

The Project Scheduling and Decision Mechanism Based on the Multi-Resource Leveling

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Abstract

Except for optimizing the schedule of a project, managers tend to enhance the utilization of resources and reduce the usage fluctuation of resources. This paper is to construct a multi-resource leveling model as a decision mechanism and strategy for managers to control projects. In the multi-resource model, the resource leveling rate, RLr , is established and the smaller the leveling rate, the more resources' usage of a project is leveled. The multi-resource leveling model will help managers to control and manipulate the implementation and usage of different types of resources for better project scheduling. In this research, a global search to find the optimal solution was conducted and the software Visual Basic (VB) was used as the programming language to perform the searching. A practical example was provided to test and verify the model and obtained excellence performance result.

Keywords: project scheduling, resource leveling, resource allocation.

Introduction

For the major result and concern of the well known methods in project management, including Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT), is the time-only information. Another situations occurred in the traditional project are the single type of resource applied and without any limitation of quantity of resources can be used for activities of a project. Nevertheless, in reality for most projects, resources allocation is still the critical and challenge problem for management. Hence, researchers continuously pay attention to this problem. Basically, there are three major types of researches on resource allocation problem: first is the time and cost trade-off problem, second is the resource leveling problem, and the third is the project scheduling under fixed resource limits. Among these studies on project optimization concerning resources limitations, we found that how to properly arrange those limited resources will be the major achievement of today's businesses.

From the analysis and reveal from the technique of project resource requirement profile, the over fluctuation of resource daily usages can be a significant phenomenon of applying CPM and PERT network analysis techniques nowadays. This over fluctuation of resource phenomenon can be problems that lead to resources waste in project(s) and low resources utilization of project(s). The problems induce our interest in studying on leveling the multi-resources and constructing a project decision mechanism for enterprise management and project managers. Accordingly, the main goals of this research are to make the daily usage of resources as consistent as the demands and to achieve the most resource leveled and the lowest cost for project which can reduce resources idle and resources waste.

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Original Considerations on Project Management

Tools for project scheduling, such as Gantt charts and PERT/CPM networks, are the time-only information based and have existed for some time. However, these tools have significant shortcomings for settings characterized by constrained resources and multiple projects that arrive dynamically. 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. The basic project scheduling problem without resource constraints is from a computational point of view easy. Optimal solutions can be obtained relatively fast.

Solving Problems for Resources Scheduling

The project-scheduling problem under resource constraints has been studied to a large extent (Demeulemeester and Herroelen 2002). The resources leveling problem is one major topic of this research field. Both during the project and at project completion, the completion of schedule is facilitated through the controlling and usage of resources employment of a project schedule. This process is more cost effective than other dispute resolution alternatives.

In the early researches, methods on solving resources scheduling problems were focused on mathematical models and heuristic models. In 1963, Kelly applied heuristic models to solve the project resource constraint scheduling problem; those proposed models included both serial method and parallel method. In 1973, Davis used two mathematical models, including both linear programming and dynamic programming, to find the optimal solution. Morse and Whitehouse (1988) proposed applying either single rule method or ranking rule method to calculate the proper resources allocation on activities for construction projects. These research methods are generally simple and effective for single type of resource problems.

For the resources constraint researches, many were devoted on resource leveling problems. Easa (1989) once used deviation absolute value of same resource level and required resource level to solve resource leveling problem. In 1996, Younis and Saad applied genetic algorithm to develop a computerized program for optimizing the resource leveling on multi-resource projects. Leu and Yang (1999) applied the fuzzy theory and genetic algorithm for the uncertain property of time on projects and to find the optimal schedule for resource allocation under limited resources. In 2000, Leu et al. applied also the genetic algorithm to overcome the resource leveling problem on construction engineering and developed a decision support system for solving multi-resources leveling problems.

All above researches are basically for either single-type of resources problems or applying algorithms to find solutions. Although this can shorten the computation time for finding solution, it cannot guarantee to get the optimal solutions and to obtain the best quality of solutions. This paper will construct a multi-resource leveling model as a decision mechanism and strategy for managers to control projects. The resources allocation and limited situations are also considered for finding the best solution. The visual basic (VB) programming is also used for simulation and analysis.

Method

The decision mechanism and strategy for this research will be based on the so call resource leveling rate (RLr). The smaller the leveling rate, the more resources' usage of a project is leveled. This also reveals that the resources capacities are well utilized and work loadings for activities are leveled. The multi-resource leveling model will then help project managers and management to control and manipulate the implementation and usage of different types of resources for better project scheduling.

