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Heuristic Selection for Housing Projects: A Case of Total Resource Usage

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ABSTRACT
Resources required for the execution of housing projects fluctuates randomly. This uneven disposition of resources has resulted to high project cost and avoidable elongation of project duration. Admittedly, maintaining optimum resource level in housing projects during implementation is one of the major challenges of project managers. Construction industry practitioners that play leading roles in housing development have continuously searched for priority rules that are easy to adopt to ensure resource optimality during construction. This paper highlights the usefulness of total resource usage heuristic in the resource allocation process that guarantees greater resource utilization in housing projects.

KEYWORDS: *Heuristics, resource allocation, housing project, resource utilization*

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I. INTRODUCTION

The shelter needs of man are provided through a series of processes. These processes which involve several stages, utilizes machines, men of varying skills, materials, space and time. The transformation process, which utilize raw resources share the characteristics of a project. The project manager is required by function to plan, organize and control resources of the project activities so that the project is not only completed on schedule but within the estimated cost and performance limits. The success rate of a project is accordingly measured by the extent to which these tripartite project criteria of cost, time and performance are achieved. The knowledge of the effect of project resource level on the project cost throughout the project life therefore remains fundamental to the successful completion of any project. Notable complexities introduced in the construction industry by the technological innovations have in the opinion of Spinner (1997) made job co-ordination and resource allocation practically more difficult. This difficulty has called for the search for better resource scheduling model(s). Resource scheduling process allocates available resource capacities to jobs, activities and or customers. It is considered as the most constrained decision in the hierarchy of capacity planning. Resource scheduling, a time-phased plan, ensures the determination and allocation of resources within the resources' limits in the best manner. *Oxley and Poskitt* (1980) opined that resource scheduling is time related and involves the leveling of project resources. The assumption of unlimited resource availability by network techniques could no longer hold, they said. This is because the constraining indices of the different resource categories are not the same at all points of the project during implementation. They rather considered resource availability at the required quantity and time in the project life as critical. They then concluded by recommending resource leveling and smoothening as the solution for resource and time constrained situations, respectively.

II. WORK CONTENT

Attempts at ascertaining the level of project resources which should be kept for any given project activity assumed another dimension with the application of work content methodology. Work content is defined as the average usage of a particular resource over the entire project duration as determined by the critical path technique. The reason for this may be due to the fact that work content is a by-product of resource usage, the main determinant of price of the product. The project completion time in a limited resource situation is also a function of individual activity time, maximum resource level and intensity of usage of all the resources and above all the activity selection at each node when more than one activity is due for consideration. With all these complexities, *Akpan* (1997) observed that there is bound to be idle resource usage as a result of precedence or resource constraint or both. In a simplified form, work content may be mathematically expressed as:

$$work\ content = \left[\sum_{j=1}^{n} QD \right] / P - - - - - - - - - - - - - 2.2$$

Where Q = Quantity of a particular resource demanded by an activity
D = Duration of each activity
n = Number of activities
P = Project duration

The above calculation is done for all resources and the values so computed are normally raised to the nearest integer. He contended that this measure of work content is inadequate because a particular activity may require more resources for a particular type than the calculated values. Secondly, the resources were not uniformly utilized, as the application of work content seems to imply. He further affirmed that resource levels based on work content have failed to produce the project duration as dictated by the critical path technique and that estimates derived thereof are unnecessarily high for some resources. As a result, he adopted random activity selection heuristic with resource utilization so as to enable the selection of that resource which ought to be increased to give a reduction in project completion time.

Earlier work by *Muggard et al* (1974) favored the choice of resource utilization using *GERT*-Q. GERT-Q incorporates limited resource availability as well as resource identification and *GERT*-III-Q [a simulation model of *GERT* that allows queue to build up at certain nodes], they were able to identity the 'bottleneck' stations as the stations with highest mean waiting time and also a very high percentage utilization. Their results also revealed that an overall time reduction of 26.2% when a bottleneck station was eliminated with an additional station in parallel. With the discrete nature of the problem under investigation, it was also found that two or more resources are likely to have the same utilization percentage. More variables were then introduced to break the tie each time with an improved result. The different resources were assigned cost, and then discounted using a continuous flow pattern with discrete discounting of the form:

$$c_n = \sum_{K=1}^{N} \left(\int_0^n c(t)dt \right) (1+r)^{-n} - - - - - - - - - 2.3$$

Where c_n = Discounted cash flow
N = Number of resources
C (t) = Cash flow
r = Interest rate

When all effort failed to break the tie, "constraining index' was envisaged. The constraining index is defined as the number of times the resource requirement has hit the resource ceiling i.e. the time units in which the resource requirement is equal to maximum resource available and the higher the number, it is assumed, the more constrained it is. If the index is zero, it indicates that the resource in question is available in sufficient quantity for the chosen schedule. He then concluded that, this combined approach of resource utilization and constraining index is more superior model in constrained resource problems.

