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TIME-DRIVEN ACTIVITY-BASED COSTING TO OPTIMIZE CREW CONFIGURATIONS OF LINEAR REPETITIVE PROJECTS

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Abstract: Linear Repetitive Projects (LRP), such as highways and pipelines, are an important part of our infrastructure. LRP crew optimization has not been investigated in the literature. LRP depend primarily on the production rate resulting from the equipment and crew composition for each operation. Inefficient crew configuration could affect the time and cost of LRP. The objective of this research is to develop and illustrate a model for determining the optimum crew configuration assigned to complete a Linear Repetitive Project. This model will utilize Time-Driven Activity-Based Costing as a tool for tracing costs within a process back to individual activities. Monte Carlo simulation will be used to select the best crew configuration from a range of possible configurations. The research outcomes indicate that optimizing crew configurations could reduce the cost and duration of LRP and should not be overlooked. This research could help departments of transportation to reduce the cost and duration of highways and other pipeline projects.

1 INTRODUCTION

Meeting or exceeding a contractually-defined schedule objective is often one of the most important measures of project performance. The schedule, or elapsed construction time, can often be shortened by assigning excess crews (personnel plus necessary equipment) to non-controlling activities. This assures that crews assigned to the controlling activities are always working at full capacity. However, the ultimate cost consequences to the project are often difficult to estimate. This schedule compression strategy may adversely impact project cost performance because the overstaffing of non-controlling activities may result in wasted or idle time in these activities. Crew configuration plays a significant role in crew productivity. The American Association of Cost Engineers (AACE 2011) defines productivity as a "relative measure of labor efficiency, either good or bad, when compared to an established base or norm". There are many factors that affect the productivity of labor in construction. Crew configuration inefficiency is one of the most common reason for low productivity of labor (Intergraph 2012). This research utilizes Time-Driven Activity-Based Costing (TDABC) to optimize construction crew configuration to reduce schedule time. The objective of this research is to develop and illustrate a model for finding the optimum crew configuration, from a range of possible configurations, assigned to complete a defined quantity of work in a timely and cost-effective manner.

2 LITERATURE SEARCH

The concept of Activity-Based Costing (ABC) was first defined in the late 1980s by Robert Kaplan and William Burns. Initially ABC focused on the manufacturing industry where technological developments and productivity improvements had reduced the proportion of direct labor and material costs, but increased the proportion of indirect or overhead costs. ABC has attracted high levels of interest from both academics and practitioners since its emergence (Bjornenak and Falconer 2002). ABC was developed as an approach to address problems associated with traditional cost management systems, which tend to be usable to accurately determine actual production and service costs, or provide useful information for operating decisions. ABC is defined as “an approach to the costing and monitoring of activities which involves tracing resource consumption and costing final outputs. Resources are assigned to activities, and activities to cost objects based on consumption estimates. The latter utilize cost drivers to attach activity costs to outputs” (Chartered Institute of Management Accountants 2008).

ABC has been used in the construction industry for developing cost estimates in which the project is subdivided into discrete, quantifiable activities or a work unit. The activity must be definable where productivity can be measured in units (e.g., square feet of concrete pavement poured). After the project is broken into its activities, a cost estimate is prepared for each activity (Back et al. 2000). Also, ABC has been used in the construction industry to forecast the optimum duration of a project as well as the optimum resources required to complete a defined quantity of work in a timely and cost effective manner (Maxwell et al. 1998).

Although traditional ABC systems provide construction managers with valuable information, many have been abandoned or never were implemented fully. The traditional ABC system is expensive to build, time consuming to process, difficult to maintain, and inflexible when needing modification (Kaplan and Steven 2007). These problems are particularly acute for small companies that are not likely to have a sophisticated information processing system. Further, ABC is very expensive for medium-sized to large companies.

To overcome the difficulties inherent in traditional ABC, Kaplan and Steven (2007) presented a new method called “Time-Driven Activity-Based Costing (TDABC)”. The new TDABC has overcome traditional ABC difficulties, offering a clear, accessible methodology that is easy to implement and update (Kaplan and Steven 2007). TDABC relies only on simple time estimates that, for example, can be established based on direct observation of processes (Azhdari and Lalisarabi 2015).

