A SIMULATION MODEL FOR RESOURCE CONSTRAINED SCHEDULING OF MULTIPLE PROJECTS

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Since the late 1950's, Critical Path Method (CPM) and Programme Evaluation and Review Technique (PERT) have been widely used in the construction industry for planning and scheduling construction projects. The major drawback of these two techniques is the assumption of unlimited resource availability. In many real life situations, construction projects must be scheduled under limited resources. The problem becomes more and more complex when the resources are allocated and shared among multiple projects. This challenge of allocating scarce resources to the competing activities of different projects is of great concern to any project manager. Such decisions need to be made quickly. The availability of a decision rule or heuristic, which will be effective in minimising the total project tardiness, can be especially valuable. A simulation model has been developed to schedule the activities in the multiple projects when the resources are highly constrained.

Keywords: heuristic rules, multiple projects, resource management, scheduling, simulation.

INTRODUCTION

Construction planners typically use scheduling techniques to determine the sequence of activities necessary to complete a project. The scheduling techniques they employ provide important information crucial to a project's success. Critical Path Method (CPM) and Programme Evaluation and Review Technique (PERT) are the two traditional techniques that have been used for scheduling a project (Elsayed and Nasr 1986). The major drawback of these two techniques is the assumption of unlimited resources availability (Weist 1967, Cooper 1976). In other words, the critical path through the project network is based solely on the time requirements of the activities, regardless of the resource requirements of each activity (Elsayed and Nasr 1986). In many real life situations, construction projects must be scheduled under limited resources. If resources are highly constrained, then at some point of time during the execution of the project there will be several activities that will be precedence feasible. The activities which have no precedence constraints are termed as precedence feasible activities. When there are not enough resources to carry out all the precedence feasible activities then the critical path time or the duration of the project may get extended. This challenge of allocating scarce resources to the competing activities of different projects is of great concern to any project manager.

The scheduling tools CPM and PERT do not offer any help in deciding which activity

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will have the priority in a resource-constrained scheduling environment. The problem becomes more and more complex when multiple projects are involved. A multiple project scheduling problem consists of two or more number of projects, and a project is defined as a collection of activities, which consume resources, and events, which constitute point in time. Then a constrained project schedule is an assignment of a start time for each activity in the network such that the precedence and resource requirements are satisfied. Based on the above definitions resource-constrained multi-project scheduling problem is defined as scheduling two or more projects simultaneously under one given objective. There are two possible ways of representing each project: Activity on Arrow (A-O-A) and Activity on Node (A-O-N) (Stevens 1990). In A-O-A representation, the activities are represented as arrows and the nodes are used to show the precedence relationships. In A-O-N network representation, the activities are represented as nodes and the arrows are use to show the precedence relationships. In this paper A-O-N representation is adopted with deterministic activity durations and precedence relationships. The availability of a scheduling rule, which will be effective in minimising the total project tardiness, can be especially valuable for the project managers. A simulation model has been developed which will help the project managers in practice to allocate the resources to multiple projects through selecting the priority rule which holds good at that specific situation.

BACKGROUND STUDY

A Resource Constrained Project Scheduling Problem (RCPSP) arises when the available resources are not enough to satisfy the requirements of the activities that can be performed concomitantly. To satisfy this constraint, sequencing rules (also called priority rules, activity urgency factors, scheduling rules or scheduling heuristics) are

