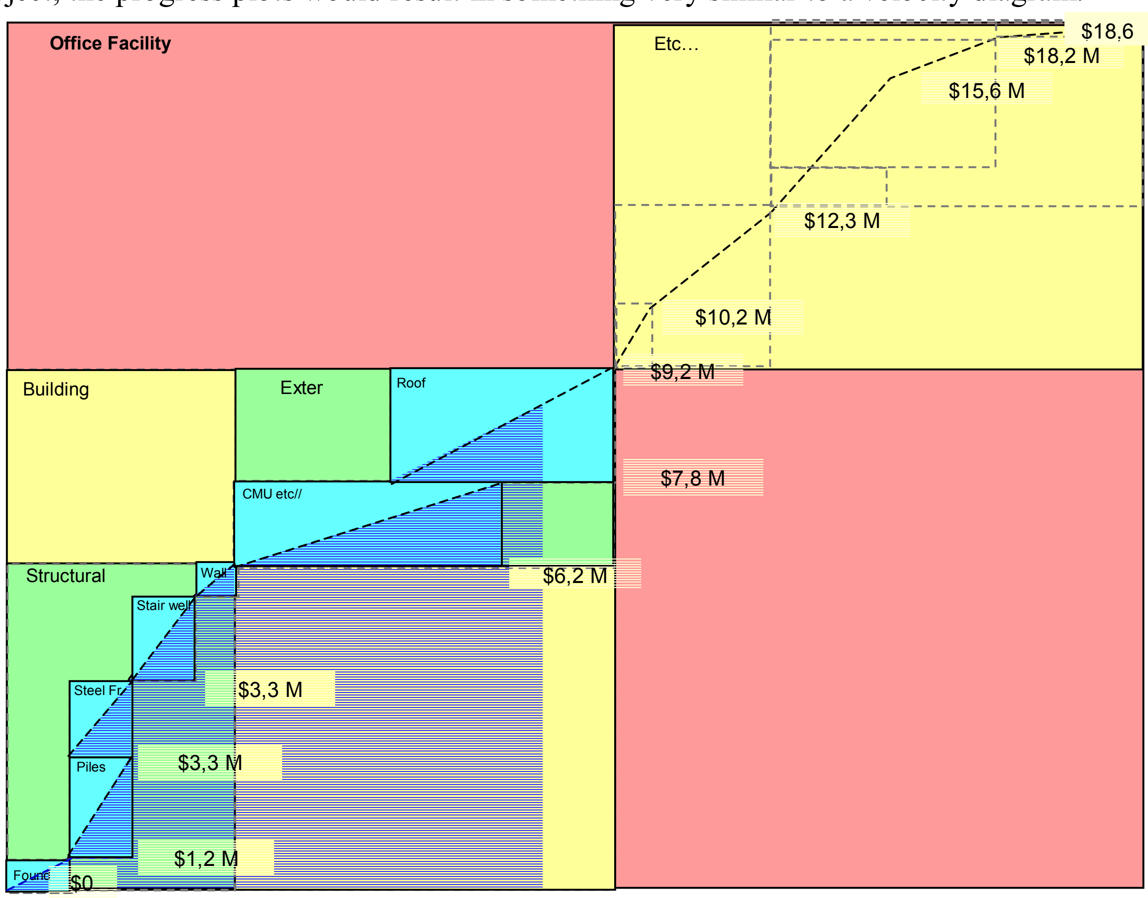


Figure 6. Example Hierarchical Visualization of Planned Progress of Work for Part of an Office Complex

Finally, the hierarchical approach is also conducive to visualization of a project utilizing the ideas of 4D-CAD whereby a facility and its construction progress can be viewed within a dynamic walk-through environment. This is made possible since the task-hierarchy is component-oriented with each task representing a physical part of the building (at different levels of detail), and therefore has a one-to-one relationship with the architectural plans.

Indeed, many 3D-CAD systems now enable designers to implement the design in a hierarchical framework as such (Issa et al. (2003)) and would thus be conducive to integration into a 4D-CAD environment using the proposed planning methodology.

CONCLUSION AND FUTURE WORK

This paper has outlined a new approach to project planning, monitoring, and control that integrates the ideas from a range of alternative planning tools and from systems science, with the objective of providing versatility in modeling all types of construction work, maintaining simplicity in use, and maximizing visual understanding of a project.

Work is on-going developing detailed project plans using this system for a variety of project types, including underground utilities operations (water pipelines, sewers, gas pipelines, and electrical conduits) for large residential projects, high-rise condominium projects, and medium-rise office facilities. The objective of these studies is to determine the successes and limitations of the proposed planning method in the real-world, and to determine refinements that increase its value as a planning tool.

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