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Determination of Optimal Crew Size in Project Segmentation to Minimize Cost

Babatunde Omoniyi Odedairo[1*] Oluwabukunmi .A. Ogunsanya[2] Berkly Ogagaoghene Anaro[3]

1. Department of Industrial and Production Engineering, University of Ibadan, Ibadan. Oyo State. Nigeria.
2. Department of Management Technology, The Bells University of Technology, Ota, Ogun State, Nigeria
3. Department of Industrial and Production Engineering,University of Ibadan, Ibadan.Oyo State. Nigeria.

*E-mail of the corresponding author: b.odedairo@ui.edu.ng

Abstract

Stakeholders and contracting board have begun to utilize innovative contracting methods that provide new incentives for reducing construction duration. These methods have placed increasing pressure on decision makers in the construction industry to search for an optimal construction plan that minimizes construction time and cost while preserving quality. This paper considers the problem of finding the optimal number of segment(s) that minimizes total project cost of a non-homogenous road construction project located in a city in South West, Nigeria. A mathematical programming model approach was adopted to obtain the optimal number of segments as opposed to when the activities of the project are scheduled sequentially. Also, Binary interaction matrix (BIM) was used to define stated relationships between fixed and variable quantities of the cost and duration respectively. Given stipulated due date of 8 months with a penalty / bonus of ₦ 63091791/month. The analysis shows that the optimal number of segments into which the project can be divided into is three and that by working in parallel the project will be completed in 5 months at a cost of ₦1,409,609,413. This is opposed to the original contract lump sum of ₦ 1, 577, 294, 775 with a normal duration of 12 months. A saving of 1.55% was realized. This work demonstrated the possibility of dividing a continuous repetitive project into a numbers of segments of equal work content, working in parallel, using optimum crew size such that the duration and the total cost of the project can be minimized.

Key words: Project Management, Scheduling, Construction planning, Natural Rhythm, Project Segmentation

1. Introduction

With rapid advancement in technology, worldwide competition and increased globalization, the philosophy of project management is continuing to play an increasing role in achieving organizational and individual objectives. This philosophy promotes an organization that is flexible and project driven (Larson and Gray, 2011). Therefore, it is nearly impossible to imagine a management career that does not include management of projects. The use of projects to create organizational changes is applicable to many industries such as; automotive, aerospace, electronics, medical, construction and manufacturing. Lewis (2007) defined project management as a system or process of planning, scheduling, managing and controlling interconnected project activities in order to achieve specific objectives or goal within specific time, budget and standards. In project management, the scheduling phase is considered a critical component; this is because the output from the scheduling function has influence on the attainment of the project objective (Mishra and Soota, 2005). Brucker (2007) defined a schedule to process n jobs J_i ($i = 1,\ldots, n$) by m machines M_j ($j = 1 \ldots m$) as the allocation of the jobs on one or more time intervals to one or more machines. Mukherjee and Kachwala (2009) considered scheduling as "the time phase of loading which decides the duration of time for a certain defined work, as well as the sequence in which the work will be done". Furthermore, Brucker et al. (1999) argued that scheduling is concerned with single-item or small batch production where scarce resources have to be allocated to dependent activities over time. Scheduling is useful in manufacturing, project management, construction, engineering, production systems, etc. In construction and engineering, the scheduling phase involves the determining of an appropriate set of activity start time, resource allocation and completion time that will result in timely completion of the project. However, a forerunner to the scheduling phase is the planning phase. This phase is fundamental and challenging in the management and execution of construction projects. Construction planning involves the definition of work tasks, determining the duration of individual task, estimation of the required resources for each task and the identification of possible interactions among the work tasks (Hendrickson and Au, 2008). Therefore, a good construction plan is expected to adequately identify the schedule of work, technical constraints between activities and the budget.

1.1 Review of Scheduling Techniques

A review of scheduling techniques (Bar chart method, Network planning method, Linear scheduling method and Line of Balance (LOB) scheduling method) and road project schedule compression methods (Scheduled Overtime, Overmanning, Multiple Shifts, LOB Multiple Natural Rhythms and Project Segmentation) identified in literature are discussed below.