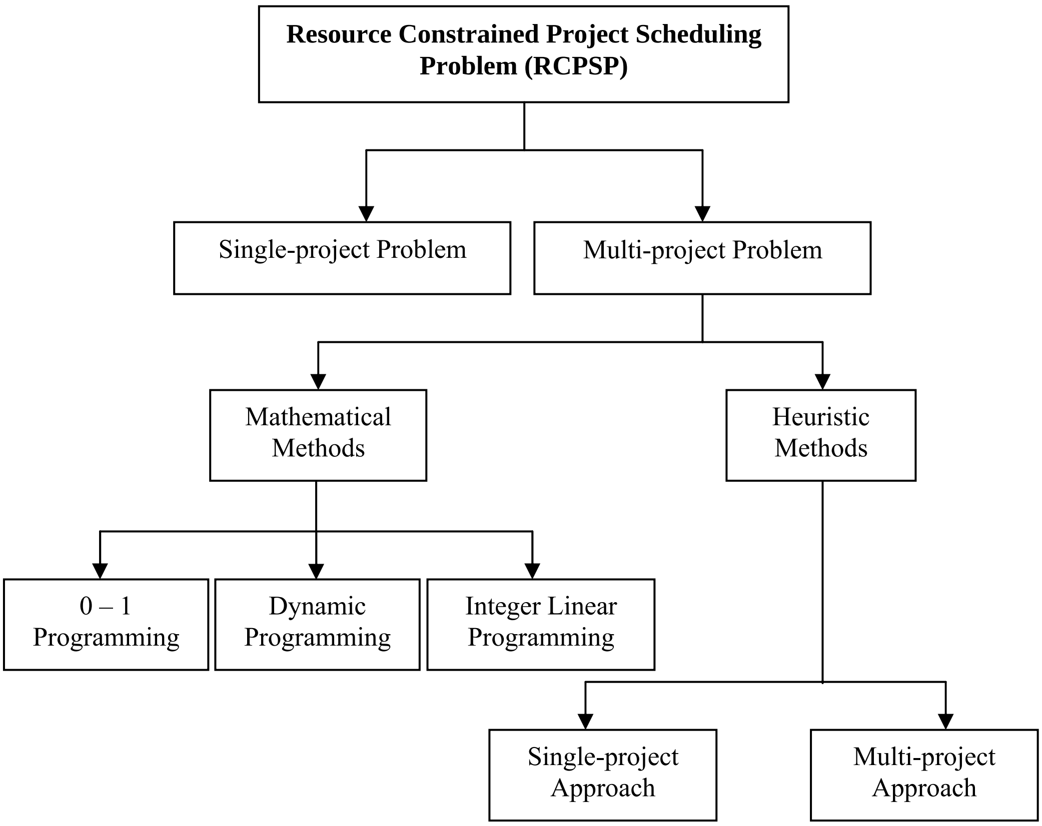

Figure 1 Classification of Resource Constrained Project Scheduling Problem

used to determine which of the competing activities will have priority for resource allocation. The RCPSP can be classified into single project scheduling problem and multi-project scheduling problem. Fig. 1 depicts the classification of the RCPSP. Two common approaches have been employed in solving the two scheduling problems are mathematical programming approach and the heuristic approach. Although, several optimum yielding techniques are available for generating RCPSP schedules, considerable solution time is required and also the optimal schedules are not generally used in practice because of the complexity involved in implementing them for large projects. Owing to the complexity involved in the mathematical formulations, a scheduling heuristic uses logical rules to prioritise and assign resources to competing activities. To date, hundreds of heuristic scheduling rules have been developed for single-project scheduling problem. There have been relatively few papers, which have studied the multi-project scheduling problem and the results of these studies varied widely. It can be seen that multi-project management (programme management) is different from single project management in different ways. Programme management is a continuous process whereas project management has a well defined finish point. The primary concern is on resources in the case of programme management, but for project management it is on time and method.

Two common approaches have been adopted for scheduling multiple projects using heuristic approach. One is single project approach and the other one is multi-project approach. In Single project approach as shown in Figure 2(a), all the individual projects are artificially combined into a single large project by adding dummy start and end activities. This is also known as consolidation model. The implementations of the consolidation model for real life projects are reported to have experienced many problems. These problems arise because of the unrealistic assumptions made, lack of synchronisation of the different update cycles, inconsistency in the data, naming and numbering of tasks etc. In multi-project approach as shown in Figure 2(b), all the individual projects are related either through the organization or through a common resource pool. The multi-project approach more realistically assumes that the different projects are related only through the resources.

