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An Efficient Technique for Smoothing Project's Demand for Multiple Resources.

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AN EFFICIENT TECHNIQUE FOR SMOOTHING PROJECT'S DEMAND FOR MULTIPLE RESOURCES

طريقة فعالة لجعل احتياجات مشروع التشييد من عناصر العمل منتظمة

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الملخص :

تهدف طرق جعل احتياجات المشروع من عناصر العمل منتظمة الى ايجاد التوقيت المناسب لكل نشاط فى المشروع فى حدود الوقت المبكر لانتهاء المشروع مع تقليل الطلب الأقصى (قمة المدرج التكرارى) لعناصر العمل أو الحد من التذبذب فى الطلب على عناصر العمل من فترة لأخرى (تردد المدرج التكرارى) . وتتعامل هذه الطرق سواء كانت تقريبية أو دقيقة مع عنصر واحد فقط من عناصر العمل ، فاذا ما أراد المقاول الاهتمام بمجموعة من العناصر فى وقت واحد فانه يتم جمع استخدامات الأنشطة لهذه العناصر بعد ضرب كل منها فى وزن يدل على أهمية العنصر للمشروع ، أى انه يتم تحويل المسألة لتتعامل مع عنصر واحد مكافىء لمجموعة العناصر ، وتعطى هذه الطريقة نتائج تقريبية . يقدم هذا البحث طريقة جديدة لحل هذه المسألة تهتم بمجموعة العناصر فى نفس الوقت ، حيث يتم تحويل المسألة لمجموعة محدودة من المسائل لاعداد البرنامج الزمنى المثالى للمشروع فى حالة عدم توافر عناصر العمل ، وفى كل من هذه المسائل يتم تقليل الطلب الأقصى على عناصر العمل بمقدار وحدة واحدة بالتناوب بين العناصر ، والتأكد فى كل مرة ان زمن المشروع لم يتعد الوقت المبكر لانتهائه ، وتستمر هذه المحاولات حتى يتم تحديد الطلب الأقصى على كل عنصر الذى يؤدى لزيادة وقت المشروع عن الوقت المبكر لانتهائه . وقدم البحث مثالا محلولا لتوضيح خطوات الحل حيث ثبت ان هذه الطريقة فعالة وتعطى مدرجات تكرارية لمجموعة من العناصر فى وقت واحد أفضل من الطرق الأخرى .

ABSTRACT

The objective of the resource smoothing problem is to schedule project activities so that the project duration does not exceed its early start duration and the project's maximum demand for resources, or the variation in this demand from one time period to another, is kept to a minimum. Many heuristic and optimal methods have been developed for solving this problem. almost all of them are concerned with smoothing a single resource. For a contractor who is required to manage several resources simultaneously, the process can be done by adding the resource rates together, according to predetermined weightings of the resources, and then smoothing the single equivalent resource. This method is inefficient and often gives approximate results. This paper introduces a new efficient technique for smoothing multiple resources concurrently. The resource smoothing problem is translated into a finite number of resource scheduling problems in order to determine minimum resource levels required to maintain the CPM project completion date. The technique can give both the minimum level and the most uniform level resource histograms. The resulting smoothed histograms are better than those produced by other methods. The technique is simple, and computationally efficient. An example is solved to show the details and results of the technique.

1. INTRODUCTION

There are two categories of scheduling resources in construction projects: resource scheduling and resource smoothing. The resource scheduling problem arises when there are definite limitations on the amount of resources available. The scheduling objective is then to allocate available resources to the activities in the manner that will result in the least delay of the CPM project completion. A programmed algorithm for optimal resource scheduling in construction has been developed by Eldosouky [1].

The resource smoothing problem arises when there are sufficient resources available and it is required to smooth out the peaks and hollows, which normally occur, in the pattern of resource usage. This situation is pronounced in order to reduce cost of shipping equipment to and from the project site, to save time required by new men to be familiar with the project, or to guarantee an even flow of application for a high-cost resource once it is assigned to the work. The scheduling objective is therefore either to reduce the level of the resources or to make the resource requirements as uniform as possible; while holding to the CPM project duration.

