Case Study

Influence of Project Bundling on Maintenance of Traffic Costs across Highway Project Types

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Abstract: Maintenance of traffic (MOT) is the process of providing transportation management and traffic control at highway work zones. MOT work is an essential part of any construction project and can constitute a significant fraction of overall project cost. It is hypothesized that MOT costs can be reduced significantly through project bundling (consolidation of several separate projects into a single contract). However, no existing study has quantified the impact of bundling on MOT costs. In addressing the issue, this paper develops statistical models that take into account the effects of bundling and other influential factors. Six construction work categories that involve 36 different project types were considered. Several significant variables were identified including the project cost, bundle size, geographical proximity, functional class, traffic volume, and letting season; It was found that the impacts of these variables on MOT cost varies significantly by project type. The study results can provide construction managers with knowledge on projects of specific attributes for which MOT cost could be reduced significantly by project bundling, and those for which bundling would have no such effect. **DOI: 10.1061/(ASCE)CO.1943-7862.0001676.**

Introduction

Maintenance of Traffic in Work Zones: Synthesis of Contemporary Literature

Maintenance of traffic (MOT), also known as temporary traffic control, is the process of providing lane management and traffic control at work zones during highway construction. This is motivated by the quest for safe and efficient flow of traffic through work zones (FHWA 2018). However, maintaining the traffic during construction is challenging. First, the reduced road capacity due to work zones often leads to increased traffic interruptions and highway congestion (Morgado and Neves 2014), which in turn causes travel delays, increased user costs, and vehicle emissions (Abdelmohsen and El-Rayes 2016). In addition, lane closures, frequent lane shifts, and speed limit changes associated with work zones pose great risk to the safety of road users and maintenance workers (Agdas and Ellis 2010). Work zone crashes account for approximately 1,000 fatalities annually (Akepati and Dissanayake 2011). Clearly, maintaining traffic at work zones is beneficial. However, doing this can be expensive; Agdas and Ellis (2010) indicated that traffic control for a typical highway construction project typically constitutes 6%–10% of the overall project cost. Recognizing that cost-effective MOT can help reduce overall project costs, Sharma et al. (2009) synchronized the schedules for construction activities and traffic closures. Also, Coleman et al. (1996), Lin et al. (2004), and Lyu et al. (2017) suggested the use of variable speed limits at work zones, and AASHTO (2001), Zhu et al. (2009), and Sun et al. (2014) suggested the use of innovative contracting methods, all in a bid to reduce MOT costs.

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Project Bundling

Another way to facilitate MOT at work zones is through the use of nontraditional project delivery methods such as project bundling (i.e., awarding a single contract for multiple projects combined). This practice continues to be motivated by the increasing recognition of its benefits in terms of the reductions in costs of the actual work done (Xiong et al. 2017; Qiao et al. 2018). It is hypothesized that the costs of auxiliary construction-related work such as MOT costs can be significantly reduced by project bundling. For individual projects located along a corridor, a coordinated bundled contract composed of such multiple projects may reduce the total work zone duration, whereas an individual contract for each project could lead to separate road use restrictions at different times. In other words, the duration of the sum is hypothesized to be lower than the sum of the duration. This is consistent with the concept of holism in system engineering (Labi 2014). Thus, project bundling could lead to shorter work zone durations and consequently, reduced costs of work zone management and traffic control borne by the contractor (Xiong et al. 2017). Reduced work zone duration, in turn, potentially helps the agency by reducing the overall contract bid amount and lowering the risk of construction-related injuries/fatalities and benefits road users and the community in terms of less traffic interruption, and reduced travel time, air and noise pollution.

It has also been hypothesized that project bundling can reduce the overall duration of construction projects, particularly where the bundled projects are in the same vicinity and share similar work types (Bordat et al. 2003). Bundling offers the contractor greater flexibility to move and coordinate resources (materials, equipment, and personnel) between different projects. As a result, a lower likelihood of project delay, less traffic interruption, and lower MOT costs can be earned. For example, the Missouri Department of Transportation bundled three highway projects into a multiple-project contract that was completed a month ahead of schedule, $2.4 million under budget, and with minimal interruptions to the road users (AASHTO 2012).

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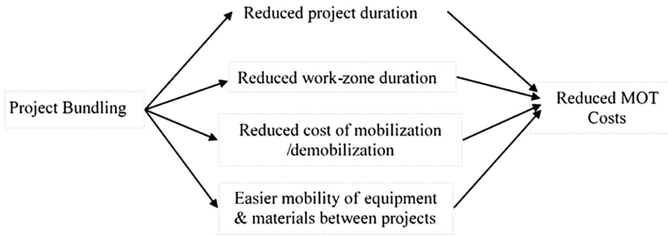

Fig. 1. Direct and indirect impacts of project bundling on MOT costs.

In addition, project bundling can lead to reduced costs of mobilization and demobilization, which is an important component of the MOT cost (Xiong et al. 2017). Demobilization work consists of activities that lead up to (or are part of) the setup and closeout of a project. The costs of these activities could be reduced through the consolidation of several projects. For a bundled contract, the demobilization costs can be combined and may be lower than the sum of demobilization costs for multiple single-project contracts that each separately contain one project. In cases where project demobilization cost is a fixed ratio of the total contract award, the cost savings from bundling may not be obvious because it is hidden in the total contract award amount that is reduced accordingly. Fig. 1 summarizes the four ways previously discussed of how project bundling influences the MOT costs directly and indirectly.

However, there is lack of existing research that quantitatively described the impacts of project bundling on the MOT cost. This paper therefore sets out to address this issue using historical contract data. Using statistical modeling, the paper seeks to answer the following questions: (1) does bundling generally lead to reduced MOT cost; (2) how much cost savings on the MOT can be generally achieved through bundling; (3) for a given set of projects, do different bundling strategies affect the MOT cost; and (4) do the bundling impacts on the MOT cost vary across different project types?

Research Approach

This paper investigates the impact of project bundling on the maintenance of traffic work by quantifying the relationship between the MOT costs and three bundling related factors: (1) kin status, that is, if the project is bundled with other projects; (2) the number of projects bundled in a contract; and (3) whether the projects are bundled along the same corridor. In this paper, six work categories (Bridge, Road, Traffic, Small Structures, Miscellaneous, and Utility) that contain 36 project types were considered in the analysis. Fig. 2 presents the general research framework that consists of two parts: average cost analysis and statistical modeling of costs. In each part, the analysis was carried out at two levels: work-category level and project-type level. The analysis at the work-category level sought to ascertain the effects of bundling and other factors on the MOT cost for each work category. However, such effects might vary greatly for different project types, even within the same work category. For example, the bundling effect may be positive for some bridge project types but insignificant or even negative for others. Therefore, if a large variation is found in the effects of critical variables on different project types in the same work category, analysis at the project-type level is preferable.

