Cost Overrun in Public-Private Partnerships: Toward Sustainable Highway Maintenance and Rehabilitation

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Abstract: Transportation agencies worldwide have been preparing themselves to face the growing demand for transportation infrastructure by forming public-private partnerships (PPP), contractual agreements formed between public and private sector entities, to allow for greater private sector participation in the delivery of transportation projects. However, there is one major concern that needs to be addressed: the issue of accurately estimating maintenance and rehabilitation costs at the project planning stage. The accuracy of these estimates plays a significant role in determining project characteristics, and in selecting appropriate projects and PPP approaches for implementation, so that they may lead to sustainable highway preservation strategies. This paper compares the contract winning bid cost with the final as-built cost of highway maintenance and rehabilitation projects, determines possible cost overruns across the projects and identifies influential factors that affect them. The analysis is performed separately by PPP contracting approach, and thereby relaxes the assumption of past research that cost overrun behaves identically across different contracting approaches. The results show that a number of factors play a role in the determination of cost overrun, including the project size (cost, duration, and length) and specific maintenance and rehabilitation activities. **DOI: 10.1061/(ASCE)CO.1943-7862.0000854.** *© 2014 American Society of Civil Engineers.*

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Introduction

Public-private partnerships (PPP) are contractual agreements formed between public agencies and private sector entities to allow for greater participation of the private sector in the delivery of transportation projects. These partnerships aim to provide sustainable solutions in highway preservation, not only by improving product quality and reducing costs, but also by potentially reducing project duration, improving the technological aspects of construction and preservation methods, encouraging the contractors to innovate, and reducing project impact on the highway user and the surrounding environment (FDOT 2000; Zhang and Kumaraswamy 2001; Carpenter et al. 2003; Zhang 2004, 2005a, b, c; Abdel-Aziz 2007b; Anastasopoulos et al. 2009, 2010b; Kwak et al. 2009).

Highway preservation can be delivered via a variety of contracting approaches. The first and most common is traditional maintenance and rehabilitation contracting, where the design is independent of the construction phase, and the lowest bid is used as the major criterion to award the contract to the qualified bidder.

Another approach is design-build contracting and its variants, design-build-operate-maintain and design-build-operate-maintain-warrant (Abdel-Aziz and Russell 2001; Gransberg and Molenaar 2004; Abdel-Aziz 2007a). Under this approach the design is also carried out independently of the construction process. Some disadvantages related with this approach are that the public entity is entirely responsible for potential project deficiencies, innovation and life-cycle costing are not particularly encouraged, and both public and private entities need to maintain a large staff to monitor and conduct necessary highway preservation functions (Hancher 1999).

In warranty contracts, the contractor is liable for product defects or failure, and is responsible for assuring that the product meets certain preagreed performance standards. Warranties therefore motivate the contractor to deliver a superior quality product that may result in cost savings from the perspectives of longevity and cost-effectiveness in the long-term (Singh et al. 2007).

Cost-plus-time (A + B) bidding and incentives/disincentives (I/D) are contracting methods that consider both the initial construction or preservation cost in the bidding process and the time needed to complete and deliver the project (Herbsman and Glagola 1998; Carpenter et al. 2003; Choi and Kwak 2012; Choi et al. 2012). In particular, I/D methods are structured to encourage the contractor to finish the project earlier than the time indicated in the original bid document.

Lane rental is used to accelerate the completion of a preservation project by charging the contractor with a fee for occupying lanes or shoulders throughout the project duration (Herbsman and Glagola 1998).

In performance-based contracting (PBC), the contractor must satisfy the established minimum physical condition of the asset over a specified period of time. Payments are solely based on how

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well the contractor conforms to the performance standards defined in the contract (Zietlow 2005).

