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Empirical Analysis of Lump Sum Pay Item Prices for Highway Projects

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Cost estimates for Lump Sum (LS) pay items are typically completed using historical information from similar projects or knowledge from subject matter experts. Since LS pay items are mainly unitless and do not have a consistent relationship with their quantities, it imposes a critical burden on estimating accurate prices of LS pay items for highway projects. State highway agencies (SHAs) often encounter significant variations in prices of LS pay items throughout the project development process. Inaccuracies of prices of LS pay items can cause significant cost escalation, project delay, and scope change. However, the current literature indicates that few studies have focused on exploring factors affecting the prices of LS pay items for highway projects. Thus, the overarching objective of this study is to identify and analyze factors affecting the prices of LS pay items used for highway projects. This study analyzed Traffic Control Lump Sum (TCLS) and Grading Complete Lump Sum (GCLS) pay items collected in the state of Georgia, using statistical analysis. This study identified the relationships between the prices of the LS pay items and important project-related factors, such as construction cost, estimated contract time, and major projects. The findings of this study help SHAs estimate more accurate prices of LS pay items and develop more accurate construction costs for highway projects.

Key Words: Big Data, Lump Sum Items, Regression Analysis, Tukey-Kramer Post-hoc Analysis

Introduction

State highway agencies (SHAs) in the United States often encounter inaccuracy of cost estimates for their highway projects during the project development process (PDP) because of a lack of reliable and complete project information. Since the project scope and design are not complete during the PDP, cost estimators/engineers in state highway agencies (SHAs) have difficulties in developing accurate cost estimates for pay items of a highway project. Inaccuracy of cost estimates during the PDP can trigger significant cost discrepancies, scope changes/creep, project delays/cancellations. SHAs use pay items to represent works following the agencies' standard specifications for highway construction and contract documentation (Baek et al. 2016; Baek and Ashuri 2021). During the PDP, the detailed quantities and specific pay items that are representative of projects' scope and design should be determined to ensure accurate cost estimates of projects. Thus, it is critical to develop accurate cost estimates for individual pay items, which produces total construction costs for highway projects.

Several studies have focused on identifying factors affecting pay items of construction projects to improve the accuracy of construction costs. For instance, Wilmot and Cheng (2003) studied 2,827 highway and bridge contracts, collected in the state of Louisiana to estimate the cost of highway projects using key pay items, such as embankment, concrete pavement, and asphalt pavement. The authors utilized a regression analysis in developing multiplicative formulations of key pay items for forecasting the future construction cost. This study also showed that item prices are significantly influenced by several factors, such as the quantity of a pay item and the location of contracts. Chou et al. (2006) developed a preliminary cost-estimating system by analyzing 2,222 projects, collected in the state of Texas. This study estimated the total cost of a project using the predicted quantities of the major work items (e.g., excavation, flexible base, and work zone pavement markings). Shrestha et al. (2014) study 151 road projects in the state of Nevada to determine the correlation between the bid costs of unit price items and quantities of items. The author developed regression models to forecast bid costs of unit price items and showed that the quantities of items have a critical impact on estimating bid costs of unit price items.

A study conducted by Ilbeigi et al. (2015) analyzed 841 highway projects in the state of Georgia to evaluate the impact of price adjustment clauses on the unit bid price of asphalt line items. The authors developed regression models and identified several important variables that affect the bid price of asphalt line items, such as the quantity of the line item, total contract price, and the asphalt cement price index. Cao et al. (2018) used more than 1,400 highway projects to predict the unit prices bids for resurfacing projects. The authors identified 20 most important features through the Boruta analysis, such as geographical characteristics of a project location (e.g., terrain, region), the quantities of bid items, and the number of asphalt cement plants around a project location and used them in developing a forecasting model for unit price bids. In follow-up work, Baek and Ashuri (2019) analyzed the submitted unit price bids for major asphalt line items used for resurfacing and widening projects let in the state of Georgia between 2008 and 2015. The authors developed a random parameter model to estimate the unit price bids for asphalt line items while taking into account unobserved heterogeneity of the geographical location and time of a project. The authors identified important factors affecting the unit price bids for asphalt line items, such as the quantity of the item, total contract price, and pavement length.

