A COMPOSITE COST-TIME TRADE-OFF MODEL FOR MULTI-STOREY PROJECT FAST TRACKING #128

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ABSTRACT

Whilst enormous research effort in project fast-tracking determine the efficacy of specific methods and policies that would guarantee strict compliance with project programs, less have been reported on combining existing models for improved performance opportunities. In this paper, the task of presenting a composite model for large project cost-time trade-offs and duration fast-tracking is undertaken. The methodological procedures followed in formulating the models were carefully delineated and the proposed models validated using a real-life example. The optimal crash time obtained was in total acquiescence with all the problem constraints. The results show that a composite project crashing model can be very useful in achieving optimal values of important variables regarding fast-tracking.

Keywords: Composite model, Cost-time trade-off, Project fast-tracking, optimal crashing values

1. INTRODUCTION

Shortening the estimated completion period of a project by crashing the duration of a number of activities and avoiding delays can guarantee aversion of costly variations that often threaten contractors' delivery dates. Clients normally detest being dragged to vary the initial project cost, especially when the variation will cause more expenses. Strictly speaking, variation of cost and completion period of a project can become necessary during the project execution period, for other reasons not directly traceable to the contractor's action or inaction. It may not be required to consider all activities during a project fast-tracking effort, primarily due to a most likely adverse labour productivity consequences and eventual prohibitive cost. The least cost approach to effecting project crashing can be achieved by selecting certain activities in the critical path that can be performed earlier than previously scheduled, with less effect on the overall project cost. There seem to be no observable correlation between time and cost of a project such that both can be compromised efficiently to meet the ever increasing pressure to deliver quicker, qualitative, better and value oriented projects (Svejvig, et al., 2019; Salmasnia et al., 2012). The baseline practice is therefore to plan the crashing in a manner that allows optimal trade-off with the reduced time. In particular, for large-scale projects, crashing decisions can become indispensable in order to deliver on or before project completion dates. Expensive variations can ultimately result in unwarranted litigation and loss of business goodwill due to delayed projects. The literature is vast in studies on project crashing and cost-time trade-offs but the composite models are not as ubiquitous. There can be several reasons why contractors resort to fast tracking projects, though not all fast-tracked projects result in positive impact (Chang et al., 2019, Kokkaew and Wipulanusat 2014). Some of the reported reasons include saving on bonuses, making more profit from savings on number of days, avoiding adverse weather and site conditions as well as building good customer trust and goodwill (Ballesteros-Perez et al., 2019; Bakry et al., 2014). Opinions are varied on the best course of action to follow in achieving optimal project crashing. Traditional Mathematical techniques have long been suggested (Abbasi and Mukattash, 2001; Murali and Rao, 1998; Wiley et al., 1998). The methods can be helpful when appropriate variables are captured, though metaheuristic methods are reputed for possessing the capabilities of taking care of some complexities and stochastic situations normally encountered in real world projects (Aghaie and Mokhtari, 2009; Liao et al., 2011, Doerner et al., 2008).