Bar charts method still remain popular because they are simple to use and easy to understand. However, bar chart does not show detailed information that is necessary to effectively manage a project. Such information includes; float time activities and dependencies between activities. The Network methods are primarily; the Critical Path Method (CPM) and Project Evaluation and Review Technique (PERT). The latter was introduced to handle variation and uncertainty that accompany activity duration. CPM is applicable to projects that have multiple interdependency relationships between succinct activities and it is an excellent tool for scheduling projects with discrete activities. However, when applied to repetitive activities, the resulting schedule will have a small number of activities if the duration of the activities is large or an excessive number of activities when the duration are subdivided into places or locations (Garold et al, 2005).When applied to construction projects, it assumes the activities can be divided into relatively small discrete activities which can be sequenced in order of performance. Therefore, to effectively utilize CPM to schedule road projects; it is necessary to focus on repetitiveness of activities, rather than on interdependency of the activities (Arditi et al, 2002; Garold et al, 2005).

The Linear Scheduling Method (LSM) is used to schedule continuously repetitive projects which are performed continuously along the length of the horizontal alignment of the project. It is a method useful in alignment-based projects; example of such projects is the construction of a bridge and box culvert in a highway project. The Line-of-Balance scheduling technique (LOB) is a variation of the linear scheduling method that allows the balancing of operations such that each activity is continuously performed. This scheduling method applies to point-based projects. Example of point-based projects includes multi-unit housing, etc. Notably, the ability of LOB technique to analyze production rate and provide information on the duration of activities allows for its usage in estimating the optimum crew size for each activity to maintain flow of work during project execution. Optimum crew size is defined as a combination of trade workers, materials, and equipment required guaranteeing maximum productivity of an activity. The rate of output that a crew of optimum size can produce is called the “natural rhythm” of the activity.

A road project schedule compression can be achieved by (i) increasing the work hours (i.e. scheduled overtime) and (ii) adding more resources through the following methods: Overmanning, Multiple shifts and Project segmentation. Scheduled overtime is a method of accelerating project by subjecting the workers to work outside their normal working hours for a premium wage. The extra work includes extra hours of work at the end of their daily work hours and work done during non-working days. Productivity and quality preservation has been proven to be affected due to fatigue when excessive scheduled overtime is used. Also, in using scheduled overtime, there is a limit to project compression. Despite these limitations, major advantages of overtime include: ease of application, ensure less inconvenience and improved safety to stakeholders.

In terms of adding resources to compress project schedule; overmanning is a project duration reduction method achieve by adding extra workers, equipment, and materials to work content. Manning level is a key factor in labour productivity as a crowded work area coupled with improper combination of trade workers and equipment may create crew interference which can hamper productivity. A research carried out by Borcherding (1989) showed that firms reported a drop in productivity that range from 15 to 32% for activities overmanned. Arditi et al (2002) termed the method as the worst project schedule compression technique. These observations portray overmanning not to be a cost effective method in schedule compression.

Multiple shifts method is a schedule compression method which involves the use of extra workers and same equipment on a project at differently scheduled periods. The extra cost implications of multiple shifts include (i) the cost of lightening the work place (ii) premium wage to workers for working during odd hours of the day (iii) provision of engineering support to handle breakdown of equipment due to continuous usage and (iv) indirect costs arising from uncertainties. A major disadvantage of multiple shifts is the uncertainties of working into the night. For example; in Nigeria, multiple shifts for road construction may be unrealistic considering the epileptic supply of energy in the country. Despite this limitation, multiple shifts minimize inconvenience to users.

Project segmentation involves dividing a project into number of segments in other to work on them simultaneously (Shtub and Raz, 1996). The decision to break a project into segments is solely on project management team guided by project completion time, extra cost on project and the feasibility of breaking the project into segments. The extra costs incurred in project segmentation are mostly from equipment mobilization and traffic flow management. Major advantages of project segmentation include (i) ease of application (ii) quality preservation (iii) increased productivity, (iv) normal work flow (v) work space sustenance and (vi) ability to achieve desired project duration.

In Nigeria, the need for rehabilitation of existing roads is partly due to the poor quality delivered by contractors in the past. During these repairs, time is usually a critical factor to consider due to inconveniences to other road users which could have social, economic and safety implications. Therefore, while emerging contracts in the road construction industry are time constrained, the quality of such projects should not be compromised. Hence, the need for construction companies to search for an optimal/near optimal construction plan that minimizes project completion time while giving utmost consideration to cost and quality.

