Optimization of Resource Cost Based on Availability

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ABSTRACT

Project management software packages carry out resources planning on the basis that the allocation of any scarce resource is constrained by two levels of availability: the Normal Availability and the Total or Maximum Availability. Giving the usual interpretation to these two levels of availability, two types of inaccuracies can be detected in the resource cost computations. Firstly, the cost of unused resources below the normal availability is ignored. Secondly, the resources in excess of the normal availability are provided at the same unit cost as those within the normal avaialability. The software packages such as Hornet Project Management report identical resource costs irrespective of the chosen levels of normal and total availabilities because of these inaccuracies. Thus, the planner lacks an appropriate criterion for selecting the optimum levels of resource availability. The task of finding the optimum levels would be an operational research problem, the solution of which may not be easy to obtain. This paper describes a method that enables the planner to compute the real resource cost after eliminating the errors and to select the two levels such that the real cost is a minimum. The optimization process is carried out within the environment using a program compiled in the language of the software. The application of the method is illustrated with the resource planning for a construction project of 30 activities using the Hornet project management software. The variation of the real cost with the total availability indicates the existence of two distinct minimum cost solutions - one corresponding to a time-limited resource levelling schedule of the unlimited resources situation and the other to a resource scheduling schedule under a limited resources situation. The real cost is a minimum for a specific value of normal availability for the two optimum total availability values. An arbitrary choice of the normal and total availability levels could lead to the real cost being higher by amounts varying between 10 and 30 percent.

Key Words
project management software; resource planning; normal and total availability; real cost; optimum availability levels

INTRODUCTION

Project management software packages for scheduling of projects by the critical path method have continued to evolve with enhanced capabilities. But even today the overall success with respect to construction projects remain far below expectations (Paulson, 1992). The planners or users beginning an acquaintance with the software packages are not fully appreciative of their capabilities. The problems relate to difficulties in the formulation of the appropriate input and in the interpretation of the output. The planning of the resources, which is of prime importance in generating a feasible schedule, is one area in which problems are encountered.

In resource planning, the commercially available software packages adopt a similar strategy that is based on two levels of availability for each scarce resource identified by the user. The Hornet project management software describes these two levels as the Normal Availability and the Total or Maximum Availability. The adoption of this strategy introduces certain implications both in the provision and the costing of the resources. The implications are not readily evident, and the user lacks guidance on the setting of these two levels.

This paper will attempt to examine the implications, evolve a definite and meaningful objective for resource planning, and devise a method for achieving this objective.

RESOURCE LIMITS

The concept of defining the normal and total availability levels is applicable to the labour and plant resources. The plant resources can either be owned or hired. The hiring option is frequently chosen except in the case of big plant such as tower cranes. If the hiring option is adopted, then the need to set the availability levels can be ignored, and it can be reasonably assumed that the resources would be available whenever required. The labour resources, however, pose complicated problems in planning and scheduling. In the context of the construction industry in Singapore, labour resource must be regarded as an extremely scarce resource that merits attention in the planning stage. This study centres around the planning of the labour resource.

With respect to the labour resource, the normal availability refers to the number of men that would always be available at site. The total or the maximum availability is the maximum number that can be made available. Arising from the above definitions, the following important principles must be borne in mind:

(a) The number of men allocated to any one activity must not exceed the total availability.
(b) The total use of men on any one day must not exceed the total availability.
(c) If, at any time, some of the men within the normal availability are not engaged on any activity then they must be regarded as idling.

RESOURCE COST

Project management software packages have the capability of calculating the cost of each type of resource that is being planned to be used on the project. The resource cost is calculated on the basis of the amount of resources allocated to the individual activities and not by considering the actual amount present at site. This approach introduces two flaws. Limiting our attention to a labour-type resource, the normal availability indicates the number of men who would always be present at site. If, on a certain day, the proposed schedule results in the total requirement being less than the normal availability, then the under utilization on that day must be regarded as idling resources. The cost of the idling resources is not reckoned in the cost calculations performed by the software. Also, the unit cost of the resource in excess of the normal availability (hereafter referred to as the **extra resource**) is taken to be the same as the unit cost of the resource within the normal availability. This does not reflect reality and in fact negate the purpose of setting the two availability levels. The underlying reason for introducing the concept of the two availability levels must be to restrict the use of the resource in amounts over and above the normal availability. This can only be achieved by placing a premium on the cost of the extra resource. The premium must reflect the impact of the scarcity and also accommodate the administrative costs involved in such an approach.

