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ACTIVITY SCHEDULING IN THE DYNAMIC, MULTI-PROJECT SETTING: CHOOSING HEURISTICS THROUGH DETERMINISTIC SIMULATION

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ABSTRACT

Tools for project scheduling, such as Gantt charts and PERT/CPM networks, have existed for some time. However, these tools have significant shortcomings for settings characterized by constrained resources and multiple projects that arrive dynamically. This paper identifies the power and benefit that deterministic simulation can bring to the practice of project management and project scheduling. The paper is intended for those in the daily practice of project management, and those in the field of developing project management software. Deterministic simulation using available project data to choose an activity scheduling heuristic not only allows for the establishment of good project schedules, it determines ahead of time which resources will be assigned to specific project activities.

1 INTRODUCTION

Tools to aid in project scheduling, once activity durations and precedence relationships are known, have existed for some time. Such tools include Gantt charts (Meredith and Mantel 1995), and the networking tools of Critical Path Method (CPM), and the Program Evaluation and Review Technique (PERT). (See Weist and Levy (1977) for an extensive discussion of PERT and CPM.) These tools are so well understood they are incorporated in most, if not all, popular project scheduling software packages such as MS Project, Primavera, and Time Line (PC Magazine 1995).

As valuable as these tools are, they have serious limitations for project activity scheduling in practice. Their use assumes unlimited personnel and other resources for assignment to project activities exactly when required. They are also applied to one project at a time. In many practical environments where project scheduling is an important activity, resources are constrained in number and more than one project is active at any one time. This paper identifies how deterministic simulation can be used to overcome these project scheduling shortcomings.

2 THE PROJECT SETTING

There are many settings, including computer software development, new product development, accounting auditing practices, legal practices, medical practices, and home building, where there are multiple projects active at any time. A common and important characteristic of such settings is that resources needed by the multiple projects are drawn from a common pool or set of resource pools where the number of resources is limited.

When resources are limited to the point of being constraining, then at some time during a project there will be multiple activities that are precedence feasible when there are not enough personnel or resources to start all of these activities. When resources are highly constrained, some projects cannot be accomplished within their critical path (CP) times. The process of deciding which precedence feasible activities will be given access to the limited personnel first becomes a critical decision in determining both the amount of project extension beyond the CP time and the rate of resource utilization that will occur over the planning horizon. The PERT/CPM technique of single project scheduling offers no help in this resource-constrained scheduling situation.

The dynamic, multi-project environment is one where all of the projects to be performed for a specific time frame are not known at initial project planning time. Figure 1 depicts this setting, which is typical for new product development and R & D situations where projects arrive and are activated dynamically over time. The project networks in Figure 1 are constructed in activity on node (AON) format with the activity identification (ID) numbers in the nodes. Sample activities for the first two projects shown in Figure 1 are given in Tables 1 and 2

