Applicability of Heuristic Approach in Planning and Scheduling Project

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Abstract
This paper focuses on the application of heuristic approach in solving scheduling problems of ongoing project. This study is primarily aimed at providing a suitable heuristic for finding an optimum resource level, which ought to be kept over the project execution period, and a sensitivity analysis of which resource type ought to be increased in order to reduce the project completion time towards the ultimate. The use of resource utilization and a "constraining index" in the search for optimal solutions to this problem of meeting delivery date requirements, and optimize utilization of multiple resources in project and minimize other resources.
Keywords: Heuristic; resource constraints; constraining index.

1. INTRODUCTION

A project has been stated (Turner *et.al*, 1978) as an endeavour in which human, material and financial resources are organised, in a novel way, to undertake a unique scope of work, of a given specification, within the constraints of cost and time, so as to achieve a beneficial change defined by quantitative and qualitative objectives. The success of a project rests on the planning and scheduling of the resources associated with it. Planning and scheduling are common to number of different engineering domains such as in the area of building a football stadium, roads, and bridges, administering a large research contract, performing major transplant surgery, establishing a production line, or earning a university degree. All of these projects have some similarities. Each is made up of several tasks or activities with specific duration. Each activity has precedence relationships. That is certain activities cannot be started until others have been completed.

Planning and Scheduling are distinctly different activities. The plan defines what must be done and restrictions on how to do it; the scheduling specifies both how and when it will be done. The plan refers to the estimates of time and resources for each activity, as well as the precedence relationship between activities and other constraints. The schedule refers to the temporal assignment of tasks and activities required for actual execution of the plan. In addition, any project includes a set of objectives used to measure the performance of the schedule and/or the feasibility of the plan. The objective determines the overall performance of the plan and schedule.

Project planning and scheduling addresses the problem of resource allocation. This could be through critical path methods, which optimizes time and other factor based on unlimited resource availability or optimization of resources under limits of time frame. However, resource optimization problems in project scheduling are mostly classified into three main groups as follows:

(1) Time/cost trade-off analysis;
(2) Unconstrained (unlimited) resource optimization;
(3) Constrained (limited) resource optimization.

These optimization problems have one thing in common and that is cost. The methods of approach are somewhat different. The first group treats cost as a convenient homogeneous measure of resources which act or interact so as to cause the requisite activities to be completed, whereas the last two concentrate on the resources as prime cause of cost which have to be minimized by opting for a scheduling which makes this possible, (Akpan, 1997).

Project scheduling problems normally come within the realm of longest route problems, which means finding the longest path through the network. Based on the objective function, any of the above problems could be solved using either an analytical method such as linear programming or a heuristic. This work, however, is not intended for the first group, that is time/cost trade-off analysis. We discuss the second group minimally; the bulk of work is concentrating on the third group.

Construction management which is an aspect of project management was defined as a combination of tools and techniques such as PERT and CPM and managerial control methods. The tools of project management are more advanced than managerial and projects often fail due to the disproportionate amount of effort placed on managerial systems. Structured project management techniques provide a framework for project management tools to operate. They concentrate on the definition of the project, determining the project organisation, problem solving and life cycle structures and the correct level of information for each part of the project structure.

The function of planning, scheduling and controlling advance in construction and manufacturing work has been carried out in the past by various talented individuals, each with a specific perspective in mind on how a specific project should be built. As projects have become more complex, these individuals have had to seek or device new or improved planning aids to help them to more fully comprehend, evaluate, and remember the numerous ramifications of these more complicated construction undertakings. Therefore, the main objectives of the study were, first, to establish critical path method for effective project planning and, second, to develop heuristic base approach to minimise resources with the aid of C^{++} program to handle complex resource allocation problems and to meet targeted date.

2. COMPARATIVE STUDIES OF DIFFERENT HEURISTICS

Comparative studies in literatures assess the effectiveness of different heuristics available. Studies in this area have been conducted in four directions. The early pioneer, Kelly (1963), was more interested in those heuristics that give the shortest project duration and found it difficult to recommend any heuristic, which gives the overall best, result in all projects, but rather recommended that the best test of the 'goodness' of a particular approach is the one which produces 'reasonable' schedules for actual projects. A second group, Mize (1964), Pascoe (1965), Knight (1966) and Fendley (1968), concentrated mostly on comparing the relative effectiveness of different heuristic rules; and the third group, Patterson (1973) and Davis (1975) concerned themselves with the effectiveness of these rules relative to the optimum. The ever growing interest in multi-project multi-resource problems gave rise to a fourth group interested in comparing those heuristics which are good for single projects and those for the multi-project. The early pioneers concentrated on single projects.