Placing the premium on the extra resource is consistent with the suggestion made in Singapore recently that the foreign worker levy be charged on a two-tier system. Each company would be entitled to a quota of foreign labour. A lower levy would be chargeable as long as the employment of foreign labour is within the quota. If additional foreign labour is recruited, then a higher levy would be paid.

RESOURCE PLANNING OBJECTIVE

The need to minimize the use of the extra resource becomes immediately apparent if the premium payable is taken into account. In this paper, the term **total real cost** denotes the the actual cost of the resource calculated after eliminating the two inaccuracies. The total real cost is made up of the following two components:

(a) The cost of providing the normal availability on every day of the project.
(b) The cost of providing the extra resource at a unit rate that includes the premium.

The resource planning objective would then be to set the availability levels such that the total real cost is a minimum.

MATHEMATICAL PROGRAMMING

The problem discussed in the preceding sections is concerned with the use or allocation of scarce resources in the best possible manner so that the cost is minimized. A mathematical programming approach is suitable.

Notation

- C - Total real cost of resource
- D - Duration of the project in days
- M - Total number of men working on a day
- N - Normal availability of resource
- p - Premium for extra resource / normal unit cost
- r_j - Daily resource allocation for activity j
- R_i - Total requirement of resource on day i
- T - Total availability of resource
- u - Normal unit cost (unit cost of resource within normal availability)
- X_{ij} - Activity schedule (binary integer) variable (0,1)
- Y_i - Resource aggregate (binary integer) variable (0,1)
- Z - Equivalent total normal use
- Z_s - Value of Z given by software

Scheduling Constraints

(1) Any one activity must not be allocated daily resource above the total availability.

$$r_j \leq T \quad \text{for all } j \tag{1}$$

(2) The total requirement of the resource on any day must not exceed the total availability.

$$R_i = \Sigma X_{ij} r_j \leq T \qquad (2)$$

$X_{ij} = 1$ if activity j is scheduled on day i

$X_{ij} = 0$ otherwise

Total Real Cost

The total real cost (C) comprises the cost of employing the normal availability on every day of the project and providing the extra resource whenever required.

$$C = u N D + \Sigma Y_i (R_i - N) u p \qquad (3)$$

$Y_i = 1$ if $(R_i - N) > 0$

$Y_i = 0$ otherwise

Equivalent Total Normal Use (Z)

A variable, Z, could be defined such that Z represents the equivalent total amount of resource that would have the same cost as the total real cost C if all resources are paid at the normal unit cost u.

$$Z = C / u = N D + p \Sigma Y_i (R_i - N) \qquad (4)$$

It is more convenient to use Z instead of C as the objective function because then the need to assign a value for the normal unit cost u will not arise.

Optimization Problem

The optimization problem then becomes:

Minimize Z subject to scheduling constraints (1) and (2). (5)

SOLUTION TO OPTIMIZATION PROBLEM

The optimization problem of minimizing the equivalent total normal use Z is subject to the two scheduling constraints. The two constraints represent the scheduling problem under a limited resources situation. The resource scheduling capability of the project management software can be used to obtain a feasible schedule of activities for a given value of the total availability. The activity schedule variable X_{ij} can be assigned its values from the feasible schedule, and the total resource requirement R_i can be determined. There will be 2100 values for X_{ij} and 70 for R_i to be computed for a small project having 30 activities and a duration of 70 days. However, most software packages can generate the values of R_i on their own.

