TIME PREDICTION MODEL FOR HIGHWAY CONSTRUCTION

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Abstract

This paper presents a time prediction model for asphaltic road construction. The model is developed by determining factors influencing the time duration of critical activities and lag times. The critical activities are classified into five groups: preparation, earthwork, subbase, base and incidental. The data of forty completed highway projects during 1992 to 1997 are collected from the Department of Highways in Thailand. Using a multiple regression method, the time prediction equations of all critical activities and lag times are developed. The total project duration can be estimated using a Critical Path Method (CPM) by summing the predicted times of activities which are on the critical path. The average errors from the prediction model and the traditional estimation method when compared with the actual construction time of the seven new completed projects are within $\pm$13% and $\pm$28%, respectively. The estimation time from the prediction model is also highly correlated with the actual project time. As a result, the model provides a reasonable estimate for the project duration of asphaltic road construction, especially when using the result in the planning stage.

1. Introduction

The estimation of construction time is one of the key factors for planning and managing projects effectively. Traditionally, the estimation of road project duration usually relies on the estimator's judgment and experience based on the productivity rate of construction machines [1-3]. As a result, some factors that affect the variation of construction time are often disregarded.

The actual completion times of many road construction projects indicate a large error in the traditional estimation. For example, more than sixty percent of completed road projects in Thailand in between 1996 to 1998 were delayed from their schedules [4]. Although several mathematical and statistical models have been developed in order to help make project duration estimation easier and more accurate, the models still have some limitations. For instance, factors influencing the construction time are not sufficiently incorporated to estimate project duration [5-6]. In addition, highly subjective judgment is used to identify the influencing factors [7]. The purpose of this research is thus to develop a time estimation model for highway construction based on historical data of factors affecting project duration by using a statistical approach.

2. Methodology & Model Development

Traditionally, road construction in Thailand uses a bar chart as a planning tool because it is easily developed and understood. Therefore, this research uses a bar chart as a basis to develop a model. Based on a bar chart, the major construction activities and their sequential lag times are determined by observing master plans and actual construction schedules of historical project information and interviewing project managers and planners. Using a critical path method (CPM), only critical activities that have large errors between planned and actual time are considered. Next, the factors affecting each critical activity and lag time are identified based on a literature survey [3, 8-9]. Experts in road construction in Thailand are consulted to review

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these factors in order to select only significant ones. Finally, the model is developed based on a multiple regression method. The data are from forty highway construction projects completed between 1992 and 1997, in order to exclude the effect of the economic recession. Data include the actual construction time for each activity and thirty-four time-influencing variables, both quantitative and qualitative. A backward estimation procedure at a 95% confidence level is utilized to select only statistically significant variables to be incorporated into the model.

The major construction activities were classified into seven primary work packages: preparation, earthwork, subbase, base, surface, structure, and incidental, as shown in Figure 1. After reviewing several actual construction schedules and interviewing experts, the structural work and surface work is excluded because it is usually not determined as a critical activity. Therefore, only five primary activities (not including structure and surface) are used to develop the model. In addition, five lag times (A, B, C, D, E) which link between activities are assumed to have a start-to-start relationship. For example, the subbase activity can start only after the earthwork activity has started for at least Lag A days.

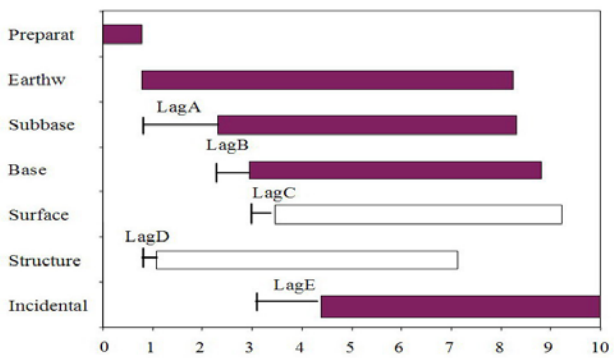

Figure 1 The major activities and their sequential lag times of road construction

After the critical activities and lag times are selected, the next step is to identify factors influencing each critical activity and their sequential lag times by reviewing the literature and interviewing ten project managers. Dependent and independent variables, both quantitative and qualitative, are finally designated using historical data mentioned previously. The results from the regression analysis are given below.

