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A MODEL FOR TESTING THE IMPACTS OF DIFFERENT PROJECT RESOURCE ORGANISATIONS ON THE CONSTRUCTION PROGRAMME

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ABSTRACT

This paper reports on a computer model which has been developed to realistically simulates the progress of projects. The major part of the model is a heuristic scheduler that has been run under three types of project resource organisations. The three organisational regimes used are central management, section management with co-operation between the sections and independent section management. The resultant project duration under given resource constraints has been used in each of these project management regimes as a measure of the efficiency of the resource scheduling process. It has been found that the scheduling is more effective in the case of section management with co-operation between the sections than the other two cases.

KEY WORDS

Resource Organisation, Simulation, Resource Scheduling

1. INTRODUCTION

Construction projects are often large and complex; they consist of many different types of work; change rapidly; and are carried out in a changing and frequently harsh environment. Despite this clients want them completed in a minimum time possible and to budget. In an attempt to achieve this, project managers often rely on the use of various common planning and control techniques available.

The common techniques of network planning such as the Critical Path Method (CPM) and PERT are concerned with minimising project duration. They assume no limit on the availability of the resources to be employed to complete all project activities on schedule. This unrealistic assumption can lead to ineffective resource usage and project delays. In practice, most projects are limited to the number of resources they can use and in order to schedule activities with resource constraints, other techniques have to be employed. Resource allocation has been a major concern of research since the advent of the CPM/PERT network techniques. Since late 1950 many algorithms have been developed to solve the problem of resource-constrained project scheduling including theoretical optimisation and heuristic rules, see for examples Kelly(1959), Pascoe (1965) and Mawdesley (1973).

Heuristic scheduling approach is one of the simplest and effective methods, which has been proposed for the allocation of limited resource to the activities of a project. Researchers have used heuristic approaches to get an acceptable solution that may not necessarily be optimal, Khattab and Soyland (1996), Tam and Palaneeswaran (1999). In general these approaches employ decision rules to decide the order for the activities to proceed at any stage of the project. This implies that, depending on the decision rules to be used, a priority number will be associated with each activity at any time during the project.

Heuristic methods of allocating limited resources for project scheduling also allow construction firms or managers to apply these techniques for example, when they wish to carry out several projects with the same resources. In most cases the total availability of these resources become constraints and must therefore be recognised in the planning of the individual project. Usually when the projects are large, the resource allocation is carried out in two ways: the allocation of resources to all the projects is integrated into one multi-project plan, or the resource allocation for each project for only the resources being shared is integrated in one multi-project functional plan.

In carrying out multi-project scheduling, construction firms or managers strive to provide more efficient bases for project resource planning and scheduling because quite often special skills and resources are required to be utilised across many networks simultaneously. Multi-project scheduling techniques permit the movement of these skills and resources from one project to another, as if the networks of the different projects are linked together, even when they appear to be independent of the each other. The movement of resources from one site to another may be considered as a job and time for transferring of resources between projects should be taken into consideration, see Battersby (1970) and Abdul Ahfur (1984).

Despite the fact that abundant literature exists on both the relationship and importance between project organisation structures on one hand and planning and scheduling on the other hand, very little attempts have been made in the past to measure and quantify the effects of the these two aspects on each other, see Brod and Pohani (1990) and Harrison (1992).

This paper describes the development of a computerised simulation model that considers the problem of multi-section scheduling which is based on the same principle as multi-project scheduling. In this paper, the whole project is represented by a single precedence network. Sections are assumed to be located within the same site and therefore the time needed by resources to move between sections is regarded to be too small to be taken into consideration.

This paper also describes the use of the model to investigate the effects of three types of management regimes in a sectionalised project on the project schedule. The resultant project duration, under limited resource levels, has been used in each of the three cases as a measure of the efficiency of the scheduling process.

2. PROJECT RESOURCE ORGANISATION

A project should be organised to facilitate production. The project manager is responsible to his superiors for the site in its totality. On small sites he will carry out most of the management work himself and part of this work may involve planning and controlling the work of the plant and labour employed on the various activities. The manager will agree a long-term plan to fulfil the major objectives of the project and also prepare the short-term plans to ensure efficient use of project resources.