This problem of resource smoothing has been solved by two distinctly different approaches. The first category includes heuristic approaches which are usually used to give good (not optimal) solution. The basic idea of these methods is to shift the noncritical activities in a systematic order according to some rules-of-thumb. Examples of these methods are the works by Galbreath [2], and Harris [3,4]. The advantage of these methods is that they can handle large projects. The second category consists of procedures designed to produce the optimal solution using integer programming techniques. Example of these methods is the model developed by Easa [5]. Optimization models are suitable only for small networks because of the mathematics used.

Both the heuristic and optimal approaches were developed to smooth a single resource. However, they can be applied directly to smooth multiple resources if the prime concern in the construction project is to smooth a common base (e.g. cash flow) in which each resource rate is considered as the sum of these proportionate values for each activity. After smoothing on the common basis the individual resource rates can be added to give the resource demand histogram for the use of management.

For other cases in which it is required to smooth distinct resources directly, the resources can be smoothed in series; one priority at a time.

This method will cause some activities to be shifted from a previous position established by the smoothing of a higher priority resource. Therefore, when smoothing resources in series the resource which is smoothed last will have the controlling values. Another approach to smooth multiple resources concurrently is to adding the resource rates together (according to some assumed set of weightings), smoothing the resulting resource sums and separating the resource sums into their respective histogram values at the end of the solution. This approach gives approximate results as will be seen later in the paper.

In this paper, an efficient technique for smoothing construction project requirements for multiple resources is introduced. The technique assumes an early start schedule derived from the CPM network computations, reduces resources maximum usage by one unit (one resource at a time) and checks feasibility of the new production level using a program for optimal resource scheduling. This process continues until the minimum level of resources that keeps the project CPM completion time unchanged is obtained. During this analysis, the minimum resource improvement coefficients, which indicate the most uniform resource requirements are obtained. The technique is simple and gives the optimal smoothing of multiple resources in a finite number of trials. An example is given to demonstrate the details of the technique.

2. DEFINITION OF PROBLEM VARIABLES

Fig. 1 shows a typical resource histogram. The elements $y_1, y_2, \ldots, y_D$ represent the daily (or weekly) usage of the resource over the interval 1 to D. The area of the histogram represents the total usage of the resource, TU. Thus, for a resource k

$$TU_k = \sum_{i=1}^{D_k} y_{ik} \quad (1)$$

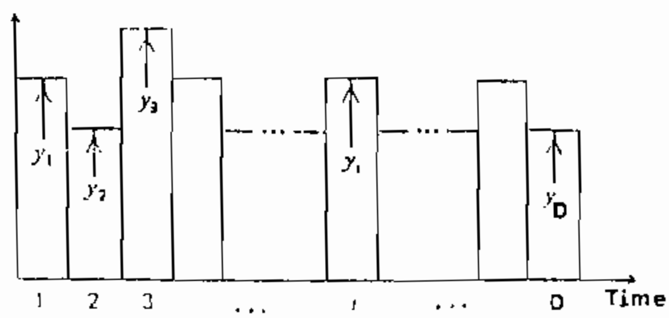


Figure 1. A Typical Resource Histogram

where D_k is the duration of resource k. The average usage of resource k, AVR_k, is the smallest integer which is greater than or equal to (TU_k / D_k). Let the greatest usage of resource k by a single activity, out of the project n activities, be R_k. Then a lower bound on the production level of resource k, LB_k, that keeps the project CPM completion time unchanged is

$$LB_k = \max [AVR_k, R_k] \tag{2}$$

Project resources must be classified as key or secondary resources. Key resources are those that are either scarce or expensive. It is, therefore, normal to smooth only key resources. Let the number of key resources in the project be K. The hollowest of a resource histogram, at any stage of the smoothing process, is called resource lowest usage, RLU. On the other hand, the peak of a resource histogram, at any stage of the smoothing process, is called resource maximum usage, RMU. The objective of the smoothing process is to reduce RMU of the K resources of the project to be as close to their LB as possible. The minimum level histogram of a resource is defined as the resource histogram with the lowest RMU.