Regardless of the PPP approach, highway project cost overrun is a critical issue for any road agency, given the increasing user expectations and general scarcity of federal and local funding (Bordat et al. 2004). Identifying factors that contribute in cost overrun can potentially lead to sustainable highway preservation strategies. To that end, cost overrun has been widely studied in the literature (Rowland 1981; Jahren and Ashe 1990; Turcotte 1996; Kaming et al. 1997; Chan and Kumaraswamy 1997; Korman and Daniel 1998; Al-Momani 2000; Jacoby 2001; Akran and Igwe 2001; JLARC 2001; Chang 2002; Flyvbjerg et al. 2002, 2003, 2004; Frimpong et al. 2003; Kyte et al. 2004; Bordat et al. 2004; Bhargava et al. 2010). However, one of the limitations of past research is the assumption (typically due to data limitations) that cost overrun, along with other cost characteristics, behaves the same across different contract approaches (Gransberg et al. 2007; Gransberg and Riemer 2009; Bhargava et al. 2010; Choi et al. 2014). A study of cost overrun by PPP contracting approach would ideally identify the corresponding influential factors, thereby establishing relationships that enable more accurate predictions of cost overrun likelihood and amounts/rates that are approach-specific. This represents the motivation for the current study.

Method and Data

The criterion for evaluation in this paper, cost overrun, is defined as

$$\%CO_{ki} = 100 \times [(C_{Fki} - C_{WBki})/C_{WBki}] \quad (1)$$

where %CO is the percent cost overrun of the project i of the PPP contracting approach k under consideration, relative to the corresponding winning bid cost, C_{WB}, of the project, and C_F is the actual final as-built cost after the project is complete and delivered.

In line with the current state of practice (McCullouch et al. 2009; Anastasopoulos et al. 2011a, b) and the literature (Gkritza and Labi 2008; Anastasopoulos et al. 2010b, c, 2012), both the likelihood and amount of cost overrun are investigated, as it has been shown that different factors may affect them (due to the limitation of the cost overrun likelihood approach to account for the magnitude of the cost overrun). The factors' magnitudes and effect on the overrun likelihood and amount can differ as well.

In Eq. (1), the cost overrun %CO is positive when the actual final as-built cost C_F is higher than the winning bid cost C_{WB}, and negative when the actual final as-built cost is lower than the winning bid cost. One possible approach to estimate the probability of one of these two discrete outcomes is through the use of discrete outcome models for categorical variables (binary as in the presented case that there are only two outcomes, 0 or 1). To that end, binary probit and logit models were considered, with the probit model providing a superior statistical fit (the main difference between the two lies in the assumption made for the disturbances, with the logit model assuming the disturbances are Weibull–Gumbel extreme value type I-distributed, and the probit assuming they are multivariate normally distributed). The binary probit model can be defined as

$$P_{ki}(\mathrm{CO}) = \Phi[(\beta_{\mathrm{CO}} X_{\mathrm{CO}ki} - \beta_{\mathrm{CU}} X_{\mathrm{CU}ki})/\sigma] \quad (2)$$

where $P_{ki}(\mathrm{CO})$ is the probability of observation i in PPP approach k having cost overrun, $\Phi(\cdot)$ is the standardized cumulative normal distribution, X_{CO} and X_{CU} are vectors of factors affecting the probabilities for the cost overrun or no overrun (including cost underrun) outcomes, CO and CU, respectively, and σ is a scaling parameter that determines the discrete outcomes and is typically set to one. For estimating the parameter vector β, standard maximum likelihood methods can be used (see Washington et al. 2011).

The amount of cost overrun, calculated as a percentage using Eq. (1) to provide a comparable measure of cost overrun for projects of different sizes, is a continuous variable that takes positive or negative values depending on whether the PPP yielded cost overrun or underrun, respectively. Linear regression can be used to model the relationship between a continuous dependent variable and one or more independent variables. The linear regression model is of the form

$$\%\mathrm{CO}_{ki} = \beta_{ki} + \beta_{\mathrm{CO}} X_{\mathrm{CO}ki} + \varepsilon_{ki} \quad (3)$$

where $\%\mathrm{CO}_{ki}$ is the dependent variable [as defined in Eq. (1)] and is a function of a constant term, β_{ki}, and a constant, β_{CO}, times the value $X_{\mathrm{CO}ki}$ of independent variable X for observation i ($i = 1, 2, \ldots, n$) in PPP approach k, plus a disturbance term, ε.

