Graphical Methods for use in Allocating Resources

A paper presented jointly by P. Gomez and A. H. Wootton based upon postgraduate research studies carried out in the Department of Construction and Environmental Health at the University of Aston in Birmingham.

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This paper presents a visual, graphical and manual methodology for allocating resources in a multi-project environment.

INTRODUCTION

Many management methods and techniques, which have their origins in other sections of industry have, in recent years, been introduced into the construction industry. In some cases specific methods developed by operational research groups in the manufacturing sector have been especially adapted for application to the construction industry.

There is however a dichotomy insofar as the developments, in what we might term "scientific management", have not had the level of response that one might have expected. There is plenty of evidence to show that over the past twenty five years considerable progress has been made in the development of management techniques based upon scientific or mathematical concepts, yet the practice of construction management has tended to rely upon empirical short term expediencies for resolving many of the everyday problems with which it is confronted. One could say, in all fairness, that "a construction manager would rather live with a problem that he cannot solve than accept a solution that he cannot understand." Perhaps the solutions have appeared too complicated or the form of presentation has been a deterrent to their adoption, there is some evidence to indicate that a visual presentation of both the problem and its solution can gain acceptance whereas a mathematical formulation is ignored or even discarded.

Accordingly, this paper is primarily concerned with methods which emphasise the visual, graphical and manual applications so that a response to the methods presented can be rapidly stimulated and then sustained by the simplicity and ease of understanding that the methods require. When one is utilising graphical methods one takes advantage of a human's ability to analyse visually in both two and three dimensional models whereas most heuristic methods of resource allocation that require the use of a computer utilise a step by step analysis and usually deny the manager scope to use his own imagination and creativity characteristics to sort out improved solutions.

The method presented is not an optimal one but is intended to serve as a management tool in the search for better solutions to the, almost, continuous problem of resource allocation in a multi-project environment. It is assumed that the reader is familiar with the network analysis approach to project scheduling.

Scheduling Projects containing several activities which are not necessarily in the same sequence

The basis of the methods presented can be found in the work of Akers and Friedman (1965) on production scheduling with two projects, later extended by Szwic in 1969. The first part of this section explains the original method and then, in the second part, goes on to extend the method to other applications using graphical examples.

Contractors involved with several non-repetitive projects that need to be effectively co-ordinated in order to improve their potential utilisation (see Note (a)) could find the method useful, for it has the facility of opening up and/or improving the range of alternatives available for exploration by the construction manager.

Civil engineering projects, which usually require a large plant deployment, could be improved dramatically by this methodology since the plant available would be utilised to greater economic effectiveness.

A. Method applied to TWO projects having several activities in different sequences

We are firstly concerned with the basic method for optimising plant allocation decisions in cases of multi-project scheduling with a view to minimising the total duration of the projects in cases where two projects have equal priorities and in which it is not possible to interrupt the execution of the activities. All activities are critical.

Method Description

0. Assign the number .1. to the project that has the longest duration then assign the number .2. to the other project.
1. Graph out the duration of Project 1 activities, in ascending order of precedence on the horizontal (X-X) axis. Similarly graph out the duration of Project 2 on the vertical (Y-Y) axis.
   (*NB:* Total times on Project 1 $\geqslant$ total time on Project 2).
2. Find the rectangular areas where the duration on the first plant item on Project 1 coincides with that same plant requirement on Project 2. Crosshatch the area which corresponds to the time when both projects require the same item of plant.
3. Repeat for all plant items.
4. Start at the origin and produce a 45° line (if possible) until it strikes a hatched area. Follow the edge of the area to its corner and then continue the 45° line. If you strike a corner of an oblong then generate alternative solutions by following each edge. A 45° line means progress on both projects, if the line is vertical the Project 2 is preferred, if the line is horizontal the Project 1 is carried out.

Note (a): Potential is used in the physical sense of capacity for productive work as a means of grouping together similar categories of resources such as manpower and/or plant.

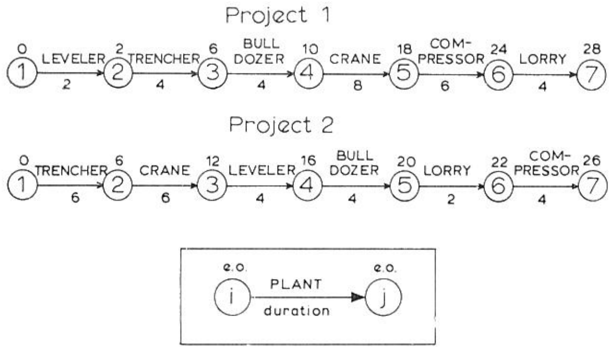

Fig 1.

