

Limited - Resource Allocation in Construction Projects

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The limited-resource allocation problem arises in many construction projects when there are different limitations on the amount of resources available to the contractor. The scheduling objective is to hold project duration to a minimum while resolving the resource conflict by shifting the activities until the resource requirements do not exceed the amount of resource available. The objective is to minimize project duration using the resources available and increase the utilization of equipment and labor force available. Numerous computer packages have been developed for limited – resource management. Some of these packages assign priorities to the project activities based on measures obtained from the critical path calculations. The objective of this paper is to demonstrate the major difference between the approach taken by one commercial computer package and one of the priority ranking procedures developed in some of the heuristic techniques.

Key Words: Limited Resources, Project Scheduling, Resource allocation, Resource Leveling

Introduction

The most efficient method for developing a construction schedule is to use computer programs. The objective for a contractor is to create the most efficient schedule possible and maximize the usage of the available resources. Scheduling, allocating, and leveling resources for a project can be a time consuming task unless a computer program is used. In most cases, computer programs will give adequate solutions. However, when resource requirements exceed the amount of resources available, the computer programs do not provide the optimum scheduling solutions. The best solution is defined in this paper as the one with the shorter project duration.

When generating a schedule by hand, the scheduler uses his/her experience with similar projects to make decisions concerning time, resources available and cost involved to create a schedule. A set of preprogrammed procedures is used when generating and calculating the schedule using computer software packages like Primavera for Windows. Primavera generates a schedule based on the critical path (CP) calculations and assigns priorities to the project activities based on those CP calculations. These CP calculations are based on unlimited resources available. This paper will show that the default procedures used by Primavera when leveling project activities with limited project resources do not consistently give the best solution to the problem.

Theory and Background

Heuristic Priority Rules

The basic premise of most heuristic procedures for resource-constrained project scheduling is to use a priority rule to rank the activities, and then schedule the ranked activities such that the resource limitations are not violated and the shortest possible project duration is obtained. There are a large number of different heuristic priority rules proposed. Table 1 below lists eight rules proposed by Khattab and Choobineh, (1991).

Table 1

Khattab and Choobineh's Proposed Eight Rules

No.	Priority	Mathematical form
1	$\frac{\text{Activity time} + \text{time of all sons}}{\text{Activity resource} + \text{resource of all sons}}$	$\frac{T_i + \sum_{j \in NF_i} T_j}{R_i + \sum_{j \in NF_i} R_j} \forall i$
2	Total time of sons	$\sum_{j \in NF_i} T_j \forall i$
3	(Activity time + time of all sons) - (total time of parents)	$(T_i + \sum_{j \in NF_i} T_j) - \sum_{j \in P_i} T_j \forall i$
4	Activity time + time of all sons	$T_i + \sum_{j \in NF_i} T_j \forall i$
5	$\frac{\text{Activity time} + \text{time of all sons}}{\text{Number of immediate sons}}$	$\frac{T_i + \sum_{j \in IF_i} T_j}{\sum_{j \in IF_i} X_j} \forall i$
6	$\frac{(\text{Time of immediate sons} / \text{Resource of immediate sons})}{\text{Activity resource} / \text{Activity time}}$	$\frac{\sum_{j \in IF_i} T_j / \sum_{j \in IF_i} R_j}{R_i / T_i} \forall i$
7	Activity resource	$R_i \forall i$
8	$\frac{\text{Activity time}}{\text{Activity resource}}$	$\frac{T_i}{R_i} \forall i$

Where:

- i or j Activity index, i=1, 2, ..., n
- T_i Time required to complete activity I
- R_i Resource required to complete activity I
- NF_i Set of activities that follow activity I
- IF_i Set of activities that immediately follow activity I
- X_j Number of immediate sons

The Critical Path Method (CPM) - based group of rules are used in most computer software packages developed for construction project management. Priorities are assigned to the activities based on measures obtained from the critical path calculations. Note that the calculations are made assuming unlimited resources are available. This paper will compare the CPM heuristic with priority rule 7 listed in Table 1 by scheduling and comparing four real projects. When leveling, priority rule 7 gives the activity with highest resource demand the highest priority.

Resource Leveling vs. Resource Allocation

Resource Allocation and Resource Leveling are the two basic categories for scheduling resources. Resource allocation is used when there are definite limitations on the resources available. When leveling using resource allocation techniques, both the non-critical and critical activities are shifted with the objective to extend the project duration as little as possible beyond the original critical path length. Resource allocation depends on a list of criteria for how to allocate limited resources within a specific period. The available resources need to be compared to the resource demanded by a given activity.