In practice, large projects usually split into sections to facilitate project organisation. The selection of sections is often based on the characteristics of site or on functional requirements of the work involved. Sections are allocated a proportion of the site resources to carry out their work and sections managers are made responsible for the performance of their sections to the project manger. The project manger's personal work in this case has commonly less to do with detailed short term planning of the work except to ensure its conformity with his overall plan. The resource allocation problem in this case is similar to multi-project scheduling takes place within a given resource constraint. This work has simulated this problem and a single project has been tested under the following concepts:

- *Central Management*: In this kind of project organisation, the project is not split into sections and the project manager is assumed to be the person who is responsible for allocating the resources to all the activities of the project. The model also assumes that there is a single resources pool available for the whole site.
- *Independent Section Management*: In this case, the model simulates the project as being divided into sections. Each of the sections has its own resource pool that is independent of the others. For the purpose of the experiments, it has been considered in this case that there is no kind of co-operation between sections of the project concerning the sharing of resources between them.

- *Sections Management with Co-operation*: In this case, co-operation between various sections with respect to the movement of resources between them is considered. Co-operation between sections is based on the idea of having a common or residual pool into which all the surplus resources that are not used by any section are kept to be available to other sections.

A single project has been chosen and resource scheduling experiments were then carried out on it to examine the effects of dividing it into sections. The project is treated under the above three types of resource organisation. As a result of each experiment, project duration is produced and used as an indicator of how efficient the resource scheduling process is. The resultant project duration from the various experiments are presented and discussed later in a later section of the paper.

3. BASIC MODEL

The model is designed to be a day-by-day heuristic scheduler that has variable resource levels and which gives variable duration for the activities. It is a serial sort scheduler in which the network calculations are performed only once at the beginning of scheduling, see Kelly (1959), Lockyer and Gordon (1996), Kolisch (1996). It is based on the assumption that a certain predetermined number of each type of resource required by the activities being available for the use of the project. The scheduler uses the latest start time as a major sort. This implies that, at any one time, if two or more activities compete for the same resources when there is insufficient number of these resources to operate all of them concurrently, priority will be given to the activity with the earliest latest start time. If required, this decision rule can be changed without any alteration to the structure of the model.

The scheduling of the activities in the model is considered daily. If an activity needs either of resources or of materials cannot be satisfied, then that activity has to be abandoned for that day. As a natural consequence of this, an activity can be stopped due to the shortage of either resources or materials and then restarted when there are enough of both of them to schedule the activity. This means that an activity can be split over two or more periods of time and then proceed at different rates of progress depending on the level of resources available.

The types of events that can take place at any time in the scheduler are the start or finish of an activity, material delivery and stock out, resource hiring and firing.

The activity model used here allows changing the duration of an activity by altering the amount of resources between specified limits. Several authors in the past have suggested this type of model since variable duration activity, in general, is closer to real life than fixed duration model Kelly (1959), Battersby (1970). To facilitate the estimation of activity duration on the basis of such model, a mathematical relationship between the number of resources working on the activity and the duration is assumed. This relation is represented by Figure 1. The relationship is approximated as shown by the dotted line on the same figure in order to simplify the calculations. The resource requirement of each activity is specified in terms of the quantity of work required by each resource to finish the activity.
The duration of an activity is calculated as follows:

$$D_i = \frac{w_i}{n_i} + M \qquad (1)$$

Where

$D_i =$ *the duration required by resource i to comlete the activity*

$w_i =$ *work quantity for resource i*

$n_i =$ *number of resource type i used*

$M =$ *minimum duration of the activity*

The above mathematical relation is applied in the scheduler for every type of resource used by the activity. The activity duration is taken to be the largest of the resulting resource durations.

The minimum duration (M) for an activity can be determined for example on the basis of assumed physical constraints such as space. An upper limit of each resource is assumed above which an increase of that resource will not affect the speed of the activity. This limit differs from one resource to another. This assumption is made because, in real life, the number of resources working on an activity is usually affected by the type of work involved and the space available for these resources to work on that activity. There is a physical limit, for example, to the number of excavators and labourers that can work in or near a hole to be excavated on a construction site. If the number of resources on the activity exceeds a certain limit, it will result in extremely inefficient working conditions and might result in no work being carried out at all. Also too many resources in a limited space will undermine safety on site.