Kang and Choi (2015) discuss a certain adaptive threshold policy that can be used to crash a project activity to the proportion with which the starting time is delayed. The presentation introduce a new term called "reserved starting time" to signify the delay magnitude. The study holds that the starting time policy is best for a series-graph project and suggested an algorithm based on heuristic policy from a combination of starting time values of specific paths for arbitrary-graph projects. Use of such methods can help define project boundaries and existing studies attest to the maxim (Ballesteros-Perez, 2017). Conversely, a combined project control technique that measures progress against programmed of projects for early detection of possible variability is documented (Martens and Vanhoucke, 2019). Unlike starting time delay due to Kang and Choi (2015), the authors adopt 'tolerant limit' approach proposed earlier (Martens and Vanhoucke, 2017) for effective monitoring of progress and creation of action inducers when a project duration presents characteristics of being exceeded. The presentation argue that deviation of complex projects from original plans is almost always inevitable but variability reduction steps, based on monitoring and control techniques (De Marco, 2018), can compress the duration of certain activities for eventual optimal completion. In another research effort, Yang (2007) describe how a complex project can be crashed along multiple directions (time and cost) using the effectiveness, robustness and efficient capabilities of particle swarm optimization (PSO) algorithm. In its implementation, small to moderate project cost-time trade-off fast-tracking problem parameters were treated as certain. Deterministic solution methodologies are usually proffered to tackle certainty problems (Feng et al., 2000). Nevertheless, unspecified conditions of the real project environment like environmental data availability and accessibility issues, weather conditions and funding consistency can create significant degree of uncertainty in the project management model. Past researchers have laboured on crashing multi-complex projects within uncertainty criterion using Fuzzy set theory (Liang et al, 2003, Gocken, 2013; Ghazanfari et al., 2009). This approach is plausible but the ranking of Fuzzy numbers can present a rigorous and complicated deterministic process (Gocken, 2013), in addition to nonexistence of known natural order for Fuzzy numbers (Wang and Kerre, 2001). Attempts to shorten the duration of certain activities so as to complete the project within time bounds have received attention of hybrid modelling researchers. The main objective is usually to enhance the completion probability with a mathematical programming model. Next, a hybridized technique is employed to solve the resulting model. Mokhtari et al. (2010) is a typical example of this formulation, where a hybrid approach constructed on the basis of cutting plane technique and Monte Carlo (MC) simulation is presented. Other good examples are also available (Tiwari and Johari, 2015). Evolutionary algorithm is not left out in project maximum completion period compression effort. In particular, Meier et al. (2016) propose the use of multi-objective evolutionary algorithm, called e-MOEA. The algorithm, according to the authors, can identify the Pareto set of best time–cost trade-off solutions to certain iterative project development crashing models discussed elsewhere (Meier et al., 2015). Comparatively, heuristic algorithms frequently suffer global optimum convergence problems, just as meta-heuristic algorithms has also been reported to possess significant computational global optimum convergence problems as well (Bettemir and Birgonul, 2017). Bettemir and Birgonul (2017) further blame exact methods for inherent complexity which can pave way for implementation difficulties, on the part of construction planners. The authors propose a new model with optimum or near-optimum solutions for discrete time-cost trade-off problems. It is called "a minimum cost-slope based fast converging network analysis algorithm". The algorithm was shown to evidently differentiate between the extremes of crashing costs despite being a useful tool when considering local minimum elimination.

While there have been substantial documented evidence of publications based on determination of specific methods and policies that would guarantee strict compliance with preset project programs, at worst; or reduction in the estimated date of completion; less have been reported on combining some of the models for easier, quicker and better application and performance of project and consttruction managers. The applicability problems of existing models rightly hinted by Bettemir and Birgonul (2017) is too weighty to be ignored in an effort to make matters simpler for construction planners. Construction of models with somewhat less general implementation effort is essentially important as local contractors in developing countries may not have the needed resources to hire super qualified and very competent construction crew that can handle complex models. Unfair enough, there have been negligible attempt to categorize existing project crashing approaches in terms of location, training or competence specificity rather than carrying forward of a general applicability assumption. The result can be treatment of excellent crashing models as academic exercise short of profitable project management tools due to paucity of operation and expert resources. In an attempt to ameliorate the void, especially in technology infrastructural deficit areas, this paper follows already laid ideas (Mokhtari et al. 2010; Feng et al., 2000) to present a simpler-to-apply composite model that can provide optimal time-cost trade off in large projects. In implementation, the Lindo software is used to obtain optimal crash cost while the proposed model is used to deduce optimal crash time. The approach used in the study gave an impressive result.