Attempting to minimize the variation in the demand of a resource from one time period to another means trying to make the resource histogram approaches a rectangle. The resource improvement coefficient, RIC (given by Harris [3]) measures the approachability of a resource histogram to be a rectangle. At any stage in the smoothing process, this coefficient can be calculated using Eq. 3.

$$RIC = \frac{D_k \cdot \sum_{i=1}^{D_k} y_{ik}^2}{(TU_k)^2}, \quad k = 1,2,\ldots,K \tag{3}$$

Ideally, the value of this coefficient would be one; hence, the nearer the value of RIC is to one, the more closely the resource histogram is to a rectangle. The most uniform level histogram of a resource is defined as the resource histogram with the lowest RIC.

3. ASSUMPTIONS

The assumptions of the new technique are:

1. Project activities are assumed to be time continuous. An activity cannot be interrupted once begun.

2. Resources are demanded by an activity in constant amounts throughout the duration of the activity. Thus, an activity will have a constant rate of utilization of the resource.

3. The CPM project completion date is assumed fixed. The smoothing technique will not extend the project duration.

4. Key resources must be defined in the order that reflects their relative importance to the project. Priority is given to reducing the maximum usage of the earlier resource by one unit, if possible, before attempting to reducing the maximum usage of the following resources.

4. THE SOLUTION PROCEDURE

The new technique of smoothing multiple resources simultaneously aims at determining the minimum level of the project K resources that must be provided to keep its early start completion time unchanged. To achieve this goal the RMU of the K resources determined by CPM analysis are considered. However, any known reduced values of RMU, which keep the CPM project duration unchanged, may be considered as the starting point. Beginning with resource 1 and continuing to resource K, an attempt is made to reduce the RMU of each resource by one unit. Resources are dealt with according to the preference order established by the scheduler. A program of optimum resource scheduling is used to determine project duration corresponding to the reduced resource level. If it is greater than the CPM duration, then the RMU is increased by one unit and this value is considered the minimum production level of the resource. Otherwise, the technique turns to the next resource. This process of reducing RMU by one unit and checking the corresponding project completion time continues until an attempt is made to reduce a value of RMU below its lower bound given by Eq. 2 or until the minimum production level of the resource is verified by the resource scheduling program.

Having reduced the value of RMU of one of the resources by one unit, it may happen that the actual value of RMU of the resource, and in some cases values of other resources, are reduced by more than one unit. Two reasons behind this favoured situation: the new position in time occupied by the noncritical activities to satisfy the reduced level of the resource and the resource rate values.

During the process of determining the minimum level of the project resources, the improvement coefficients of the respective histograms are calculated using Eq. 3. The minimum value of these coefficients represent the most uniform requirement of the resources. In some cases, the minimum production level of the resource will give the minimum RIC; i.e. the histograms of minimum level of the resource and most uniform level of the resource will be identical. In the remaining cases, the RMU of the most uniform level histogram will be a little higher than that of the minimum level histogram.

Now, a detailed description of the technique will be given.

1. Prepare an activity schedule using CPM. Determine project duration T_o. Calculate RMU_k and RIC_k, $k = 1,2,\ldots, K$.

2. Consider first resource; $k = 1$.

3. If the minimum level of resource k has been determined, go to step 11.

4. Otherwise, if $RMU_k = LB_k$, then consider the minimum level of resource k equals RMU_k and go to step 11.

5. Otherwise reduce RMU_k by one unit.

6. Call program for optimum resource scheduling and determine project duration T'.

7. If $T' = T_o$, go to step 9.

8. Otherwise increase RMU_k by one unit and consider the minimum level of resource k equals RMU_k. Go to step 11.

9. Calculate actual values of RMU_k and the corresponding values of RIC_k, $k = 1,2,\ldots, K$.

10. Compare values of RIC_k, $k = 1,2,\ldots, K$ with previous values. A tolerance of 0.5% is allowed. Store the lowest values of RIC_k and the corresponding values of RMU_k, $k = 1,2,\ldots, K$.

11. Increase k by 1. If $k > K$ go to step 12, otherwise go to step 3.

12. Have the minimum level of the K resources been determined? If yes, stop. If no, go to step 2.

Obviously, the proposed technique is copmuter-based. The number of trials required to give the optimum solution is finite and depends, of course, on number of resources included in the smoothing process, mass usage of the resources by the project activities, and the difference between RMU values determined by CPM and those achieved at the end of solution.