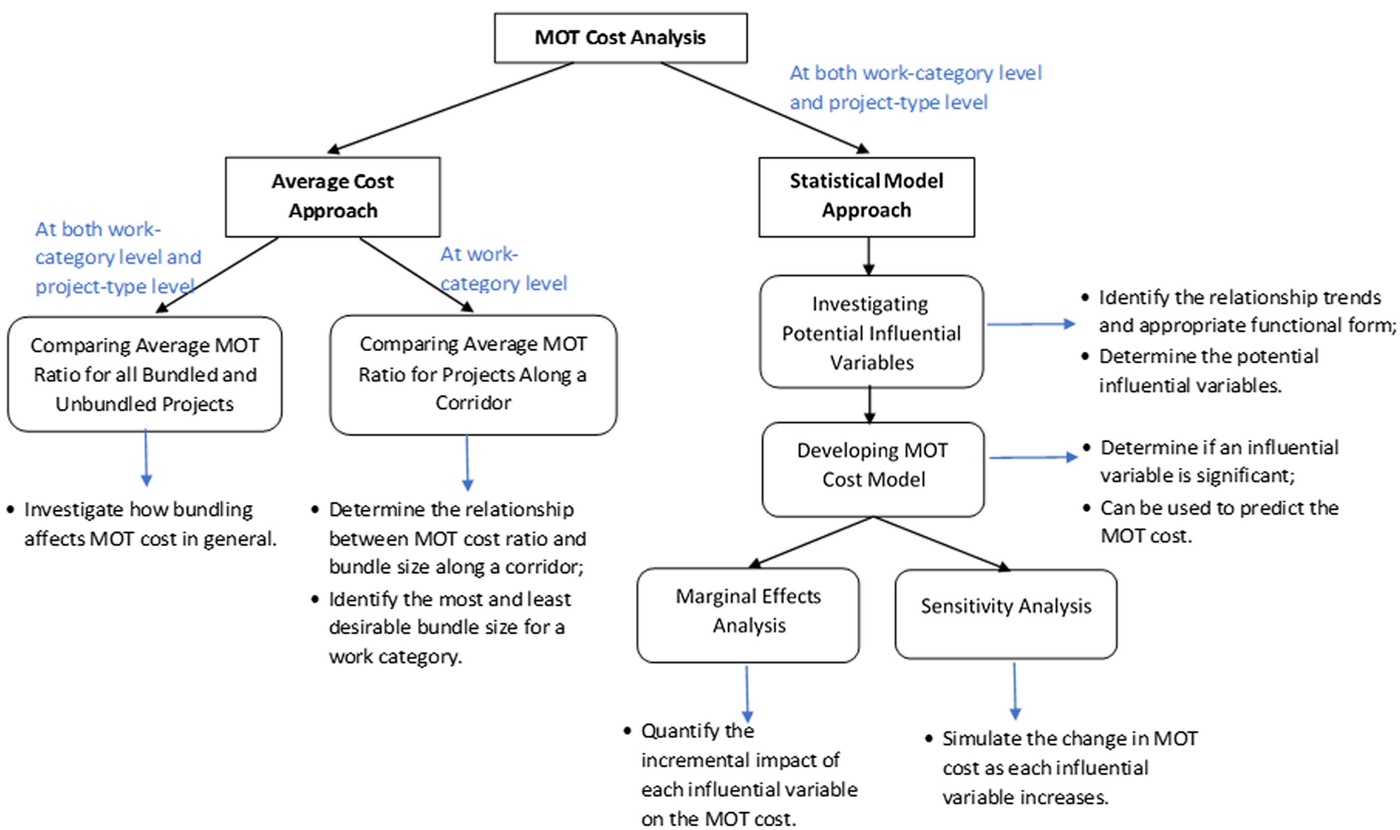

Fig. 2. Research framework.

Average Cost Approach

The average cost approach is an inventory costing method in which the cost of each item in an inventory is calculated based on the average cost of all similar goods in the inventory (Sinha and Labi 2011). In this paper, the average cost approach was used to calculate the average ratio of MOT cost to project cost, (MR) [as defined in Eq. (1)] for each project type (or work category) as shown in Eq. (2)

$$MR_i = \frac{MOT\ Cost\,(Total\ cost\ of\ all\ MOT\ pay\ items\ in\ a\ project)}{Project\ Award\,(Over\ all\ Project\ Cost)} \tag{1}$$

$$Avg.MR_j = \frac{\sum_{i=1}^{n_j} MR_i}{n_j} \tag{2}$$

where MR_i is the MOT cost ratio for project i; $Avg.MR_j$ is the average MOT cost ratio for the jth group of projects; and n_j is the number of projects in group j. Group refers to project type or work category.

To investigate how bundling affects the MOT cost of a project, the average MOT cost ratios for bundled and unbundled projects were compared for each group (work category or project type) of projects. The average cost approach is convenient and useful especially when the sample size is large. However, using the average cost to represent the cost of all projects of the same project type tends to be unreliable in estimating the MOT cost for an individual project, because of the large variation in site conditions across different project locations and the effect of economies of scale and other factors. One way to control the variation due to site conditions is to compare the average MOT cost ratios for projects along the same highway corridor. In this paper, seven corridors in the state of Indiana were selected for the corridor analysis. The average MOT cost ratio was calculated for projects with the same number of kins (number of projects in a bundle) in the same contract for each work category.

Statistical Modeling Approach

To account for the effect of economies of scale and other potential factors on MOT cost, regression models were developed for each work category and for each project type, respectively. The mobilization and demobilization cost items were removed from the MOT cost before modeling, because the demobilization costs in Indiana are capped at approximately 5% of the overall total contract cost (Xiong et al. 2017), and are therefore independent of any factor (variable) of MOT cost. Prior to the development of the MOT cost regression models, the two major effects (economies of scale and economies of bundling) were investigated. This began with the preparation of scatter plots of the unit cost versus each of two variables: (1) project size (measured in terms of project cost) and (2) bundle size (measured in terms of the number of bundled projects in a contract). These scatter plots helped identify the appropriate functional form for the subsequent statistical model.

The explanatory variables considered for the model development include Project Award (*PA*) amount (which helps account for scale economies), Number of Bundled Projects (Nr) in a contract and Same-Corridor indicator (which helps account for the bundling effect), average daily traffic volume (ADT), and indicator variables representing the road class, urban location, and time of letting (Table 1).

After investigating several functional forms, a logarithm transformation of both dependent and independent (continuous) variables was found to provide the best fit to the observed trends in the data. The proposed log-log linear model is given in Eq. (3). The initial linear equation (with a log-log transformation of each continuous variable) can be transformed into a power function [Eq. (4)] by taking the exponent of both sides. The MOT cost model can be also transformed into a MOT cost ratio model [Eq. (5)], by dividing both sides of Eq. (4) by the Project Award amount

$$\begin{aligned} ln\,(MOT\ Cost) = \beta_0 + \beta_1 * ln\,(PA) + \beta_2 * ln\,(NBP) \\ + \beta_3 * SC + \beta_4 * Int + \beta_5 * Urban \\ + \beta_6 * ln\,(ADT) + \beta_7 * Wint \end{aligned} \tag{3}$$

$$\begin{aligned} MOT\ Cost = PA^{\beta_1} * NBP^{\beta_2} * ADT^{\beta_6} \\ * e^{\beta_0+\beta_3*SC+\beta_4*Int+\beta_5*Urban+\beta_7*Wint} \end{aligned} \tag{4}$$

$$\begin{aligned} MOT\ Cost\ Ratio = PA^{\beta_1-1} * NBP^{\beta_2} * ADT^{\beta_6} \\ * e^{\beta_0+\beta_3*SC+\beta_4*Int+\beta_5*Urban+\beta_7*Wint} \end{aligned} \tag{5}$$

where β_0 is the estimated constant term; β_i is the estimated coefficient for the ith variable; and PA, NBP, ADT, SC, Int, $Urban$, and $Wint$ are the explanatory variables listed in Table 1.

Marginal Effects and Sensitivity Analyses

A marginal effect is a measure of the instantaneous effect that a change in a particular explanatory variable has on the dependent variable, when the other covariates are kept fixed. The marginal effect of an explanatory variable is obtained by computing the derivative of the conditional mean function with respect to that variable. In the regression model of Eq. (4), the marginal effects

Table 1. Description of the dependent and explanatory variables considered in the model

Variables	Type	Variable name	Description
Dependent variables	Continuous variables	MOT cost	Maintenance of traffic cost in a project.
	Continuous variables	MOT cost ratio	Ratio of MOT cost to the total project award.
Explanatory variables	Continuous variables	Project award ($) (*PA*)	Award amount of the project (cost in 2015 constant dollar).
		Number of bundled projects (*NBP*)	The number of projects bundled in a contract.
		Average daily traffic (ADT)	Traffic count for road where the project is located.
	Indicator/binary variables	Same-corridor indicator (*SC*)	1 if all the projects in a contract are on the same corridor; 0 otherwise.
		Interstate indicator (*Int*)	1 if the project is on interstate; 0 otherwise.
		Urban indicator (Urban)	1 if the project is an urban project; 0 otherwise.
		Letting In Winter indicator (Wint)	1 if the project is let in winter; 0 otherwise.

of a continuous variable such as Project Award or Bundle Size (NBP) on the MOT cost, can be determined using Eqs. (6) and (7). The marginal effect of a binary indicator variable (such as the Same Corridor indicator) on the MOT cost can be calculated using Eq. (8). The marginal effect of an influential variable on MOT cost ratio (MOT Cost/Project Award) can be determined using Eqs. (9)–(11)

$$\frac{\partial(MOT\ Cost)}{\partial(PA)} = e^{\beta_0} * \beta_1 * PA^{\beta_1 - 1} * NBP^{\beta_2} * ADT^{\beta_6} * e^{\beta_3 * SC + \beta_5 * Int + \beta_6 * Urban + \beta_7 * Wint} \tag{6}$$

$$\frac{\partial(MOT\ Cost)}{\partial(SC)} = \beta_3 * PA^{\beta_1} * NBP^{\beta_2} * ADT^{\beta_6} * e^{\beta_3 * SC + \beta_4 * SC + \beta_5 * Int + \beta_6 * Urban + \beta_7 * Wint} \tag{7}$$

$$\frac{\partial(MOT\ Cost)}{\partial(SC)} = \beta_3 * PA^{\beta_1} * NBP^{\beta_2} * ADT^{\beta_6} * e^{\beta_3 * SC + \beta_4 * SC + \beta_5 * Int + \beta_6 * Urban + \beta_7 * Wint} \tag{8}$$

$$\frac{\partial(MOT\ Ratio)}{\partial(PA)} = (\beta_1 - 1) * PA^{\beta_1 - 2} * NBP^{\beta_2} * ADT^{\beta_6} * e^{\beta_3 * SC + \beta_4 * SC + \beta_5 * Int + \beta_6 * Urban + \beta_7 * Wint} \tag{9}$$

$$\frac{\partial(MOT\ Ratio)}{\partial(NBP)} = \beta_2 * PA^{\beta_1 - 1} * NBP^{\beta_2 - 1} * ADT^{\beta_6} * e^{\beta_3 * SC + \beta_4 * SC + \beta_5 * Int + \beta_6 * Urban + \beta_7 * Wint} \tag{10}$$

$$\frac{\partial(MOT\ Ratio)}{\partial(SC)} = \beta_3 * PA^{\beta_1 - 1} * NBP^{\beta_2} * ADT^{\beta_6} * e^{\beta_3 * SC + \beta_4 * SC + \beta_5 * Int + \beta_6 * Urban + \beta_7 * Wint} \tag{11}$$

Sensitivity analysis is the study of how the uncertainty in the output of a mathematical model or system (numerical or otherwise) can be apportioned to different sources of uncertainty in its inputs (Cruz 1976). In this paper, sensitivity analysis was carried out at the work-category and the project-type levels. This was done to simulate how the MOT cost ratio changes as in response to changes in a given explanatory variable, while keeping all the other variables fixed.