This paper considers the need for speedy completion while preserving quality at the lowest possible cost of a non-homogenous road construction project located in a city in South West Nigeria. The objective is to use a mathematical programming model approach to obtain an optimal number of segments as opposed to when the activities of the project are scheduled sequentially. The remainder of the paper is presented as follows. In section 2, a description of the problem and mathematical model is presented. Thereafter, in section 3, a case study project was described. Section 4 contains results while conclusion and recommendation is contained in section 5.

2. Problem Description and Model Formulation

A road construction firm must exhibit expertise through a competitive bidding advantage over competing companies during the bidding process by providing an innovative approach to reducing project duration and cost while preserving the quality. Road construction activities must technically follow the sequence shown in figure 1 (Grund, 1991; Chudley, 1991). The work activities (tasks) involved in a road project represent the necessary framework to permit scheduling of activities such that proper estimation of the resources required for individual activities and necessary precedence or required sequence among the activities can be identified. Based in Ibadan, South West Nigeria, company XYZ is considering the optimal number of segments to divide a road construction project with equal work content such that work will be done in parallel using optimum crew size.

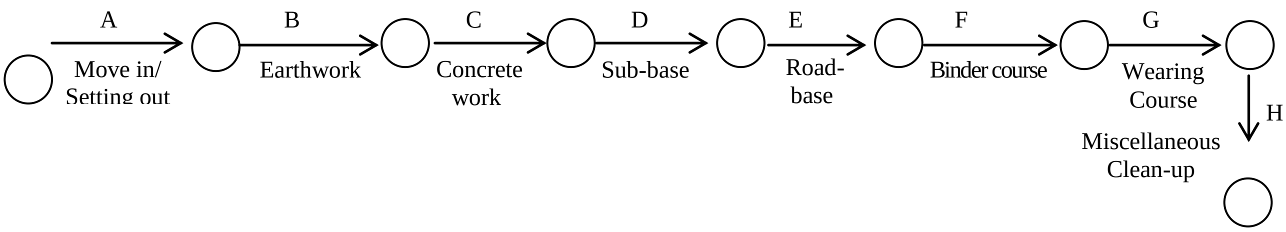

Fig. 1 Network diagram of the precedence relationships between activities in a road project.

2.1 Model Formulation

The mathematical model considered for this work has its foundation on the idea of project segmentation as originally introduced by Shtub and Raz (1997).

2.1.1 Basic Notation and Terminologies

2.1.1.1 Indices

i : Index for project segment (i =1,…,I)
j : Index for project activities (j = 1,…..,J)

2.1.1.2 Notations and Terminilogies

L: Total length of the road to be constructed (kilometers).
L_i: Size of project segment *i* in kilometers.
$\bar{C}_j$: Cost of performing activity *j* (₦).
C_j: Cost of performing activity *j* per unit work content (₦/crew hours).
$\underline{t}_j$: Duration of performing activity j.
t_j: Duration of performing activity j per unit work content (months/crew hours).
l_k: Size of the repetitive parts (metres) in which the project's work content is to be estimated.
W(L): The overall work content of the project in crew hours.
$W(L_i)$: The work content of a project segment L_i in crew hours.
$W(l_k)$: The work content in crew hours for each of the l_k size part.
$W(L_j)$: The total work content of each of the *j* activities j = 1,2,…J.
$W(L_F)$: The total work content for the fixed *j* activities j = 1,2,…J.
$t_{ij}[W(L_i)]$: Duration of activity j on segment i in months (including set up time)
$C_{ij}[W(L_i)]$: Cost of performing activity j on segment *i* in naira (including set up cost if required).
C_{Fj} – The fixed cost associated with the set-up work for the segment regardless of the segment size
C_{vj} – The variable cost of executing activity *j* per unit of work content.
ST_{ij}: Start time of activity j on segment i .
FT_{ij}: Finish time of activity j on segment i .
I: Number of segments
DD: Project due date.
P: Penalty in naira [per period for completing the project after its due date.
B: Bonus in naira [per period] for completing the project earlier than the its due date.
K: The number of the l_k parts in the project.
Z: Total cost of the project including bonuses or penalties if applied.
CT: Actual project completion time.