To test the efficacy of this technique, the above procedure was programmed in FORTRAN for an IBM AT 386 computer. The new program for smoothing multiple resources simultaneously, named P3, uses the resource scheduling program developed by Eldosouky [1]. Both programs have the same computer RAM requirements approximately.

5. APPLICATION

The following example is adopted from Harris [3]. Table 1 lists the activities of a small construction project, their durations, predecessors and resource rate for each of two resources. Resource 1 has been chosen to have first priority and resource 2 to have second priority. The histograms of the resources according to activities early start timing are shown with dotted lines in Fig. 2.

The minimum moment algorithm developed by Harris was used to smooth the combination of the two resources. Two cases were considered: (1) resource rates are added without weightings (2) resource rates for resource 1 are weighted over resource rates for resource 2 by a ratio of 2.69 to 1.00. The results of this heuristic approach are given in Table 3. The respective histograms for case 1 are shown with thin lines in Fig. 2.

The proposed technique was used to smooth the two resources simultaneously. Sixty seconds of CPU time were required to get the solution using program P3. The solution steps are given in Table 2. This Table illustrates the discussion given in section 4. Trial 0 includes values of RMU given by CPM analysis where project duration equals 20 days. These are $RMU_1 = 13$ and $RMU_2 = 18$. The lower bound on the production levels of the resources are $LB_1 = 5$ and $LB_2 = 8$. In trial 1, RMU_1 is reduced to 12 while RMU_2 is kept at 18. These values give the same project duration, but the actual values of RMU become $RMU_1 = 9$ and $RMU_2 = 17$. In trial 2, RMU_2 is reduced to 16 while RMU_1 is kept at 9. These values give the same project duration. This process continues until trial 9 where RMU_1 is reduced to 5. This value gives an extended project duration. Therefore RMU_1 is increased to 6 and this value is considered as the minimum level of resource 1. In trial 10, RMU_2 is reduced to 10. This value keeps the CPM duration unchanged. A further trial, no. 11, is made to reduce RMU_2 to 9, but this value gives a prolonged project duration. Thus RMU_2 is increased to 10 and this value is considered as the minimum level of resource 2. As the minimum level of the two resources has been obtained the process is terminated.

Table 1. Data for the Example Project

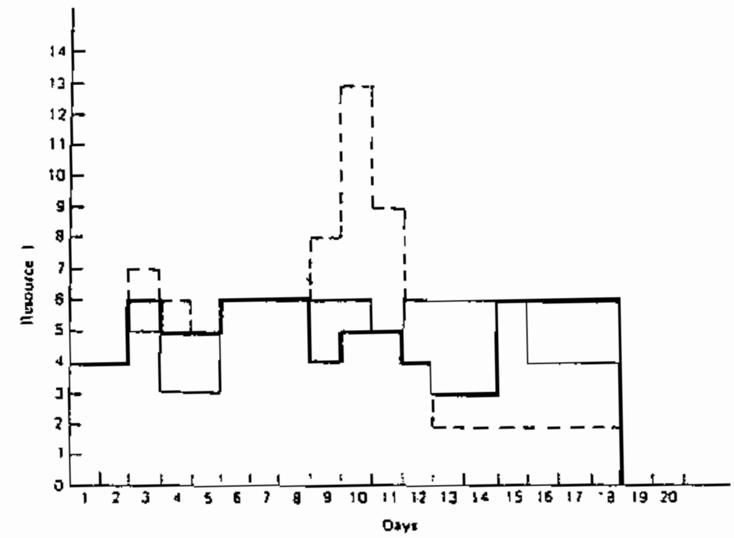
Activity	Duration (days)	Predecessors	Resource Rates	
			Resource 1	Resource 2
ST	0	-	-	-
A	2	ST	0	2
B	3	ST	2	3
C	3	ST	2	0
D	2	A	1	4
E	6	A	2	5
F	6	B	3	2
G	6	C	1	0
H	4	C	0	5
K	2	D,E	4	5
L	7	E,F	2	0
M	3	A,G	2	8
N	2	A,G,H	4	3
P	2	K,L,M,N	0	0