Preliminary Analysis

Data Collection and Collation

The data used in this paper were provided by the Indiana Department of Transportation (INDOT) through the agency's Official Bid Tabulation, Site Manager, and Scheduling Project Management System (SPMS) databases. There were 4,611 projects and 2,528 contracts in the combined data set. For each project, the databases contained bid item details and project characteristics (project type, size, expenditure, location, contractor's information, and so forth). The projects were categorized into six work types (Bridge, Road, Traffic, Small Structure, Miscellaneous, and Utility) and further classified into 36 different project types (column one of Table 3). Of the 2,528 contracts, 784 are bundled-project contracts (that is, have multiple projects) and the rest are single-project contracts (containing only one project). The cost data can be classified into three different levels: contract cost, project cost, and pay item cost. The Project Award is the award amount (dollars) for a project and the contract's award amount is the sum of the project awards of all projects in that contract. At the pay item level, unit cost, quantity, and total amount are provided for each pay item in a project. The sum of the costs of all the pay items in a project is equal to the project's award. The MOT cost for a project was extracted from the pay item level data by summing the costs of all the MOT-related pay items [e.g., demobilization, hot mix asphalt (HMA) for temporary pavement, temporary access lane, temporary bridge, temporary markings, and maintaining traffic (a lump sum bid item used to compensate for the labor expenses), and so on]. All the cost data were adjusted to account for inflation across the different years of cost reporting using the Construction Price Index (CPI) provided by the Bureau of Labor Statistics (BLS), with a base year of 2015 [Eq. (12)]

$$\mathrm{Cost}_{Year=2015} = \frac{CPI_{Year=2015}}{CPI_{Year=i}} * \mathrm{Cost}_{Year=i} \tag{12}$$

Comparison of the Average MOT Cost Ratio across Project Types

The MOT cost can be a major component of the overall construction budget. For some work types, MOT as a percentage of the total project cost (project award) is very high (e.g., 16.12% for thin deck overlay). The average MOT cost and MOT cost ratio (ratio of the MOT cost to the overall project award) can be found in Table 2. It was found that Road work, on average, has a much higher MOT cost than project types of other work categories; however, Bridge work is associated with the highest MOT cost ratio (12.27% on average).

To analyze how the MOT cost is affected by project bundling, using the average cost approach, the average MOT cost and MOT

Table 2. Comparison of average MOT cost ratio between bundled and unbundled projects at the work-category level

Work category	Total no. of observations	Average MOT cost for all projects	Average MOT cost ratio for all projects (%)	Average MOT cost ratio for stand-alone projects (%)	Average MOT cost ratio for bundled projects (%)	MOT cost ratio reduction due to bundling (%)
Bridge	1,730	$68,829	12.27	9.10	13.12	−4.02
Road	1,154	$288,826	8.83	9.47	7.89	1.58
Traffic	1,140	$38,915	7.63	8.70	7.18	1.52
Small structures	508	$22,394	6.89	8.16	6.04	2.12
Miscellaneous	174	$37,116	9.52	7.29	13.26	−5.96
Utility	40	$75,067	8.05	61.71	6.63	55.08

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Table 3. Comparison of average MOT cost ratio between bundled and unbundled projects at the project-type level

Project type	Total no. of observations	Avg. MOT cost ratio: All projects (%)	Stand-alone projects (%)	Bundled projects (%)	MOT cost ratio reduction due to bundling (%)
B1-new bridge	303	5.78	6.13	5.73	0.41
B2-bridge replacement	210	7.19	7.54	6.94	0.60
B3-superstructure replacement	56	9.26	6.20	10.71	−4.52
B4-deck replacement	63	8.12	8.45	8.00	0.45
B5-bridge widening	50	6.68	6.15	6.78	−0.63
B6-bridge deck overlay	325	8.70	9.36	8.44	0.93
B7-thin deck overlay	167	16.12	11.51	16.68	−5.17
B8-miscellaneous bridge rehab and repair	556	19.93	12.10	21.40	−9.30
R1-new road construction	66	5.77	6.26	5.75	0.51
R2-added travel lanes	61	8.17	11.41	7.02	4.39
R3-patch and rehab pavement	101	11.34	11.79	10.21	1.59
R4-partial 3	556	9.17	9.30	8.78	0.52
R5-road rehabilitation (3R/4R)	37	7.10	7.31	7.04	0.27
R6-wedge and level only	15	8.04	8.33	4.00	4.34
R7-sight distance correction	22	6.97	7.59	5.66	1.93
R8-shoulder rehab and repair	2	5.39	N/A	5.39	N/A
R9-pavement, other	11	8.63	8.66	8.53	0.13
R10-pavement replacement	138	8.22	8.51	7.81	0.70
R11-intersection improvement	106	8.92	9.46	8.45	1.00
R12-interchange work	39	8.75	14.54	7.70	6.84
T1-ITS	25	6.53	6.22	6.76	−0.54
T2-signing	123	7.13	8.75	6.93	1.81
T3-traffic signals	192	7.45	7.46	7.44	0.02
T4-pavement markings	14	14.81	30.20	8.65	21.55
T5-guard rail, cable barrier, and wall	38	8.58	8.71	7.89	0.82
T6-lighting	27	7.24	9.33	5.80	3.53
S1-pipe lining	244	5.86	7.69	5.20	2.49
S2-small structure installation	219	7.78	8.45	7.10	1.35
S3-small structure maintenance and repair	45	8.11	8.10	8.13	−0.03
M1-demolition	72	6.64	6.48	8.69	−2.21
M2-channel and ditch work	48	15.40	10.50	17.42	−6.92
M3-stormwater improvements	3	10.48	9.53	12.39	−2.86
M4-slide correction	35	8.35	7.24	9.68	−2.45
M5-paths, sidewalks, and curb ramps	16	7.25	8.17	6.53	1.64
U1-railroad work	1	61.71	61.71	N/A	N/A
U2-utility relocation	38	6.63	N/A	6.63	N/A

cost ratio were calculated for single and bundled projects at the work-category level (Table 2) and at the project-type level (Table 3). At the work-category level, bundling was found to be associated with, on average, a lower MOT cost ratio for Road, Traffic, Small Structures, and Utility work and a higher ratio for Bridge and Miscellaneous work. At the project-type level, reductions in the average MOT cost ratio were observed when projects are bundled, with regard to all Road projects and most Traffic and Small Structures project types. With regard to Bridge work, the benefits of project bundling on MOT cost saving were determined for new bridge, bridge replacement, deck replacement, and bridge deck overlay. With regard to most Miscellaneous work (except M5-Paths, Sidewalks, and Curb Ramps), it was observed that the MOT cost ratio increased when projects were bundled. In addition, Road and Traffic work seem to benefit the most from project bundling in terms of MOT cost savings. Regarding Road work, the reduction in the MOT cost ratio due to project bundling was found to be most significant for R2-Added Travel Lanes, R6-Wedge and Level Only, and R12-Interchange Work. With regard to Traffic work, T4-Pavement Marking was found to be associated with the highest reduction—a 21.55% decrease in the MOT cost ratio with bundled projects compared to stand-alone projects of this project type.

Comparing Average MOT Cost of Bundled and Unbundled Projects along a Corridor

In using the average cost approach, the large variations associated with different asset and facility types, and the different site conditions can lead to bias. Therefore, corridor analyses of MOT costs for projects on a given road corridor were carried out. Due to the limited sample size, this was done at the work-category level only. Then the MOT cost ratios for stand-alone projects and bundled projects (with different numbers of kins) along the same road corridor for each work category, were compared.