Davis (1974) in one of his studies tried many heuristics rules in different problems and found that a particular heuristic may produce a better result in one and fails in another. He concluded that in order to be certain of achieving the 'best' solution, it might be necessary to try several different heuristics and to select the best, which may likely give the optimal or near-optimal result. The research conducted by Russel (1986) based on six heuristics using 80 different problems also confirmed this finding.

Davis and Patterson (1975) extended the studies which further to consider a third problem, the effectiveness of these heuristic rules relative to the optimum. They considered 83 problems, consisting of 57 different networks, and they found that Minimum job slack (MINSLK) rules gives the least overall percentage increase above the optimum (5.1%) and an optimum duration for 24 such networks; while the shortest imminent operation (SIO) fair badly with an overall percentage increase of 15.3% and only one network having the optimum duration. From their analysis, it was also found that the MINSLK gave the overall best result in all cases followed by latest finish time (LFT), which recorded 6.7% on average percentage with 17 optimum results.

Kurtulus and Davis (1982) conducted similar to which Davis and Patterson (1975) studies for the multi-project-scheduling situation, and their conclusion was that the shortest activity for shortest project (SASP) and maximum total work contents (MAXTWK) were found to be more superior to the other scheduling rules. Also, studies conducted in a more conventional production system have confirmed the superiority of certain priority rules over others. Huq and Bernardo (1995) found that MINSLK performs better compared to FCFS (first come first serve), EDD (early due date) and SPT (shortest processing time) in their selection of shop control procedures on the sensitivity of job mix and load capacity bottlenecks on inventory and due date performance in a manufacturing system, (Akpan, 2000).

To find a more suitable heuristic for this work, the idea of using earliest finish and total float was proposed. From the finding so far superior to all the others and in majority of cases, an optimum solution similar to that derived using an analytical technique has been recorded provided one is willing to exercise some patience and use a sizeable number of runs.

3. UNCONSTRAINED RESOURCE OPTIMIZATIOM

There is a clear indication that the resource profile resulting from the critical path schedule is not always adopted totally, (Akpan, 2000). The assumption that only the resources required by each activity are maintained as adopted by time/cost-off analysis with its associated cost is unrealistic. It is, practically, not possible to hire and fire labour at will to fit in nicely with daily labour need. Even if this were possible with labour, it may not be possible with fixed assets jointly used in project execution. It is therefore certain that a minimum level of some sort of resources must be maintained throughout a reasonable period of time or the entire project duration. With this reality comes idle capacity, which is inevitable in any system.

Efforts towards the minimization of this idle capacity have resulted in the use of resource smoothing techniques. These techniques attempt to achieve optimal usage by avoiding high peaks and deep valleys in the project resource profile. This is achieved by starting some activities with floats in the high peak regions at a later date and on assumption that, the valleys will be filled to smooth the resource profile, subject of course to time constraints (i.e. project duration as determined by the critical path technique). The exercise though straightforward in a single resource situation becomes complex when many resources are involved because as one peak is leveled, a worse case involving another resource may spring up. Only Burgess et al. (1962) have attempted a two-resource model and Weist (1967) as reported by Moder et al. (1970).

In this work, the procedure adopted is the use of the highest resource profile of the critical path schedule for individual resources as a base. A sizeable number of runs using the program were being carried out and the optimal or near-optimal solution was being the one with the lowest resource profile. To be absolutely certain that the correct one is chosen the different resources were weighted by assigning cost (the same for all the resources or different depending on one's objective) and the trial run with the highest resource utilization would give the optimum result.

4. FORMULATION

The network analysis approach is adopted for analyzing all data collected and expressing them in terms of event and float time analysis. In terms of resource management, heuristic based approach was used in the area of resource allocation in order to maintain a steady level of resource utilisation. The heuristic rule technique involves:

(1) Determination of the resource required in the operation of each activity.