For the traditional way of resource leveling technique, the activities with higher usage of resources will be smoothed and moved to those activities with lower usage of resources, as Figure 1 (a) shows. The attempt of the moves is to level the usages of activities smoothly. However, in this research, we propose a totally new different way of smoothing direction which is from the maximum resource required to compress the blank area as the Figure 1 (b) shows. The mathematic model of resource leveling rate (RLr) is basically the difference between daily resource limitation and daily actual resource requirement. For the goal function value of the resource leveling rate is the smaller the better. The smaller for the difference value, the smoother the resource loading. Nevertheless, due to limited resource quantities, the reducing of resource leveling rate is not unlimited; after certain value, the make-span of the project will then have to be extended. The goals of this research are as the follows: 1. modeling the resource leveling rate (RLr) and constructing the control mechanism which related to *resource-limited scheduling* problem; 2. finding the days of project prolonged based upon the leveling rate; 3. finding the most feasible number of resources under the multi-resource constraint.

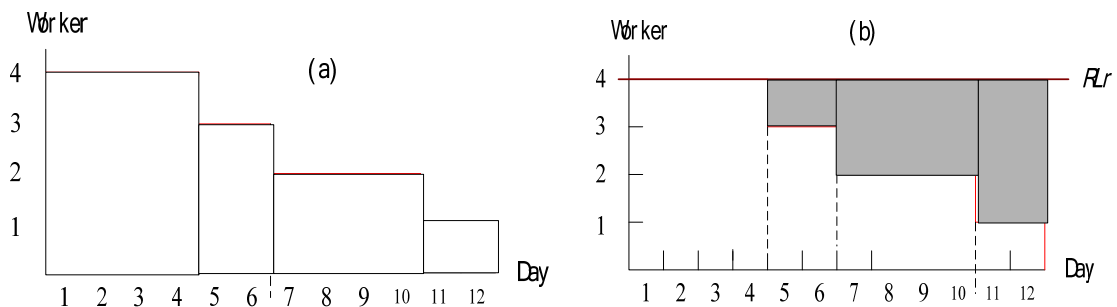


Figure 1. Different ways of smoothing and leveling: (a) move the red area into smoother situation; (b) reduce the blue area by compressing the maximum required for achieving leveling situation

Research Assumptions

1. the precedence relationship of activities are known and the posterior activities cannot start before predecessors are finished,
2. activities are indivisible and durations of activities are fixed and known,
3. there is no preemption,
4. all types of resources are limited and quantities cannot be suddenly increased or decreased,
5. all resources are integer and known,
6. the setup time is included in activity duration time,
7. there are no discussion on cost and duration crash problem.

Notations

RLr : representing resource leveling rate

i : number of activity, $i=1, \dots, I$, where I is the total number of project.

t : scheduling time spot, $t=1, \dots, H$.

H : the completion time under resource constraint; $H=CP(1+A)$.

CP : the project critical path duration time under unlimited resources constraint.

A : due date slack rate of a project.

T_i : completion time spot of activity i .

T_1 : start time point of the project.

d_i : duration time of activity i .

G_i : the set of all direct successive activities of activity i .

$$X_{it} : \begin{cases} 1, & \text{if activity } i \text{ is proceeding at time } t \\ 0, & \text{otherwise.} \end{cases}$$

$$C_{it} : \begin{cases} 1, & \text{if activity } i \text{ is completed at time } t \\ 0, & \text{otherwise.} \end{cases}$$

$$S_{it} : \begin{cases} 1, & \text{if activity } i \text{ is started at time } t \\ 0, & \text{otherwise.} \end{cases}$$

r_{ik} : each period resource requirement of the k^{th} type of resource for activity i .

R_k : each period of available resource amount of resource k .

ES_i : the earliest start time of activity i under unlimited resource constraint.

EF_i : the earliest finish time of activity i under unlimited resource constraint.

SLK_i : total slack time of activity i .

S_i : the set of successive activities of activity i .