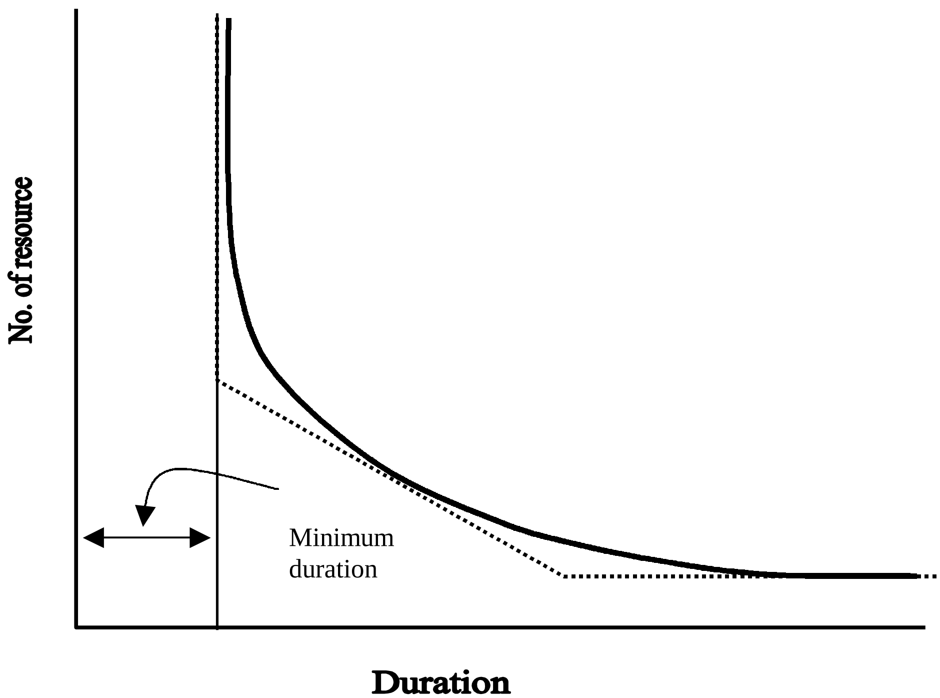

Figure 1: Activity's Resource-Duration Relationship

As well as the upper limit of resources that can be used by any activity, a minimum limit of resources below which work will not proceed is assumed, such as 1 labourer, 1/10 of a machine. The allocation of part of a machine to an activity means either a full machine is working part of the duration or a full machine is shared with other activities. For convenience of simulation, the division of machines has been made into 10 parts.

In addition to the limits of resources on activities, the model also simulates the effect of supervision on the progress of the work and the productivity of labour. It uses exponential mathematical relationship between the productivity of labour and the ratio of the number of foremen to the number of operatives. It assumes labour productivity to be 50 % of the optimum if no supervision is involved in the work. Using such assumption, a 'productivity factor' is calculated using the following formula:

$$PF = 1 - \frac{0.5}{e^{R}} \qquad (2)$$

where

$PF =$ Productivity *factor*

and

$$R = \frac{Number\ of\ \ foremen}{Number\ of\ \ operatives}$$

The final duration of an activity can then calculated as being the maximum duration based on resources divided by the productivity factor.

It may be worth mentioning here that the productivity factor may differ from one section of the work to another as a result of the degree of supervision available in each section.

3.1 Resource Representation

In the model, physical resources have been divided into three categories. These are skilled and unskilled operatives, machines and subcontractors. Each of the these categories was given a different code number in order to be able to distinguish between them during scheduling.

The utilisation factor of the resources in the model is calculated as being the ratio between the total resources employed and the total resources provided.

To be realistic, the model also addresses the problem of non-attendance of resources by using a uniformly distributed random number between 0 and 0.2 for the allowance of absenteeism within labour. This means that there is a possibility of non-attendance of 20% of the total number of labour every day as a maximum.

The hiring and firing of resources in the model take place at the end of every week if required. The decision of hiring and firing is made in accordance with the planned schedule times of these resources. The procedure is performed in such a way that the type and number of resources are associated with the section number for or from which these resources are hired or fired.

3.2 Materials Representation

In order for scheduling to take place in the model, requirements of activities from materials should be also gratified. Materials in the model have been classified as follows:

- *Consumable materials*: These are the kind of materials that are usually used throughout the project by all the activities, such as sand, cement etc. Materials of this kind usually become part of the work they have been used to construct and therefore can be used only once.
- *Special materials*: Special materials are those that are not in common use among many activities. They are used for special kinds of activities and not for the others. An example of such a material would be bridge bearings.
- *Re-usable materials*: This type of material differs from the others in that materials of this kind can be used more than once (e.g. shuttering and scaffolding).

A different wastage factor for each material is assumed from experience and wastage is considered to occur on delivery, although in reality it is generally a function of duration and condition of storage as well as usage. This has been done to simplify the model.