Constrained resource scheduling

The concept of constrained-resource scheduling is aimed at minimizing the periodic fluctuation of resource levels. This is done by shifting tasks within their slack allowances and still ensuring that the maximum resource availability levels at those points are not exceeded (*Kernzer* 1995). This will undoubtedly lead to longer project duration. The purpose is to create a smoother distribution of resource demand, supply and usage. The optimum resource levels of the various resource categories under this situation can be obtained either by heuristic or mathematical models. Historically, a lot of work has been done in this area of constrained resource problems, analytical and heuristic abound. *Gonguet* (1969) utilized linear programming in his model formulation. He commented that while there is no difficulty in problem formulation, there are a large number of variables and constraints even for small sized problems and as such, the model has very little practical application. A similar approach was adopted by *Pritsker et al* (1969) and *Prabhaker* (1970). While *Davis and Patterson* (1973) approached the problem using a branch and bound algorithm and *Balas* (1971) and *Talbot* (1980) used implicit enumeration and integer programming. They all recorded little improvement and came out with the same conclusion as *Gongue*t (1969).There are basically two fundamental approaches to constrained-resource allocation problems: heuristic and optimization models. While heuristic employs rule of thumb and produces reasonable and better solution, optimization models seek the best solution through an objective function and constraint equation(s), which limits its application. I shall dwell on heuristic models in this paper. Readers interested to know more about optimization models are referred to earlier work of the author.

III. HEURISTIC MODELS

The difficulties with the analytical problem formulation, particularly in constrained-resource situation gave rise to the renewed interest in heuristic-based procedures *Meredith* and *Mantel* (1995). Heuristic models start with the PERT/CPM schedule and analyze resource usage period-by-period and resource-by-resource. In a period when the available supply of resources are exceeded, the heuristic examines the tasks in that period and allocates the scarce resources to them sequentially, according to any given priority rule.

We shall look at six heuristics for the purpose of the paper. They are minimum slack, greatest resource utilization, greatest resource demand, most possible jobs, shortest processing time and total resource usage heuristic.Greatest resource utilization rule gives priority to that combination of activities or projects that result in maximum resource utilization or minimum idle time during each scheduling period. This rule, according to *Meredith* and *Mantel*[1995], was found to be approximately and as effective as the minimum slack rule for multi-project scheduling, where the criterion used is project slippage. Greatest resource demand heuristic assigns priority on the basis of total resource requirements, with higher priority given to activities with the greatest resource demand. Project or task priority is computed as:

$$priority = d_j \sum_{i=1}^{m} r_{i,j} ------------2.4$$

d_j = duration of activity j

r_{ij} = per period requirement of resource i by activity j

m = number of resource types

In most possible jobs heuristic, priority is given to the set of activities that result in the greatest number of activities being scheduled in any period. This rule requires the solution of 0-1 integer program. In shortest processing heuristic, time tasks are ordered in terms of duration, with the shortest first. In general, this rule will maximize the number of tasks that can be completed by a system during some time period.

Minimum slack heuristic, activities are ordered by the amount of slack with the one with the least slack going first. In this regard, resources would be devoted to critical or near critical activities, delaying those with greater slack. Delay of an activity uses some of its slack, so the activity will have a better chance of receiving resources in the next allocation.Random Activity Selection rule, which forms the core of *Akpan*[2000] but appeared minor in the earlier work of *Davis*[1975] selects the activities randomly. In it, parallel activities are randomly selected, ranked and scheduled. Those activities that cannot be scheduled due to insufficient resources are moved forward to a later time period. This procedure is repeated and continued until all the activities are scheduled.Total Resource usage heuristic believes that resources available can be either allocated in full and or in part at any point of the project. The model envisages that the remainder of any uncompleted activity is carried over to the next time period and this will form part of the workload for that time period for consideration.

IV. HEURISTIC SELECTION

Works of *Fendley* (1968), *Kurtulus and Davis* (1982), *and Kurtulus and Davis* (1985) focused on the best heuristic for resource scheduling. While their findings vary somewhat because of their differing assumptions, the minimum slack rule was found to be the best. This choice according to them was based on the fact that minimum slack heuristic results to minimum project schedule slippage, the best utilization of facilities and a minimum total system occupancy time. Other studies were also going on to find a heuristic of general application. *Kelly* (1963) in his earlier work did not recommend any single heuristic as the best for all projects but rather recommended that the best test of goodness of a particular heuristic should be the one, which produces 'reasonable' schedule. *Davis* (1974) in one of his study tried heuristic in different problems and found that a particular heuristic may produce a good result in one problem and fail in another. He concluded that in order to be certain of achieving the best solution, it may be necessary to try different heuristic and to select the one which may give the optimal or near optimal result. The results recorded so far have increased the range of uncertainty in the choice of heuristic that should be considered generally suitable and optimal. In efforts to narrow the region of choice, the idea of random activity selection was proposed by *Akpan* (2000).