Model Construction

- The objective function:

$$\min RLR, \quad \text{where } RLR = \sum_{k=1}^K \sum_{t=1}^H \left(R_k - \sum_{i=1}^I r_{ik} X_{it} \right)^2 \quad (1)$$

Subject to

- $T_1 = \min(T_i) = 0;$ (2)

- $\sum_{t=ES_i}^H X_{it} = d_i, \quad i=1, \dots, I;$ (3)

- $T_j \geq T_i + d_j, \quad \forall j \in S_i, i=1, \dots, I;$ (4)

- $X_{it} = \sum_{v=t}^{\min\{t+d_i-1, H\}} C_{iv}, \quad i=1, \dots, I, t=ES_i, \dots, H;$ (5)

$$\bullet \sum_{i=1}^I r_{ik} X_{it} \leq R_k, \quad k=1, \dots, K, \quad t=1, \dots, H; \quad (6)$$

$$\bullet \sum_{t=ES_i}^H C_{it} = 1, \quad i=1, \dots, I; \quad (7)$$

$$\bullet T_i = \sum_{t=ES_i}^H tC_{it}, \quad i=1, \dots, I; \quad (8)$$

Model Description

1. for the objective function:

Eq. (1) is the resource leveling rate (*RLr*). The smaller the leveling rate, the more resources' usage of a project is leveled. It is sum of square of the difference between daily resource limitation and daily actual resource requirement. For the objective function value as the resource leveling rate is the smaller the better. The smaller for the difference value, the smoother the resource loading. We found the square function is able to demonstrate the status of leveling. For example, if day x needs six workers and day $x+1$ needs two workers, the sum of square is $6^2+2^2=40$; then, if after executing leveling process, day x needs four workers and day $x+1$ needs four workers too, the sum of square is $4^2+4^2=32$. The difference between those two sums is eight. This can reveal the smoothing status directly and the importance after leveling. Hence, in this research, the sum of square is adopted as an important tool for resource leveling.

2. for the constraints:

- a. Eq. 2 is the constraint of project start time.
- b. Eq. 3 is to calculate the activity duration.
- c. Eq. 4 shows the precedence relationship of activities.
- d. Eq. 5 illustrates the activities are indivisible and ensures once any activity started, that activity will continuously processes until it is completed.
- e. Eq. 6 limits each period resources needed can not exceed the available quantities of resources.
- f. Eq. 7 makes sure every one activity will be completed within certain point of time during project make-span.
- g. Eq. 8 is to calculate the finish time point of activities.

Numerical Example and Analysis

The software package of Visual Basic (VB) was used as the programming language to perform the simulation and search. The searching is based on the global search to find the optimal solution of a multi-resource project. The interface of this resource leveling program is based on Microsoft VB 6.0 and Access. The computer platform was a Pentium 4M-CPU 2.20GHZ PC with 512MB RAM for execution simulation.

Example Applied

A factory extended project is provided for testing and analysis. The entire extended project includes field reorganization, machines installation, warehouse layout, mechanical and

electrical installation, recruit, education and training, piping installation, system test, etc. The primary information of those major activities, including precedence relationship, durations, resource types and quantities, is listed in Table 1. Figure 2 shows the network structure of the project.

Table 1. The Primary Information of the Factory Extended Project Example

Job	Start node	Finish node	Duration (week)	Earliest start time	Resource 1's requirement	Resource 2's requirement	Resource 3's requirement
A. Field re-organization	0	1	2	0	5	6	5
B. Operators call-up	1	2	4	2	6	3	4
C. Machine installation	1	4	9	2	2	5	3
D. Warehouse layout	1	5	5	2	2	6	4
E. Mechanical and electrical installation	1	6	4	2	4	3	5
F. Recruit	2	3	2	6	6	3	2
G. Education and training	3	4	2	3	3	1	1
H. System test	4	7	1	5	5	6	5
I. Piping installation	5	6	2	1	1	3	3
J. Final Setup	6	7	1	2	2	3	4

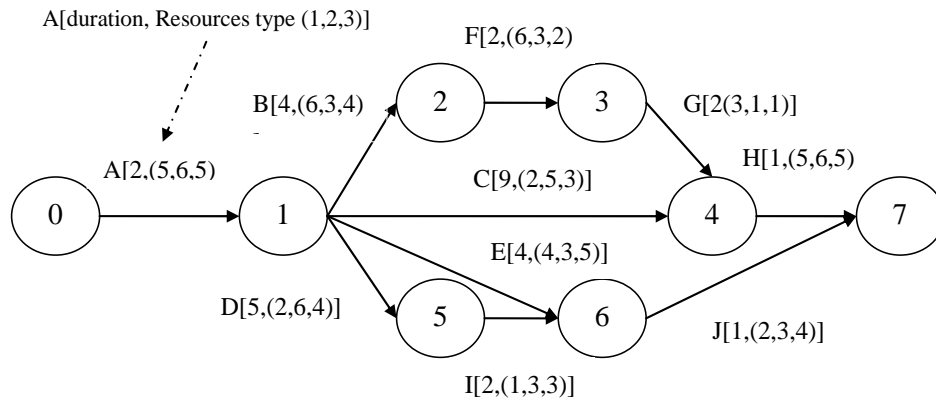


Figure 2. The Network Structure of the Factory Extended Project Example

Table 2. The Objective Values and Project Durations after Resource Leveling

Resource 1's amount	Resource 2's amount	Resource 3's amount	Project duration	Objective value
12	14	12	12	539
10	11	10	16	587
8	9	8	19	464
6	6	5	30	449

Table 2 shows the best results after trying different combinations of resources and project durations. One can easily observed that when resource amount keeps lower down,

the project duration will keep extended. From Figure 5, one can see that the project duration is even extended to 30 weeks.