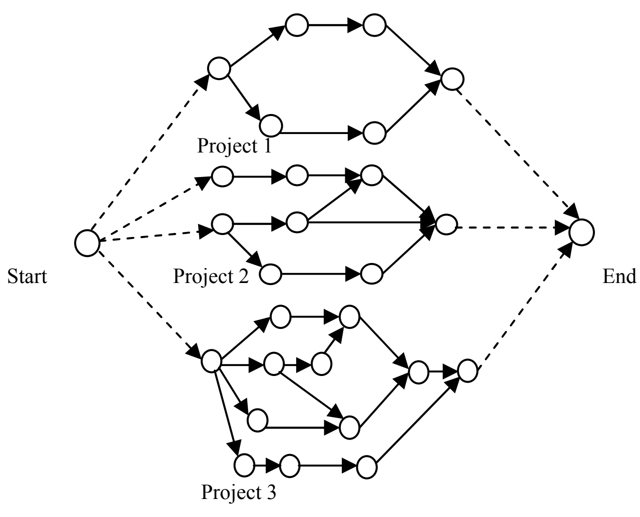

Figure 2(a) Single project Approach

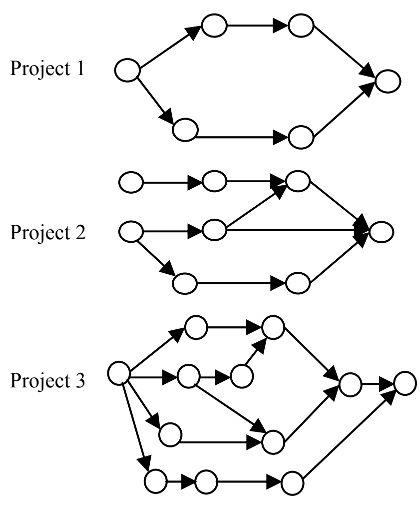

Figure 2(b) Multi-project Approach

The scheduling rules developed for single project scheduling are not always effective in a multi-project setting. The solution obtained from these augmented single project models may be significantly different from those found by multiple project approaches (Kurtulus and Davis 1982). The choice of the scheduling rule is dependent on the objective. As the objective changes, the scheduling rule will also changes accordingly. None of the rules can always produce the best solution for all the problems at all times (Tsai and Chiu 1996). To overcome this in the simulation model, the project manager has to select the priority rule to know which one is most suitable for the organisation's project settings at that specific instant.

Need for the study

The efficient utilization of limited resources among multiple projects is one of the most important issues in construction project management. The impact of even a small improvement in the management of multiple projects can be enormous, because up to 90% by value, of all projects are carried out in multi-project environment (Payne 1995). The allocation of resources can be made considerably flexible by considering various scheduling alternatives. This necessitated a detailed study to model the environment realistically and to make the allocation of limited resources flexible and efficient.

SCHEDULING RULES

As stated earlier, scheduling rules are used to determine which of the competing activities will have priority for resource allocation. A good scheduling rule should be simple, unambiguous, easily understandable, and easily executable by the one who uses it. There are in existence today literally hundreds of heuristic-based scheduling rules available for single project scheduling problem. In contrast, little research has been done on rules developed specifically for multi-project scheduling problem. Scheduling rules can be broadly classified as process-time based, due-date based, resource based, cost based or penalty based. Some of the good performing rules are shortest activity from shortest project (SASP) rule (Kurtulus and Davis 1982), minimum slack (MINSLK) rule (Pritsker et al. 1969, Allam 1988, Mohanty and Siddiq 1989), minimum late finish time (MINLFT) rule (Yang and Sum 1993), maximum total work content (MAXTWK) rule (Lova et al 2000), maximum penalty (MAXPEN) rule (Kurtulus and Narula 1985), critical ratio (CR) rule (Tsai and Chiu 1996), minimum weighted latest start time and scheduling activity time (LSSA) rule (Tsai and Chiu 1996) and first come first served (FCFS) rule(Dumond and Mabert 1988, Yang and Sum 1993). Out of which it has been reported that the following rules are performing well in minimizing the total project delay.

Shortest Operation First Rule

This is one of the most popular rules and it is based on the duration of an activity. It is a best example for process-time based rule. The process-time based rules ignore the due-date information of the projects. The SOF rule is effective in minimizing the total flow time (Anavi-Isakow and Golany 2003). The activity with the minimum duration is chosen for scheduling.