2. METHODOLOGY

This study adopted a mathematical modelling and theoretical design approach. To satisfy its cleavage of demystifying some of the complexities associated with some existing models, which makes practical application difficult, especially in developing countries, a chronological procedure for generating the optimal cost-time trade-off fast tracking model is provided. Figure 1 presents the generalized procedural steps used in building the model, which also shows the steps followed in the study. Basically, the modelling begins with construction of a sequential unambiguous activity-precedence relationships of all the tasks involved in the project. This step can allow for the network diagram (ND) showing the earliest start time (EST) and earliest finish time (EFT) as well as the latest start time (LST), latest finish (LFT) and corresponding durations to be constructed. With ND in place, the computation of the earliest and latest dates normally results in determining the critical path(s). Knowledge of the procedure for carrying out these first line computations (ES, EF, LS, LF and CP) have been assumed in this presentation, though interested readers can refer to any standard operations management literature (Sharma, 2005) for more clarifications. Specifically, the project evaluation and review technique (PERT) was adopted for the study because it offers the opportunity of dealing with a three-time estimate, which to a large extent, takes care of the uncertainties in the project life from the duration point of view. The final expected time offered by the procedure is combined with other project possibilities and variabilities to yield a rich and working time data that can be used for realistic calculations. During this stage, all the cost information, both pre and post duration compression is determined in line with the time data. A conventional fast tracking model and a mathematical model can be applied thereafter to give a simple-to-apply composite model similar to the one proposed in this study. We consider the case of completing a project within the scheduled normal time as a basis for modelling the crashing of the duration and cost. The basic assumption that the crashing is limited to certain critical activities is made in the analysis. In line with past researchers (Mokhtari et al. 2010; Feng et al., 2000), the initial basic feasible solution is deemed to allow crashing to start from activity times that offers the least cost slope value among the CPs, and gradually progress to a successive critical path, until the least possible time is achieved. In other words, the activities in the CP with minimum joint slope takes precedence in consideration for crashing, even if a new path(s) become critical following crashing. The exercise is discontinued after crashing critical activities to fall within desired minimum possible time. The decision variables are the start time of each activity, the reduction in the duration of each activity due to crashing, and the finish time of the project. The constraints include; 1) the maximum reduction in time for each activity cannot be exceeded; 2) the project finish time must be less or equal to the new desired finish time; and 3) the precedence relationship of all the activities must be respected. Since the whole idea of project fast tracking is to deliver the project in a less time than would have been obtained without crashing, the proposed model consider the crashing period and cost vis-à-vis best activities that can be crashed to achieve desired result.

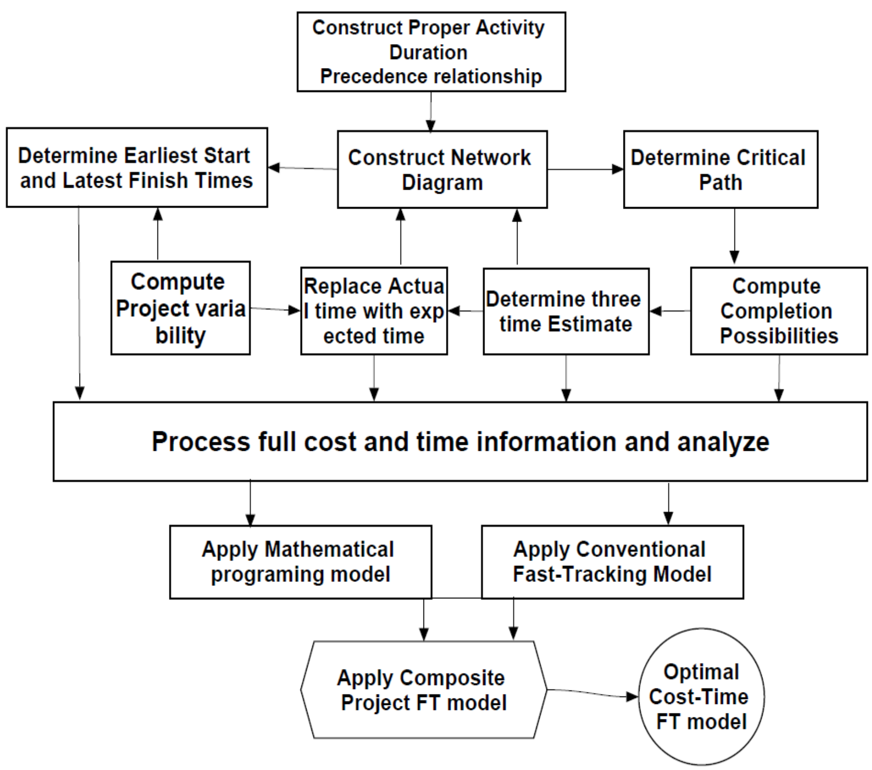

Figure 1. Model for the multi-storey project fast tracking

3. MODEL DEVELOPMENT

The generalized Mathematical programing model for minimizing the total cost of a given project, in particular; extra cost of crashing activities subject to necessary constraint that the duration must be within the project completion date can be represented by equation (1). The objective function to be minimized is thus:

Minimize

$$Z = Cost1x_A + Cost2x_B + \cdots + Cost(n)x_N \tag{1}$$

Where cost1, cost2 down to cost (n) are the difference between the crash cost and the normal cost of activities on the critical path and Z is the objective function.
The assumption is made that the normal cost and crash cost of completing the project in line with the normal time and crash time are determined *a-pri-ori*.