The next step is for the planner to set the normal availability level N. The resource aggregate variable Y_i can then be given its values and Z can be determined using equation (4). Keeping T constant, N can be varied and the corresponding Z obtained. The whole procedure must be repeated for other possible total availability levels. The optimum combination must be obtained by examining the whole spectrum of values for Z.

Solution within the Software Environment

The solution outlined in the preceding section would be tedious if it is obtained outside the project management software environment. It is possible to overcome this difficulty if the optimization process is performed within the software environment. Advanced software packages permit the development of programs written in their own languages to carry out tasks beyond their own standard operations. The Hornet project management software was used in this study. A command file called the **optim.ins** consisting of a set of instructions written in the Hornet programming language was created to calculate the Z values using the information available from the scheduling process. The procedure is simple. All the standard information necessary to operate the software and to obtain the activity schedule must be entered. Initially, only the total availability level is specified and resource scheduling is done. At this stage, the command file optim.ins is executed. The Z values can be obtained as an output on the screen or on a printer. The total availability level is now changed and the procedure repeated.

APPLICATION

The method of determining the two resource availability levels such that the total real cost is a minimum is illustrated using the information from a project involving the construction of a trench for a geotechnical experiment station. The project consists of 30 construction activities. Labour was identified as a critical scarce resource. The activity data used in the planning of the project and in the subsequent optimization process are given in Appendix 1.

Scheduling

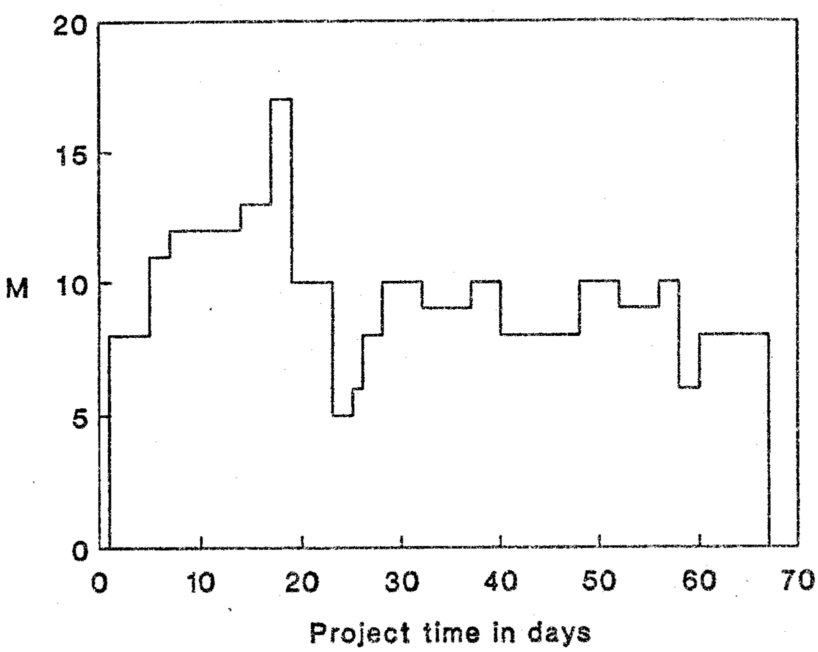
Initially, time scheduling was carried out. Time scheduling generates a schedule of activities subject to the logical constraints while ignoring any limitation in the availability of the resources. The project duration is 67 days, which is the shortest possible time.

A histogram for the use of the labour resource produced by the software is shown in Fig. 1. The histogram corresponds to the earliest start schedule. The maximum number of men required is 17, and the demand for the resource is fluctuating considerably. The largest daily requirement for a single activity is 10 (see the data in appendix 1). Thus, the planner can impose lower and upper bounds on the total availability T as follows:

$$10 \leq T \leq 17 \qquad (6)$$

Theoretically, the normal availability can vary from zero to T.