The time-driven approach avoids the costly, time-consuming, and subjective activity-surveying task of conventional ABC. It uses time equations that directly and automatically assign resource costs to the activities performed and transactions processed. Only two parameters need to be estimated: the capacity cost rate for the project (Eq. 1) and the capacity usage by each activity in the project (Eq. 2). Both parameters can be estimated easily and objectively (Kaplan and Steven 2007). Kaplan and Steven (2007), further define the capacity cost rate and the capacity usage as follow:

[1] Capacity cost rate = total estimated cost / (total number of working hours X workers’ efficiency rate)

[2] Capacity usage rate = capacity cost rate X activity duration X quantity

To date, TDABC appears not to have been used in the construction industry and this research may be the first attempt to use TDABC to reduce construction projects’ cost and duration.

3 METHODOLOGY

3.1 Analysis Process

Construction projects that contain several identical or similar units are usually known as repetitive or linear projects. Repetitive projects are regarded as a wide umbrella that includes various categories of construction projects and represents a considerable portion of the construction industry, and contain uniform repetition of work. The objective of this research is to use Time-Driven Activity-Based Costing (TDABC) to optimize construction crew configuration to reduce repetitive projects time. This research develops a model for finding the optimum crew configuration, from a range of possible configurations, assigned to complete a defined quantity of work in a timely and cost-effective manner. The model presented by this research uses the following analysis process:

1. Develop a process flowchart in activity on node format for the activities required to perform the project.
2. Add time and cost distributions to the activity nodes.
3. Use TDABC to make estimates for the capacity usage rate of each activity.
4. Conduct simulation using Monte Carlo method for each alternatives variation of crew. The mean and standard deviation of the elapsed time and activity cost for each set of alternatives should be calculated.
5. Compute the shift cost which is equal to the actual activity cost rate times the number of shifts needed to do the work.
6. For each alternative, compute excess costs by subtracting the mean activity cost from the shift cost.
7. Select the best crew and equipment configuration depending upon best elapsed time and least excess costs.

MATLAB ® is used to computerize the above analysis process. MATLAB ® is a multi-paradigm numerical computing environment and fourth-generation programming language. The MATLAB ® language provides a variety of high-level mathematical functions you can use to build a model for Monte Carlo simulation and to run those simulations. Utilization of the MATLAB © simulation package is proposed in this research to evaluate different crew pairing alternatives and to choose the best available alternative.

3.2 Case Study Example

The literature search indicated that a case study originally presented by Maxwell (1998) could be used as a source of data to develop this model. This case study illustrates the excavation of the basement of an addition to the Texas A&M Evans Library. The project was timely and the entire operation could be videotaped from a second-story window in the existing, adjacent Evans Library building. The excavation of the basement is a good example of repetitive projects because it contains several identical activities.

The spotting of haulers, loading of haulers using a shovel, hauling to dump site and return, and stockpiling of soil units before loading were selected as the activities to be modeled based upon the contractor's plan of work. Videotaping, combined with on-site observations of these activities, occurred during Monday and Tuesday of the first week of work. First, activity times for spotting, loading, hauling and return, and stockpiling were obtained from videotape and on-site analysis of the entire operation. These data were then converted to distributions using a least-squares fitting technique (Abourizk et al. 1992). The rounded and adjusted distributions are shown in Table 1. TRI signifies a triangular distribution; UNI, a uniform distribution, and AVE an average value. For triangular distributions, the corresponding numerical values are low, most likely, and high. For uniform distributions, the values signify: lowest and highest.

Table 1: Activity time data

Activity	Activity Time Distributions (min)			
		Low	Most likely	High
20 cu yd.: load with shovel	TRI	3	6	9
20 cu yd.: haul, unload, return	TRI	18	33	48
20 cu yd.: spot for loading	TRI	14	25	36
20 cu yd.: spot for loading	TRI	1	2	4
15 cu yd.: haul, unload, return	TRI	15	28	41
		Lowest	Highest	
15 cu yd.: load with shovel	UNI	2	6	-
15 cu yd.: spot for loading	UNI	1	3	-
Shovel: maintain stockpile	UNI	3	9	-
		Average		
Shovel: idle	AVE	1	-	-

The excavation operation requires the four types of crews shown in Table 2: (1) 1.5-cu yd. shovel and operator; (2) 20 cu yd. hauler and operator; (3) 15-cu yd. hauler and operator; and (4) a spotter. The 15-cu yd. 15- cu yd. hauler and the spotter were not used on weekends. A 6-day work week with an overtime rate adjustment for weekends was used in all cases. 8-hour shifts were used in the analysis. Personnel payroll rates and equipment rental rates were obtained from the job foreman. These data were aggregated to daily and per minute rates as shown in Tables 2-4. Table 5 contains the combined crew cost rates.