The data used in this study include 601 contracts that were let or completed in the United States and abroad (in countries in Africa, Asia, Europe, North and South America, and the Pacific) between 1996 and 2007. More specifically, the data include 78 traditional maintenance contracts, 99 traditional rehabilitation contracts, 49 design-build, 101 PBC, 44 lane rentals, 144 warranties, and 86 A + B + I/D, implemented in Africa (32 contracts), Asia (54 contracts), Europe (62 contracts), South America (64 contracts), the Pacific (38 contracts), and North America (351 contracts). Out of the 308 US-based contracts, 51 were from Texas, 72 from Virginia, 90 from Indiana, 25 from Minnesota, 48 from Florida, and 22 from Alaska. Descriptive statistics of selected variables are presented in Table 1. The data were collected and collated from the Word Bank Resource Guide, FHWA, G. Zietlow's PBC website, the British Columbia, Republic of Serbia, Tanzania National Road Agencies, and from other resources (Porter 2002; Segal et al. 2003; Zietlow 2004, 2005; Stankevich et al. 2005; Pakkala 2005; Robinson et al. 2006; FHWA 2007). Also, data were collected from the following transportation agencies with the help of many officials: Indiana, Minnesota, Florida, Virginia, Texas, and Alaska. For detailed data descriptions, see Anastasopoulos (2007).

To ensure comparability across the years, all project costs are converted and expressed in year 2007 US dollars using "Price Trends for Federal-Aid Highway Construction" (Sinha and Labi 2007) and the following equation:

$$C^* = C_{\mathrm{ref}} \times \frac{I^*}{I_{\mathrm{ref}}} \quad (4)$$

where C^* is the project cost (e.g., winning bid cost, actual final as-built cost, etc.,) in any year, C_{ref} is the project cost in a reference year (in this case, 2007), I^* is the price index for the year of the C^*, and I_{ref} is the price index for the reference year.

Another key estimation issue is to ascertain whether the estimated model parameters are spatially transferable. Spatial transferability implies that the estimated parameter coefficients are stable over space, i.e., between the United States and international contracts. For this, the likelihood ratio test is used (Washington et al. 2011)

$$X^2 = -2 \times [\mathrm{LL}(\beta_J) - \mathrm{LL}(\beta_{US}) - \mathrm{LL}(\beta_A)] \quad (5)$$

where US and A represent the two regions, the United States and abroad, respectively, between which the transferability of parameters is being tested, $\mathrm{LL}(\beta_J)$ is the log likelihood at convergence of the model estimated with the data from both regions, $\mathrm{LL}(\beta_{\mathrm{US}})$ is the log likelihood of convergence of the model using the United States PPP contracts, and $\mathrm{LL}(\beta_A)$ is the log likelihood of convergence of the model using the PPP contracts from abroad.

For all the PPP approaches considered in this study, the likelihood ratio tests showed that, at a 0.90 level of confidence, there is no evidence to reject the null hypothesis (H_0) of equality across the two data segments. Thus, the model results are considered consistent across both spatial regions.