Sections of seven major roads in Indiana that had multiple projects in the last few years were selected for the corridor analysis: I-65, I-69, I-70, I-465, US31, US24, and State Road 25. To quantify the impacts of bundle size on the MOT cost at a corridor level, the average MOT cost ratio was calculated for each different Bundle Size [Nr of Bundled Projects (*NBP*)] for projects along the same corridor. This was repeated for each work category. The sample distributions of the calculated average MOT cost ratio for each *NBP* are presented in Figs. 3(a and b) for the I-65 and US31 corridors. The *optimal* bundle size (that is, the one with the least MOT cost ratio) and the least favorable bundle size (that is, the one with the highest MOT cost ratio) were identified. This was done for each work category and each corridor (Table 4). In all corridors except

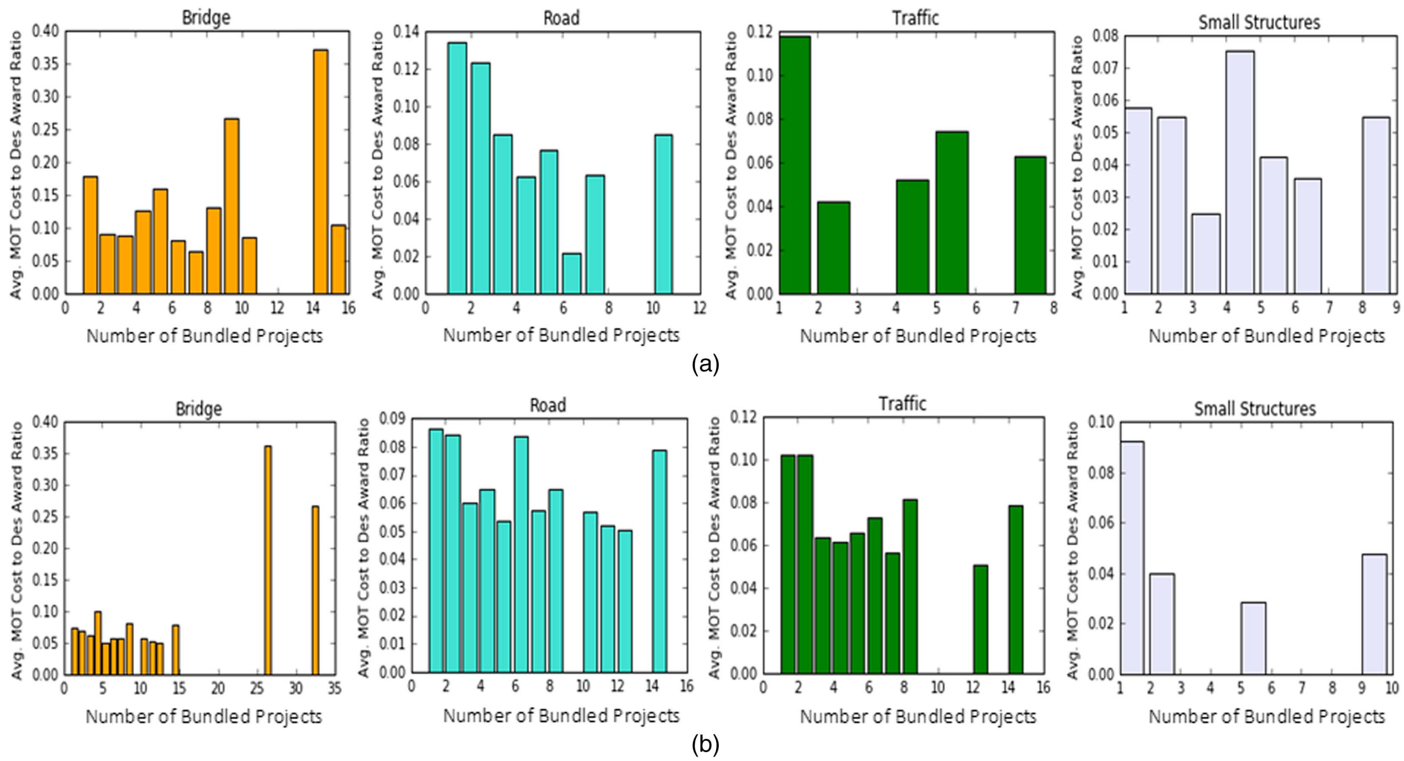

Fig. 3. MOT cost ratio versus bundle size for projects along two selected corridors: (a) corridor I-65; and (b) corridor US31.

US24 and for all Road work, the MOT cost ratio was consistently the highest when the bundle size is equal to one, that is, a standalone project. The bundle size that yields the lowest MOT cost ratio varies significantly across the project types, but hovers mostly between nine and 12. This is consistent with results given in Table 2, in which single projects were found to have a higher MOT cost ratio compared to bundled projects, irrespective of Road work type. For Bridge work, the MOT cost ratio of bundled projects sometimes decreases slightly as the bundle size increases, but starts increasing after a certain point and eventually even exceeds the MOT cost ratio observed for single projects. The results in Table 3 found that for some bridge project types, the average MOT cost ratio of bundled projects generally exceeds that for single projects. This might be because the benefit of bundling dissipates when a project is bundled with too many kins. For Traffic and Small Structure projects, a generally decreasing or *U* shape was observed for most road corridors. For Miscellaneous projects, the MOT cost ratio generally increased as the bundle size increased. These findings are mostly consistent with the average MOT cost ratio comparison results obtained previously.

Model Development for Maintenance-of-Traffic Cost

Preview: Economies of Scale and Economies of Bundling

The average cost approach can provide some information on comparative MOT costs across different project types, but it fails to account for the simultaneous effects of two key cost factors: scale economies and bundling effects. As such, in this section, two major influential variables—project cost and bundle size (the number of bundled projects in a contract)—are analyzed by studying scatter plots. These analyses can provide some insights into the relationship between the MOT cost or the MOT cost ratio and the critical variables, and helps determine the appropriate functional forms to use in regression analysis. As previously discussed, the 5% fixed demobilization cost was removed from the total MOT cost, so that the variation of MOT cost due to an influential factor can be discerned more clearly.

The MOT cost is expected to be largely determined by the overall project award (cost), because the latter reflects not only the project size but also the project complexity and work quality. In general, MOT cost is expected to increase as the overall project cost increases. However, the MOT cost ratio might decrease as the overall cost increases for most project types (Fig. 4) due to economies of scale. This means that, as the project size increases and the MOT cost increases, the percentage of MOT cost in the total project cost decreases.

One of the benefits of project bundling is that it can lead to more cost-effective maintenance of traffic during the construction period (Bordat et al. 2003). Therefore, it is expected that the MOT cost ratio for each bundled project will decrease as more projects are bundled into a contract. As shown in Fig. 5, a significant decrease in the MOT cost ratio was observed for Road, Traffic, and Small Structure work, as the bundle size increases—particularly from one to two projects. This indicates that, as the bundle size increases, greater cost savings could be earned on maintenance of traffic, due to the economies of bundling. For bridge projects, the MOT cost ratio was found to exhibit a generally decreasing trend as the bundle size increases; however, when the bundle size passes a certain point, the Bridge work MOT cost ratio stops decreasing or even starts increasing. This indicates that, when the bridge contract becomes too large, benefits of project bundling to the maintenance of Traffic work vanishes. For Miscellaneous and Utility work, the scatter plots showed no clear trends between MOT cost ratios and the bundle size.

Table 4. Bundling sizes with minimum and maximum MOT cost ratios by work category and corridor

Corridor (route)	Work category	No. of observations	Optimal bundle size (with minimum MOT cost ratio)		Least favorable bundle size (with maximum MOT cost ratio)	
			Bundle size	Minimum MOT cost ratio (%)	Bundle size	Maximum MOT cost ratio (%)
I-65	Bridge	12	7	6.3	14	37.1
	Traffic	5	2	4.2	1	11.8
	Road	8	6	2.1	1	13.4
	Small structure	7	3	2.5	4	7.6
	Miscellaneous	2	2	7.2	1	7.8
I-69	Bridge	13	10	4.5	16	44.3
	Traffic	6	2	3.0	12	10.5
	Road	8	10	4.5	1	14.9
	Small structure	6	8	2.1	1	8.3
	Miscellaneous	2	1	10.5	10	12.0
I-70	Bridge	12	3	6.1	32	43.0
	Traffic	4	7	2.9	4	10.6
	Road	6	7	2.9	1	9.9
	Small structure	3	2	2.1	1	6.7
I-465	Bridge	8	13	6.8	9	40.5
	Traffic	5	14	5.8	5	9.2
	Road	8	14	5.8	1	14.7
	Small structure	3	2	3.6	1	9.6
US-31	Bridge	14	12	5.1	26	36.2
	Traffic	10	12	5.1	2	10.3
	Road	12	12	5.1	1	8.6
	Small structure	4	5	2.9	1	9.3
	Miscellaneous	2	1	5.2	10	12.0
	Utility	4	12	5.1	6	8.4
US-24	Bridge	9	9	5.0	16	44.3
	Traffic	5	9	5.0	2	9.2
	Road	5	9	5.0	2	9.9
	Small structure	4	6	2.8	1	10.7
State road-25	Bridge	7	2	5.3	14	7.5
	Traffic	3	5	6.2	14	7.5
	Road	7	2	5.5	1	9.2
	Small structure	2	1	7.0	3	11.2
	Miscellaneous	2	1	5.9	14	7.5