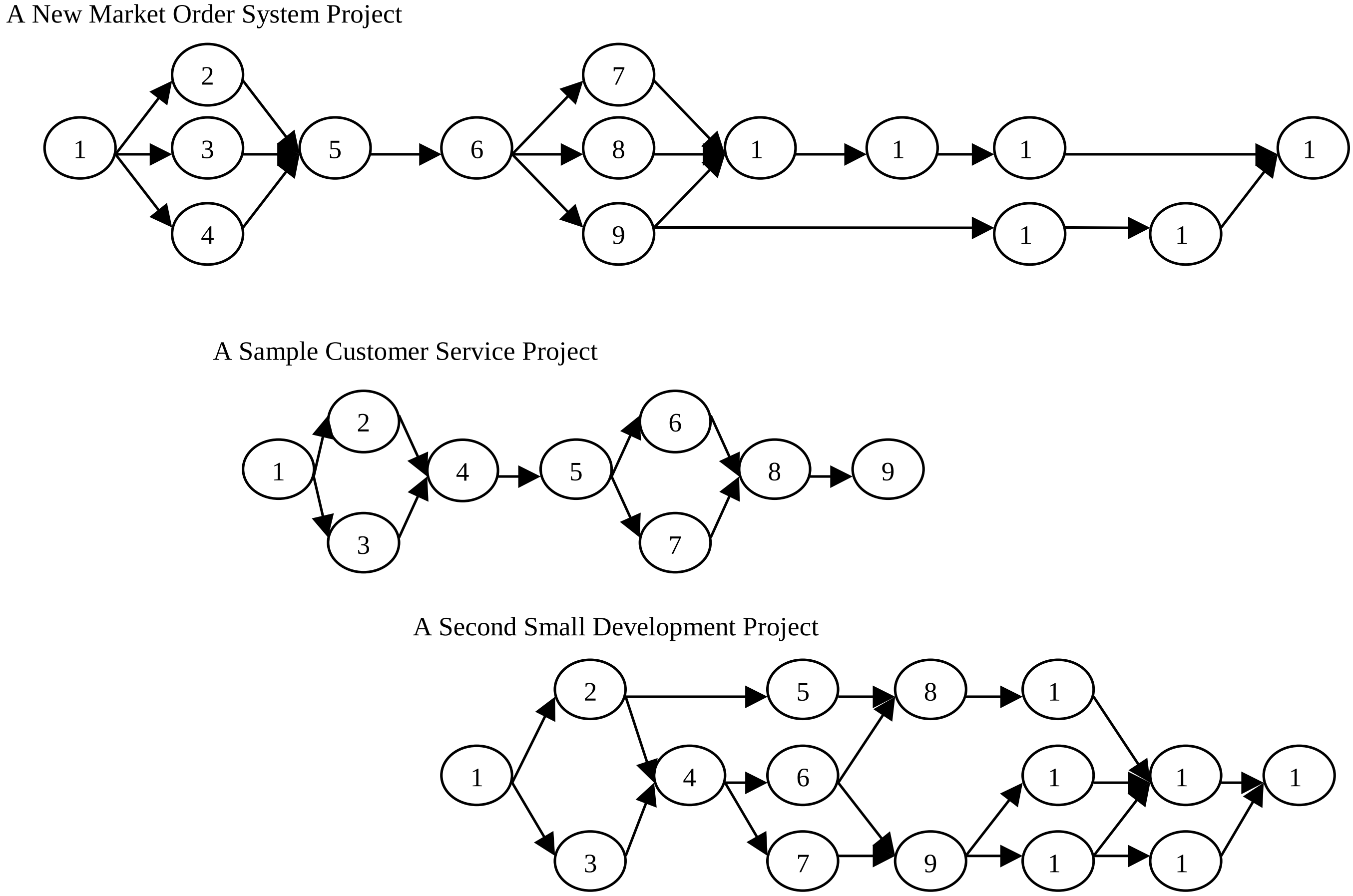

Figure 1: The Multi-Project Setting with Dynamic Arrivals

respectively in order to give a sense for the types of projects that might occur in the situation under consideration. Table 1 shows the activities and precedence relationships for the development of a new market order processing system. Table 2 shows a typical set of activities and precedence relationships for a small customer service project. While the activities for the third project in Figure 1 are not identified explicitly, the project is there to show that new development projects continue to arrive dynamically through time. Again, neither Gantt nor PERT/CPM addresses the decisions needed for this dynamic, multi-project setting.

3 HEURISTIC APPROACH

In the multi-project setting, the scheduling challenge is one of assigning resources from one or more resource pools to specific activities from multiple projects that are precedence feasible at any given time. Such decisions need to be made quickly. The availability of a decision rule, or heuristic, that is known to be effective toward minimizing project extension and maximizing resource utilization can be especially valuable.

Optimization techniques are feasible only for the smallest of projects due to the time complexity of their solution methods. This is especially true for multi-objective optimization techniques. However, even when optimization is initially feasible, it suffers from the fact that it acts like a black box. It gives an optimal answer to a specific problem. When any change occurs, the problem must be reformulated and a new optimal answer calculated. Change in project planning and scheduling is inevitable and constant. This, combined with the solution times for optimization, make such an approach infeasible for the dynamic, multi-project setting.

The practical solution involves the use of heuristic decision rules. However, there are a vast number of heuristic rules from which to choose. Table 3 presents a sampling of project activity scheduling heuristics that have shown success in different experimental research efforts.

Table 1: An Abbreviated Project Plan for a New Market Order Processing System

ID #	Activity Description	Imme-diate Prede-cessor
1	Kick off meeting	--
2	Gather and document the marketing order taking system requirements	1
3	Gather and document the purchasing and receiving department requirements	1
4	Gather and document the operations department requirements	1
5	Integration and approval of all departmental requirements	2,3,4
6	Complete system overview design	5
7	Complete database detailed design	6
8	Complete user interface detailed design	6
9	Complete coding detailed design	6
10	Complete design review and signoff	7,8,9
11	Development	10
12	Unit and system testing	11
13	Develop user training materials	9
14	User training	13
15	Implementation and cut over	12,14

Table 2: A Sample Project Plan for a Customer Service Project

ID #	Activity Description	Imme-diate Prede-cessor
1	Customer service problem call / notification	--
2	Detailed interview of customer	1
3	Detailed interview of original software design team and review of detailed documentation	1
4	Determination of problem root cause and reproduction of the problem	2,3
5	Brainstorm for solutions and development of solution	4
6	Modify the database	5
7	Modify the code	5
8	Test the modifications	6,7
9	Implement the solution	8

Table 3: A Sampling of Resource-Constrained Project Scheduling Heuristics

Scheduling Heuristic	Description for project activity resource loading & initiation (RL & I)
MinSlack	RL & I first the precedence-feasible activity with the minimum total slack.
SPT	RL & I first the precedence-feasible activity with the shortest activity duration.
SASP	RL & I first the precedence-feasible activity with the shortest duration from the shortest project.
MinLFT	RL & I first the precedence-feasible activity with the minimum late finish time
MaxNPV	RL & I first the precedence-feasible activity that will maximize the project net present value.