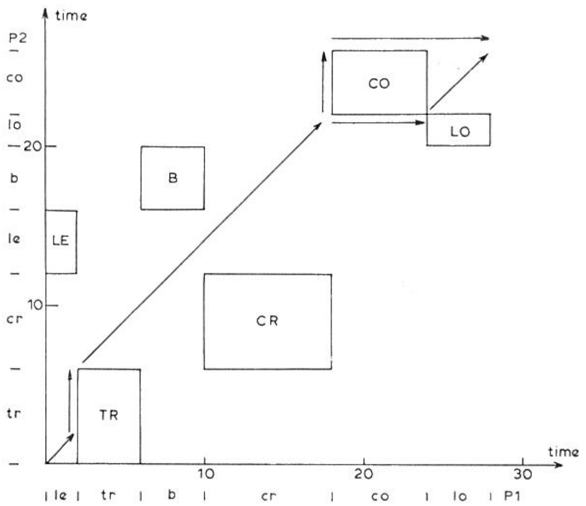

Fig 2.

5. Again calculating from the origin a time schedule can be aggregated to give an overall duration in which all items have been allocated according to whichever option you exercised.

Figures 1 and 2 illustrate a two project example using various plant items with competing utilisation demands.

It is interesting to note that if the upper route is taken then Project 1 has a delay of four units of time and the lorry for Project 1 would have to wait ten units of time, alternatively if the lower route is preferred then Project 2 would have to wait six units of time and the lorry for Project 1 would have to wait only six units of time. The example shows how the method can be used to clarify alternative decisions in the case of scheduling two projects with similar priorities. Other decision areas are brought out, for instance it is possible to delay the start of Project 1 by four units and then to evaluate which project would use the compressor first. *Table 1 refers.*

Compressor used first by	Project Completion Date		Waiting time for Lorry
	Project 1	Project 2	
Project 1	32	32	6
Project 2	36	26	10

TABLE 1

B. Method applied to more than two projects with several activities in different sequences

In this case the previous method is extended to *THREE* or more projects.

Method Description

0. Classify the projects according to their relative priorities. (First step in improving the selection of alternatives).
1. Apply the previous method to the *TWO* projects with the highest relative priority (i.e. steps 1–5).
2. Set out result of step 1 along horizontal (X-X) axis and treat as one project then set out Project 3 on the vertical (Y-Y) axis.
3. Repeat previous method (i.e. steps 2–5 inclusive).

Note: The same restrictions from the previous method apply but, where possible, avoiding the waiting time for projects with the higher priorities previously scheduled. It is important to distinguish between activities which can be interrupted and those which cannot. The diagonal line will change direction and go through the rectangle either vertically or horizontally which would imply that the resources has been re-assigned to a different project.

4. When a solution has been achieved, then the next highest priority project (Project 4) is graphed out on the vertical (Y-Y) axis and scheduled against the previous solution for three projects on the horizontal (X-X) axis. This procedure continues until the project queue has been eliminated.

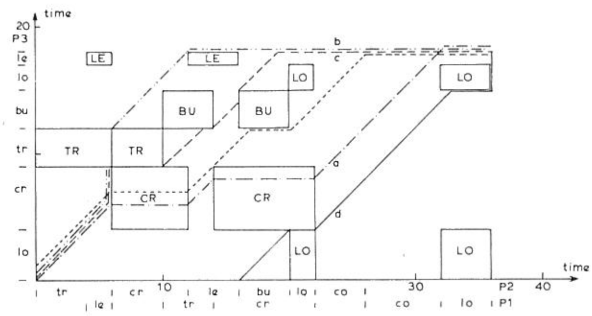

Fig 3.

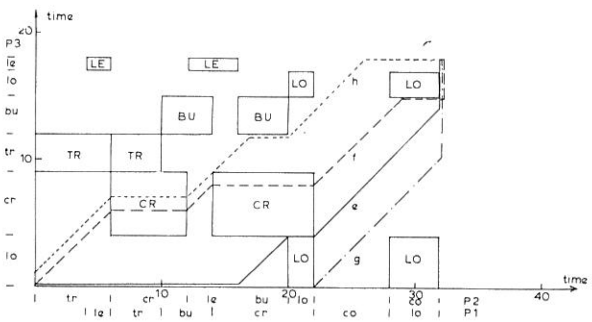

Fig 4.