The decision variables can be determined as follows:

x_j = reduction in the duration of activity j due to crashing the activity for $j = A, B \ldots N$
Let y_{finish} = Project duration, i.e. the time to reach the FINISH node. The constraints then is $y_{finish} \leq N$, where N is the time to reach the finish node. It is reasonable to introduce $x_{A,}, x_B, \cdots x_N$, into the model so that appropriate value can be assigned to y_{finish}.
y_j = start time of activity j (for $j = B, C \ldots N$) given the values of $x_{A,}, x_B, \cdots x_N$.
By treating the FINISH node as individual activity, the definition of y_j for activity y_{finish} also fits the definition of y_{finish}.
For each activity $(B, C, \ldots N, FINISH)$ and each immediate predecessors, the start time of all the activities are directly related to the start time and duration of each of its immediate predecessors according to the inequality:

$$start\ time\ of\ activity \geq (start\ time - duration)\ of\ immediate\ predecessor$$

Denoting i an j as the earliest time of an activity starting with i, and ending at node j, y_{ij} as the number of weeks an activity is crashed, then, the problem can be re-formulated as a linear programming model of equation (2), which accounts for crash times and cost. Thus, the decision variables can be denoted as follows:

$$Z = C_c ijY_{Aij} + C_{cij}Y_{Bij} + \cdots + C_c ijY_{Nij} \tag{2}$$

Where:
C_c = the crashed cost
To help the linear programming model assign the appropriate value to y_{finish}, given the values of $y_A, y_B \ldots y_N$, we introduce X_J = start time of activity j (for $j = B, C, D \ldots N$).
We treat N as another activity with a zero duration. As presented in literature (Ozor and Iwuchukwu, 2014), each of activities B, C…N, FINISH) and the corresponding immediate predecessors can be represented by the relationship:

$$start\ time\ of\ an\ activity \geq (start\ time + duration)\ of\ immediate\ predecessor$$

By considering the normal times, each activity duration can be obtained as follows:
Duration of activity j = its normal time - x_j. That is for any activity say K in a network diagram, with an immediate predecessor, J,

$$X_K \geq X_J + duration - Y_J \quad (3)$$

This kind of relationship can be written for any number of precedence relationship so that a complete LP model can be obtained. The resulting LP model is of the form:

Minimize

$$Z = xijY_{Aij} + xijY_{ijBij} + \cdots + xijYij_{mij} \quad (4)$$

Subject to the following constraints:

A. *Maximum Reduction Constraint:*

$$Y_{mi} \leq x_{ij}$$

Where:
x_{ij} = the duration of the activity starting at point i and ending at point j

B. *Non- negative Constraint:*

$X_{mi} \geq 0$, $y_{mi} \geq 0$

C. *Start –Time Constraints:*

In the stated objective function above, observe that there is only one constraint for each activity with just one immediate predecessor activity. Also, there are two constraints for each activity with two immediately preceding activities. Generally, we have n constraints associated with each activity with n immediately preceding activities such that:

$$X_{mi} \geq X_{mi-1} + K_i - y_{mi-1}$$

Where:
m_i = the individual activity m at point i ($i = 1,2,3, \ldots, N.; \quad N = last\ activity$)
X_{mi-1} = the number of immediate predecessor activities

Recall that the immediate predecessor activity of the first activity in most projects is zero as the project must start somewhere at which there was no activity at all. Accordingly, for a project with activities $A, B, C, \ldots, Y$, say, activity A has zero predecessor and X_A is zero. For the immediate predecessor at the final activity,

$$X_{finish} \geq X_Y + k - y_y$$

Where:

k = the duration of the immediately preceding activity.