Alternate likelihood ratio tests of the following form were also conducted (Washington et al. 2011):

$$-2[\mathrm{LL}(\beta_{ba}) - \mathrm{LL}(\beta_a)] \quad \text{and} \quad -2[\mathrm{LL}(\beta_{ab}) - \mathrm{LL}(\beta_b)] \qquad (6)$$

where $\mathrm{LL}(\beta_{ba})$ is the log-likelihood at convergence of the model using the converged parameters from region b (using only data from region b) on region a's data (restricting the parameters to be region b's estimated parameters), $\mathrm{LL}(\beta_{ab})$ is the log-likelihood at convergence of the model using the converged parameters from region a (using only data from region a) on region b's data (restricting the parameters to be region a's estimated parameters), and $\mathrm{LL}(\beta_a)$ and $\mathrm{LL}(\beta_b)$ is the log-likelihood at convergence of the model using region a's and b's data, respectively. The statistic is chi-square distributed with the degrees of freedom (DOF) equal to the number of estimated parameters in β_{ba} (or β_{ba}) and the resulting chi-square statistic provides the probability that the models have different parameters. The results from the alternative tests were essentially equivalent to the likelihood-ratio test presented in Eq. (5) and that the null hypothesis that the parameters are equal could not be rejected at the 0.90 level of confidence. The combination of the tests illustrated in Eqs. (5) and (6) provides strong evidence that the region-specific models provide statistically similar explanatory parameter estimates to the non-region-specific models presented in Tables 2 and 3, which is also in line with the initial finding that dummy variables for each country were statistically insignificant. Table 4 presents the aforementioned likelihood ratio tests. Further evidence may be provided through an elaborative spatial analysis, which falls outside the scope of the current paper.

Model Estimation Results

For each of the seven PPP approaches for project delivery (traditional maintenance contracting, traditional rehabilitation contracting, design-build, PBC, lane rentals, warranties, and $\mathrm{A+B+I/D}$), models of cost overrun likelihood and amount were developed, and are discussed in the following sections.

Cost Overrun Likelihood Model Results

The likelihood of each PPP approach resulting in cost overrun was investigated using the binary probit model, and the results of the best model specifications are presented in Table 2. All model variables are statistically significant at the 0.90 level of confidence, and their signs are intuitive.

For the relationships between project characteristics (planned duration, length, and engineer's cost estimate) and the likelihood of cost overrun in PPP contracts, the findings are insightful. For the traditional, design-build, lane-rental, and warranty contracting approaches, the results suggest that, assuming all other variables held constant, the longer the planned duration (in years) and length (in lane-miles), the higher the likelihood of cost overrun; whereas for the PBC and $\mathrm{A+B+I/D}$, the higher the duration and length, the lower the likelihood of cost overrun. Similarly, for the design-build and warranty contracting approaches, the higher the engineer's cost estimate, the higher the likelihood of cost overrun. By contrast, for PBC and $\mathrm{A+B+I/D}$ the opposite relationship holds; high engineer's cost estimate results in lower likelihood of cost overrun. In addition, it is found that the higher the number of activities included in a PBC, the lower the likelihood of cost overrun. These findings indicate that large-sized projects, in terms of duration, length, and cost, are generally more likely to have cost overrun, with the exceptions of PBC and $\mathrm{A+B+I/D}$. In the literature (Gransberg and Ellicott 1996; Skutella 1998; Ybarra 1998; Anderson and Russell 2001; Ernzen and Feeny 2002; Hastak et al. 2003; Liautaud 2004; Zheng et al. 2004; Zietsman 2004; Zhang 2006; Anastasopoulos et al. 2010a, c), similar relationships are found to exist between large-sized projects and their likelihood of having cost savings (expressed as percent cost savings of the PPP contracting approach, relative to the corresponding in-house approach). Given the nature of the contracting approaches, it is intuitive that PBC and $\mathrm{A+B+I/D}$ aim to cut costs and offer incentives towards that direction, whereas such an effort is not strongly considered by the other PPP approaches.