		Alternatives						
		a	d	e	f	g	h	j
Total duration in project order number	1	32	32	28	28	28	28	32
	2	26	26	32	32	32	32	26
	3	32	23	20	49	18	27	27
Completion date in project order number	1	36	36	32	32	32	33	37
	2	26	26	32	32	32	33	27
	3	32	39	36	49	40	27	27
Starting date in project order number	1	5	5	5	5	5	6	6
	2	1	1	1	1	1	2	2
	3	1	17	17	1	23	1	1
Waiting times	Lorry	16+10	10	6	16+6	2	16+1+3	16+1+7
	Crane	0	2	2	0	2+4	0	0

Note: The values quoted for the starting and finishing dates of the projects are given according to the rule that the value of the starting date corresponds to the first instant and the value of the finishing date corresponds to the last instant of that date.

TABLE 2
ALTERNATIVE PROGRAMME SCHEDULE

Figures 3 and 4 illustrate an example of THREE projects. The previous example solution of thirty six unit time duration for Projects 1 and 2 has been set out on the X-X axis and Project 3 (which has a lower priority) has been set out on the Y-Y axis. This was the upper route and is shown on Figure 2. The lower route gave a duration of thirty two units of time and is shown on Figure 4.

The figures give a range of alternative solutions but in certain cases the system can produce an erroneous solution as shown in cases "b" and "c". In these situations the higher priority projects have been interrupted which is basically a contradiction of the original selection process. A rule that must be applied therefore is that a line that is drawn at any point MUST represent the situation of all of the projects represented in the diagram.

Line "d" in Figure 3 gives a result when activities are not interrupted. In Figure 4 line "e" gives a similar result.

Table 2 summarises the numerical results which could lead to a decision taking into account variables such as the cost of plant waiting time, liquidated damage cost incurrence, the cost of overheads/general expenses which can be proportional or, in some cases, disproportional to the duration of the project. The effect of any premium for finishing the project earlier than the contract date can also be gauged.

C. Method applied to projects with parallel activities

It is possible to extend the previous method to the analysis of projects which have activities in parallel. To solve such problems it is necessary to break down the network into single lines with equal levels of priorities. Usually, in parallel situations, priorities are assigned taking into account the free and total slack for the line. Each line can be treated as an independent project, even projects with complex networks can be dealt with by the method. All one has to do is to draw as many graphs as there are independent parallel lines less one.

The "one project and one potential" case has been fully analysed and solved using heuristic methods of scheduling activities on slack paths. This method only requires the basic early and late start and finish times and total slack times, but has not been fully developed for solving the problem of multi-projects and multi-resources in an "exact" way and the following extract from a publication by Joseph J. Moder and Cecil R. Phillips entitled "Project Management with CPM and PERT" is interesting in this context:—

"More involved questions, dealing with multi-projects and multi-resources, require formal procedures that can be programmed for computer processing. Even with a computer, however, the complex combinatorial nature of the resource allocation problem usually precludes the objective of obtaining an optimal solution. However, we will undoubtedly see continuing improvements to current procedures, such as the one developed by Davis, seeking optimal solutions under restricted assumptions".

"While algorithms for optimal solutions to the general scheduling problem offer little promise with the current state of computational resources, the difficulty of the problem and its implications is too formidable to be adequately handled entirely "by hand". Heuristic scheduling rules, programmed to give "good" schedules have been the basis for practical working systems developed to date. This approach, however, makes very limited use of the "imagination" available to the planner himself and often must make necessarily naive assumptions as to his goals and alternatives. This problem must be considered seriously in the future, in view of the ever-increasing ability to communicate with the computer itself in a direct and expeditious way. The widespread availability of remote or local access to a computer leads one to speculate about the not too distant future when the planner himself can suggest alternatives for exploration in real time, and allow the machine to rapidly compute all the consequential implications. This ap-

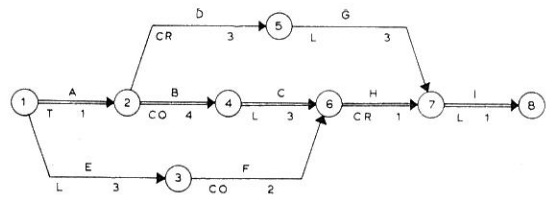

Fig 5.