When there are insufficient resources available, the activity has to be rescheduled to free necessary resources. In the case where two activities require the same resources simultaneously and there are insufficient resources to start both activities as planned, the activity with the highest priority will get the scarce resource first.

Resource leveling is used when there are enough resources, but the fluctuations of resource usage need to be leveled. The project duration calculated by the critical path initially remains fixed. The leveling process is accomplished by shifting only the non-critical activities within their floats.

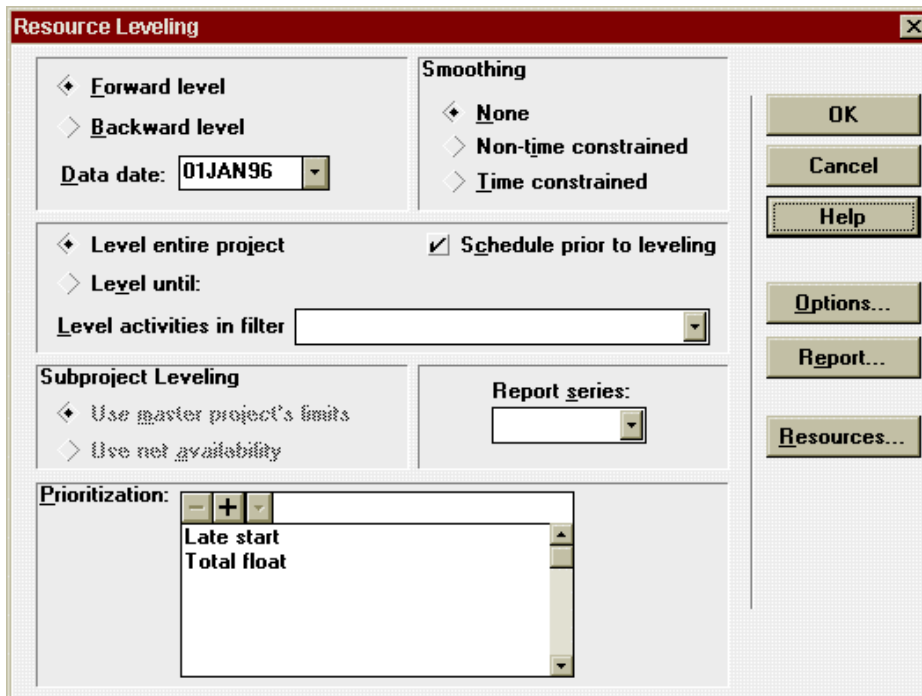


Figure 1. Primavera Resource Leveling Options.

Primavera for Windows (P3) was used for scheduling and leveling the example projects described later in this paper. Below is a brief description on how P3 levels a project. Note that P3 first schedules and calculates the Critical Path.

P3 needs the following data to level a project. Start Dates, End Dates if a fixed end project, normal and maximum resource usage (money, labor, equipment), and resource usage for each activity. There are several options to select before leveling a project. The most important options are described in the Primavera Reference Manual, (1993) and are summarized below:

Forward level/Backward level

Forward leveling schedules a project using early dates. Predecessors are leveled before their successors. Primavera levels from the first activity with no predecessors to the last activity with no successors. Backward leveling schedules a project based on late dates. Leveling begins with the last activity in the network with no successors and ends at the beginning of the network.

Smoothing

The purpose of smoothing is to obtain a more uniform profile of resource usage. During leveling, P3 checks whether the resource requirements exceed the normal limit. If they do, P3 delays the activity as long as positive float is available. There are three options to choose from, 1) None, 2) Non-time constraint, and 3) Time constraint smoothing.

When smoothing is not used (when None is selected) and an activity cannot be scheduled and cannot be delayed any longer because all float has been used, the available quantity jumps from the normal limit to the maximum limit.

Non-time-constrained smoothing is a process that changes resource availability from the normal limit to the maximum limit using a series of steps rather than a single leap. P3 divides the difference between the normal and maximum limits into 10 increments. If the normal limit is exceeded, P3 increases the maximum limit by the first increment and tries to schedule the activity. If the normal resource requirement still exceeds the limit, P3 increases the limit again by the next increment.

Time-constrained smoothing is used when the end date of a project is rigid, and additional resources must be sought to meet overload conditions. Time-constrained smoothing assumes a doubled maximum limit of resource availability so you can schedule as many resources as possible during leveling for activities that are constrained by time. P3 does not increase availability past the activity's late finish.