The work type is also found to influence the likelihood of cost savings. Table 2 shows that work types that typically have high costs or a high level of implementation risk (e.g., in terms of change orders), such as bridge-tunnel preservation and pavement repair, are more likely to result in cost overrun. For the traditional rehabilitation, PBC, and $\mathrm{A+B+I/D}$ contracting approaches, bridge-tunnel preservation is associated with a generally higher likelihood of cost overrun. This effect is found to be more pronounced for the $\mathrm{A+B+I/D}$ contracting approach than it is for the traditional rehabilitation and PBC contracting approaches. Similarly, for pavement repair, the results suggest that the traditional rehabilitation and warranty contracting approaches yield a higher likelihood of cost overrun.

By contrast, a number of relatively low-cost work types with typically low level of implementation risk (e.g., in terms of change orders), such as guardrail repair, culvert-gutter-drainage, electrical systems maintenance, landscape maintenance, litter removal, vegetation/tree maintenance, and emergency facilities maintenance/response, are found to be less likely to result in cost overrun. For the traditional rehabilitation and warranty contracting approaches, the results suggest that guardrail repair yields a lower likelihood of cost overrun. For the traditional rehabilitation, warranties, and $\mathrm{A+B+I/D}$ contracting approaches, culvert-gutter-drainage repair activities are also found to generally yield a lower likelihood of cost overrun. For traditional maintenance contracting, a number of maintenance work types (electrical systems maintenance, landscape maintenance, litter removal, and vegetation/tree maintenance) are found to be associated with a lower likelihood of experiencing cost overrun. Finally, for PBC, emergency facilities maintenance/response work types are found to have a lower propensity of cost overrun.

Cost Overrun Amount Model Results

The best model specification estimation results for the amount of cost overrun (in percentage) are shown in Table 3. The model variables are statistically significant at the 0.90 level of confidence and their signs are intuitive, with positive constant terms for the traditional, design-build, lane rentals, and warranty models, and with negative constants for the PBC and the $\mathrm{A+B+I/D}$. This indicates that, all other variables held constant, the traditional, design-build, lane rentals, and warranty contracting approaches are expected to have cost overrun, whereas PBC and the $\mathrm{A+B+I/D}$ are expected to have cost underrun. This is a reflection of the average (over the data sample) cost overrun values illustrated in Table 1, indicating that the developed models produce reasonable constants.

With regard to the relationship between the project characteristics (planned duration, length, and engineer's cost estimate) and

Table 1. Descriptive Statistics of the Selected Variables by PPP Approach

Key variables	Mean	Standard deviation	Minimum	Maximum
Traditional contracts (maintenance) ($N = 78$)				
Contract duration (years)	2.95	2.65	0.20	6
Contract length (lane-miles)	58.56	98.31	0.06	869
Contract final cost (million 2007 US dollars)	2.71	1.64	0.05	21
Cost overrun/underrun (%)	17.3	28.3	−11.2	256.8
Traditional contracts (rehabilitation) ($N = 99$)				
Contract duration (years)	1.62	2.01	0.16	6
Contract length (lane-miles)	35.49	88.61	0.11	880.5
Contract final cost (million 2007 US dollars)	3.28	2.10	0.01	21
Cost overrun/underrun (%)	15.9	33.2	−6.1	348.9
Design-build ($N = 49$)				
Contract duration (years)	2.44	2.04	0.21	6
Contract length (lane-miles)	44.56	30.38	1.14	105
Contract final cost (million 2007 US dollars)	17.07	12.09	0.05	60
Cost overrun/underrun (%)	11.4	18.5	−19.4	116.7
PBC ($N = 101$)				
Contract duration (years)	6.26	5.28	1.00	25
Contract length (lane-miles)	3,768.62	5,020.93	12.43	22,500
Contract final cost (million 2007 US dollars)	80.03	82.96	0.06	378
Cost overrun/underrun (%)	−4.3	19.1	−38.7	26.2
Lane rentals ($N = 44$)				
Contract duration (years)	2.66	2.04	0.21	5.9
Contract length (lane-miles)	40.10	28.51	1.19	106.5
Contract final cost (million 2007 US dollars)	14.85	13.90	0.04	58
Cost overrun/underrun (%)	5.6	14.5	−13.4	69.8
Warranties ($N = 144$)				
Contract duration (years)	3.23	1.78	0.22	6.1
Contract length (lane-miles)	56.79	29.23	1.20	123
Contract final cost (million 2007 US dollars)	28.49	15.57	0.06	66
Cost overrun/underrun (%)	18.7	30.0	4.1	274.6
A + B + I/D ($N = 86$)				
Contract duration (years)	2.58	2.35	0.25	9.19
Contract length (lane-miles)	40.21	33.30	1.16	117
Contract final cost (million 2007 US dollars)	19.43	18.61	0.05	65
Cost overrun/underrun (%)	−4.5	22.4	−22.3	86.7