V. METHODOLOGY

The paper adopted a comparative analysis of the six heuristic models to analyze project data of ten selected projects. Project time overrun and average resource utilization were the two criteria to assess the degree of optimality of the heuristic models. The average resource utilization is computed by the summation of resources actually allocated for the project duration divided by the product of resource ceiling and completion time; while the time overrun is computed by the project duration when the priority is applied less the project normal duration without the application of the priority rule divided by the actual duration. The result is multiplied by 100. Mathematically, the average resource utilization is computed using the following formula:

$$ru = \frac{\sum_{i=1}^{i=n}[r_i]}{c \; x \; n} \; x \; 100\% -------------4.1$$

Where
Ru= average resource allocation
n = project completion time using the priority rule
c = resource ceiling
∑[r] = summation of the resources actually allocated weekly

While the project time overrun is computed thus:

$$to = \frac{d_{1-} d_2}{d_2} \; x \, 100 ----------------------4.2$$

Where:
To = project time overrun
$d_{1\,=}$ project completion time using the priority rule
d_2 = project completion time using critical path.

Project 1
Resources Considered for Allocation: A-Labor and B-Labor
Resource Ceiling: 7units each

Table 1 Project Network details for case 1

Activity	Duration (weeks)	Resource Demand A	Resource Demand B
1-2	2	3	4
2-3	3	3	4
3-4	2	4	3
4-5	2	3	4
4-6	3	4	4
4-7	2	3	3
5-7	2	4	3
6-7	3	4	3
7-8	3	4	4
8-9	4	3	4

Source: Bayelsa State Housing and Property Development Authority, Nigeria 2004.

Project 2
Resources Considered for Allocation: A-Labor
Resource ceiling: 6units

Table 2 Project Network details for case 2

Activity	Duration	Resource Demand A
1-2	3	3
2-3	3	4
3-4	3	3
4-5	3	4
4-6	2	3
5-7	2	3
6-7	3	3
7-8	3	3

Source: Rivers State Housing and Property Development Authority, Nigeria 2000.

Project 3
Resources Considered for Allocation: A-Labor
Resource ceiling: 10units

Table 3 Project Network details for case 3

Activity	Duration	Resource Demand
		A
1-2	3	4
2-3	4	3
3-4	2	4
3-5	3	4
3-6	3	4
4-6	1	2
5-6	3	4
6-7	4	2

Source: Bayelsa State Housing and Property Development Authority, Nigeria 2004.

Project 4
Resources Considered for Allocation: A-Labor
Resource ceiling: 8units

Table 4 Project Network details for case 4

Activity	Duration	Resource Demand
		A
1-2	2	3
2-3	3	3
2-4	2	4
2-5	2	3
3-5	3	4
4-5	2	3
5-6	2	4
6-7	3	4

Source: Lagos State Property Development Corporation Nigeria 2000.

Project 5
Resources Considered for Allocation: A-Labor
Resource Ceiling: 6units each

Table 5 Project Network details for case 5

Activity	Duration	Resource Demand	
		A	B
1-2	1	4	3
2-3	1	3	4
2-4	2	4	4
3-4	3	2	2
4-5	3	4	2
4-6	2	2	3
5-6	1	2	4
6-7	2	4	4

Source: Lagos State Property Development Corporation Nigeria 2004.

Project 6
Resources Considered for Allocation: A-Labor
Resource Ceiling: 4units each

Table 6 Project Network details for case 6

Activity	Duration	Resource Demand	
		A	B
1-2	3	3	1
1-3	2	2	3
2-3	1	4	1
2-4	2	2	1
2-5	1	3	2
3-7	3	4	1
4-6	2	3	3
5-7	3	2	1
6-7	1	3	2
7-8	1	3	3

Source: Lagos State Property Development Corporation 2000.

Project 7
Resources Considered for Allocation: A-Labor
Resource Ceiling: 5units

Table Project Network details for case 7

Activity	Duration	Resource Demand
		A
1-2	1	4
2-3	2	3
2-4	3	1
3-5	2	2
3-6	1	2
4-6	1	3
5-7	1	4
6-7	2	2
7-8	1	3

Source: Lagos State Property Development Corporation Nigeria 2004.

Project 8
Resources Considered for Allocation: A-Labor
Resource Ceiling: 4units

Table 8 Project Network details for case 8

Activity	Duration	Resource Demand
		A
1-2	2	3
1-3	1	2
1-4	3	3
2-4	1	2
2-6	2	4
3-4	2	1
3-7	3	2
3-5	4	3
6-7	1	2
6-8	2	4
5-8	1	3
7-8	3	3
4-7	4	3

Source: Lagos State Property Development Corporation Nigeria 2004.