$$0 \leq N \leq T \qquad (7)$$



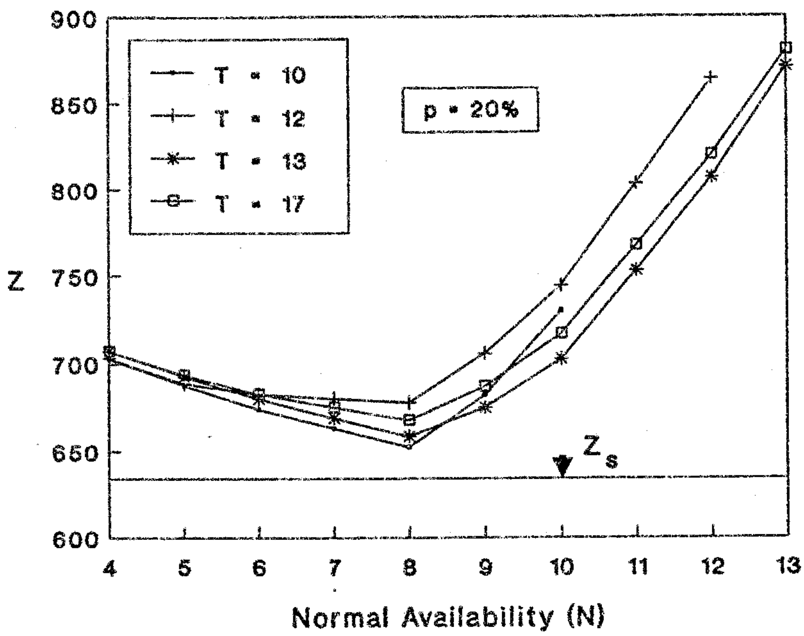
T = 17 corresponds to the earliest start schedule. It may be possible to achieve the same duration while using T less than 17 by carrying out time limited resource levelling. Table 1 shows that for T ≥ 13 the duration is unchanged. If T ≤ 13 then the duration is increased. This denotes that there is insufficient men and the scheduling problem is now transformed to one of resource scheduling for a limited resources situation. It can be deduced from Table 1 that T = 13 is appropriate if the shorter duration of 67 days is preferred while T = 10 can be chosen if the longer duration of 76 days is acceptable.

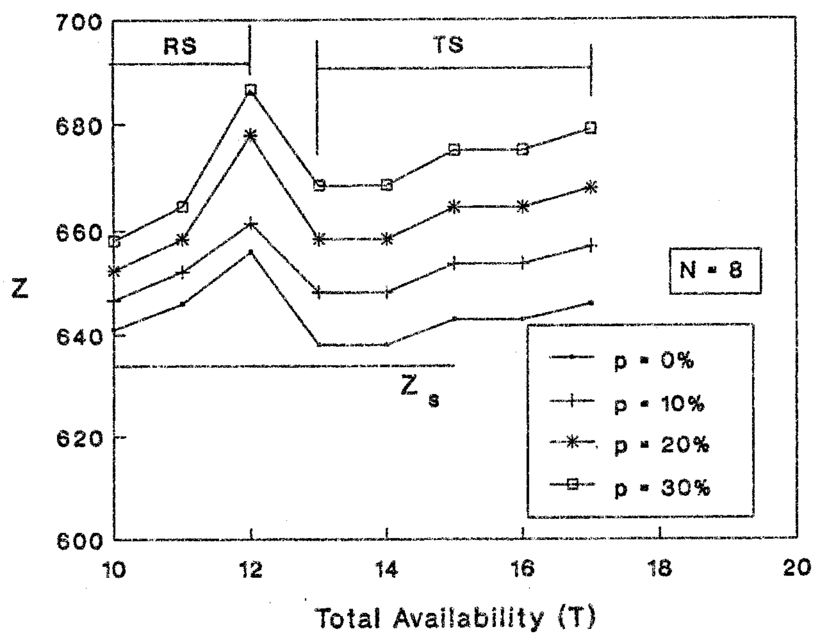
T	D (days)
17	67
15	67
13	67
12	76
10	76