e_{jxy}: Binary relation between the fixed cost and duration of accomplishment of the fixed workload x of activity j and the segment work content y.

e_j: Binary interaction matrix of fixed cost and duration of accomplishment of the fixed workload of activity j and the segment work content. $e_{jxy} \in e_j$

q_{jzy}: Binary relation between the variable cost and duration of accomplishment of the variable workload z of activity j and segment work content y.

q_j : Binary interaction matrix of variable cost and duration of accomplishment of the variable workload of activity j and the segment work content, $q_{jzy} \in q_j$

Earliness: Number of periods (months) the project is completed before its due date (if the project is late or on schedule, Early = 0, otherwise Early = (DD – CT).

Lateness: Number of periods (months) the project is completed after its due date (if the project is on schedule or completed before its due date, Late =0 otherwise Late = (CT – DD).

2.1.2 Assumptions

The assumptions upon which the formulation and application of the model is based are as follows:

1. The project can be divided into a number of segments (I), each requiring the same set of activities.
2. The activities are performed in the same (pre-determined) sequence on each segment of the project.
3. The duration and cost of performing each activity on each segment depend on the work content of the segment given as crew hours. This assumption is relaxed later on.
4. The total cost of the project is the execution cost of performing all the activities on all the segments and possibly either a penalty for late completion of the project (assuming a pre-specified due date), or a bonus for early completion of the project.
5. To schedule the project, the work content of each segment has to be determined as well as the timing of the activities on each segment.
6. The use of optimum crew size is a necessity with regard to the duration and cost determination for each of the activity.
7. The crews are to work at their natural rhythm (normal pace).
8. The identification of the set-up (non-segment work content) and segment work content dependent (variable) activities must be done through expert knowledge.
9. The project is composed of l_k size repetitive parts where each part may be homogenous.

2.1.3 Decision Variables

ST_{ij}: Start time of activity j on segment i

FT_{ij}: Finish time of activity j on segment i

X: Number of segments

L_i: Size of project segment *i* in kilometers.

2.2 Model Formulation

2.2.1 Binary Interaction Matrix

For the applicability of the model, the fixed cost and fixed duration of activities as well as the variable cost and variable duration of activities will be determined by experts using the binary interaction matrix (BIM) tool. BIM defines a binary relation between two quantities; it is a Systems analysis tool which is extensively (Charles-Owaba and Lambert, 1988). The interaction is developed by seeking expert knowledge on the subject “yes” or “no” answers to contextual question(s). A contextual question is a system objective base question which is used to determine whether or not such relationship as may be defined exists. The binary relation of fixed cost and fixed duration with work content is defined below:

$$e_{jxy} = \begin{cases} 1, & \text{if activity j has a fixed cost and duration of accomplishing a fixed workload x that is independent of the segment work content y (that is, it is set-up activity in nature)} \\ 0, & \text{otherwise} \end{cases}$$

Thus: $e_j = \{e_{jxy}\}$ (1)

Therefore, C_{Fj} and t_{Fj} becomes:

$$C_{FJ} = \bar{C}_j \times e_{jxy} \quad (2)$$

$t_{Fj} = t_j \times e_{jxy}$ (3)

The binary relation of variable cost and duration with work content is defined below:

$$q_{jzy} = \begin{cases} 1, & \text{if activity j has a variable cost and duration of accomplishing a variable workload z that is dependent on the segment work content y.} \\ 0, & \text{otherwise} \end{cases}$$

Thus: $q_j = \{q_{jzy}\}$ (4)

Therefore, to calculate C_{vj} and t_{vj} is as shown below:

$C_{vj} = C_j \times q_{jzy}$ (5)

$t_{vj} = t_j \times q_{jzy}$ (6)

2.2.2 Total Cost of Project

For a project to be considered continuous, $W(L_i)$ must have a value in the range $0 < W(L_i) \leq W(L)$. Such a project is non-homogeneous if the duration and cost of segments depends on the specific part of the project included in the segment as opposed to homogenous projects where the duration and cost of the project segment depends only on the length of the segment. The project is considered linear if the duration and cost of segments are linear functions of the segment's work content. Each segment has a set-up (fixed) works and variable works with corresponding cost and duration implications as shown in equation 7 and 8 below.