Minimum Slack Rule

This rule has been widely used as a benchmark rule in resource-constrained multi-project scheduling problem. This rule makes use of the total slack that is available for an activity and the activity with the least slack will be taken up for scheduling. This rule is shown to be quite effective in minimizing the total project delay (Pritsker et al. 1969, Allam 1988, Mohanty and Siddiq 1989).

Shortest Activity from Shortest Project Rule
This rule is especially developed for multi-project problem and found effective in minimizing the total project delay in most categories of the problem (Kurtulus and Davis 1982). This rule first gives priority to the project and then to the activities that are competing for resources in that particular project. The SASP rule is a simple additive combination of the resource-unconstrained critical path time and the duration of the activity.

First Come First Served Rule
This rule is often used as a bench mark rule in project scheduling. First eligible activity is assigned the highest priority. In other words, the activity which has been waiting in the queue for longer time is chosen for loading. FCFS rule is frequently used because of its simplicity and performed well in the past research in minimizing the project delay and flow time (Dumond and Mabert 1988, Yang and Sum 1993). It has also performed well in minimizing the mean absolute lateness and mean weighted lateness (Bock and Patterson 1990).

SIMULATION MODEL

Assumptions
The following assumptions have been made in the development of the simulation model for resource-constrained scheduling of multiple projects:

1. The Activity-on-Node (A-O-N) network is known for all the projects.
2. The activity duration and precedence relationships are deterministic.
3. Activity splitting is not allowed.

   The activities cannot be sliced into two or more at any case. For example, for constructing a compound wall for a building and the construction of a compound wall is considered as a single activity. It cannot be sliced into North West wall construction, South East wall construction, etc.
4. Once an activity is started, its progress is not interrupted.
5. The quantity of resources required for each activity is constant throughout the project.

The various steps involved in simulation process are shown is Figure 3. A brief description of the steps is as follows:

1. The activity durations and resource requirements for each project were randomly generated from two independent uniform distributions over the interval 1 and 9.
2. An initial feasible schedule is determined by using the traditional critical path calculation without considering the resource constraints. This schedule however reflects any restriction on the start and finish times of the activities. Store the early start time (ES), early finish time (EF), late start time (LS), late finish time (LF) and total slack (Slack) for all the activities.
3. Set current time t =1 and resources available at time t (R_t) = total resources available (R_a).
4. All the activities from all the projects that are precedence feasible are arranged into an eligible activity list sorted according to a priority scheduling

rule. If there are available resources to be assigned to start project activities, then the activity is scheduled to start at the current time t. Once an activity is scheduled, the activity is deleted from the list and the resources assigned to