Regression Model Development and Results

The proposed functional form [Eq. (3)] was applied to develop a MOT cost model for each work category (except Utility work, due to limited MOT data). All the explanatory variables listed in Table 1 were tested and selected through stepwise regression, and only the significant variables were kept in the model. The final regression results are presented in Table 5. The adjusted R-squared values all exceed 0.5 for Road, Traffic, Small Structures, and Miscellaneous work categories, indicating a fairly good fit. The model for Bridge work, however, has a relatively low R-squared value (0.294). This might be due to the limitation of the work-category level model discussed previously: when the effects of the explanatory variables on the MOT cost vary greatly across different project types within the same work category, a universal model at the work-category level is not sufficient to account for those variations. Therefore, for Bridge work, it may be preferable to develop a model for each project type within that work category.

According to the regression results, the Project Award amount is the most significant influential variable. For all work categories, the *PA* coefficient has a positive sign, indicating the MOT cost increases significantly as the overall project cost increases. The coefficients of Project Award are smaller than 1 for Bridge, Road, Small Structures, and Miscellaneous work. According to Eq. (5), a *PA* coefficient (β_1) smaller than 1 indicates that the MOT cost ratio decreases as the project award increases (economies of scale). The coefficient of Project Award is very close to 1 for Traffic work, indicating that the MOT cost is increasing proportionally (with a nearly constant MOT cost ratio) as the project award increases.

The bundling effect on the MOT cost was analyzed in terms of the bundle size (number of bundled projects) and *geographical* proximity (whether projects are bundled along the same corridor). The bundle size was found to be a significant variable for Bridge, Road, Traffic, and Small Structures, but not significant for Miscellaneous work. The coefficients estimated for the bundle size (Nr of Bundled Projects) were found to be negative for all project types, indicating that, when the overall project cost and all the other variables are the same, the MOT cost for a project decreases as more projects are bundled in a contract (economies of bundling). This is intuitive because the benefit of project bundling is generally expected to be higher when projects are bundled along the same corridor. The reason is that resources, construction materials, and maintenance of traffic costs can be shared and coordinated more easily if all projects in the contract are located on the same road corridor. The Same-Corridor indicator was found to be a significant factor (with negative signs) for Bridge, Small Structures, and Miscellaneous work, but not for Road and Traffic work. This means that, for Bridge, Small Structures and Miscellaneous work, the MOT cost can be further reduced by bundling if the bundled projects are located along the same corridor.

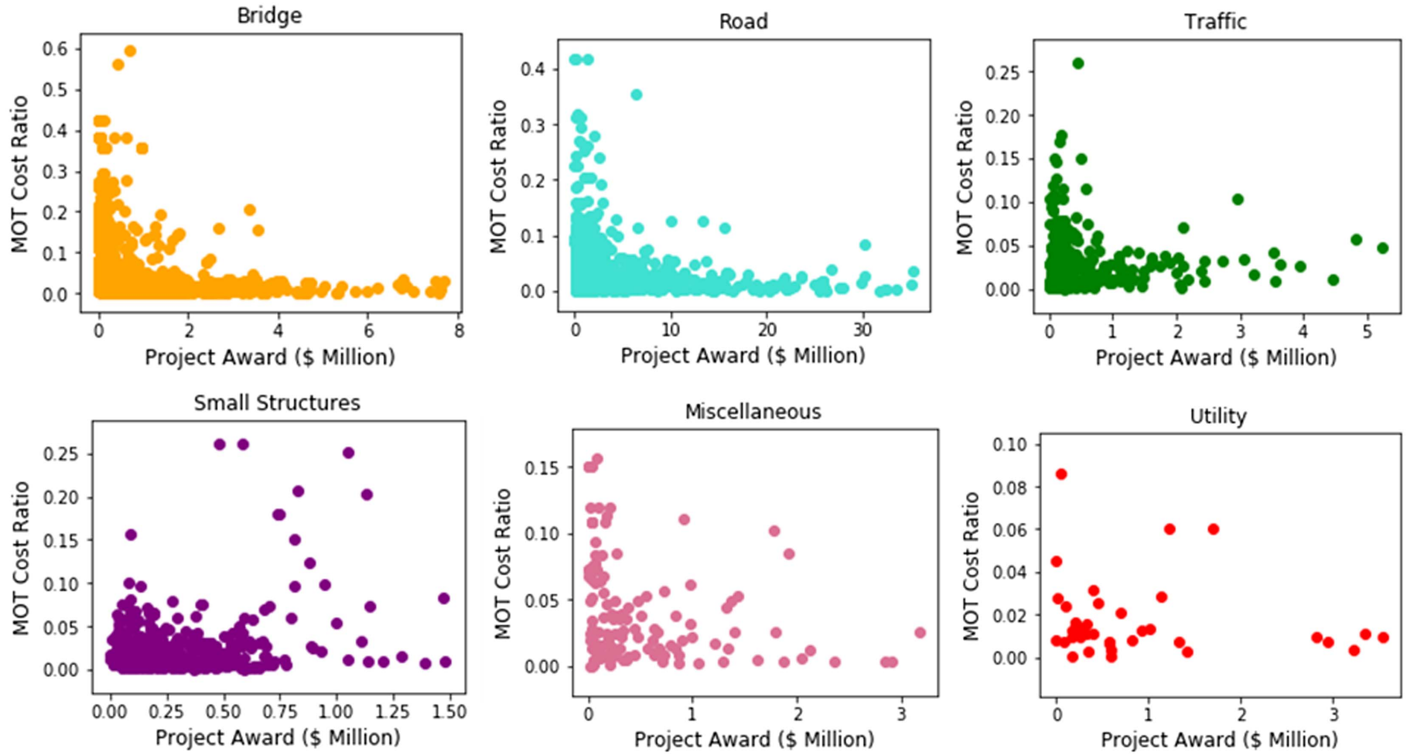

Fig. 4. Effect of project award on MOT cost ratio.

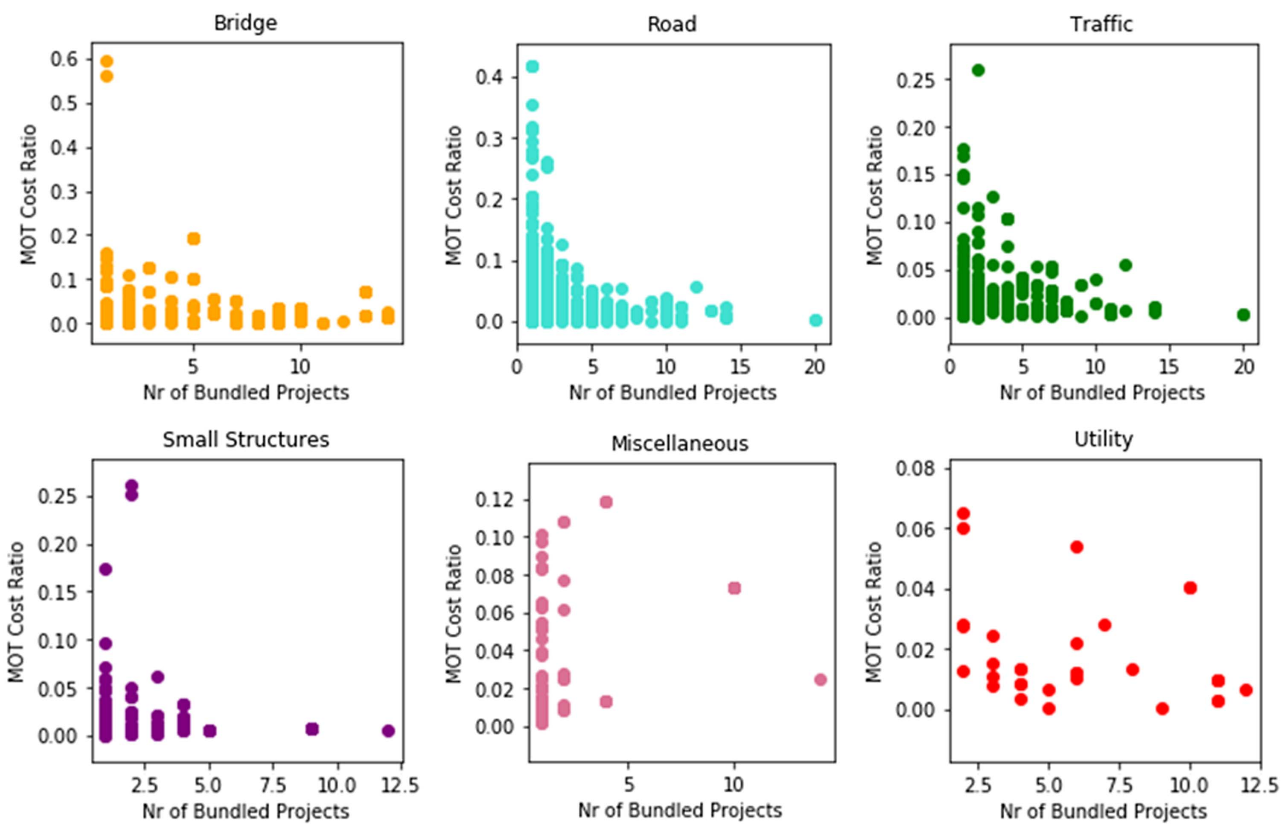

Fig. 5. Effect of bundle size on MOT cost ratio.