$$C_{ij}[W(L_i)] = C_{Fj} + [C_{Vj} \times W(L_i)] \quad (7)$$
$$t_{ij}[W(L_i)] = t_{Fj} + [t_{Vj} \times W(L_i)] \quad (8)$$

The execution cost of the project $\mathrm{EC_p}$ is given by equation 9, while total cost of the project $\mathrm{TC_p}$ is shown in equation 10.

$$EC_p = \sum_{j=1}^{J} C_{Fj} + W(L)\sum_{j=1}^{J} C_{Vj} \quad (9)$$
$$TC_p = EC_p + f(CT) \quad (10)$$
$$TC_p = \sum_{j=1}^{J} C_{Fj} + W(L)\sum_{j=1}^{J} C_{Vj} + f(CT) \quad (11)$$

From equation 11, f(CT) is a function of the completion time of the project defined as follows:

$$f(\mathrm{CT}) = \begin{cases} \mathrm{P\,(CT - DD)} & \text{if CT} \geq \text{DD} \\ -\mathrm{B(DD - CT)} & \text{if CT} < \text{DD} \\ 0 & \text{if CT} = \text{DD} \end{cases} \quad (12)$$

2.2.3 Optimal Number of Segments

To find the optimal number of segments that minimizes $\mathrm{TC_p}$, let CT *(I)* denote the completion time of the project when W (L) is divided into *I* equal segments, therefore; $\mathrm{TC_p(I)}$ becomes:

$$TC_p(I) = EC_p(I) + f[CT(I)] \quad (13)$$

From Eqn. 13, we can solve for $\frac{dTC_P(I)}{d(I)} = 0$, to obtain the optimal value of I. At $I_{optimal}$, $TC_p(I)$ is expected to be at minimum. Resolving this differentiation for the two cases of completing the project after its due date (penalty) and completing the project ahead of its due date (bonus) gives:

$$I\,(Penalty) = I_p = \sqrt{\frac{PW(L)\sum_{j=1}^{J} t_{vj}}{\sum_{j=1}^{J} c_{fj}}} \quad (14)$$

$$I\ (Bonus) = I_b = \sqrt{\frac{BW(L)\sum_{j=1}^{J} t_{vj}}{\sum_{j=1}^{J} c_{fj}}} \qquad (15)$$

2.2.4 Segmentation of a non -homogenous project with Linear Cost and Duration Model

The formulation of the mathematical programming model to minimize the total project cost and duration of a continuous, non-homogeneous project with linear cost and duration functions is presented below:

$$\text{Min } Z = I\sum_{j=1}^{J} C_{Fj} + W(L)\sum_{j=1}^{J} C_{vj} + f(CT) \qquad (16)$$

s.t.

$$\sum_{k=1}^{K} l_k = L \qquad k = 1,2\ldots,K \qquad (17)$$

$$W(L_i) = \sum_{l_k \in L_i} W(L_k) \qquad (18)$$

$FT_{ij} \le ST_{ir}$ for all $_i \in I$, $j,r \in J$, j prec r (19)

$ST_{ij} + t_{ij}[W(L_i)] \le FT_{ij}$ for all $i \in I$, $j \in J$ (20)

$CT \ge FT_{ij}$ for all $i \in I$ (21)

Early = DD – CT (22)

Late = CT- DD (23)

Early, Late, ST_{ij}, F_{ij}, $CT \ge 0$ (24)

In the formulation, the objective function in equation 16 minimizes total cost of the project when the project is divided into segments of equal work contents**.** Constraint 17 represents total size of the project as the sum of the different l_k repetitive parts. Constraint 18 ensures that the work contents of a project segments L_i consisting of a number of increments is equal to the sum of their work content. Constraint 19 represents the predetermined sequence of activities performed on the same project segment such that activity j is an immediate predecessor of activity r. Constraint 20 shows the relationship between the start time of each activity, its duration and its finish time. Constraint 21 ensures that actual project completion time is determined by the completion time of the last activity on each segment of project. Constraint sets 22 and 23 calculates the number of time periods (months) the project finishes ahead of its due date (Early > 0) or after its due date (Late > 0).Constraint (24) enforces non-negativity on the value of Early, Late, ST_{ij}, FT_{ij} and CT.