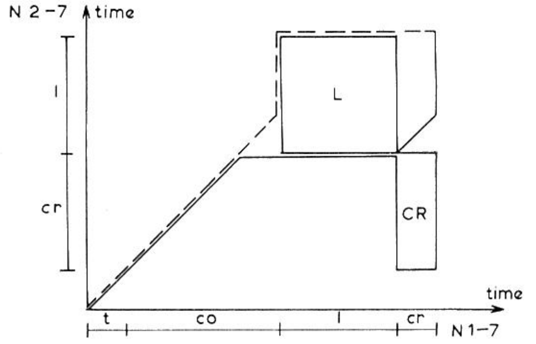

Fig 6.

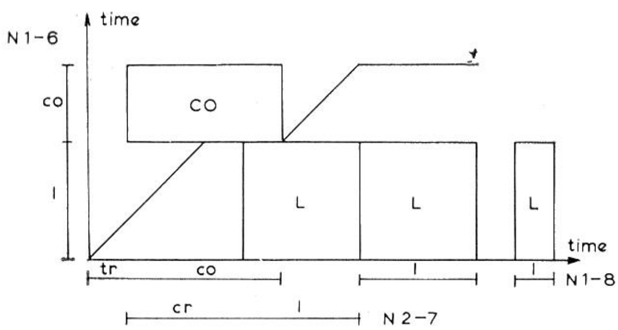

Fig 7.

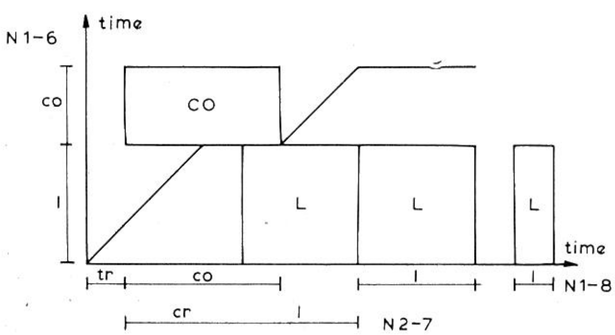

Fig 8.

proach would be a true exploitation of the heuristic approach in which the machine would be a very valuable tool, serving to amplify rather than supplant the technicians' imagination".

(Note: Davis, E. W., "An Exact Algorithm for the Multiple Constrained-Resource Project Scheduling Problem" - PhD Dissertation, Yale University, May 1968).

In general terms the authors of this paper share the viewpoint expressed by Moder and Phillips, but think that the graphical methods presented herein could satisfy present requirements for a simplified method for manual operation that contained a facility for extension into computer application in conjunction with video-communication systems.

The example illustrated in Figures 5, 6, 7 and 8 shows the method applied to a network with activities in parallel lines which cannot be assimilated with others on the critical path.

Figure 5 is an arrow diagram representation of the project which has a critical route and two sub-critical, parallel and independent routes.

Figure 6 graphs out the critical route with the next route in order of criticality and produces alternative solutions.

Figures 7 and 8 compare each of these alternatives against the next sub-critical route again offering alternative solutions upon which to take a decision. The process is repeated for as many sub-routes as are involved or one wishes to consider.

One important characteristic of the methodology put forward in this paper is that the person using the method is given the opportunity to use his ability to think in a lateral sense and is not confined to a linear approach. A computer has to elaborate information in a clear and concise sequence of logically linked steps and cannot evaluate a graph or diagram by surface observation, the method presented enables the manager/operator to generate and evaluate alternative solutions by surface observation.

For the future, a computer, acting as an auxiliary unit, could prove helpful to managers concerned with the type of problem illustrated and a computer configuration utilising a video terminal unit which would accept a magnetic pencil, for example, could reduce routine work considerably. The computer could produce diagrams, calculations and printouts visualised and selected by the operator and the person taking the decisions would be afforded the opportunity to apply a degree of creativity in his thinking which in itself is self-rewarding. Thus creation of the final decision would remain within the control of the decision taker and with this fact in mind, the following truisms can be stated:—

1. Remember that a manager, more often than not, would rather live with a problem that he cannot solve than accept a solution that he cannot understand.
2. Managers do not always require or desire the optimum solution, they just want to be better off than they are now.
3. That from observations carried out in operational research and/or management science consultancy work, the first twenty per cent of the effort and/or the money and/or the time spent on a project results in about eighty per cent of customer/client satisfaction.