Table 5. Regression model for each work category

Work category	Variables	Estimate	Std. error	t-value	p-value
Bridge work	Intercept	1.199	0.421	2.845	4.50×10^{-3}
	Log (project award)	0.543	0.026	21.210	9.76×10^{-88}
	Log (no. of bundled projects)	−0.115	0.044	−2.590	9.69×10^{-3}
	Same corridor indicator	−0.522	0.095	−5.512	4.16×10^{-8}
	Interstate indicator	0.296	0.091	3.246	1.19×10^{-3}
	Urban indicator	−0.183	0.086	−2.118	3.43×10^{-2}
	Log (ADT)	0.140	0.037	3.810	1.45×10^{-4}
	No. of observations = 3,245; $R^2 = 0.294$				
Road work	Intercept	−1.700	0.464	−3.668	2.55×10^{-4}
	Log (project award)	0.773	0.026	29.446	3.40×10^{-142}
	Log (no. of bundled projects)	−0.370	0.054	−6.901	8.53×10^{-12}
	Interstate	0.301	0.103	2.914	3.64×10^{-3}
	Urban	0.148	0.075	1.981	4.78×10^{-2}
	Log (ADT)	0.141	0.041	3.464	5.51×10^{-4}
	No. of observations = 1,538; $R^2 = 0.503$				
Traffic work	Intercept	−5.180	0.702	−7.375	1.10×10^{-12}
	Log (project award)	1.013	0.049	20.542	5.10×10^{-63}
	Log (no. of bundled projects)	−0.258	0.072	−3.565	4.12×10^{-4}
	Log (ADT)	0.112	0.068	1.645	1.01×10^{-1}
	Letting in winter	0.163	0.125	1.304	1.93×10^{-1}
	No. of observations = 373; $R^2 = 0.617$				
Small structures work	Intercept	−4.292	0.715	−6.005	3.72×10^{-9}
	Log (project award)	0.930	0.050	18.636	4.04×10^{-59}
	Log (no. of bundled projects)	−0.562	0.070	−8.084	4.84×10^{-15}
	Same corridor	−0.310	0.140	−2.217	2.71×10^{-2}
	Interstate	−0.503	0.157	−3.200	1.46×10^{-3}
	Log (ADT)	0.186	0.046	4.012	6.95×10^{-5}
	Letting in winter	0.128	0.095	1.354	1.76×10^{-1}
	No. of observations = 502; $R^2 = 0.561$				
Miscellaneous work	Intercept	−0.779	0.775	−1.006	3.17×10^{-1}
	Log (project award)	0.833	0.073	11.375	9.87×10^{-20}
	Same corridor	−0.931	0.275	−3.387	1.01×10^{-3}
	Interstate	0.470	0.253	1.858	6.61×10^{-2}
	Urban	−0.302	0.211	−1.434	1.55×10^{-1}
	No. of observations = 105; $R^2 = 0.632$				

Other variables were included in the models to account for the variations of the MOT cost caused by different locations, site conditions, and weather conditions. According to the model results, for Bridge, Road, and Miscellaneous work, projects at Interstate highways were found to have higher MOT costs compared to those at Non-Interstates, and lower MOT costs for Small Structures work. The MOT costs of urban projects were found to be generally higher compared to their rural counterparts, but lower for Bridge and Miscellaneous work. The ADT was found to have significant impacts for Bridge, Road, Traffic, and Small Structures work, with positive signs, indicating that MOT cost increases significantly as the traffic volume increases. Finally, the Letting In Winter indicator was found to be an influential factor for Traffic and Small Structures work, indicating that projects commencing in the winter season are associated with generally higher MOT cost compared to those let in other seasons. This is an interesting finding that could be attributed to extra site facilities or processes to ensure that personnel or certain materials are kept warm.

The regression procedure described previously was used to develop a specific model for each project type. As previously discussed, the models at the project-type level compared to the work-category level, are inherently more capable of capturing the variations in the data, albeit with a reduced sample size. Models were developed for only those project types with more than 20 observations. Table 6 presents the regression result for each project type. The interpretations of the explanatory variables are the same as those explained in a previous section for the work-category level. At the project-type level, it was found that the MOT costs can be significantly reduced by increasing the bundle size for Bridge work B1, B4, B6, Road work R1, R2, R4, R7, R10, and R11, Traffic work T2, and Small Structures work S1 and S2. With regard to project types in which the bundling effects were found to be not significant due to the limited sample size, further investigations might be needed in the future.

Marginal Effect Calculation

The marginal effects of each influential variable on the MOT cost (and MOT cost ratio) were determined for all projects in the study data set. The average marginal effects are presented in Table 7 for each work category and for each project type. The average marginal effects can be used to measure, for projects grouped by work category or project type, the magnitude and direction of the incremental effect of a change in a given explanatory variable on the MOT cost (or MOT cost ratio). For example, the marginal effects of Project Award on the MOT cost and MOT cost ratio are 0.01986 and −5.94E-07, respectively, for Bridge work. This means that a \$1 million increase in the Project Award will generally increase the MOT cost by \$19,860 and reduce the MOT cost ratio by 0.594%.

At the work-category level, a comparison of the magnitudes of the marginal effects of each variable on the MOT cost and MOT cost ratio at the work category level is presented in Table 8. It was observed that the MOT cost is most sensitive to Project Award for Miscellaneous work, and the MOT cost ratio is most sensitive to

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Table 6. Regression model results for each project type

Work type	Explanatory variables								Observations	R2
	Intercept	Log (*PA*)	Log (*NBP*)	*SC*	Interstate	Urban	Log (ADT)	Winter		
B1	−6.559	1.167	−0.385	−0.944	−1.005	0.649	—	0.670	202	0.374
B2	−11.192	1.345	—	−0.389	—	−0.844	0.282	0.274	202	0.515
B3	−12.184	1.324	0.427	—	0.833	−0.907	0.355	—	57	0.551
B4	−10.053	1.465	−0.466	—	—	—	—	—	63	0.383
B5	−10.843	1.155	—	—	—	−0.475	0.413	0.590	46	0.505
B6	−4.521	0.854	−0.373	—	—	−0.532	0.333	—	323	0.387
B7	−3.816	1.035	—	−0.399	—	0.581	0.056	—	161	0.440
B8	−1.189	0.791	0.471	−0.192	0.544	−0.620	—	—	484	0.387
R1	−5.056	1.106	−0.762	−0.936	−1.149	—	—	—	52	0.294
R2	−2.593	0.910	−0.359	—	0.437	0.282	—	—	66	0.796
R3	−0.922	0.822	—	—	0.356	—	—	—	100	0.577
R4	−1.270	0.705	−0.171	—	0.414	—	0.205	—	541	0.391
R5	−3.983	1.025	—	—	−0.766	−0.428	—	—	46	0.649
R7	−4.960	1.042	−1.429	—	—	—	—	0.724	24	0.602
R10	−2.896	0.943	−0.252	—	0.332	—	—	—	142	0.371
R11	−2.066	0.823	−0.502	−0.762	—	0.245	0.188	—	105	0.390
R12	−1.323	0.825	—	—	0.446	—	—	—	45	0.606
T1	−4.334	0.990	—	—	0.777	—	—	—	24	0.776
T2	−6.714	1.025	−0.462	—	0.344	0.479	0.207	0.356	103	0.728
T3	−3.876	0.983	—	—	−0.619	—	—	—	180	0.426
T5	−0.573	0.797	—	—	−0.360	—	—	—	30	0.767
T6	7.1783	—	0.7548	—	—	—	—	—	25	0.205
S1	−1.600	0.838	−0.717	−0.224	—	−0.115	—	0.190	240	0.668
S2	−6.529	0.985	−0.428	−0.538	−1.989	—	0.408	—	216	0.381
S3	−8.162	1.209	—	−2.318	—	0.815	0.369	—	46	0.424
M1	−5.995	1.147	—	—	1.451	—	—	—	20	0.747
M2	−0.250	0.793	—	−0.389	—	−0.634	—	—	42	0.721
M4	2.175	0.616	—	−1.084	0.982	—	—	—	34	0.266