3. Illustrative Example

The data used was collected from the contract proposal of the dualisation of Mokola-Sango-U.I.-Ojoo road project as presented by a local construction company. The project was supervised by the State Ministry of Works and Transportation. The project consists of the eight activities as shown in table 1. The road has a total length of 8.5 kilometers with a project completion date of 12 months under the linear ordering of the activities. The project was awarded at a lump sum of N1, 577, 294, 775. The elemental cost of each activity of the project as presented in the contract proposal is shown in table 1. The move-in / setting out in table 1 covered other activities such as the relocation of the power and telecommunication infrastructure and payment of compensations to individuals and groups whose properties were affected in the process of the road construction activities. Therefore, we assume that the actual amount meant for our defined move-in/setting out activity is 72% of the stipulated amount for preliminary/setting out. Also, the contingency (miscellaneous) information presented in table 1 is assumed to be about 21.25% of the total amount for contingencies (miscellaneous) activity and the remaining portion left out to cater for unanticipated expenses that may arise in the course of the project execution. A break-down of the precedence relationship between project activities, duration of each activity in months , total work content , duration / work content tj , Cost/work content Cj and Total cost Cj are presented in table 2. The work content presented in crew hours for each of the activities is based on the estimated duration for each activity. The estimated duration is an assumption of 5 working days in a week at 8 hours per day. The enumerated work contents for the earthworks and concrete works vary from location to location. Due to lack of information on production rates for each location's variation in work content, weighting factors were allotted to the different significant causes of these variations from part to part in the mentioned activities to manifest the non-homogeneity of the project. In table 3, the fixed and variable costs /durations of each activity is presented

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Table 1. Elemental cost of each project activity as presented in the contract proposal

S/N	Elemental analysis	Percentage of the proposed cost of the project.	Amount (₦)
1	Clearing	0.050	788647.39
2	Earthwork	5.000	78864738.75
3	Cleaning and repair of culverts and drains	0.100	1577294.78
4	Demolition of culverts and drains	0.090	1419565.30
5	Extension of existing culverts	0.080	1261835.82
6	Excavation of existing culverts	0.085	1340700.50
7	Construction of new lined drains (gutters)	14.400	227130447.60
8	Construction of new culverts	1.720	27129470.13
9	Construction of retaining walls	4.290	67665945.85
10	Construction/setting of kerbs	8.590	135489621.20
11	Construction of sub-base	2.640	41640582.06
12	Construction of road (crutch stone) base	10.200	160884067.10
13	Construction of binder course	20.170	318140356.10
14	Construction wearing course	18.28	288329477.50
15	Contingency (miscellaneous)/clean-up	10.000	157729477.50
16	Preliminary/setting out	4.305	67902540.06

Table 2. Cost of the Defined Activities for the Road Project

S/N	Activities		Event		Duration t_j	Duration (weeks)	Total work content W(Lj) (crew hours)	Duration/work content t_j (months/crew hours)	Cost/work content C_j (₦/crew hours)	Cost C_j (₦)
	Code	Description	From	To						
1	A	Move-in/setting Out	1	2	0.6	2.57	102.8	4.37×10^{-4}	23,765.23	48,889,828.84
2	B	Earthwork	2	3	1.9	8.14	325.6	9.24×10^{-4}	4,144,117	85,252,782.60
3	C	Concrete work	3	4	2.3	9.86	394.4	1.12×10^{-3}	222,348.57	457,415,484.80
4	D	Sub-base	4	5	1.8	7.71	308.4	8.75×10^{-4}	20,241.39	416,405,820.60
5	E	Road-base	5	6	1.7	7.71	308.4	8.26×10^{-4}	78.205.36	160,884,067.10
6	F	Binder course	6	7	1.5	6.43	257.2	7.29×10^{-4}	154,647.27	318,140,356.10
7	G	Wearing course	7	8	1.3	5.57	222.8	6.32×10^{-4}	140,156.27	288,329,484.90
8	H	Miscellaneous/clean-up	8	-	0.9	3.86	154.4	4.37 × 10-4	16,292.78	33,517,513.97