3.1 Variability of Activity Times

There are two mainstream methods normally adopted in project analysis. One, already introduced earlier in this paper, is the project evaluation and review technique (PERT). The other one is the critical path method (CPM). In PERT, the project completion time is usually computed in a similar manner as in CPM approach, but by substituting the three-time-estimate of the activity duration with the expected activity time, and the variance of the activity completion time. Consequently the expected completion time of the project can be derived as well as the variability in the project completion time. In clearer terms, the estimated completion period of a project (μ_P) can be expressed in terms of the earliest and latest finish times, just as variability prospects in the project completion time (σ_P) can be expressed in terms of the sum of the square root of the variances of the critical path activity times.

Accordingly;

$$\mu_P = max\ (EFT)\ =\ max\ (LFT) \quad (5)$$

$$\sigma_P^2 = \sum_{j_c=A}^{j_c=N} VAR_{j_c} \quad (6)$$

Where:

j_c = activities on the critical path beginning with the first of such activities, A, and ending with the last one, N.

3.2 Computation of Project Completion Possibilities

The main thrust of this presentation is to ensure that a very handy and applicable project management methodology that can permit the easy administration of the job of construction overseers is put in place. The various outcomes that can occur in the life of the project must be known and the magnitude computed *ab-initio*, so that policies for realistic results can be planned with minimum error. Therefore, we recommend that the probability of whether a project will experience variation after a careful design of programmes or otherwise can be computed using the time of the initial activity-precedence relationship table and the various duration allocated to different activities. As stated earlier, this can necessitate the use of a properly constructed network diagram showing the array of earliest start and latest finish values. We consider the case of a given project with specified deadlines c and d (assuming $c < d$) say, and a total completion period of X. Borrowing from the central limit theorem (CLT), we can represent the sum of independent random variables with a normal distribution when there is a significant increase in the number of random variables. The random variables for the particular case of large scale projects is assumed to be approximately very large. Towards this connection, the CLT is considered appropriate from the stand point of a large scale project because there are many activities in the first instance. Also, the individual activities that make up the entire project, no matter how infinitesimal, contributes a corresponding amount of time to the total project duration, which for the purpose of precise cost-time trade-off modelling, cannot be neglected. Another reason for the choice of CLT is that the project durations are mostly 'expected times' or simply mean time estimates. The CLT makes the computation of approximate confidence intervals about an estimated mean possible. Accordingly, the project completion period can be approximated by a normal distribution with mean ($\tilde{\mu}$) given by:

$$\tilde{\mu} = \sum_{i=1}^{i=n_c} \frac{cp_t}{n_c} \tag{7}$$

Where:

cp_t = duration of activities in the critical path

n_c = number of activities in the critical path

As stated earlier, the techniques for determining the critical path is thoroughly discussed in literature (Sharmer, 2005). However, for cost-efficiency purposes, activities on the critical path that gives the least cost slope are normally considered during crashing. There are three possibilities trailing the project delivery on the fast tracked completion period, otherwise called the new completion period, in line with the assumption made for c and d, which include:

i) The project does not exceed the new deadline (d_{new}), i.e , $p(x \leq d_{new})$
ii) Another possible situation is where the project exceeds the new deadline (d_{new}), in which case; $p(x > d_{new})$. This can also be represented as the converse of the project not exceeding the new deadline (d_{new}). That means; $1 - p(x \leq d_{new})$.
iii) The last possible condition is that the project is completed on the expected date of completion, which means that $p(x = d)$, and in what looks like a fourth instance;
iv) The project can fall in between c_{new} and d_{new}. Hence, $(c \leq x \leq d_{new})$.

The c_{new} and d_{new} can represent the new commencement date and completion date of the last activity. Note that the extreme case of the project being completed on normal dates of completion is carefully omitted at this point, because the study is on project fast-tracking and as such, a certain alteration of the original scheduled completion date is definite. The full implementation of the CLT so adopted, require the re-parameterization of x into the standard normal distribution and subsequent determination of the area under the normal distribution curve. To do this, we compute z values from:

$$z = \frac{x - \tilde{\mu}}{\sigma} \tag{8}$$

Where:

x = c_{new} or d_{new},

z = standardized normal variate. It can be called by NORMSDIST (x) in EXCEL or determined from the students normal distribution Table.

