# A PROACTIVE APPROACH FOR RESOURCE CONSTRAINED SCHEDULING OF MULTIPLE PROJECTS

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**ABSTRACT:** The AEC (Architecture/Engineering/Construction) industry is facing a competitive world after it entered into the 21$^{st}$ century. Due to improper planning and scheduling, the construction projects face severe delays in completion. Most of the present day construction organisations operate in multiple project environments where more than one projects are to be managed simultaneously. But the advantages of planning and scheduling as multiple projects have not been utilized by these organisations. Change in multi-project planning and scheduling is inevitable and often frequent, therefore the traditional planning and scheduling approaches are no more feasible in scheduling multiple construction projects. The traditional scheduling tools like CPM and PERT do not offer any help in scheduling in a resource-constrained environment. This necessitated a detailed study to model the environment realistically and to make the allocation of limited resources flexible and efficient. This paper delineates about the proactive model which will help the project managers for scheduling the multiple construction projects.

*Keywords: Multiple Projects, Project Management, Resource Constrained Scheduling, Proactive Model*

## 1. INTRODUCTION

Project Management is becoming increasingly important in today's competitive environment. Projects face delays in project completion due to improper planning. The high degree of complexity, tight competition, and scarcity of resources involved in real life projects necessitates the application of modern management techniques for the satisfactory achievement of objectives and smooth execution of the projects. The introduction of network techniques made the planning and scheduling of projects systematic and scientific, and the advancements in computing facilities made their application in real life projects feasible. Since the late 1950's, CPM and PERT have been widely used in the construction industry for planning and scheduling construction projects. These tools do not offer any help in deciding which activity will have the priority in a resource-constrained scheduling environment. Present day construction projects are severely constrained on the availability of resources. The availability of resources is fundamental in the activation of a construction project. For construction activities, timely resource allocation is crucial to avoid unnecessary waiting time of resources and delay of activities, especially under the condition of limited supply of resources. Timely resource allocation, i. e., determination of an activity that has the highest priority to obtain resources at that instant is a dynamic decision-making process dependent on real-time information during a construction process. When there are limited resources to fulfil the demand of multiple activities from multiple projects, allocation rules should be formulated considering the trade-off between costs and time. The project managers always realized the importance of resource allocations and their effect on activity durations.

Multi-project scheduling is significantly different from single project scheduling in many aspects. The variation in the properties of resources, activities, projects and the solutions algorithms add to the complexity of this problem. The necessity of managing multiple projects, mostly of different nature, within one time frame, in a resource constrained environment makes the problem a challenge to a construction organisation.

Furthermore, in real life there exists an inevitable dependency among the activities for the use of the same scarce resource, as a result of which the problem of resource constrained scheduling becomes difficult. Moreover, another problem with multiple projects is that they can have an independent existence with separate goals and problems, and yet draw at least some resources from a common pool, and they must be integrated into the management control and reporting systems of the resource pool [1]. The construction organisation desires to minimize the completion time of all the projects. The earlier research works reported do not realistically address many of the fundamental issues such as prioritisation; sharing of resources etc. This necessitated a detailed study to model the environment realistically and improve the process of managing the multiple projects more effective. In this paper, a proactive model has been developed for multi-project scheduling which caters to the needs of the present day construction organisations.

## 2. RESOURCE CONSTRAINED SCHEDULING

A resource constrained scheduling problem arises when the available resources are not enough to satisfy the requirements of the activities that can be performed concurrently. To satisfy this constraint, sequencing rules (also called priority rules, activity urgency factors, scheduling rules or scheduling heuristics) are used to determine which of the competing activities will have priority for resource allocation. In priority scheduling rules whenever an activity is requiring a resource and if the resource is free, then engage the resource with the activity; otherwise place the activity in the resource's queue, or whenever a resource becomes free, choose an activity from the queue according to a chosen priority and engage the resource with the chosen activity. Although, several optimum yielding techniques are available for generating resource constrained problem 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.