Table 3. Fixed and Variable Costs /durations of activities

S/N	Activities		Event		Fixed cost C_{fj} (₦)	Variable cost C_{vj} (₦/Crew hours)	Fixed duration t_{Fj} (months)	Variable durations t_{vj} (month/Crew hours)
	Code	Description	From	To				
1	A	Move-in/setting Out	1	2	48,889,828.84	——	0.6	——
2	B	Earthwork	2	3	——	4,144,117	——	9.24×10^{-4}
3	C	Concrete work	3	4	——	222,348.57	——	1.12×10^{-3}
4	D	Sub-base	4	5	——	20,241.39	——	8.75×10^{-4}
5	E	Road-base	5	6	——	78205.36	——	8.26×10^{-4}
6	F	Binder course	6	7	——	154,647.27	——	7.29×10^{-4}
7	G	Wearing course	7	8	——	140,156.27	——	6.32×10^{-4}
8	H	Miscellaneous/ clean-up	8	—	33,517,513.95	—	0.9	——

4. Result

Given the concept of optimum crew size working at their natural rhythm, it is obvious that the shortest project duration corresponds to the least cost solution. This is demonstrated by the solution from the analysis of the data using the model. The use of the model is to demonstrate the possibilities of minimizing project cost by dividing a continuously repetitive project into a number of equal segments; such that work can proceed in parallel using optimum crew size working at their natural rhythm.

Given stipulated due date of 8 months with a penalty / bonus of ₦ 63091791/month. The analysis done shows that the optimal number of segments into which the project can be divided into is three, and that by working in parallel the project will require a total cost of ₦1,409,609,413 with a completion duration of 5 months. The profit is the total proposed cost of the project minus the total cost TC(3) and the other costs . Such other costs as earlier stated are 28% of the preliminary left out amounting to ₦19012711.22 and 78.75% of contingencies (miscellaneous) totaling ₦124211963.50. Therefore, estimated savings can be gotten by subtracting TC (3) and other costs from the proposed project cost: ₦ (1,577,294,775 – 1,409,609,413 – 19,012,711.22 – 124,211,963.50) = ₦24, 460,687.28. This savings is about 1.55% of the proposed total cost of the project.

A proper look at the model shows that the total cost of the project is a function of two costs: execution and completion time cost functions. The former is directly related to the number of segments and the latter is inversely related to the number of segments. This means the execution cost is an increasing function of the number of segments while the completion time cost function is a decreasing function of the number of segments which is reflected respectively as shown in table 4. Furthermore, increase in the execution cost as observed in the analysis is a reflection of the increase in the number of set-up activities (equipment's mobilization) in accordance with the numbers of segments. This is because the set-up activities are segment dependent and instead of being carried out once through the project length as in the case of linear ordering of the project, they are executed segment by segment with seemingly the same cost and duration in the segmentation. Also, a very important factor that affects the total cost of the project is the bonus and penalty rates.

Table 4. Comparative analysis to identify optimal number of segments

Number of Segments (I)	Completion Time (months)	Execution Cost EC_p (I)	Completion Time $f[CT(I)]$	Total Cost of Project $TC_p(X) = EC_p(I) + f[CT(I)]$
2	6.75	₦1,516,477,444	- ₦78,864,738.75	₦1,437,612,705
3	5.00	₦ 1,598,884,786	- ₦ 189,275,373	₦ 1,409,609,413
4	4.13	₦ 1,681,292,129	- ₦244,354,506.543	₦ 1,436,937,622

5. Conclusions and Future Research

In this paper, the need to reduce duration and minimize total while preserving the quality of the project cost in road construction projects was established. The need to get the optimum number of segments a road project should be divided into and work to be carried out simultaneously using optimum crew sizes working at their natural rhythms was established.

The optimization criteria of the formulated model was, however, limited to the minimization of the total cost of the project, where the total cost of the project was presented as a function of the execution cost and completion time (duration) cost functions. Binary interaction matrix was used to define stated relationships, which led to formulations carried out to enhance the application of the developed model to any given field. The use of the model for the reduction of project completion time and cost was demonstrated. For subsequent work and application of the model, analysis to ascertain the level of inconvenience that may come out of road

project segmentation and likely avenue of diversion to ameliorate this negative impact can be quantified. Also, savings from indirect cost through duration reduction can be considered.

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