The problem of orders and deliveries of materials in real life has been simulated in the model by keeping a predetermined list of order and delivery times for all the materials on site. The delivery of each kind of material then takes place automatically at the specified time.

Control of orders and delivery of materials is a very important factor on any construction site, in order to ensure the arrival of materials in time and at the same time to avoid excessive storage requirements. The deliveries of consumable and re-usable materials in the model take place regularly throughout the project. On the other hand, just like in real projects, special materials have to be ordered sometime before they are needed. In order to simulate this, the model assumes that the start of any activity, that requires a special material, to be dependent on the time taken to deliver that material. This time represents the duration of the order activity of the special material.

4. EXPERIMENTS AND FINDINGS

The model is designed to simulate any project but the project chosen for the experiments consists of 40-activities, which represent the construction of a footbridge. A precedence network has been used to represent the relations between the activities.

Table 1: **Resource Levels Used In The Scheduling Experiments**

Resource level	Resource 1- Grader	Resource 2- Shovel	Resource 3- Lorry	Resource 4- Pile rig	Resource 5- Steel fixer	Resource 6- Excavator	Resource 7- Carpenter	Resource 8- Labourer	Resource 9- Dumper	Resource 10- Crane	Resource 11- Sub-contractor
1	2	2	4	4	9	2	9	13	3	3	1
2	3	3	6	4	17	4	18	25	5	3	2
3	6	6	12	8	34	8	36	50	10	6	4
4	10	8	20	16	42	12	42	58	16	12	6
5	14	10	28	24	50	16	48	66	22	18	8
6	18	12	36	32	58	20	54	72	28	24	10

In practice, sections of the project are usually chosen according to their areas on site or to the types of work involved. In the model, the project was divided into five main sections. The activities of the project have been divided between the different sections of the project in such a way that there is no sharing of any activity between two or more sections. Each section with a different number of activities and has a resource pool, which is independent of the others.

For each of the resource management regimes discussed earlier, six experiments have been carried out varying the resource level in each. In the ‘ section’ case, each of the resource levels shown in Table 1 represents the sum of the number of each kind of resource in the section pools.

In all the experiments, priority was given to the activities with the earliest-latest start time independent of their section. Priority based on latest start time was chosen because it seems to produce a better schedule, Pascoe (1965). The results are shown in Table 2. This table shows that for all the six resource levels used, section management with co-operation always gave shorter project duration and hence a better schedule than in the cases of the other two types of project management regimes.

The reported results of the above experiments indicate that for the same resource level, the scheduler gave different project durations under the different types of organisation. They also indicate that project duration decreases as the resources level increases but there is no linear relationship between the two.

In the case of independent section management where there was no co-operation between sections, the project duration was always the longest. The indications provided by these results seem to be realistic since the activities in this case can only use resources from their own section pool, which represent only a portion of the site total resources.

Table 2: The Results Of Project Duration (In Days) Under Different Types Of Organisation

Resource level	* Priority is given to the activities with the earliest-latest start time		
	Central management	Independent section management	Sections with Co-operation
1	820	1705	736
2	597	854	477
3	379	518	369
4	358	468	349
5	341	439	339
6	332	419	326

On the other hand, the results have indicated that the scheduler gave shorter project durations in the case of section management with co-operation than in the case of central management. This, however, may appear to be unrealistic since the resources available to schedule the activities in the latter case represent the sum of the number of resources in all the section pools. Nevertheless, the analysis of the results has shown that in the case of central management, resources were made available to all activities in the project and that scheduling was carried out according to the priorities set for these activities. This resulted in a very narrow selection of activities to be scheduled first which prevented the start of some remaining activities. On the other hand, in the case of sections with co-operation in which resources were allocated to sections, there was an opportunity for greater number of activities to start at the same time.

5. CONCLUSIONS

This paper has shown that the type of project organisation employed influences the efficiency of the method of allocating resources to the activities.

Three types of project organisation for managing resources have been used. The results of the experiments have shown that project duration is always longer in the case of independent section management than in the other two types. The scheduler has also given shorter project duration in the case of sectionalised management with co-operation than in the centralised type of management. This is because the first case provides an opportunity to schedule a greater number of activities at the same time. In one case the reduction in project duration under section management with co-operation was as much as 20% compared to that under central management. This ,however, is not expected to be always the case. The efficiency of resource utilisation is generally dependent on the methods of selecting priorities and sections as well as the methods of distributing the site resources among these sections.

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