### 2.1 Research on Resource-constrained Multi-project Scheduling

Research on the scheduling of multiple projects has been directed primarily towards developing efficient scheduling rules which perform well in minimizing the total project delay. The MINSLK rule found to perform well in minimizing the total project delay [2], [3], [4]. When resource availabilities are very tight MINSLK is the best rule irrespective of the performance criteria [3]. Mohanty and Siddiq [4] compared the performance of the Integer Goal Programming (IGP) model and heuristic based scheduling rules in a multi-project environment and found that scheduling rules produced better performances. Amongst the scheduling rules tested, MINSLK proved to be the best for the performance criterion project slippage, total project delay and resource-idle time. In a study of Kurtulus and Davis [5], SASP rule minimized the total project delay in most categories of the problems. Kurtulus and Narula [6] studied the resource-constrained multi-project scheduling problem under the assumption that delays corresponding to projects carry unequal penalty and found MAXPEN rule as the best rule for more constraining values of AUF; MINSLK otherwise. A multi-project management model to control projects has been developed by Tsubakitani and Deckro [7]. They coded the SASP priority rule to schedule the projects and the actual model was developed from an operating firm in the Japanese housing industry. In the same year Bock and Patterson [8] designed a computational experience based on the work of Dumond and Mabert [9] with three factors: Due Date setting strategy, Algorithm based on priority rule and Resource pre-emption strategy. This work shows that priority rules based on FCFS and MINSLK (DD) have the best performance minimizing mean weighted lateness and mean absolute lateness. After this Lawrence and Morton [10] studied the due date setting algorithm with a good performance minimizing mean weighted tardiness and mean weighted delay. Tsai and Chiu [11] concluded that the performance of the developed CR and LSSA rule was dominant under the performance criteria of total project delay and also for the maximum number of times that a scheduling rule can obtain a best solution. Yang and Sum [12] have found MINPDD rule to produce the shortest mean flow time and lowest mean tardiness. Lova et at [13] developed a multi-criteria heuristic algorithm taking into account aspects such as time – mean project delay or multi-project duration increase – as well as project splitting, in-process inventory, resource levelling or idle resources. Chiu and Tsai [14] studied the multi-project scheduling problem by incorporating both the project delay penalty and early completion bonus in the objective function. Anavi-Isakow and Golany [15] showed the dominance of SOF rule with respect to flow time and also effective in throughput and lateness with respect to due dates. Kanagasabapathi and Ananthanarayanan [16] developed a simulation model for scheduling multiple projects when the resources are highly constrained.

## 3. MULTI-PROJECT SCHEDULING

A multi-project scheduling problem consists of number of projects, and a project is defined as a collection of activities, which consume resources, and events, which constitute point in time [5]. 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. The best choice for the scheduling rule is highly dependent on the objective; no single universally acceptable scheduling rule exists. As the objective changes, the scheduling rules will also changes accordingly. The important features of a multi-project scheduling are identified to be the total system approach with a control structure, prioritisation of projects and sharing of resources.

### 3.1 Prioritisation of Projects

The priority of the activity depends on the properties of the activity itself and that of the parent project. The priority of the parent project is the major factor deciding the overall priority of the activity. It is considered that the identification of the factors and evaluation of their importance in the prioritisation is one of the most critical aspects of multi-project scheduling. The factors, in general just identified such that the maximum priority project satisfies the objectives of the organisation to the best. The most fundamental objective of any construction organisation can be recognized as minimization of overall cost incurred, which in turn maximizes the profit for the company.

### 3.2 Resource Sharing

The concept of resource sharing is one of the characteristics of multiple project environments. The fact that many resources are shared by the projects has not been considered in the earlier single project based scheduling models making the schedule unrealistic and inferior. Initial models developed for multiple project scheduling considered all resources as shared from the central resource pool. When a project requires a resource from the central pool, it will be allocated based on availability and competition from other projects.

### 3.3 Linking resources of a project to its work environment

In the single project environment, a relation between a project and its resources are simple, so it is easy for the project managers to memorize the relation. In the multi-project environment, the relation is very complex. Therefore, the project managers have to manage all of the relation by themselves then the management will be a burden on them.

## 4. PROACTIVE APPROACH

As stated earlier, scheduling rules are used to determine which of the competing activities will have priority for resource allocation. 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. The best choice for the scheduling rule is highly dependent on the objective; no single universally acceptable scheduling rule exists. As the objective changes, the scheduling rules will also changes accordingly. None of the rules can always produce the best solution for all the problems at all times [11]. This is due to the fact that several problem characteristics such as network structures, available resources and their types and problem sizes are crucial to the results. Some of the good performing rules listed in Table 1 are reported to be performed well in minimizing the total project delay.