Prioritization

During resource leveling P3 establishes a list of activities in topological sequence. As resources are leveled, if more than one activity can be leveled at the same time, the prioritization codes are used as a tie-breaker. P3 levels the activity having the highest priority code before the ones with the lower priority codes.

Default Layout

P3 suggests a default layout for the leveling procedure that will be used unless the user changes the default parameters. The most important feature in the leveling process is Prioritization. By default P3 suggests using “late start” as the first parameter to level by, if two activities can be leveled at the same time the “total float” will decide which activities start first.

Primavera suggests an extensive list of parameters that can be used to prioritize activities. Fig. 2 shows the default list. “Activity Description” and “Activity ID” are the first two options Primavera lists for the user. No projects should be leveled using these and the majority of the options given since they have no significance to the leveling process.

Discussion of Results

To compare P3 for Windows with priority rule number 7, four real projects were scheduled. The projects varied in size, complexity and resource availability. Each project was scheduled using information given from the contractors involved in the project.

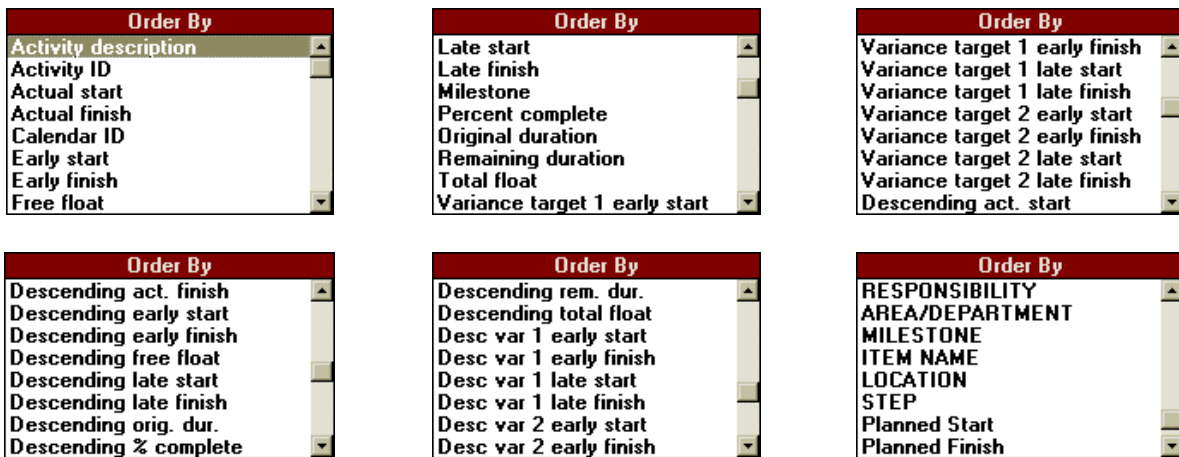


Figure 2. Prioritization Options.

Priority Rule using Primavera

To use the priority rule with P3 we assigned each activity a number from “1” to “10” by defining an extra field using the command “activity codes”. This number reflects the activities total resource need. The activities using the highest number of “man hours” are assigned the number “1”. When leveling the project the “priority rule” has to be selected as the first priority. Second priority was chosen to be “total float”. Four construction projects were selected for this study.

Project 1: Lincoln Northeast High School addition

The project is an approximately \$3 million dollars addition and remodeling of the Lincoln Northeast High School. The three story addition is constructed of masonry exterior walls with interior steel column and steel joist decking system. The new addition consists of a media center,

new classrooms, library, and teacher's work stations. The project consists of two phases. Phase 1 has a one year duration. Then phase 2 overlaps with phase 1 during the summer vacation. The project consists of 80 activities and must be completed by December 1996, for a total duration of 19 months.

Project 2: First Data Resources

The project consists of constructing a 144,000 ft² output service facility. The building is to be constructed using a steel framing, open web steel joists, precast exterior panels and a concrete slab flooring system. The owner has requested the building to be completed in six months. The project consists of 71 activities.

Project 3: Southeast Community College, Cafeteria/Bookstore addition

The project has a 12-month duration and consists of constructing a new Cafeteria and Bookstore for the Southeast Community College. The project consists of 45 activities.

Project 4: Dr. Gewain Office Building

The project is an \$800,000 dollar construction of a two-story office building. The construction duration is approximately six months. The scheduling started in the middle of the period. The project had a fixed end date for completion of the first floor, because of a tenant's need. The project consisted of 58 activities.