3. Results of Analysis

Table 1 summarizes the results from a regression analysis of the five major activities: preparation, earthwork, subbase, base, incidental and three sequential lag times among these activities.

Table 1 Results of regression analyze of critical activities and lag times

Activities	R^2	Adjusted R^2	F-Sig.	Type
Preparation	0.551	0.500	0.000	Linear
Earthwork	0.712	0.612	0.000	Exponential
Subbase	0.632	0.537	0.000	Linear
Base	0.769	0.748	0.000	Linear
Incidental	0.624	0.600	0.000	Linear
Lag A (Earthwork →Subbase)	0.881	0.859	0.000	Linear
Lag B (Subbase→ Base)	0.807	0.789	0.000	Linear
Lag E (Base→ Incidental)	0.875	0.861	0.000	Linear

For example, the values of R^2, adjusted R^2 and the F-statistic of the linear regression equation of subbase activity are 0.735, 0.705 and 0.000 respectively. This means that the relationship between the dependent variable and the independent variables can be explained by the equation at the 95 percent confidence level.

From the analysis, the regression equations are derived for each critical activity and their sequential lag times. The time prediction equations for all critical activities and lag times, which are represented in days, are shown in Equations 1-8. The total project duration can be also estimated by the sum of durations of all activities and lag times that are on the critical path, as shown in Equation 9.

$$\text{PREPARATION TIME (days)} = 44.54 + 12.47\text{Rainfall} - 0.33\%\text{Urban} + 30.23\text{Rolling} + 54.76\text{Mountainous} \quad (1)$$

$$\text{EARTHWORK TIME (days)} = \text{Exp}\,[3.69 + 0.18\text{Rainfall} + 0.24\text{Mountainous} + 0.36\text{Medium CBR} + 0.84\text{Bad CBR} + 1.65(10)^{-2}\text{Length} + 0.27\text{Wide} - 0.04\text{ S\_roller} - 3.33(10)^{-3}\text{Truck}] \quad (2)$$

$$\text{SUBBASE TIME (days)} = -19.88 + 135.98\text{Rainfall} + 2.25(10)^{-3}\text{Subbase Vol.} + 141.76\text{Mountainous} + 14.58\text{Subbase Thk.} \quad (3)$$

$$\text{BASE TIME (days)} = -131 + 187.23\text{Rainfall} + 46.87\text{Wide} + 4.96\text{Length} \quad (4)$$

$$\text{INCIDENTAL TIME (days)} = -956.78 + 1.50(10)^{-3}\text{Sodding} + 4.51\%\text{Urban} + 113.73\text{Wide} + 153.18\text{Lane} \quad (5)$$

$$\text{LAG A (days)} = -181.32 + 31.12\text{Rainfall} + 3.42(10)^{-4}\text{ Select Vol.} - 5.06\text{Grader} + 199.73\text{Earthwork/Subbase} \quad (6)$$

$$\text{LAG B (days)} = -79.86 - 3.43\text{ V\_roller} + 0.04\text{Subbase Time} + 109.63\text{Subbase/Base} \quad (7)$$

$$\text{LAG E (days)} = -81.89 + 1.16\%\text{Urban} + 3.49(10)^{-4}\text{ Sodding} + 97.46\text{Base/Incidental} \quad (8)$$

$$\text{TOTAL TIME (days)} = \text{PRERARE TIME} + \text{LAG A} + \text{LAG B} + \text{LAG E} + \text{INCIDENTAL TIME} \quad (9)$$

The descriptions of all variables are briefly explained in the Appendix. The errors from the estimation model and the traditional method compared with the actual duration of each activity are shown in Figure 2. It can be noticed that the prediction model gives more accurate predictions than the traditional estimation method for all activities.