Figure 1 depicts the proactive model framework for resource-constrained multi-project scheduling. In the model, the lower-level decisions like scheduling the activities within a project are managed by the individual project/site managers. The project managers are responsible for performing the activities with the resources that are allocated to the project. The higher-level decisions like allocating the resources and prioritising the projects are controlled by the resource pool manager and programme manager respectively. The resource pool manager is responsible for allocating the resources to the projects based on the priority assigned to those projects. The programme manager is the key person in the construction organisation when it is managing multiple projects with limited set of resources.

**Table 1.** Selection of scheduling rules

| Scheduling Rule | Description |
|---|---|
| Shortest Operation First | The precedence feasible activity with the minimum activity duration is scheduled first |
| Minimum Slack | The precedence feasible activity with the minimum total slack is scheduled first |
| Shortest Activity from Shortest Project | The precedence feasible activity with the shortest duration from the shortest project is scheduled first |
| First Come First Served | The precedence feasible activity which arrived first into the system is scheduled first |

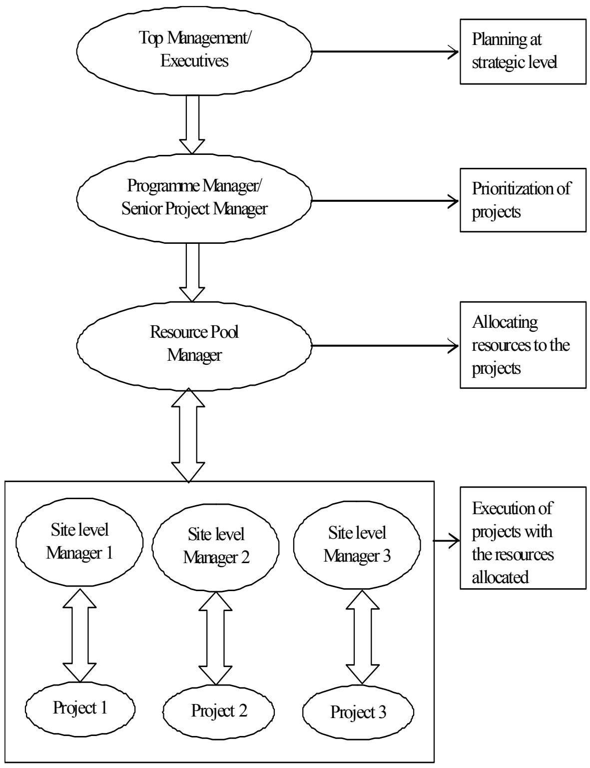


**Figure 1.** A proactive model framework for resource-constrained multi-project scheduling

### 4.1 Project Scheduling Algorithm

The various steps involved in the scheduling algorithm are as follows:

1. 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.

2. Set current time t =1 and resources available at time t ($R_t$) = total resources available ($R_a$).
3. 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 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.
4. If the resources are not enough to satisfy the requirements of the activities in the eligible activity list then advance t = t + 1 or to appropriate time and update the resources available at time t.
5. The above steps were repeated until there are no activities for scheduling. At that time the scheduling is complete for a selected priority rule.
6. The scheduling process will be repeated by changing the priority scheduling rule.

### 4.2 Advantages

First, it reduces the complexity of managing the projects by separating the responsibilities into different levels. Thereby increasing the information sharing and coordination among the different projects. Secondly, it provides greater autonomy and flexibility for managing the projects independently. This improves the effective planning of resources and scheduling of activities in a multi-project environment.

## 5. CONCLUSION

The scheduling of resource-constrained multi-project scheduling is an ongoing research consideration since its evolution. Although the area has been much explored academically, the practical application of these efforts is rarely realized in the construction industry. The basic reason is that the projects managers are not familiarized with the advancements in the project scheduling techniques. This research work gives a broader insight into the proactive approach for multi-project scheduling environment, which is indispensable for the present day construction organisations. This approach helps the project managers and analysts to select appropriate scheduling rules at that particular instant. This effective scheduling framework can be applied to similar scheduling problems such as job shop scheduling problems, assembly job shop scheduling problems, a limited number of machin

es and personnel scheduling problems etc. Thus the framework can prove helpful in effective control and coordination of works under execution.

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