Table 2: Crew operating cost rates (8-hour/day)

Cost of operation by crew	Rate/min		Rate/day	
	Weekday	Weekend	Weekday	Weekend
20-cu yd. hauler	0.9625	1.1038	462.00	529.80
15-cu yd. hauler	0.8617	-	413.60	-
1.5-cu yd. shovel	1.4246	1.5975	683.80	766.80
Spotter	0.1667	-	80.00	-

Table 3: Labor cost rates (8-hour/day)

Labor Cost	Wage/hr	Weekday/min	(Weekend/min) * 1.5
Truck driver	16.95	0.2825	0.4238
Shovel Operator	20.75	0.3458	0.5188
Spotter	10.00	0.1667	0.2500

Table 4: Equipment cost rates (8-hour/day)

Equipment Cost	Rate/day	Weekday/min	Weekend/min
20-cu yd. hauler	326.40	0.6800	0.6800
15-cu yd. hauler	278.00	0.5792	0.5792
1.5-cu yd. shovel	517.80	1.0788	1.0788

Table 5: Combined crew cost data

Rates	Dollars/Minutes Costs	
	Weekday	Weekend
20 cu yd.: load with shovel	2.39	2.70
20 cu yd.: haul, unload, return	0.96	1.10
20 cu yd.: spot for loading	1.13	1.10
15 cu yd.: load with shovel	2.29	-
15 cu yd.: haul, unload, return	0.86	-
15 cu yd.: spot for loading	1.03	-
Shovel: idle	1.42	1.60
Shovel: maintain stockpile	1.42	1.60
20 cu yd.: waiting for stockpile	0.96	1.10
20 cu yd.: waiting for shovel	0.96	1.10
15 cu yd.: waiting for stockpile	0.86	-
15 cu yd.: waiting for shovel	0.86	-
Shovel: waiting for hauler	1.42	1.60

Table 5 shows the dollars per minutes cost for the activity and control nodes. The data available in Table 5 will be adapted as the capacity usage rate variable in the Time-Driven Activity-Based model. Further, the combined crew cost rates in Table 5 will be used in the Monte Carlo simulation to select the best crew configuration. The result obtained from TDABC model will be compared with the result published by Maxwell (1998) who used traditional ABC. To compare the two results, a statistical analysis will be conducted. Namely analysis of variance (ANOVA) will be used to determine if the simulation outputs are different (Devore 2016). The analysis target is to quantify the magnitude of improvement that TDABC model presents.

4 MODEL VALIDATION

Before the model proposed by this research can be applied in the construction industry, it should be verified and validated. Model verification and validation is an important step to demonstrate that the newly developed model is a suitable approach to solving the research problems and that the model runs correctly. Model verification will involve two steps. The first step is to ensure that the model performs the required functions and that the numerical procedures are correct. The second step is to solve any errors or inconsistencies in the model. To verify the integrated model, a numerical example drawn from the literature will be used. The result of this example will be calculated manually and through the use of the model. The results will be compared to verify that the model procedures are correct and the model performs as expected. Model validation is a more complex issue since it measures the soundness and effectiveness of the model. The model validation answers the question, “Does the model solve the research problems?”. Badiru (1988) stated that model validation can take several forms such as measuring performance level, measuring level of deviation from expected outputs, and measuring the effectiveness of the model output in solving the problem under consideration. In order to validate the TDABC model, MATLAB © codes will be applied to case studies drawn from literature. Other pertinent validation approaches will also be examined (i.e., face validation).

5 RESULT

The goal of this research is to develop and illustrate a model for finding the optimum resources required to complete a defined quantity of work in a timely and cost effective manner. The concept of Time-Driven Activity-Based Costing (TDABC) is used to define the scope of the work in terms of activities to be accomplished. Monte Carlo simulation is used to select the best crew configuration from a range of possible configurations. The expected research outcomes indicate that optimizing crew configurations could reduce the cost and duration of repetitive projects and should not be overlooked. This research could help departments of transportation to reduce the cost and duration of highways and other pipeline projects. The model presented in this research has great potential for designing midcourse corrections for projects that have gone out of control; and they are experiencing cost and/or schedule overruns. Future research could include the integration of TDABC with other optimization techniques to provide a more comprehensive model.

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