Optimizing Z

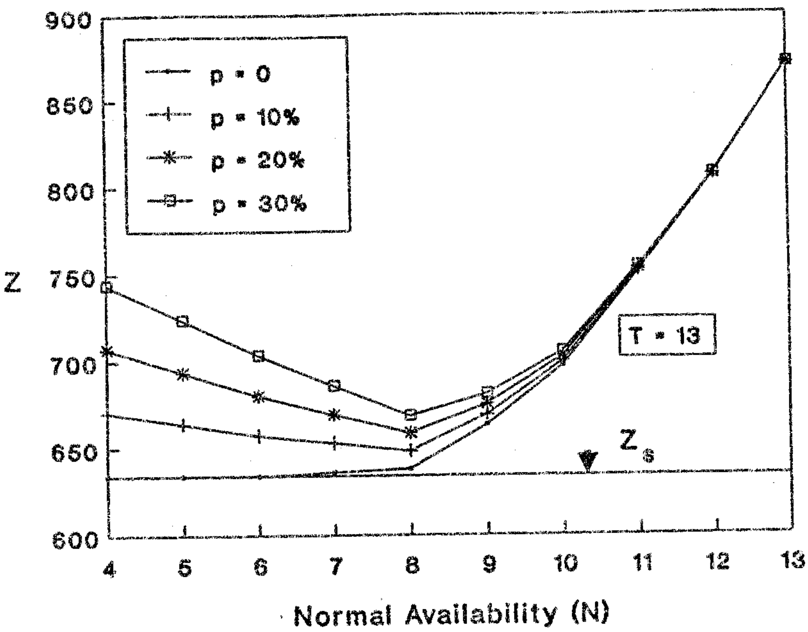
The equivalent total normal use Z depends on both T and N. The variation of Z with N for various values of T is shown in Fig. 2. Fig. 2 was obtained using a premium of 20% on the extra resource. It can be observed that the optimum value for N is 8 irrespective of the value for T. Similar patterns were observed for other values of the premium. It is significant to note that the value of the equivalent total normal use reported by the software Z_s is 634 in all the cases considered.

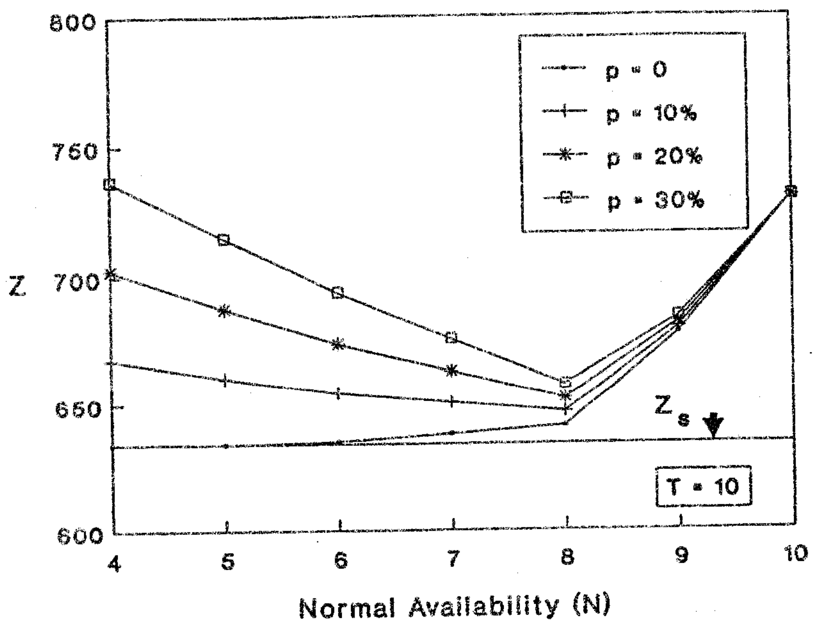
Fig.3 shows how Z responds to variation in T and at different premiums. N was kept fixed at the optimum value of 8. A delineation of the two approaches to scheduling, time scheduling (TS) and resource scheduling (RS), is distinctly shown. The graph further confirms the decision that either T = 13 or T = 10 must be considered. It is useful to observe that the intermediate level T = 12 results in a higher cost than both T = 10 or T = 13.