Note: 1 mile = 1.61 km; A + B + I/D = cost-plus-time and incentives/disincentives; PBC = performance-based contracting.

the amount of cost overrun in PPP contracts, the findings are in accordance with the likelihood models discussed previously. For the traditional, design-build, lane-rental, and warranty contracting approaches, Table 3 shows that, assuming all other variables held constant, the longer the planned duration (years), the length (lane-miles), and the engineer's cost estimate, the higher the cost overrun amount, whereas for the PBC and A + B + I/D, the opposite effect is observed. (For A + B + I/D, the engineer's cost estimate does not result in a statistically significant variable at the 0.90 level of confidence.) In addition, it is found that the higher the number of activities included in a PBC, the lower the cost overrun amount. As previously discussed, these findings indicate that large-sized projects, in terms of duration, length, and cost, generally lead to increased PPP cost overrun, with the exceptions of PBC and A + B + I/D.

Akin to the earlier observed trends, in terms of the effect of the work type on the amount of cost overrun, activity types that have high costs or a high level of implementation risk (e.g., in terms of change orders), such as bridge-tunnel preservation (in the traditional rehabilitation and the A + B + I/D models), pavement (in the PBC, warranty, and A + B + I/D models), and shoulder repair (in the warranty and A + B + I/D models) tend to increase the amount of cost overrun. Low-cost work types with a typically low level of implementation risk (in terms of change orders), such as guardrail repair (in the warranty model), culvert-gutters-drainage (in the traditional rehabilitation, warranty, and A + B + I/D models), landscape maintenance and litter removal (in the traditional maintenance and PBC models), rest areas and vegetation/tree maintenance (in the traditional maintenance model), and illumination repair/maintenance and mowing (in the PBC model), are all found to reduce the amount of cost overrun.

More specifically, as indicated by the regression coefficients, a unit increase in the planned project duration (i.e., one year), would generally result in the following increases in cost overrun (on average): 1.0% for traditional maintenance, 1.2% for traditional rehabilitation, 0.5% for design-build, 0.8% for lane rentals, and 1.8% for warranty contracts. It would result in the following reductions in cost overrun: 0.9% for PBC and 0.7% for A + B + I/D contracts. A unit increase of contract length (i.e., 100 lane-miles) is found to be generally associated with the following increases in cost overrun (on average): 0.8% for traditional maintenance, 0.8% for traditional rehabilitation, 0.2% for design-build, 0.6% for lane rentals, and 0.8% for warranty contracts. However, for the PBC and the A + B + I/D contracting approaches, a 100 lane-miles increase of contract length results in 0.3 and 0.5% reduction in cost overrun (on average), respectively. A $1 million increase of the engineer's cost estimate is found to be generally associated with the following increases in cost overrun (on average): 0.3% for traditional maintenance, 0.3% for traditional rehabilitation, 0.1% for design-build, 0.2% for lane rentals, and 0.4% for warranty contracts. It would result in 0.1% reduction in the cost overrun for PBC. Finally, a one-unit increase in the number of activities included in a PBC is

Table 2. Model Estimation Results for the Likelihood of Cost Overrun by PPP Approach