(2) Determination of the resource ceiling; it is the average usage of a particular resource over the entire project duration as determined by the critical path technique, mathematically this can be expressed as:

$$\text{Resource ceiling} = \left(\sum_{i=1}^{i=n} QD\right) \Big/ P \qquad (1)$$

Where: Q = the number (quantity) of a particular resource demanded by activity,
D = the duration of each activity,
n = the number of activities, and P is the project duration.

(3) Determination of the total resource requirements for each period of time; sum up the resources and the resource ceiling according to a common decision rule.

(4) Establish decision rule as Earliest Start and Total Float

5. PROJECT CASH FLOW

The Net Present Value (NPV) of one resource on an activity at time t from the start is given as
Therefore, NPV of cost of one resource for the duration of the activity is given as
When n is the duration of the activity. In general, starting and ending times for different activities would vary.

$$C^*_j = \frac{C_j}{(1+r)^t} = \mathrm{C_j}\,(1+\mathrm{r})^{-t} \qquad (2)$$

Consider time a_j and b_j as starting and ending times.

$$C^*_j = \int_0^n \mathrm{C_j}\,(1+\mathrm{r})^{-t}\,\mathrm{dt} \qquad (3)$$

$$C^*_j = \int_{aj}^{bj} \mathrm{C_j}\,(1+\mathrm{r})^{-t}\,\mathrm{dt} \qquad (4)$$

∴ Equation (3) becomes:

$$C_j^* = \int_{aj}^{bj} \mathrm{C_j}\,(1+\frac{\mathrm{r}}{\mathrm{h}})^{-ht}\,\mathrm{dt} \qquad (5)$$

Where r = compounding interest rate on a yearly basis. If compounding interest rate were to be on h intervals per year, we would have

In the limit as h $\rightarrow \infty$, $(1 + r/h)^h \rightarrow e^r$ mathematical limit In the limit therefore, in the limit, equation (5) becomes:

$$C_j^* = \int_{aj}^{bj} C_j \, e^{-rt} \, dt \tag{6}$$

∴ taking all resources (N) on an activity, equation (6) becomes:

$$C^* = \sum_{res=1}^{N} \int_{aj}^{bj} C_j \, e^{-rt} \, dt \tag{7}$$

Therefore, with M activity in the entire project, we have:

Total project cost $$C = \sum_{act=1}^{M} \sum_{res=1}^{N} \int_{aj}^{bj} C_j \, e^{-rt} \, dt \tag{8}$$

With the discrete nature of the problem under investigation it was found that two or more resources might have the same Utilization percentage. More variables were introduced to break the tie, each time with an improved result. The different resources were assigned cost, then discounted using a continuous flow pattern (to mimic a real-life situation as project expenditure is more likely to be on a daily basis than annual) with discrete discounting of the form:

NPV of cost of one resource on an activity at t is given as:

$$C_j^*(t) = \frac{C_j}{(1+r)^t} = C_j (1+r)^{-rt} \tag{9}$$

∴ NPV of cost of one resource for the duration of the activity is given as:

$$C_j^* = \int_0^n C_j (1+r)^{-t} \, dt \tag{10}$$

∴ For N resources on an activity equation (10) becomes:

$$C^* = \sum_{res=1}^{N} \int_0^n C_j (1+r)^{-t} \, dt \tag{11}$$

Therefore, cost for M activities in the entire project

$$C = \sum_{act=1}^{M} \sum_{res=1}^{N} \int_0^n C_j (1+r)^{-t} \, dt \tag{12}$$

Where r is the interest rate and C_j is the cash flow. For the purpose of this work the interest rate is fixed at 11% assuming 52 working weeks in a year. When all efforts failed to break the tie, a "constraining index" was envisaged. The constraining index is defined as the number of times the resource requirement has hit the resource ceiling (i.e. those time units in which the resource requirement is equal to maximum resource availability), and the higher the number, it is contended, the more constrained the resource is. If the index is zero, it indicates that the resource in question is available in sufficient quantity for the chosen schedule. The following expressions below are used to compute the Utilization and the weighted Utilization of the resources assigned to activities in project.