Table 7. Average marginal effect (for work-category level model)

Work category	Project award ($)	No. of bundled projects	Same corridor	Interstate	Urban	ADT	Letting in winter
			Average marginal effect of each influential variable on MOT cost				
Bridge	0.01986	−521.97	−5,412.45	3,069.309	−1,893.80	0.42582	—
Road	0.02144	−15,016.35	—	19,920.737	9,789.37	0.98947	—
Traffic	0.01688	−1,408.983	—	—	—	0.04418	1,500.542
Small structures	0.01385	−2,077.68	−1,444.50	−2,338.243	—	0.23221	595.271
Miscellaneous	0.03407	—	−10,631.92	5,370.998	−3,449.58	—	—
			Average marginal effect of each influential variable on MOT cost ratio				
Bridge	-5.94×10^{-7}	−0.001085	−0.019104	0.010834	−0.006685	4.43×10^{-6}	—
Road	-1.81×10^{-8}	−0.008401	—	0.008355	0.004106	6.53×10^{-7}	—
Traffic	-2.20×10^{-9}	−0.002379	—	—	—	1.36×10^{-7}	0.002712
Small structures	-1.10×10^{-8}	−0.005873	−0.004625	−0.007487	—	9.12×10^{-7}	0.001906
Miscellaneous	-2.70×10^{-7}	—	−0.038094	0.019244	−0.012360	—	—

Table 8. Summary of the comparisons of sensitivity results across work categories

Variables	Order of work categories based on sensitivity	
	For MOT	For MOT cost ratio
Project award ($)	M > R > B > T > S	B > M > R > S > T
No. of bundled projects	R > S > T > B	R > S > T > B
Same corridor	M > B > S	M > B > S
Interstate	R > M > B > S	M > B > R > S
Urban	R > M > B	M > B > R
ADT	R > B > S > T	B > S > R > T
Letting in winter	T > S	T > S

Note: B = bridge; R = road; T = traffic; M = miscellaneous; and S = small structures.

Project Award for Bridge work. The impacts of bundle size (number of bundled projects) and bundling geographical proximity (whether projects are bundled along the same corridor) on both the MOT cost and MOT cost ratio were found to be greatest for Road work and Miscellaneous work, respectively. In addition, the MOT cost for Road work was found to be influenced most significantly by road functional class (Interstate versus Non-Interstate, Urban versus Rural), while the MOT cost ratio was found to be most sensitive to the road functional class for Miscellaneous work. With regard to the ADT, its impact on the MOT cost is the greatest for Road work, and its impact on the MOT cost ratio is most significant for Bridge work. Both the MOT cost and MOT cost ratio for Traffic work were found to be influenced the most by weather

Table 9. Average marginal effects (for the model at the project-type level)

Project type	Project award ($)	No. of bundled projects	Same corridor	Interstate	Urban	ADT	Letting in winter
			Average marginal effect of each influential variable on MOT cost				
B1	0.004719	−1,184.876	−10,173	−10,830	6,994	—	7,220
B2	0.017395	—	−14,503	—	−31,467	0.004026	10,216
B3	0.035697	9,057.936	—	35,675	−38,844	0.009571	—
B4	0.028883	−8,162.166	—	—	—	—	—
B5	0.017992	—	—	—	−8,526	0.004276	10,590
B6	0.020457	−2,581.403	—	—	−6,231	0.007976	—
B7	0.062404	—	−5,208	—	7,583	0.003376	—
B8	0.072786	1,082.813	−1,190	3,371	−3,842	—	—
R1	0.004972	−11,348.856	−56,574	−69,448	—	—	—
R2	0.018210	−17,536.26	—	90,072	58,125	—	—
R3	0.037340	—	—	15,417	—	—	—
R4	0.022499	−6,949.336	—	19,761	—	0.006542	—
R5	0.021586	—	—	−115,233	−64,386	—	—
R7	0.021227	−43,833.37	—	—	—	—	18,896
R10	0.021007	−16,740.305	—	32,528	—	—	—
R11	0.024594	−9,779.071	−21,347	—	6,864	0.005618	—
R12	0.020878	—	—	102,340	—	—	—
T1	0.022362	—	—	32,457	—	—	—
T2	0.019092	−1,707.996	—	2,735	3,809	0.002964	2,831
T3	0.016286	—	—	−1,857	—	—	—
T5	0.025988	—	—	−14,415	—	—	—
T6	—	1,283.072	—	—	—	—	—
M1	0.021578	—	—	37,790	—	—	—
M2	0.054500	—	−2,905	—	−4,735	—	—
M4	0.018818	—	−16,301	14,767	—	—	—
S1	0.011278	−1,043.511	−491	—	−252	—	416
S2	0.017332	−2,978.346	−4,665	−17,247	—	0.00717904	—
S3	0.016752	—	−10,016	—	3,521	0.00511283	—
			Average marginal effect of each influential variable on MOT cost ratio				
B1	7.54×10^{-10}	−0.000608	−0.005085	−0.005413	0.003496	—	0.003609
B2	3.54×10^{-9}	—	−0.005555	—	−0.012052	0.004027	0.003913
B3	7.07×10^{-9}	0.005196	—	0.022459	−0.024454	0.009571	—
B4	7.80×10^{-9}	−0.005380	—	—	—	—	—
B5	2.62×10^{-9}	—	—	—	−0.004918	0.004276	0.006109
B6	-1.40×10^{-8}	−0.004765	—	—	−0.012744	0.007977	—
B7	2.54×10^{-8}	—	−0.024057	—	0.035031	0.003376	—
B8	-8.98×10^{-7}	0.005523	−0.017668	0.050058	−0.057051	—	—
R1	6.68×10^{-11}	−0.001119	−0.004208	−0.005166	—	—	—
R2	-3.35×10^{-9}	−0.004122	—	0.008745	0.005643	—	—
R3	-7.42×10^{-8}	—	—	0.016172	—	—	—
R4	-1.58×10^{-8}	−0.004706	—	0.013212	—	0.006542	—
R5	1.40×10^{-10}	—	—	−0.016131	−0.009013	—	—
R7	2.11×10^{-9}	−0.027479	—	—	—	—	0.011512
R10	-6.94×10^{-10}	−0.004356	—	0.007396	—	—	—
R11	-1.48×10^{-8}	−0.011346	−0.022771	—	0.007321	0.005618	—
R12	-6.12×10^{-9}	—	—	0.011287	—	—	—
T1	-3.97×10^{-10}	—	—	0.017551	—	—	—
T2	4.41×10^{-9}	−0.003847	—	0.004927	0.006861	0.002965	0.005099
T3	-3.81×10^{-9}	—	—	−0.010255	—	—	—
T5	-6.63×10^{-8}	—	—	−0.011739	—	—	—
T6	—	0.010177	—	—	—	—	—
M1	2.14×10^{-8}	—	—	0.027297	—	—	—
M2	-8.02×10^{-7}	—	−0.026735	—	−0.043572	—	—
M4	-1.49×10^{-7}	—	−0.033115	0.029999	—	—	—
S1	-4.44×10^{-8}	−0.005957	−0.003218	—	−0.001652	—	0.002729
S2	-8.85×10^{-10}	−0.005817	−0.009466	−0.034998	—	0.007179	—
S3	1.50×10^{-8}	—	−0.032118	—	0.011293	0.005113	—

conditions compared to other variables, as evidenced by the greatest average marginal effect that was exhibited by the Letting In Winter indicator variable.

The average marginal effects of the two major factors (economies of scale and economies of bundling) were then compared at the project-type level (Table 9). It was found that the impact of project overall cost (economies of scale) on the MOT cost is relatively high for Bridge work B7, B8, Road work R3, R11, Traffic work T5, Miscellaneous work M2, and Small Structures work S2 compared to other project types. Further, its impact on MOT cost ratio is greater for Bridge work B7, B8, Road work R3, R4, R11, Traffic work T5, Miscellaneous work M2, and Small Structures

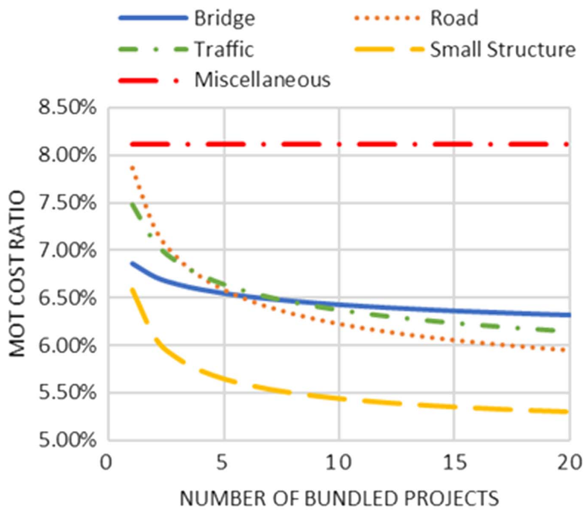

Fig. 6. Sensitivity of MOT cost ratio to bundle size (at work-category level).

work S1 compared to other project types. In terms of the bundling effect, the magnitude of the reduction effect of bundle size (economies of bundling) on the MOT cost is greater for Bridge work B4, Road work R2, R10, Traffic work T2, and Small Structures work S2 compared to other project types. In addition, such reduction effect on the MOT cost ratio is more pronounced for Bridge work B4, B6, Road work R2, R4, R10, R11, and Small Structures work S1 and S2 compared to other project types.