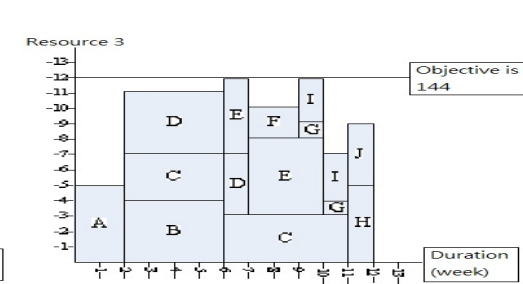
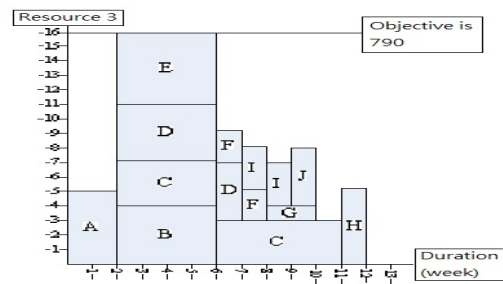
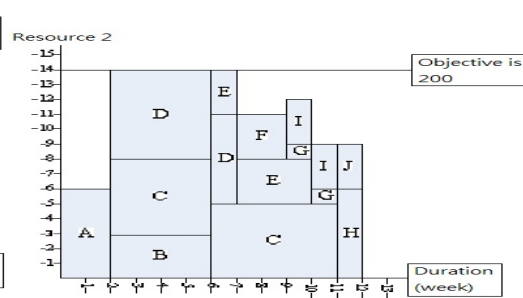
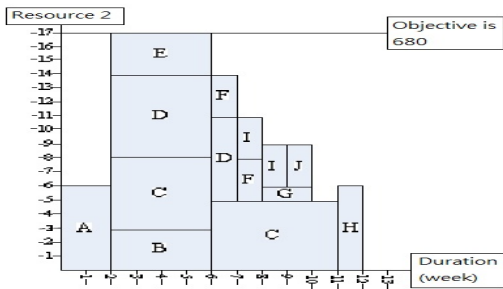
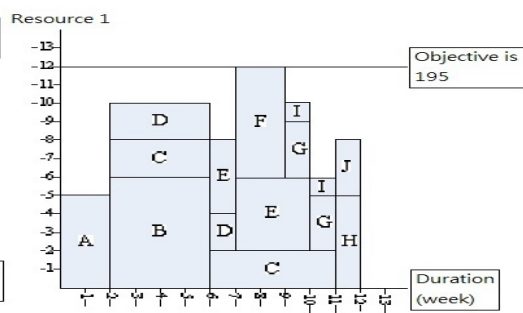
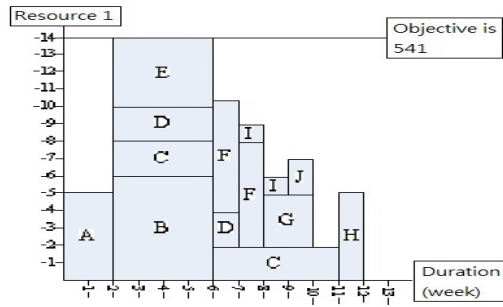


Figure 3. Multi-resource profile of 12-weeks project duration before leveling

Figure 4. Multi-resource profile of 12-weeks project duration after leveling

The Figure 3 and 4 are discussed under the project duration is not extended, i.e. without any delayed. The duration of the critical path is 12 weeks. These figures show the results of resources allocations and objective values before and after being leveled. It is worth noticing that the multiple resource types must be rearranged at the same time for each one type of resource. This is because when moving any one activity, those associated different types of resources have to be rearranged at the same time.