3.3 Conventional Project Crashing Models

Consider a mechanical installation project as part of an array of activities for the renovation of a dilapidated Auditorium with the following data, say. Denote the cost at normal project duration of an activity as C_x and the corresponding period as $T_{x.}$ Let the cost of completing the project at a new crashed time T_c be given by; C_c. The maximum activity duration reduction that can be achieved for the mechanical installation can be given by:

$$\Delta T = T_x - T_c \tag{9}$$

The corresponding cost differential associated with compressing the period of the project can be represented by the following dependence:

$$\Delta C = C_x - C_c \tag{10}$$

The slope of ΔC will be positive for all cases where the normal project cost is more than the crash cost or negative otherwise. An expression can be obtained for the periodic change in cost due to crashing. For extremely large crash cost;

$$Crash\ cost\ per\ activity\ per\ period = \frac{C_{cij} - C_{xij}}{\Delta T_{ij}} \tag{11}$$

The average fast-tracking cost is the quotient of the overall project cost due to crashing and the overall change in project duration. This can be stated as:

$$\widehat{C_L} = \sum_{i=1}^{i=j} C_{xi} \sum_{k=1}^{k=m} T_{xi}{}^{-1} \tag{12}$$

$i = 1,2,3, \cdots, j.$ $k = 1,2,3, \cdots, m.$
j *and* m are the number of cost and time elements in the crashed project respectively

3.4 Composite Project Crashing Models

The foregoing deductions in equations (9) through (12), namely; the conventional project crashing strategy and the project crashing achieved using mathematical programming approach can be combined to obtain a composite very simple-to-apply project fast-tracking cost-time trade-off model that can account for the optimal crashing period T_{op}. We consider the data in Table 1 for developing convenient optimal models for the project fast-tracking purpose.

Table 1. Normal and Crashed cost duration showing optimal values

	Normal Activity Cost and Duration Values	Optimal Value (from Mathematical model)	Crashed Activity Cost and Duration
Crash Cost	C_x	C_{op}	C_c
Duration	T_x	T_{op}	T_c

Suppose the data of the normal and crashed costs are as represented in Table 1, it can be shown that:

$$T_{op} = \sum_{ij=1}^{ij=n} T_{op} ij \tag{13}$$

$$C_{op} = \sum_{ij=1}^{ij=m} C_{op} ij \tag{14}$$

$$T_{opij} = \frac{[(T_{xij} - T_c ij)(C_{op} ij . C_{cij})] - T_{cij}}{\Delta Cij} \tag{15}$$

$$C_{op} ij = \frac{[(C_x ij - C_{cij})(T_{opij} . T_{cij})] - C_{cij}}{\Delta T_{ij}} \tag{16}$$

Where:

T_{op} = the optimal duration to which a project can be crashed
C_{op} = the optimal cost of crashing the project duration from $T = T_x$ to $T = T_{x-p}$,
p = the amount of the crashed duration

Other variables retain their previous significance. An expression for optimal crash period and cost can be written for any number of individual activities. The project managers and construction overseers can easily determine the optimal project fast-tracking limits with better time-cost trade-offs using the proposed models.

4. MODEL VALIDATION

We validate the proposed models using literature data since the thrust of the study was to develop a model that is amenable to project managers with less computational ability to implement the sophisticated models found in literature, some of which are reviewed and listed in this paper. The mathematical modelling and theoretical approach employed does not necessarily warrant field data obtained through interviews, questionnaires and site visits or data abstraction from on-going project. Hence, literature data was deemed appropriate for illustrating the model applicability. The mathematical model of equation (4) was applied to the data from a multi-storey building project abstracted from literature (Nnadi, 2013). The basic assumption that the data was correct as contained in the author's report was made because there was no other method of cross checking its authenticity. Secondly, being a report submitted for the award of an Engineering degree in a National University, the supervisor(s) is deemed to have ensured that the data was correct since the said project is located inside the University. The minimum completion period of the project abstracted from literature was given as 685 days. The methodological procedure of this presentation allowed the determination of the feasibility of handing over the project after 2 years or otherwise. Using the excel NORMSDIST (x), $p(x \leq d) = 0.879$. The reverse shows that $1 - p(x \leq d) = 0.121$. Hence, there is about 87.9% probability that the project can be completed within the scheduled time and about 12.1 % possibility of prospects of variation. The project costs and time were crashed and sample critical path activities selected as presented in Table 2. The Lindo software was employed to solve the LP model to obtain solutions for the objective function, cost values and reduced cost values. The sample results are displayed in Table 3.