(1) Utilization =

$$\frac{\sum_{1^{st}\ \text{Interval}}^{Last\ \text{Interval}} (\text{Resource usage x Interval of usage})}{\text{Resource ceiling x Project duration}} \text{ x } 100 \tag{13}$$

(2) Weighted Utilization =

$$\frac{\sum_{^{st}Resource}^{Last\,Resource} \sum_{1^{st}\ Interval}^{Last\ Interval} (\text{Resource usage x cost x Interval of usage})}{\sum_{^{st}Resource}^{Last\,Resource} (\text{Resource ceiling x cost x project duration})} \tag{14}$$

Figure 1 is the flow chart of the overall computer program of this study developed. The program consists of four subprograms, the determination of the early start times of the activities, the computation of the activities latest start times, calculation of the critical path length of the project and computes the resource allocation with its cost assigned to it.

6. ANALYSIS/PRESENTATION OF RESULTS

The study is specifically based on the construction of the oil and gas terminal water pipeline changed from Epoxy coated carbon steel to Heavy wall carbon steel. On completion of this project, water shall be supplied to all the fire fighting points in the terminal.

My sample selection process depended on the following factors:

(i) Cash flow to the contractor's purse,

(ii) Length of the pipeline.

For the first factor, the contract was based on pay-as-you-work payment schedule. Thus the best period was when the contractor had just been paid. Secondly, the length of the pipeline chosen for work to commence on also determined my sample choice. Table 1, shows the data obtained from construction site of the case study project.

Table 2 shows the computer output of schedule statistics and the critical path for the firewater pipeline renewal project. With the critical path length of 114 weeks and the critical path is activity: 1-2-4-5-6-7-9-12-17-18-19-20-21-26-27-28.

7. Sensitivity Analysis

With the resource availability ascertained, on the basis of existing resources or arbitrarily, the first option normally taken is determination of the project duration. If the project duration is unacceptably high, a reduction may be contemplated by raising the level of resources. To achieve the best result, it is only those resources, which would give maximum time reduction that should be considered. The following procedures should be adopted.

(a) Consider all the resources whose constraining indices are not to zero.

(b) Raise one at a time the resource level with the highest resource utilisation.

(c) In the case of a tie, pick the one with the highest resource utilization and highest constraining index.

8. Discussion

The existing computer program (developed software) is used to compute these schedule data automatically, requiring as inputs the activities, their performance time requirement, and the precedence relationships established. The computer output in Table 2 shows the schedule statistics for all the activities.

8.1. Analysis of Floats

Based on statistical total float analysis, table 2 shows that activity can be expand or move by the number of available time or weeks such as in the case of activity 5, 17, 18, 21, 23, 28, 29, and 37 to 41 can be move or expand by 20, 24, 27, 27, 23, 33, 25, and 23 weeks respectively without delaying the project completion time. Any expansion or movement greater than this will change the critical path and increased the overall project time. It must be realized that float can appear at the beginning of an activity, that is, the starting of the activity can be delayed after the tail event is reached; or it can appear in the activity, so that the duration time is increased beyond that initially planned; or it can appear after the activity is finished, while other activities are being concluded to reach the head event. It is important to note that all critical activities have zero total floats in their schedules.

Table 2 displayed the free float of each activity such as activity 2, 5, 28, 39, and 41 with 16, 24, 33, 23, and 23 weeks respectively. In the planning stage it may be decided to increase the duration time of these activities (for example, by reducing the resources allocated to it and thus increasing its performance time). If this is done, then the float available in previous activities will be reduced, then the free float indicates that the use of float will not affect any succeeding activities. Cases do arise where the absorption of float affects neither earlier nor later in activities and the float is then said to be independent. Activity 2, 5, 7, and 28 has independent float 16, 24, 8 and 24 weeks respectively. But floats with negative signs for instance, activity 40 has independent float of –23 weeks is taken to be zero for practical purposes.

At the time, all resources are fully utilized, the whole network becomes critical. At first sight this might appear to be a highly desirable situation in that there are no idle resources. It must be remembered, however, that idle resources represent some degree of flexibility in a project, and that to remove this flexibility might result in a state of crisis, which could have been avoided or at least alleviated – if some float had been available. Thus, we have two general comments:

(1) Floats represent under-utilized resources

(2) Floats represent flexibility.

Actually, there are over ten different paths from start to finish in the network. The longest, most limiting path requires 114 weeks for the activity sequence 1-2-4-5-6-7-9-12-17-18-19-20-21-26-27-28, which is called a critical path. In a problem such as this one, we could enumerate all the alternative paths to find the longest path, but there is no advantage in doing so because the critical path is easily determined from the schedule statistics and with the aid of the computer program.