In Figure 5, it shows the entire resource profile after leveling and of the lowest resource limitation. One can observe that each one activity will reach its minimum limitation of amount that available for executing process. The objective value, i.e. RLr for each one type of resource is the lowest. However, the project duration, i.e. make-span of project, is prolonged from 12 weeks into 30 weeks. Unfortunately, the critical path is increased into three paths. According to the proposed formulation, management can try to compress the resource level rate step by step and to see the result of the resource allocation situation from the resource profile. Therefore, decision can then be made after the most feasible combination presents. This should meet the expectation for high ranking management for running business and executing projects.

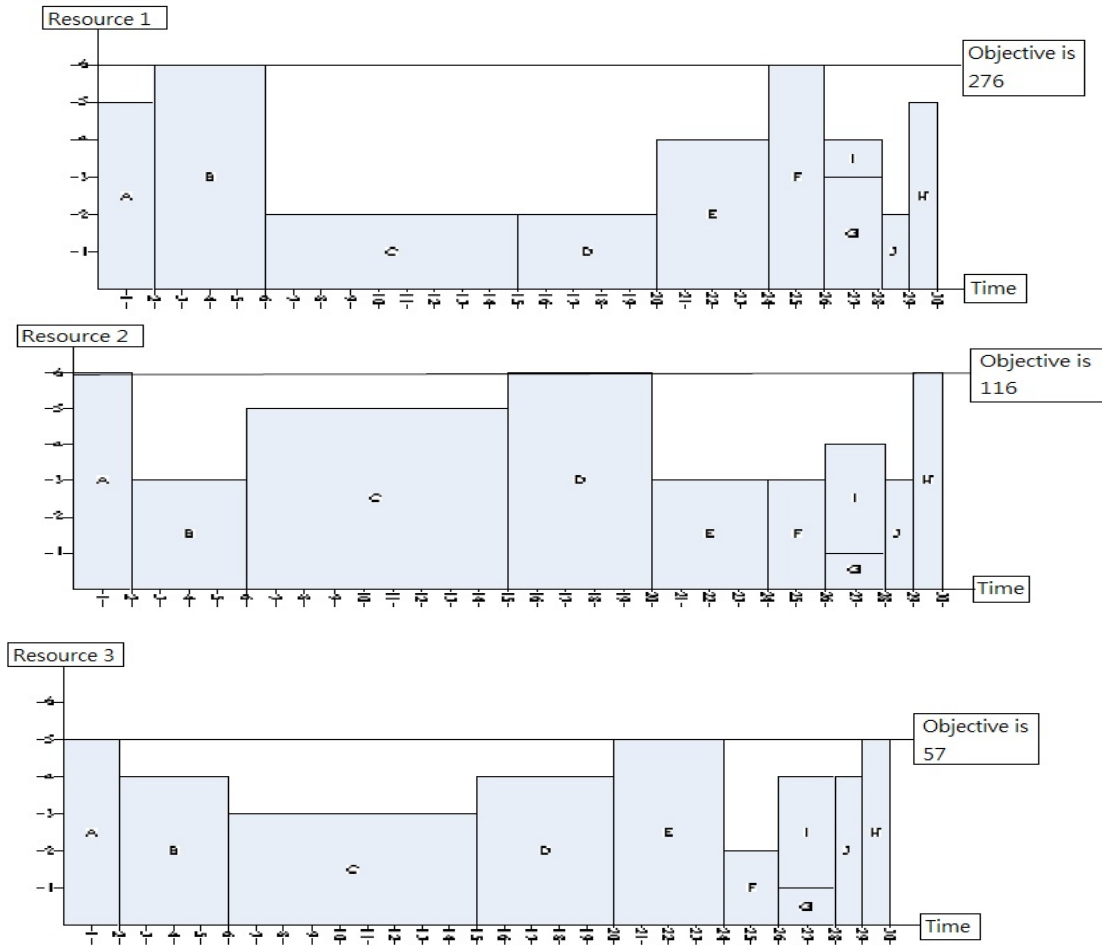


Figure 5. The Resource Profile after Leveling and of the Lowest Resource Limitation

Conclusions

The major purpose of this research is to discuss the multi-resource leveling problem with finite limitation. We use the VB programming software to construct an interface for finding solution. After example demonstration and analysis, we conclude the followings:

1. From the example shows that using the proposed leveling formulation, one can obtain the reasonable optimal solution for making feasible decision.
2. This research shows that after leveling process, multiple types of resources will influence each other and the interaction will make the project delayed. The critical path might be changed or increased. There is no such problem for single type of resources.
3. Basically the resource leveling is processed on the non-critical activities, due to slack time, to avoid extending the project duration. However, when the resource limitation and multi-resource are added into the problem, the improvement for projects is reduced dramatically and the project duration may be largely extended.

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