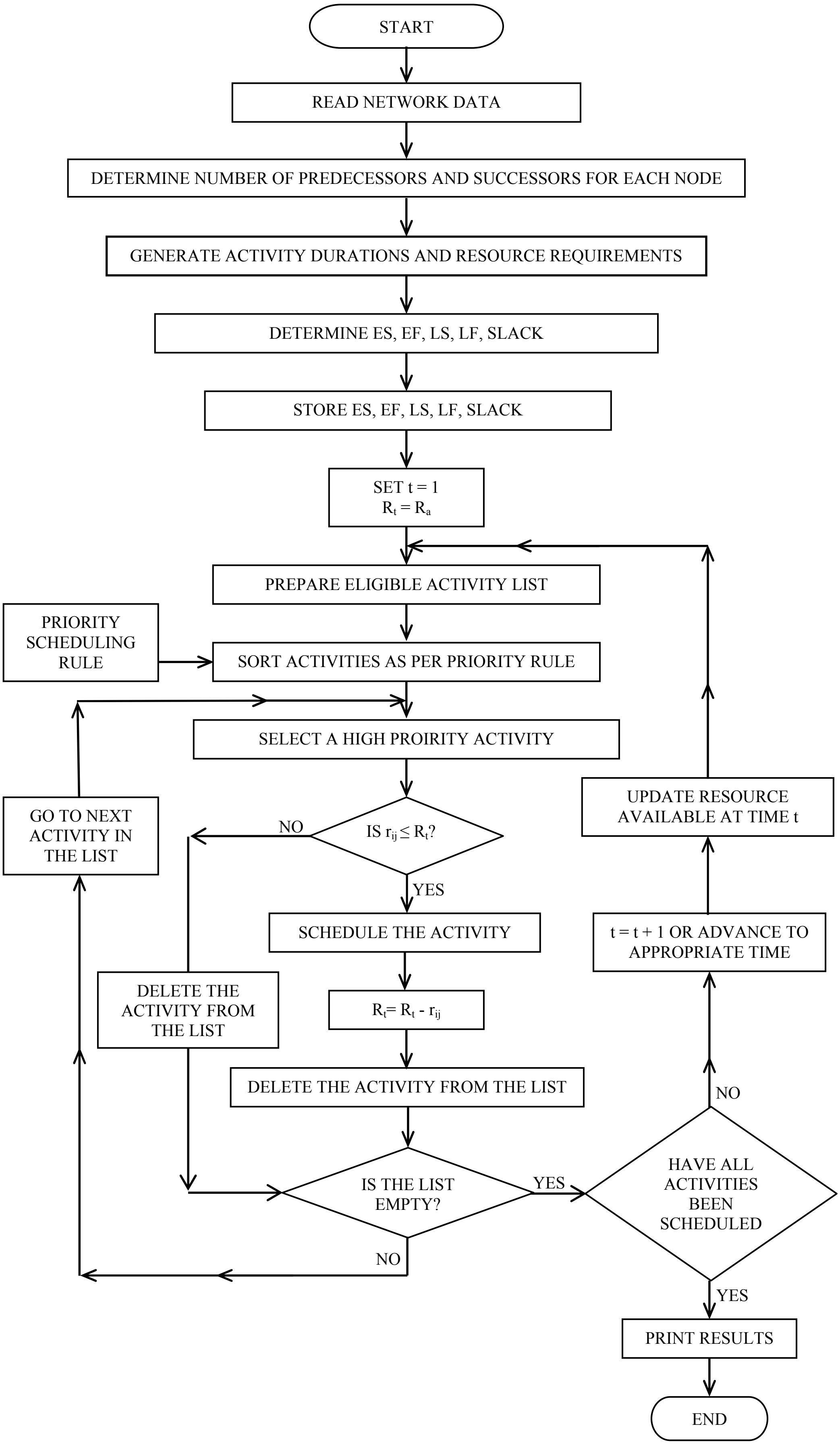

Figure 3 Flowchart showing the scheduling process in the Simulation model

them are unavailable until its completion. This is done until there are no more resources available. When an activity is completed, it frees up resources and these resources will be added to the resources available at time t. In addition, the completion of one or more activities will make its successors precedence feasible. The successors of the completed activities are added to the eligible activity list.

5. The above steps were repeated until there are no activities for scheduling. At that time the simulation is complete.
6. The simulation will be repeated by changing the priority scheduling rule.

Several simulation runs can be carried out on the project set by changing the priority rule one by one to know the average completion time of the activities and the projects as well. By knowing the average completion time of a project the project managers can easily set the project due dates. This will help the project managers to minimize the total tardiness of the project well ahead of time. This model will allow project planners to do 'what-if' analysis and can able to identify problems in the early stages of project planning.

CONCLUSIONS

The simulation model developed will allocate the resources efficiently to multiple projects. The outputs of the simulation model are the activity start time, activity finish time, the total duration of the project and the utilization of the resources. The total resources available can be altered to know the new completion time of the projects. The project manager needs to substitute the appropriate scheduling rule in the model for the projects and choose the one which is more appropriate at that point of time. The applications of the approach are as varied as the spectrum of resource-constrained multiple project settings. This simulation model can be used in practice to set realistic project due-dates well ahead of time. The simulation model can be made more realistic by incorporating a module to estimate the duration and resource requirement of each activity on a quantitative basis of work. Further improvement can be made by the way of incorporating the arrival of new projects into the model. Thus the simulation model can prove helpful in effective control and coordination of works under execution.

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