Patterson (1976) studied the relationship between project characteristics and scheduling heuristic performance for both the single project and the multi-project settings. He demonstrated that project characteristics do have an impact on the performance of different heuristics when different performance objectives, such as completion time and resource utilization, are to be satisfied. However, Patterson was not able to isolate the project characteristics that would recommend the use of specific heuristics. Instead, he concluded that when using heuristics for project scheduling, it is best to test a wide variety and to use the one that performs best for each specific situation. Deterministic simulation is an effective tool for choosing the heuristic that best fits the projects and activities under consideration and the critical performance criteria for a specific setting.

4 DETERMINISTIC SIMULATION FOR MULTIPLE HEURISTIC TESTING

The pre-conditions for using deterministic simulation as an activity scheduling tool are: establishing databases for critical project resource pools, having the activity information for known projects loaded into a project management software program, and installing the following simple, deterministic simulation algorithm into the project management software program.

4.1 Deterministic Simulation Algorithm

1. The simulation algorithm or program keeps a list of all the project activities that are currently precedence feasible and have not yet been initiated.
2. One or more databases of project resources are kept updated and accessible. The resources are usually people, but may also be machines, materials, space, or

capital funds. These databases may also contain characteristics associated with each specific resource in the file. For human resources, such characteristics may include job title and job skill set, time in job and technical proficiency, career path interest, and annual vacation schedule.

3. If there are resources available to be assigned to start project activities, then a scheduling heuristic is used to prioritize the order in which precedence feasible activities will receive resources and be initiated. In addition, the resources may also be prioritized for assignment to precedence feasible activities using a resource assignment policy based on information stored within a resource database.
4. Once the priorities are established, resources are assigned to specific, precedence feasible activities and the activities are initiated. This is done until there are no more resources available. When resources are constrained, not all precedence feasible activities may be initiated as soon as they are precedence feasible. The ones that are initiated are moved from the precedence feasible list and kept on an in-progress activity list until they complete. The resources assigned to them are designated as active, and therefore, unavailable until the activities complete.
5. When an activity completes, it frees up resources, which can be used to start new activities that are waiting on the precedence feasible list. In addition, the completion of one activity may make one or more new activities precedence feasible. In which case the new activities are added to the precedence feasible list. Again, the prioritization of activities and resources takes place, and new precedence feasible activities are initiated.
6. The cycle repeats until there are no precedence feasible activities left. At that time the simulation is complete for a specific scheduling heuristic. For that heuristic, the completion date and therefore due date for each known project has been established and personnel and other resource assignments have been predetermined into the future.

The heuristics used in each simulation test can be quite simple, as are those presented in Table 3, or they can be complicated combinations that relate to activity duration, activity slack, the number of resources or type of resources required, or even cost minimization or net present value (NPV) maximization. The rules used to prioritize personnel resources usually relate to skill set or experience level. However, career path and technical interest may also be considerations in order to develop the organization's core competencies

Such a deterministic simulation algorithm can easily be written into project management software that can then be used to test a full set of heuristics with the project activities and resource levels for a specific situation. The algorithm can be run whenever a significant change has occurred within the setting that might effect project activity scheduling. Such an event would certainly be the dynamic arrival of a new project or the situation where a critical activity finished well ahead of schedule, or more likely, when such an activity is now expected to finish well behind its original schedule. Another situation would be where there has been a significant change in resource or personnel levels available to the project setting. In any of these cases the simulation could be run to determine if the change had caused a need to modify the managerial decision criteria currently in use for scheduling newly precedence feasible activities. The time complexity of such an algorithm is less than 1 minute per heuristic test for even the largest of projects using today's desktop computing power.

Such simulations can be used in practice to set realistic milestone and project due dates for multiple projects at once. In addition, they can also determine specific resource assignments into the future and can help plan personnel assignments in order to develop competencies within organization employees and to plan their career development.

5 CONCLUSIONS

Deterministic simulation using existing project data to choose the best activity scheduling heuristic is a very viable approach to project scheduling in the resource constrained, multi-project setting where projects arrive dynamically. This simulation approach not only determines activity schedules and completion times, it determines which resources will be assigned to specific activities ahead of time.

When the critical characteristics of the project activities being scheduled and of the resources being assigned can be expressed in any manner that allows for prioritization, such characteristics can be used within a simulator. The simulator can then predict project completion times and resource utilizations using different heuristics or even combinations of heuristics.

Extensions to the basic concepts presented above may add even more value for the project manager. A graphical interface that updates as the simulation run occurs and the ability to stop and modify decision making while a simulation is in progress might give additional aid the project managers. Such extensions might allow for the gaining of excellent insights into project progress and resource utilizations, while allowing project schedulers to apply judgment that a pure heuristic approach lacks.

Simulation presents the possibility for significant improvements in project scheduling and control. Deterministic, heuristic-testing simulation, if incorporated within modern project management software represents an opportunity for the capture and use of much more information for the project manager, especially in the growing number of situations where resources are limited and multiple projects arrive dynamically.

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