Dependent variable: likelihood of cost overrun (1 if cost overrun greater than zero, 0 otherwise)	Traditional maintenance	Traditional rehabilitation	Design-build	PBC	Lane rentals	Warranties	A+B+I/D
Constant	0.922[a]	1.608[b]	0.988[a]	0.122[c]	0.611[a]	1.840[c]	0.387[b]
Project characteristics							
Planned duration (years)	0.500[b]	0.109[a]	0.189[a]	−0.394[c]	0.305[a]	0.263[a]	−0.236[a]
Length (in hundredths of lane-miles)	0.007[a]	0.015[c]	0.033[b]	−0.025[c]	0.002[a]	0.046[a]	—
Engineer's cost estimate (in million US dollars)	—	—	0.003[c]	−0.003[a]	—	0.004[b]	−0.002[a]
Number of activities included in the contract	—	—	—	−0.226[a]	—	—	—
Work type							
Bridge-tunnel preservation (1 if included in the contract, 0 otherwise)	—	0.501[c]	—	0.473[a]	—	—	2.002[b]
Pavement repair (1 if included in the contract, 0 otherwise)	—	0.188[b]	—	—	—	0.508[b]	—
Guardrail repair (1 if included in the contract, 0 otherwise)	—	−0.446[a]	—	—	—	−0.422[a]	—
Culvert-gutter-drainage (1 if included in the contract, 0 otherwise)	—	−0.361[b]	—	—	—	−0.555[a]	−1.656[c]
Electrical systems maintenance (1 if included in the contract, 0 otherwise)	−3.568[a]	—	—	—	—	—	—
Landscape maintenance, litter removal (1 if included in the contract, 0 otherwise)	−1.352[c]	—	—	—	—	—	—
Vegetation/tree maintenance (1 if included in the contract, 0 otherwise)	−1.004[a]	—	—	—	—	—	—
Emergency facilities maintenance/response (1 if included in the contract, 0 otherwise)	—	—	—	−2.509[a]	—	—	—
McFadden pseudo ρ^2	0.69	0.55	0.52	0.62	0.47	0.68	0.47
N	78	99	49	101	44	144	86

Note: 1 mile = 1.61 km; A + B + I/D = cost-plus-time and incentives/disincentives; PBC = performance-based contracting.
[a]Significant at 0.95 level of confidence.
[b]Significant at 0.90 level of confidence.
[c]Significant at 0.99 level of confidence.

Table 3. Model Estimation Results for the Amount of Cost Overrun (in Percentage) by PPP Approach

Dependent variable: cost overrun in percentage	Traditional maintenance	Traditional rehabilitation	Design-build	PBC	Lane rentals	Warranties	A + B + I/D
Constant	0.135[a]	0.148[a]	0.088[b]	−0.026[a]	0.043[c]	0.161[a]	−0.016[c]
Project characteristics							
Planned duration (years)	0.010[c]	0.012[c]	0.005[b]	−0.009[c]	0.008[a]	0.018[c]	−0.007[c]
Length (in hundredths of lane-miles)	0.008[b]	0.008[a]	0.002[a]	−0.003[a]	0.006[b]	0.008[a]	−0.005[b]
Engineer's cost estimate (in million US dollars)	0.003[a]	0.003[c]	0.001[c]	−0.001[b]	0.002[b]	0.004[b]	—
Number of activities included in the contract	—	—	—	−0.005[b]	—	—	—
Work type							
Bridge-tunnel preservation (1 if included in the contract, 0 otherwise)	—	0.194[b]	—	—	—	—	0.153[c]
Pavement repair (1 if included in the contract, 0 otherwise)	—	—	—	0.024[a]	—	0.096[c]	0.112[a]
Shoulder repair (1 if included in the contract, 0 otherwise)	—	—	—	—	—	0.028[a]	0.047[a]
Guardrail repair (1 if included in the contract, 0 otherwise)	—	—	—	—	—	−0.017[a]	—
Culvert-gutters-drainage (1 if included in the contract, 0 otherwise)	—	−0.029[a]	—	—	—	−0.031[c]	−0.023[a]
Landscape maintenance, litter removal (1 if included in the contract, 0 otherwise)	−0.040[c]	—	—	−0.047[b]	—	—	—
Rest areas, vegetation/tree maintenance (1 if included in the contract, 0 otherwise)	−0.046[a]	—	—	—	—	—	—
Illumination repair/maintenance (1 if included in the contract, 0 otherwise)	—	—	—	−0.055[c]	—	—	—
Mowing (1 if included in the contract, 0 otherwise)	—	—	—	−0.030[a]	—	—	—
Adjusted R^2	0.56	0.49	0.53	0.61	0.50	0.68	0.58
N	78	99	49	101	44	144	86