Sensitivity Analysis

Sensitivity analysis was carried out to evaluate, at the work-category and project-type levels, how the MOT cost ratios (MOT Cost/Project Award) are affected by a unit of increase in the bundle size (due to economies of bundling). The results are presented in Fig. 6 for the work-category level and in Fig. 7 for the project-type level. For the purpose of comparison with the average MOT cost ratio previously presented, the 5% mobilization and demobilization constant cost was incorporated into the total MOT cost ratio before developing these plots.

At the work-category level, it was observed that as more projects are bundled in a contract, the MOT cost ratio decreases significantly for Road, Traffic, and Small Structures work, and slightly for Bridge work (Fig. 6). At the project-type level (Fig. 7), it was observed that the sensitivities of the MOT cost ratio to the bundle size vary greatly across different project types.

Conclusion and Discussion

This paper identified and quantified the impact of project bundling and other factors on the MOT cost, which is a major component of the total project cost. Three bundling-related factors of MOT cost were analyzed: (1) the effect of whether a project is unbundled (a stand-alone project) or bundled with other projects (kins); (2) the effect of the number of projects that are bundled in a contract (bundle size); and (3) the effect of the geographical proximity (corridor co-location) of the bundled projects. The analysis in this paper was carried out at two levels: at the work-category level, a universal model was developed for all the project types in that work category;

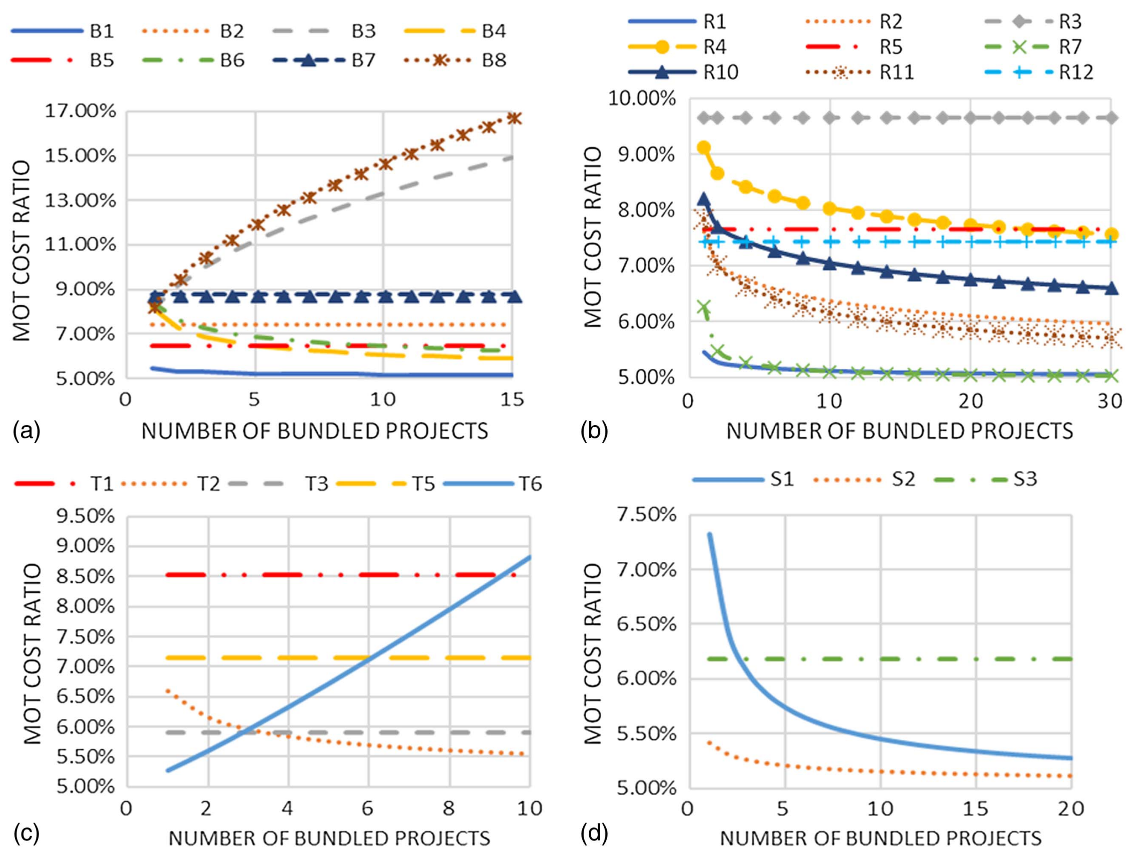

Fig. 7. Sensitivity of MOT cost ratio to bundle size (at project-type level): (a) Bridge work; (b) Road work; (c) Traffic work; and (d) Small Structures work.

and at the project level, where a model was developed for each project type.

An average cost approach was used to compare, for each work category and for project type, the average MOT cost ratio (MOT Cost/Project Award) for stand-alone (unbundled) projects and bundled projects. Bundled projects were found to have significantly lower MOT cost ratio for Road, Small Structures, and Miscellaneous work at the work-category level. At the project-type level, lower MOT cost ratios were observed for bundled Road projects, most Traffic and Small Structures projects, and about half of Bridge projects. For most Miscellaneous work (except M5-Paths, Sidewalks, and Curb Ramps), a higher average MOT cost ratio was observed for bundled projects. This paper duly recognized that the average cost approach is compromised by its inability to adequately account for large variations in site conditions across different project locations and different project sizes. To control for the variation by location, a corridor analysis (at the work-category level only) on seven major road corridors was carried out to compare the average MOT cost ratio across projects as the number of kins varied along the same corridor. It was found that, along six of the seven corridors evaluated, the MOT cost ratio is always the highest when Nr of Bundled Projects is equal to one (i.e., a project is not part of a bundle) for Road and Small Structures work. For Bridge work, a small bundle was found to be associated with a lower MOT cost ratio compared to the stand-alone projects, while the highest MOT cost ratio occurred in most cases when there are too many bridge projects bundled in a contract.

To account for the simultaneous effects of multiple possible influential factors, statistical regression models were developed for MOT cost at the work-category level and project-type level, with considerations of project overall cost (Project Award), bundle size (the number of bundled projects in a contract), bundling geographical proximity (if projects are bundled in the same corridor), road functional class (Interstate/Non-Interstate, Urban/Rural), traffic volume and weather condition (if the project is let in winter). Marginal effects analysis and sensitivity analysis were carried out to evaluate how the MOT cost and MOT cost ratio change as a particular variable changes, based on the developed regression models. From the work-category level model results, it was observed that the MOT cost of Bridge, Road, Traffic, and Small Structures can be reduced significantly by project bundling. At the project-type level, it was found that Bridge work (B4 and B6), Road work (R1, R2, R3, R4, R7, R10, and R11), Traffic work (T2), and Small Structures work (S1 and S2) can benefit from bundling in terms of MOT cost savings. With regard to the effect of geographical proximity of bundled projects, it was found, at the work-category level, bundling projects along the same corridor can lead to a lower MOT cost compared to bundling projects at different locations for Bridge, Small Structures, and Miscellaneous work. At the project-type level, such effects were found to be significant for Bridge work (B1, B2, B7, and B8), and Road work (R1 and R11), Miscellaneous work (M2 and M4), and Small Structures work (S1, S2, and S3).

These findings can be used by construction managers and project schedulers as part of their decision-making process, allowing them to take into account the potential benefits of bundling certain project types as they pertain to maintenance of traffic, an activity that is often a major component of the cost of highway projects. The developed cost models could also be used as a tool to provide reasonable estimation of the aggregated costs of MOT-related pay items for highway projects, and more, reliable values of the engineer's estimate of the MOT cost of planned highway projects.

Data Availability Statement

Data generated or analyzed during the study are available from the corresponding author by request. Information about the Journal's data-sharing policy can be found here: https://ascelibrary.org/doi/10.1061/(ASCE)CO.1943-7862.0001263.

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