Although the current literature shows that a wide range of factors affects cost estimates for pay items that are the unit basis, few studies focus on Lump Sum (LS) pay items, such as Clearing & Grubbing, Grading Complete, Mobilization, and Traffic Control. Cost estimates for LS pay items are typically completed using historical information from similar projects or knowledge from subject matter experts. LS pay items are mainly unitless and do not have a consistent relationship with their quantities (Shrestha et al. 2017), which can cause significant variations in the prices of LS pay items. Furthermore, the relationships between project-related factors and LS pay items prices are not clearly defined through an empirical study. Therefore, the objective of this study is to identify and analyze important factors that affect cost estimates of LS pay items, including Traffic Control and Grading Complete using statistical analysis.

Research Methodology and Data Collection

The overarching objective of this study is to identify and analyze factors affecting the prices of LS pay items used for highway projects. Thus, this study conducts statistical analysis, including Pearson correlation analysis, Tukey Kramer Post-hoc analysis, and multiple regression analysis, to identify important project-related factors for prices of LS pay items. This study analyzed Traffic Control and Grading Complete LS pay items developed at the final design development of PDP. The descriptive statistics for the LS pay items used for highway projects in the state of Georgia are provided in Table 1. A Traffic Control Lump Sum (TCLS) pay item represents work for managing mobility and safety impact within a project work zone and addressing traffic safety and control through the work zone using several items such as Guardrails, traffic signals, and pavement markings. And a Grading Complete Lump Sum (GCLS) pay item is for earthwork on highway or road including excavating of all materials (e.g., ditches and undesirable materials), hauling, formatting, embankments, construction shoulders, subgrades, etc.

Table 1

Descriptive Statistics of Lump Sum Items

Lum Sum Pay Items	N	Minimum	Maximum	Mean	Std. Deviation
Price for TCLS Pay Item	309	$ 10,500.000	$ 5,826,501.000	$ 309,223.965	$ 643,675.805
Price for GCLS Pay Item	267	$ 5,000.000	$ 8,739,752.000	$ 665,817.711	$ 1, 287,034.798

In addition, project-related factors were collected from the Georgia Department of Transportation (GDOT) project development documents, including GDOT Concept Report, Field Plan Review (FPR) Reports, and Preconstruction Status Reports (PSR). The list of potential variables is provided in Table 2.

Table 2

List of Potential Variables for TCLS and GCLS Pay Items

Variables	Descriptions (Sources)	Units
Construction Cost	The total amount of all pay items for a project (GDOT Concept Report)	$
Traffic Volume (ADT)	Average daily traffic (ADT) represents the total volume of vehicle traffic on a highway or road (Field Plan Review Reports)	Number
Percentage of Trucks	The Percentage of Trucks on a highway or road (Field Plan Review Reports)	%
Number of Parcels	Number of parcels for the right of way (Field Plan Review Reports)	Number
Estimate Contract Time	Estimate contract duration (Field Plan Review Reports)	Month
Traffic Control Plans	Traffic control plans contain four types for a highway or road, including (Field Plan Review Reports): • Detours • Lane Closures • Lane Closures and Detours • Lane Closures, Detour, and Flagging Operations • Lane Closures and Flagging Operations • Traffic Restrictions • No Traffic Restrictions	Boolean Indicator
Project Types	Project types (Field Plan Review Reports): • New Highway Projects (widening, new location roadways, and interchange reconstruction) • Maintenance Projects (resurfacing, pavement preservation, and restriping) • Bridge Program (maintenance and replacement of an existing bridge)	Boolean Indicator