Table 2. Sample of start-time constraints for various activity predecessor events

Single Immediate Predecessor	**Double Immediate Predecessor**	**Triple Immediate Predecessor**	**Quadruple Immediate Predecessor**
$x_B \geq x_A + 26 - y_A$	$x_P \geq X_N + 27 - y_A$	$x_R \geq X_O + 35 - y_O$	$x_Q \geq X_E + 20 - y_E$
$x_C \geq X_B + 67 - y_B$	$x_P \geq X_O + 35 - y_O$	$x_R \geq X_P + 79 - y_P$	$x_Q \geq X_H + 20 - y_H$

Table 3. Sample Results

Objective function	**Final Value ($)**	**Reduced Cost Values ($)**
z	7, 867. 867	366.1188
Y_B	0	366.1188
⋮	⋮	⋮
Y_W	0	719.601
X_X	0	1, 385. 949

The optimal crash cost presented in Table 3 was applied to models (13) through (16), see Table 4, to obtain the optimal crashing duration of the project. Table 4 presents values of crash costs computed for three sample activities in the construction of a multi-storey building project.

Table 4. Optimal duration values

	Normal Activity Cost and Duration Values	Optimal Value	Crashed Activity Cost and Duration
Crash Cost	\$6, 056. 77264	\$7, 867. 98152	\$9,773.26953
Duration	637 days	$T_{op} = 631 days$	$625\ days$

5. DISCUSSION OF RESULTS

The multi-storey building cost-time trade off model proposed in this paper is a credible alternative to ubiquitous project crashing models developed in the field of project management over the years. The procedure used in developing the final model requires very less computational effort. It was interesting to realize that the usual least cost slope assumed or followed in crashing activities in the critical path was extended to a procedure which determines the optimal crash cost for a project to be fast-tracked. In particular, the optimal crash cost presented in Table 3 can guide the decision of project managers and project owners prior to embarking on a proposed crashing scheme. The technique contemplates that the project stakeholders should be well informed about the possible cost implication of altering the original settings of the project execution strategy. Thereafter, the optimal time under which the new cost must be spent or the period at which this optimal cost is valid is determined by models (13) through (16). The expected time deduced through three time estimation reduced the total completion period to 637 days; as displayed in Table 4. These results are most valid in the absence of further delays not captured during the computation of the three time estimates. For instance; natural disasters and other unforeseen states of nature can weaken the potency of estimated times. This can necessitate more supply of funds to take care of any new resource and labour demands. The two separate time measures, namely; crashed time and optimal time are worthy of note. The former gives an idea of the direct consequences of fast tracking the duration while the later indicates the optimal cost. Also, there is a strong disparity between the cost at normal duration (\$6, 056. 77264) and the crash cost at the time (9,773.26953). It is noticeable that under the arrangement, the project was crashed from 637days to 625 days, but the cost is humongous. The optimal duration of 631 days, though higher than the crash duration, presents a more cost efficient value of 7, 867. 98152 US dollars. Therefore, careful implementation of the models developed in this study makes pertinent policy statements on fast tracking a project possible, especially on a cost-time trade off perspective. With the methodology of this study, other gates have been opened for exploration of composite approaches that can be applied to account for all possible project fast-tracking eventualities. The new models to evolve can do well to pay attention to understanding and applicability issues, especially given the low literacy level still prevalent in developing economies. Poor understanding of a crashing methodology can create room for unnecessary rush which can further engender efficiency and effectiveness issues, that can compromise the quality of the completed project.

6. CONCLUSION

The set task of presenting a composite applicable model for cost-time project fast tracking undertaken in this paper has been achieved. The methodological procedures followed in formulating the models were delineated and the resulting models validated using a literature data from a real life example multi-storey project. The optimal crash time obtained was in total compliance with all the problem constraints. The implication is that a composite project crashing model is useful in achieving optimal values of important variables. Project managers and construction administrators can make purposeful policies for efficient and effective project execution with the procedures of the study.

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