Figs. 4 and 5 indicate how Z changes with N for different values of premium charged on the extra resource. The two cases T = 13 and T = 10 are taken up for study. The premium charged exerts a considerable effect at lower values of N. The difference narrows down as N approaches T. It can be inferred from these two figures that a wrong choice of N would lead to increased resource costs. If N is taken to be 10 instead of 8 with p = 20%, it results in an extra cost of 8% and 12% for T = 13 and T = 10 respectively. Further, if N is selected to be at 13 for T = 13, the extra cost is 32%.





Final Decision

The selection has been narrowed down to two possible levels of total availability, T = 13 or T = 10. In both cases, minimum cost is achieved for N = 8. The minimum value for Z is obtained for T = 10 (see Fig. 2). However, the decision between T = 13 and T = 10 must be made only after due consideration is given to the following two factors:

(a) The client's specification with regard to the completion of the project.
(b) The indirect cost at site.

It must be borne in mind that a longer duration would mean a higher indirect cost. The saving in the resource cost can be offset by the increased indirect cost. Thus, the total of the resource cost and the indirect cost for the two cases must be determined, and a final decision can be made regarding the choice of T.

CONCLUSION

The resource cost computed by the project management software packages does not accurately reflect the actual cost incurred because the idling resources and the premium chargeable on extra resources are not considered. In order to select the correct optimum levels of availability for scarce resources, it is essential to determine the actual or real cost. The levels of availability are determined so that the real cost is a minimum. This study shows that the mathematical programming problem of optimization can be solved within the environment of the project management software using a simple program written in the language of the software.

REFERENCES

Claremont Controls (1988), *Resource Calculations.* Hornet Project Management System Reference Manual.

Paulson, B.C. Jr. (1992), *Trends in Computer Applications for Building Construction.* Proceedings, 25th anniversary Symposium, Institut für Maschinewesen Im Baubetrieb. Germany.

APPENDIX 1

The data regarding the activities of the project are given in Table 2. The logic of the precedence network for the project is provided by the immediately preceding activities described in the column named Preceding Activity.

The logic dependency is of the Finish - Start type unless otherwise stated.
# denotes dependency of the Start - Start type.
* denotes dependency of the Finish - Finish type.

The amount of labour resource required daily for each activity is given in the column named Resource Amount.

Activity Number	Description	Duration (days)	Preceding Activity	Resource Amount
1	Move in and clear site	4	-	8
2	Excavate trench	12	1	4
3	Cut reinforcement - floor	6	1	4
4	Fabricate formwork - floor	2	1	3
5	Place lean concrete - floor	2	2	7
6	Waterproof - floor	3	5	5
7	Tie reinforcement - floor	3	3, 6	5
8	Assemble formwork - floor	1	4, 7	6
9	Place concrete in floor	2	8	8
10	Cure concrete - floor	7	9	-
11	Cut & bend reinforcement - wall I	6	3	4
12	Fabricate formwork - wall I	7	4	4
13	Tie reinforcement - wall I	4	9, 11	10
14	Assemble formwork - wall I	5	12, 13	9
15	Place concrete - wall I	3	10, 14	10
16	Strip formwork - wall I	2	15	8
17	Cure concrete - wall I	7	16	-
18	Waterproof - wall I	2	16	8
19	Backfill against wall I	4	18	8
20	Cut reinforcement - wall II	6	11	5
21	Fabricate formwork - wall II	5	12	5
22	Tie reinforcement - wall II	4	19, 20	10
23	Assemble formwork - wall II	4	21, 22	9
24	Place concrete - wall II	2	17, 23	10
25	Strip formwork - wall II	2	24	6
26	Cure concrete - wall II	7	24	-
27	Waterproof - wall II	2	25	8
28	Backfill against wall II	3	27	8
29	Move Out	3	28, 26*	8
30	Provide site services (hammock type)	-auto-	1#, 29*	-