	• Location Specific Improvements (roundabout, intersections, traffic signal, pedestrian upgrade, lighting, advanced traffic management, etc.) • Systemic Improvements (guardrail, cable barrier, drainage, culvert, and nose wall)	
Major Projects	A project that has significant amounts of right-of-way acquisition, a significant change in travel patterns, or significant social, economic, or environmental effects (Field Plan Review Reports)	Boolean Indicator
Urban	Urban: an area designated by the Bureau of the Census (a population of more than 5000), Rural: an area designated by the Bureau of the Census (a population of less than 5000) (Field Plan Review Reports)	Boolean Indicator
Project Length	Length of the project (Preconstruction Status Report)	Miles
MPOs	Areas with a population greater than 50,000, defined by the U.S. Census (Preconstruction Status Report)	Boolean Indicator
Environmental Document Types	Environmental Documentation Process Types (Preconstruction Status Report): NEPA [the National Environmental Policy Act] is for projects involving federal funds or projects requiring a USDOT action. GEPA [the Georgia Environmental Policy Act] is for projects not involving Federal Funds or a project not requiring a USDOT action.	Boolean Indicator
GDOT Districts	GDOT Seven Districts (District 1-District 7) (Preconstruction Status Report)	Boolean Indicator

Results and Discussions

Pearson correlation analysis is conducted to identify significant correlations between LS pay item price and continuous variables. For the TCLS pay item, five continuous variables, including construction cost for a project, traffic volume average daily traffic (ADT), number of parcels, estimate contract time, and project length. For the GCLS pay item, six variables, including construction cost for a project, traffic volume (ADT), percentage of trucks, number of parcels for Right of Way, estimate contract time, and project length are used. The null hypothesis of Pearson correlation analysis is that there is not a significant correlation between LS pay item prices and explanatory in the population. The alternate hypothesis is that there is a significant correlation between LS pay item prices and explanatory in the population. Figure 1 shows the results of the Pearson correlation analysis for LS pay items. The results concluded that total prices of pay items for a project and estimated contract time are significantly correlated with the prices of TCLS pay items at a significant level α = 5%. In addition, the construction cost for a project, traffic volume (ADT), number of parcels for Right of Way, and estimated contract time are significantly correlated with the GCLS pay item prices at a significant level α = 5%.

(a) Pearson Correlation for TCLS Pay Item (b) Pearson Correlation for GCLS Pay Item

Figure 1. Results of Pearson Correlation Analysis for TCLS and GCLS Pay Items

This study evaluated mean differences of LS item prices between each pairwise combination of groups using a Tukey-Kramer Post-hoc Test. Group variables for TCLS pay items are traffic control plans, project types, major projects, urban, MPOs [metropolitan planning organization], environmental document type, and GDOT seven districts. The null hypothesis of the Tukey-Kramer Post-hoc test is that the two group means of LS pay item price are not significantly different, while the alternate hypothesis is that two group means of LS pay item price are significantly different. Table 3 and 4 provides the results of Tukey-Kramer Post-hoc tests for LS pay items that show pairs that have significant differences between two pairs of groups at a significant level α = 5%. The Tukey-Kramer Post-hoc test revealed that the prices of TCLS pay item of a project that uses lane closures, detour, and flagging operations are significantly higher than the prices of a project that have other traffic control plans, including lane closures, traffic restrictions, or no traffic restrictions at a significant level α = 5%. Also, there are no significant mean differences in the prices of TCLS pay items for the following comparisons of type of traffic control plans, including lane closures, detours, traffic restrictions, and no traffic restrictions. In addition, the prices of TCLS pay items for new highway projects are significantly higher than the prices for bridge programs, location-specific improvement projects, and systemic improvement projects at a significant level α = 5%. However, there are no significant mean differences in the prices of TCLS pay items for the following comparisons of project types, including bridge programs, location-specific improvements, maintenance projects, and systematic improvements. The prices of TCLS pay item for major projects are significantly higher than the prices for minor projects at a significant level α = 5%. The prices of TCLS pay items for projects, located in MPO areas are significantly higher than the prices for projects, located in non-MPO areas at a significant level α = 5%. Interestingly, group variables, including environmental document types and GDOT districts are not defined as significant group variables in terms of mean differences of TCLS pay item prices within different groups.