8.2. Resource Status Indicating Periods Changes Occurs with Cost.

The resource levels of 12, 9, 10, 10, (designated as resource 1, 2, 3, 4,) instead of 10, 8, 8, 8 (derived from work content as given in the case study project) would still have given minimum project duration of 146 weeks. However, minimum project duration of 114 weeks is possible when there is no resource imposition although the project duration can equally be as high as 270 weeks with resource constraint. The summary of status is shown in table 3. It is without doubt that the resource requirement at the ultimate, that is 114 weeks would never hold as determined by work content. If the contrary view is held, some activities must take off at start of the project such as activities 1-2, 1-3, 1-10, and 2-4, which require 10, 5, 13, and 4 of resources 1, 2, 3, and 4 together. Three of these resource types are within (in this case) the limit but more of resource 3 would be required (while in other cases, four or three resources types are within the limit but more of resource of 1, 2, and 4 may be required) and the cost assigned or estimated for activity can be checked in order to minimize other resources.

8.3. Sensitivity Analysis

The maximum resource levels when calculations are based on the two extremes of the earliest and latest starting times together with the cost of using the resource per week is given in Table 6. Figure 1 shows the flow chart of the overall program.

Suppose the organization cannot meet the level of resources obtained, but decides on feasible possibilities (sensitivity analysis): the result following the above procedure is shown in Table 4 and Figure 2. A decision to raise proportionately all eight resources at the same time is shown in Table 5, with a reduction to 72 weeks as compared to 85 weeks.

The results obtained with this number of trial runs may not necessarily be optimal. Although cost is considered a convenient homogeneous measure of resources, this is done bearing in mind that different resources cost differently. This is reflected in weighted resource utilization. The higher the utilization percentage, the higher will the return on investment and vice versa. This can be noticed in 12^{th} schedule of Table 4 where the lowest cost of N156, 214,800 is recorded, with a weighted resource utilization of 64%.

9. Conclusion

The objectives of this study were successfully attained, while the need to find a particular heuristic which always guarantees an optimal or near-optimal solution is important, the need to find the one which normally gives the best results in all situations should be of paramount importance. Earliest finish and total float seems to have satisfied this yearning. This priority rule equally is used to measure the effectiveness of other rules, which possibly may lead to their ranking in term of superiority.

It has been found that the use of work content (resource ceiling) in the determination of optimum resource levels for project scheduling is inadequate. Resource utilization combined with a constraining index has proved to be superior in search for an optimal solution. It has also been found that the latter two-optimization models are compatible to some extent, and increasing the resources gradually in the resource-constrained model may lead to a point of maximum weighted resource utilization while at the time pushing the project duration towards the ultimate; that is the duration derived using the critical path technique.

The successful completion of the any project is a function of the firms to perform key project activities, and the clarity of project responsibilities. Clear communication networks within the project team, use of performance milestones and adequate financial incentives for all groups involved. A project would run accordingly if only if these principles and techniques are applied as and at when due by the project manager while making sure that the owner interest is adequately represented in all aspects.

10. Recommendation

The pressing demand for more cost-effective and reduction in project completion time, constant updating and reporting of project status continuously pressure the project team. This necessitates the services of the professional project manager who will contain such pressure because he/she has qualitative management skill and techniques to the organizational and control aspects of projects through maximization of scarce resources with the view to achieving or exceeding project goals with the developed software. The problem of breaking down of projects into resource consuming activities and the subsequent determination of the job logic or time sequence relationships amongst them prove to be the most difficult in planning process in the construction industry. This is, in the beauty of CPM and computer program manifests. Owner (both corporate and government) should on conception of the project initiate a steering committee whose initial function would be to select a consultant for such project. The consultant should be able in conjunction with the committee members to decompose the project into activities and fit them all together with the job logic required. This can only be possible if there are experts with the job's knowledge and project management skill and tools amongst the project steering committee. It is also recommended that the desired level of project owner's participation is defined and determined before the contract of service is awarded. Adequate full-time project personnel should be seconded to the project and their respective responsibilities, duties and reporting mechanism defined so as to allow the flow of documents for review, approval or processing.

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