Project 9
Resources Considered for Allocation: A-Labor
Resource Ceiling: 6units

Table 9 Project Network details for case 9

Activity	Duration	Resource Demand
		A
1-2	2	4
1-3	3	2
2-4	3	3
2-3	4	2
4-5	2	3
3-5	3	4
4-6	3	4
5-6	2	3

Source: Lagos State Property Development Corporation Nigeria 2004.

Project 10
Resources Considered for Allocation: A-Labor
Resource Ceiling: 5units

Table 10 Project Network details for case 10

Activity	Duration	Resource Demand
		A
1-2	2	4
1-3	3	2
2-4	3	3
2-3	4	2
4-5	2	3
3-5	3	4
4-6	3	4
5-6	2	3

Source: Bayelsa State Housing and Property Development Authority, Nigeria 2004.

The outcome of the allocation for the six heuristics are as tabulated below**.**

Table 11 Summary of Resource Utilization Level

Case Studies	Heuristic Models					
	RAS	MSL	SPT	TRU	GRD	GRU
1	59%	59%	54%	62%	54%	54%
2	60%	60%	60%	67%	60%	60%
3	46%	46%	46%	46%	46%	46%
4	62%	55%	49%	64%	49%	49%
5	71%	71%	71%	71%	71%	71%
6	84%	79%	79%	100%	79%	79%
7	73%	73%	73%	73%	73%	73%
8	81%	78%	78%	100%	78%	78%
9	74%	70%	74%	90%	70%	70%
10	84%	74%	79%	95%	74%	74%

***ras- random activity selection *msl -minimum slack *spt- shortest processing time**
***tru- total resource usage *grd- greatest resource demand *gru- greatest resource usage**

Table 12 Summary of Time Overrun Level

Case Studies	Heuristic Models					
	RAS	MSL	SPT	TRU	GRD	GRU
1	10%	10%	20%	5%	20%	20%
2	18%	18%	18%	6%	18%	18%
3	0	0	0	0	0	0
4	0	8%	15%	0	15%	15%
5	0	0	0	0	0	0
6	78%	89%	89%	56%	89%	89%
7	13%	13%	13%	13%	13%	13%
8	150%	160%	160%	100%	160%	160%
9	36%	46%	36%	18%	46%	46%
10	46%	64%	55%	36%	64%	64%

The results highlighted the behavioral pattern of the heuristic models under varying project demand/availability.

The outcome of the allocation for the six heuristics are as tabulated below**.**

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Case Studies	Heuristic Models					
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1	59%	59%	54%	62%	54%	54%
2	60%	60%	60%	67%	60%	60%
3	46%	46%	46%	46%	46%	46%
4	62%	55%	49%	64%	49%	49%
5	71%	71%	71%	71%	71%	71%
6	84%	79%	79%	100%	79%	79%
7	73%	73%	73%	73%	73%	73%
8	81%	78%	78%	100%	78%	78%
9	74%	70%	74%	90%	70%	70%
10	84%	74%	79%	95%	74%	74%

***ras- random activity selection *msl -minimum slack *spt- shortest processing time**
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1	10%	10%	20%	5%	20%	20%
2	18%	18%	18%	6%	18%	18%
3	0	0	0	0	0	0
4	0	8%	15%	0	15%	15%
5	0	0	0	0	0	0
6	78%	89%	89%	56%	89%	89%
7	13%	13%	13%	13%	13%	13%
8	150%	160%	160%	100%	160%	160%
9	36%	46%	36%	18%	46%	46%
10	46%	64%	55%	36%	64%	64%

The results highlighted the behavioral pattern of the heuristic models under varying project demand/availability.

VI. DISCUSSION OF RESULTS

From the above summary allocation process, random activity selection, minimum slack, shortest processing time, greatest resource usage and greatest resource demand allocate resource to project activities that can be 100% completed and not to activities that can be completed in part at any time period of the project. This implies that resources are allocated to activities only when resource supply is equal or more than resource demand. However, the Total Resource Usage heuristic believes that resources available can be either allocated in full or in part. The model envisages that the remainder of any uncompleted activity is carried over to the next time period and this will form part of the workload for that time period for resource Out of the six heuristics, total resource usage gave the highest resource utilization and least project time overrun and is therefore adjudged the most optimal.

VII. CONCLUSION

Resource allocation under a resource-limited situation has been a source of concern, particularly, in the construction industry. Efforts at optimizing project resources during implementation stages of projects are noticeably numerous. The superiority of heuristic models and indeed total resource usage heuristic over optimization models in allocating project resources is indeed commendable. Its application in the housing sub-sector would certainly reduce resource wastage.

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