Table 3

Results of Tukey-Kramer Post-hoc Test for Traffic Control Lump Pay Item

Group Variables	Group 1	Group 2	Mean Difference	Lower	Upper	*P*-Value
Traffic Control Plans	Lane Closures	Lane Closures, Detour, and Flagging Operations	638768.302	139066.582	1138470.000	0.003*
	Lane Closures, Detour, and Flagging Operations	Traffic Restrictions	690957.216	91274.420	1290640.000	0.012*
	Lane Closures, Detour, and Flagging Operations	No Traffic Restrictions	751749.731	213003.791	1290496.000	0.001*
	Lane Closures and Flagging Operations	No Traffic Restrictions	480564.121	34440.099	926688.100	0.025*
Project Types	New Highway Projects	Bridge Program	698078.062	448411.500	947744.600	0.001*
	New Highway Projects	Location Specific Improvement Projects	659615.121	422419.900	896810.400	0.001*
	New Highway Projects	Systemic Improvements	797848.507	417764.200	1177933.000	0.001*
Major & Minor	Major Projects	Minor Projects	790575.182	633757.166	947393.198	0.001*
Urban & Rural	Rural	Urban	144721.047	654.678	288787.415	0.049*
MPO & Non MPO	Non MPOs	MPOs	218091.116	72275.884	363906.347	0.004*

Note: * indicates that null hypothesis is rejected at a significant level α = 5%.

Moreover, Table 4 provides the results of the Tukey-Kramer Post-hoc Test for the GCLS pay item. The results showed that the prices of GCLS pay items for new highway projects are significantly higher than the prices of the LS pay items for bridge program, location-specific improvement projects, systemic improvement projects at a significant level α = 5%. Besides, the prices of GCLS pay items for major projects are significantly higher than the prices for minor projects at a significant level α = 5%. The prices of GCLS pay items for projects, located in urban areas are significantly higher than the prices for projects, located in rural areas at a significant level α = 5%. The prices of GCLS pay items for projects, located in MPO areas are not significantly different from the prices for projects, located in non-MPO areas at a significant level α = 5%. However, there is no statistical evidence that the prices of GCLS pay items for projects are significantly different in group variables, including terrain types, environmental document types, and GDOT districts, at a significant level α = 5%.

Table 4

Results of Tukey-Kramer Post-hoc Test for Traffic Control Lump Pay Item

Group Variables	**Group 1**	**Group 2**	**Mean Difference**	**Lower**	**Upper**	***P*-Value**
Project Types	New Highway Projects	Bridge Program	2086340.000	1578257.000	2594424.000	0.001*
	New Highway Projects	Location Specific Improvement Projects	2194930.000	1686847.000	2703014.000	0.001*
	New Highway Projects	Systemic Improvements	2382542.000	1790288.000	2974796.000	0.001*
Major & Minor Projects	Major Projects	Minor Projects	2377093.000	2037808.000	2716379.000	0.001*
Urban & Rural	Rural	Urban	482987.326	177396.650	788578.002	0.002*
MPO & Non MPO	Non MPOs	MPOs	549516.558	236715.178	862317.938	0.001*

Note: * indicates that null hypothesis is rejected at a significant level α = 5%.

Lastly, this study conducted a regression analysis to estimate the relationship between the prices of LS pay items and explanatory variables. The null hypothesis of regression analysis is that there is no statistically significant relationship between the prices of LS pay items and an explanatory variable, while the alternate hypothesis is that there is a statistically significant relationship between the price of an LS pay item and an explanatory variable. Through Pearson correlation and Tukey-Kramer Post-hoc tests, input variables for developing regression models for LS pay items were identified. Seven variables used for developing an exploratory model for the prices of TCLS pay items include construction cost for a project, estimate contract time, traffic control plans, project types, major projects, urban areas, and MPO areas. In addition, in developing an exploratory model for the prices of GCLS pay items, eight variables, including construction cost for a project, ADT, number of parcels for Right of Way, estimate contract time, project types, major projects, urban areas, and MPO areas.