Table 2. Solution Steps of the Example Project

Trial No.	Values of RMU		Remarks
	Resource 1	Resource 2	
0	13	18	Values given by CPM analysis
1	12	18	Project duration = 20 days
2	9	16	ditto
3	8	16	ditto
4	8	15	ditto
5	7	13	ditto
6	7	12	ditto
7	6	12	ditto
8	6	11	ditto
9	5	11	Project duration > 20 days
10	6	10	Project duration = 20 days
11	6	9	Project duration > 20 days

Table 3. Summary of Results of the Example Project

Method of solution	Smoothing case	Resource 1			Resource 2		
		RMU	RLU	RIC	RMU	RLU	RIC
Minimum Moment Algorithm	Resource 1 plus resource 2	6	3	1.049	12	3	1.137
	2.69 Resource 1 plus resource 2	6	3	1.040	13	3	1.213
Proposed Technique	Most uniform level solution	6	3	1.040	11	3	1.098
	Minimum level solution	6	3	1.044	10	2	1.122



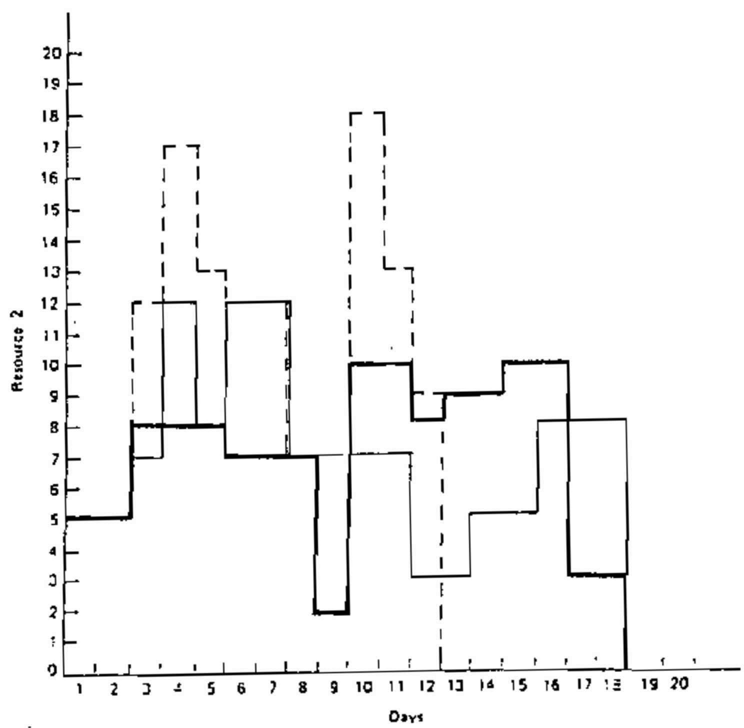


Figure 2. Histograms for Resources 1 and 2. The dotted lines represent early start histograms, the thin lines represent histograms smoothed using the minimum moment algorithm (resources added according to natural weightings) and the thick lines represent histograms smoothed by the proposed technique (case of minimum level histograms).

A summary of the results obtained by the proposed technique is given in Table 3. The minimum level histograms are shown with thick lines in Fig. 2. Now, it is obvious that the results obtained by the minimum moment algorithm are approximate. While both methods give the same values of RMU and RLU for resource 1, they give different values for resource 2. The minimum moment algorithm gives a value of RMU for resource 2 which is 20% greater (when the resource rates are added without weightings) and 30% greater (when the resource rates are added according to predetermined weightings) than that given by the minimum level solution. Evidently, weighting of resource rates for resource 1 over resource rates for resource 2 does not give any additional benefit for resource 1. The most uniform level solution has a lower RIC, but a higher RMU than the minimum level solution. The scheduler will prefer the first solution to the second if it is less costly.

6. CONCLUSIONS

This paper presents an efficient technique for smoothing project's demand for multiple resources. The technique has the following features: (a) it depends on using a program for optimal resource scheduling; (b) it guarantees the optimum smoothing of multiple resources in a finite number of trials; and (c) it can be easily programmed for the computer. The results obtained for an example project show that smoothing multiple resources by adding the resource rates according to predetermined weightings gives approximate results. The formulation presented can be used to obtain the minimum level and the most uniform level histograms. However, the technique would be extended to satisfy a preferred level histogram and this would be described in a later paper.

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