Comparison of the Projects

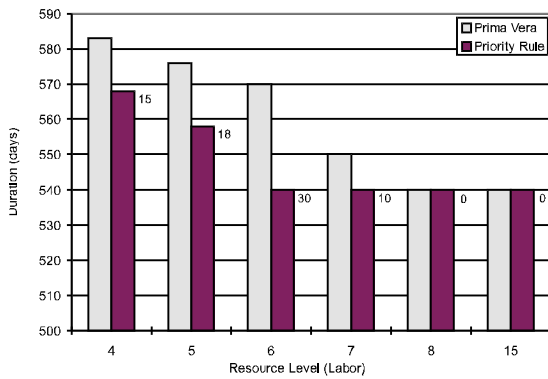
Depending on the preference and experience of the scheduler, the projects could be leveled based on any of the resources used with the project. The four projects described in this paper were leveled based on the resource "general labor".

The comparison between the CPM-based rule P3 uses and the Priority rule is charted in Fig. 3. The data indicate that the priority rule performs significantly better than the CPM-based rule. Project 1, for example, shows that with a resource level of 5 people the priority rule gives a completion date 18 days (as indicated on the graph) earlier than the CPM-based rule. With a resource level of 6 the priority rule gives completion of the project 30 days earlier than the CPM-based rule. Note that for all the projects the priority rule performs better than P3 when there are resource limitations.

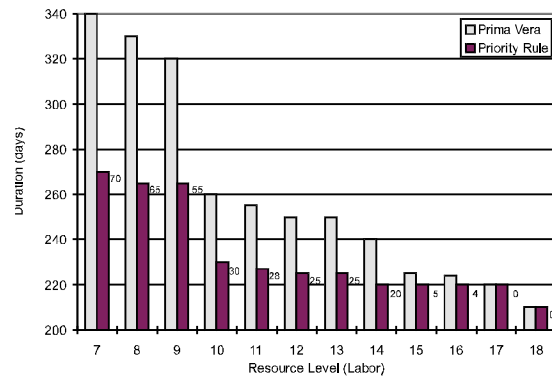
Also, P3 does not give the user the option to specify the minimum resource level needed to schedule an activity and therefore this is not taken to account when leveling the projects.

Conclusion

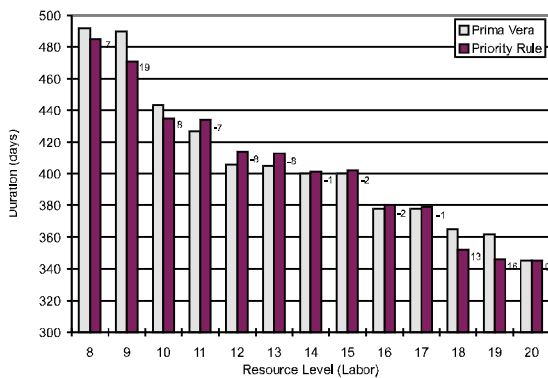
The priority rule performed significantly better than the CPM-based rule when leveling the four projects described in this paper. The priority rule performed best when leveling projects with



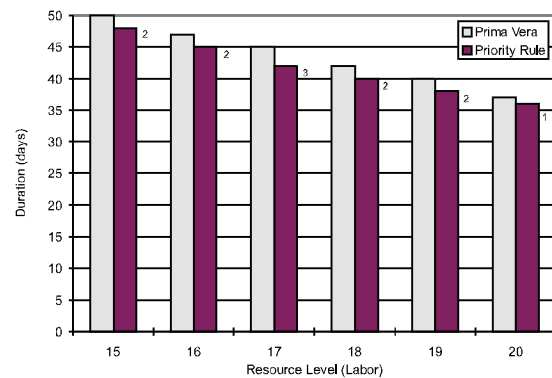
Project 1: Lincoln Northeast High School



Project 2: First Data



Project 3: Southeast Community College



Project 4: Dr. Gewain Office Building

Figure 3. Graphical presentation of the Resource Level vs. Project Duration. (Note: scale is not identical in the four plots.)

resource limitations. Other priority rules might perform better when other constraints govern the project. The experienced user of a scheduling software would not accept the default leveling procedure given by Primavera. The scheduler would need to level the project using different heuristics in order to find the best solution, which is a time consuming task. It would be advantageous to any project manager to have a computer software equipped with the option of testing the behavior of his/her project under limited resources using a set of priority rules that would result in the best duration possible for the project. This will eliminate the time consuming process of testing each rule individually.

References

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