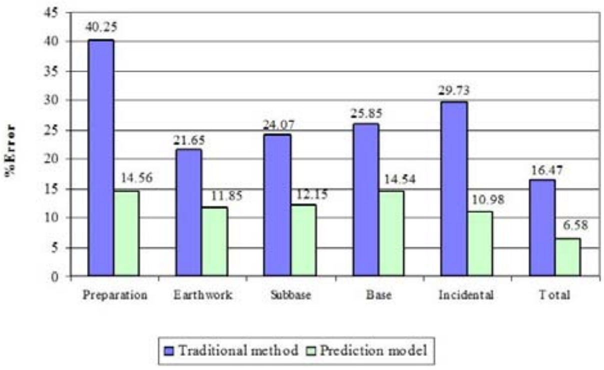

Figure 2 The percentage errors of planed project duration in each activity

Table 2 shows the major variables influencing each activity durations based on the beta coefficients from the regression analysis. For example, the variable that mostly affected the preparation time is Mountainous. Hence, estimators and planners should be careful about the accuracy of these variables when using this time prediction model.

Table 2 The major variables influencing activity durations

Dependent Variables	Major Influencing Variables
Preparation	Mountainous
Earthwork time	Bad CBR, Medium CBR, Length
Subbase time	Subbase Vol., Rainfall
Base time	Rainfall, Length
Incidental time	Lane, Sodding
Lag A	Earthwork/Subbase
Lag B	Subbase/Base
Lag E	Base/Incidental

4. Testing of Model

The predictive validity of the prediction model was tested by an analysis of the correlation between estimated time and actual times of all activities. The correlation coefficients of all activity times, lag times, and the total project time are greater than 0.837 as shown in Table 3.

The predictive accuracy of the project time prediction model was tested using seven new completed asphaltic road projects, which were not incorporated into the model. The errors of total project duration prediction using the prediction model are considerably less than those traditional estimation approaches, as shown in Table 4. Hence, the prediction model could give more accurate time prediction than the traditional approach.

Table 3 Correlation analysis between predicted times and actual times

Activities	Correlation Coefficient
Preparation time	0.896
Earthwork time	0.885
Subbase time	0.856
Base time	0.837
Incidental time	0.953
Lag A	0.967
Lag B	0.894
Lag E	0.957
Total time	0.956

Table 4 Errors of project time estimation using seven new projects data

Estimation Method	Prediction Model	Traditional Method
%Av.Error (+)	+10.06	+25.06
%Av.Error (-)	-12.88	-27.63
%Max.Error (+)	+19.77	+33.33
%Max.Error (-)	-19.29	-47.00

5. Conclusions

The objective of this research is to develop a time estimation model for asphaltic road construction projects during the planning phase. The factors affecting major activities and their sequential lag times are incorporated to establish the model as identified by a literature survey and expert interviews. The major activities, which are on the critical path, are classified into five groups: preparation, earthwork, subbase, base and incidental. Based on the critical path, a regression analysis of historical data is used to develop the time prediction equation for each critical activity and their sequential lag times.

The historical data were obtained from forty highway construction projects, which were completed between 1992 and 1997. The result of the derived model is then verified by comparing the estimation errors from the actual construction times. The maximum errors from the prediction model fell within a reasonable range ±20%, while the maximum errors of the traditional estimation method are +33% and -47%.

The time estimation model developed in this research serves as a convenient and useful tool to predict times for asphaltic road projects with a reasonable accuracy during the planning stage. Furthermore, it helps estimators and planners to be aware of the time influencing variables, which may cause project delay.

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Appendix

The variables in the prediction models are described as follows

Variables	Description	Unit
Base/Incidental	Ratio of base and incidental times	Ratio
Bad CBR	CBR less than 2	Yes/No
Earthwork/ Subbase	Ratio of earthwork and subbase times	Ratio
Grader	Number of grader	Grader
Lane	Number of lanes	Lane
Length	Length of road	Kilometer
Medium CBR	CBR between 3-5	Yes/No
Mountainous	Geographical gradient more than 7%	Yes/No

Variables	Description	Unit
Rainfall	Rainfall area > 1,500 mm./yr.	Qualitative
Rolling	Geographical gradient 5-	Yes/No
S_Roller	Number of steel wheel	Roller
Select Vol.	Selected material volume	Cubic meter
Sodding	Sodding volume	Square meter
Subbase/Base	Ratio of subbase and base times	Ratio
Subbase Thk.	Subbase thickness	Centimeter
Subbase Time	Subbase Time	Days
Subbase Vol.	Subbase volume	Cubic meter
Truck	Number of truck	Truck
%Urban	Percentage of urban area	Percent
V_Roller	Number of vibrator wheel	Roller
Wide	Width of road	Meter