Table 5 provides the results of regression analysis for the prices of TCLS pay items. Through the stepwise feature selection process, five variables are included in the exploratory model for traffic control items. The result indicates that there is a positive relationship between the prices of TCLS pay items and construction cost for a project while holding other variables in the model constant. In other words, as the project size increases, the price of the traffic control item increases. Also, bigger projects are more likely to have a greater price for traffic control. As the project size is one of the major attributes affecting traffic management plans for all road projects, larger projects require a greater number of traffic management plans for the projects because the larger projects typically have a higher impact on the public (e.g., traffic delays and safety concerns). In addition, estimated contract time has a positive relationship with the prices of TCLS pay items, while holding other variables constant. The result indicates that as the duration of a project increases, the price of TCLS pay item for a project increases.

Moreover, the prices of TCLS pay items for major projects tend to be higher than the prices of TCLS pay items for minor projects, where have fewer project requirements such as amounts of right-of-way acquisition, changes in travel patterns, and social, economic, or environmental effects. A binary variable of lane closures, detours, and flagging operations, one of the binary variables of traffic control plans, is identified as an important variable in a regression model. On average, the price of the TCLS pay item for a project that contains the traffic plans, including lane closures, detours, and flagging operations, is higher than the price of the traffic control items for a project that contains fewer traffic control plans. The more the traffic control plans in a project, the higher the price for the TCLS pay item for a project. Next, projects located in MPO areas tend to have higher prices of TCLS pay items for projects than the prices for projects located in non-MPO areas. As projects in the MPO areas are expected to have greater impacts on the traveling public, the risk to works, and the volume of traffic, it requires greater attention for traffic control, which increases the price of the traffic control item in a project.

Table 5

Result of Regression Analysis for Price of Traffic Control Lump Sum Pay Item

Model	**Unstandardized Coefficients**		**Standardized Coefficients**	***P*-Value**	**Collinearity Statistics**
	B	Std. Error	Beta		VIF
(Constant)	-196716.665	73523.111		0.008*	
Construction Cost	0.024	0.003	0.428	0.000*	1.698
Estimated Contract Time	12161.674	3997.874	0.183	0.003*	2.033
Major Projects	190416.482	92135.094	0.119	0.040*	1.861
Lane Closures, Detours, and Flagging Operations	313923.198	128213.564	0.105	0.015*	1.038
MPO Areas	126478.013	55900.437	0.096	0.024*	1.017

Note: * indicates that the Null Hypothesis is rejected; VIF indicates the variance inflation factor; B indicates unstandardized coefficients.

Table 6 shows the results of regression analysis for the prices of the GCLS pay item. Through the stepwise feature selection process, six variables were included in the model. The result of an exploratory model of the GCLS pay item indicates that there is a positive relationship between the price of the GCLS pay item and construction cost for a project while holding other variables constant. As the project size increases, the price of the GCLS pay item increases. The bigger the project size, the more the earthwork required. It results in an increase in the price of the GCLS pay item for a project. In addition, on average, the price of the GCLS pay item for new highway projects is higher than the price for other project types (e.g., bridge program, maintenance projects, and improvement projects). Traffic volume (ADT) also shows a positive relationship with the prices of GCLS pay items. The larger traffic volume on a project location is the higher prices for GCLS pay items. Similarly, the number of parcels for Right of Way is determined as an explanatory variable with a negative relation with the prices of GCLS pay items. The higher the number of parcels for Right of Way the higher the prices of GCLS pay items. Furthermore, it is found that estimated contract time for a project has a positive relationship with the prices of GCLS pay items. The result shows that the project duration is a critical factor for estimating the prices of GCLS pay items. Lastly, the prices of GCLS pay items for major projects are, on average, more likely to be higher than those for minor projects.

Table 6

Result of Regression Analysis for Price of Grading Complete Lump Sum Pay Item

Model	Unstandardized Coefficients		Standardized Coefficients	P-Value	Collinearity Statistics
	B	Std. Error	Beta		VIF
(Constant)	-264155.499	116887.453		0.025*	
Construction Cost	0.053	0.007	0.356	0.000*	
New Highway Projects	564605.462	179503.375	0.155	0.002*	1.786
Traffic Volume (ADT)	13.128	2.848	0.192	0.000*	1.961
Number of Parcels	3665.681	1731.439	0.108	0.035*	1.393
Estimated Contract Time	19824.413	7528.615	0.137	0.009*	2.096
Major Projects	472497.495	191502.680	0.129	0.014*	2.177

Note: * indicates that the Null Hypothesis is rejected; VIF indicates the variance inflation factor; B indicates unstandardized coefficients.

The results of the Analysis of Variance (ANOVA) tests are provided in Table 7. The null hypothesis is rejected at a 1% significance level indicating that overall, a combination of the identified variables used to build the stepwise regression models for both TCLS and GCLS pay items is statistically significant for explaining variation in the prices of TCLS and GCLS pay items. The adjusted R-squared for a regression model for the TCLS pay item is 0.454 (45.4%). The developed model explained 45.4% of the variance of the prices of TCLS pay items. Furthermore, the adjusted R-squared value for a regression model of the GCLS pay item is 0.670 (67%), which indicates that the developed regression model can be considered a good fit for observed prices of GCLS pay items. Therefore, it is concluded that the developed regression models for the prices of TCLS and GCLS pay items performed well in explaining the variation of the collected data of the LS pay items.

Table 7

Summaries of Regression Models for TCLS and GCLS Pay Items

TCLS Pay Item						
		Sum of Squares	**DF**	**Mean Square**	***F*-Value**	***P*-Value**
ANOVA	Regression	59094066467380.500	5	11818813293476.100	52.267	<.001
	Residual	68516044544274.000	303	226125559552.059		
	Total	127610111011654.000	308			
						Adjusted R Square = 0.454 (45.4%)
GCLS Pay Item						
		Sum of Squares	**DF**	**Mean Square**	***F*-Value**	***P*-Value**
ANOVA	Regression	298364091822523.000	6	49727348637087.100	90.888	<.001
	Residual	142253887845632.000	260	547130337867.814		
	Total	440617979668154.000	266			
						Adjusted R Square = 0.670 (67%)

Note: DF indicates the degree of freedom

Conclusions

The primary objective of this study is to identify and analyze factors that affect the prices of LS pay items for highway projects. This study used prices of Traffic Control Lump Sum (TCLS) and Grading Complete Lump Sum (GCLS) pay items used for highway projects in the state of Georgia. To achieve the goal of this study, Pearson correlation analysis, Tukey-Kramer Post-hoc test, and multiple regression analysis were conducted. The Tukey Kramer Post-hoc revealed that the prices of TCLS and GCLS pay items are significantly different in four common group variables including project types, major projects, urban areas, and MPO areas. Furthermore, multiple regression analysis for TCLS and GCLS identified the best combination of variables, such as construction cost, estimate contract time, and major projects, for estimating the prices of the LS pay items. The regression analysis revealed that construction cost and estimate contract time have positive relationships with the prices of TCLS and GCLS pay items. The projects that contain traffic control plans including lane closures, detour, and flagging operations are significantly higher prices of TCLS pay items than those that contain fewer traffic control plans. In addition, it can be concluded that more complex projects, represented by major projects, tend to have higher prices for the LS pay items.

The primary contribution of this study to the body of knowledge is that this study explored project-related variables that have not been used in previous research and identified the relationships between the prices of the LS pay items and important project-related factors. SHAs can use the identified variables to estimate the prices of LS pay items, which enables them to develop more accurate cost estimates for projects.

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