Note: 1 mile = 1.61 km; A + B + I/D = cost-plus-time and incentives/disincentives; PBC = performance-based contracting.
[a]Significant at 0.95 level of confidence.
[b]Significant at 0.90 level of confidence.
[c]Significant at 0.99 level of confidence.

Table 4. Likelihood Ratio Tests by Region for the Likelihood (a) and Amount (b) of Cost Overrun by PPP Approach

Contracting method	(a) Joint model versus	DOF	χ^2	χ^2 critical[a]	(b) Joint model versus	DOF	χ^2	χ^2 critical[a]
Traditional maintenance	Africa region model	6	5.94	10.64	Africa region model	6	5.50	10.64
	Asia region model		9.45		Asia region model		7.24	
	Europe region model		8.51		Europe region model		9.84	
	North America region model		7.38		North America region model		8.72	
	South America region model		6.46		South America region model		8.51	
	Pacific region model		7.36		Pacific region model		7.86	
Traditional rehabilitation	Joint model versus	7	8.09	12.02	Africa region model	6	7.32	10.64
	Asia region model		7.29		Asia region model		8.48	
	Europe region model		7.56		Europe region model		7.94	
	North America region model		9.38		North America region model		9.71	
	South America region model		10.88		South America region model		6.59	
	Pacific region model		6.99		Pacific region model		8.38	
Design-build	Africa region model	4	5.10	7.78	Africa region model	4	4.94	7.78
	Asia region model		4.16		Asia region model		6.29	
	Europe region model		6.94		Europe region model		5.07	
	North America region model		6.03		North America region model		3.68	
	South America region model		6.70		South America region model		5.56	
	Pacific region model		3.78		Pacific region model		3.08	
PBC	Africa region model	6	7.65	10.64	Africa region model	9	9.17	14.68
	Asia region model		6.36		Asia region model		8.80	
	Europe region model		5.80		Europe region model		10.43	
	North America region model		5.69		North America region model		8.88	
	South America region model		7.14		South America region model		9.21	
	Pacific region model		5.85		Pacific region model		7.51	
Lane rentals	Africa region model	3	4.32	6.25	Africa region model	4	4.45	7.78
	Asia region model		5.26		Asia region model		5.67	
	Europe region model		4.98		Europe region model		5.54	
	North America region model		3.50		North America region model		6.85	
	South America region model		4.33		South America region model		4.53	
	Pacific region model		2.35		Pacific region model		3.38	
Warranties	Africa region model	7	8.53	12.02	Africa region model	8	8.91	13.36
	Asia region model		5.42		Asia region model		7.56	
	Europe region model		9.43		Europe region model		6.96	
	North America region model		7.10		North America region model		9.94	
	South America region model		7.57		South America region model		10.51	
	Pacific region model		10.20		Pacific region model		8.56	
A + B + I/D	Africa region model	5	7.00	9.24	Africa region model	7	10.89	12.02
	Asia region model		6.72		Asia region model		7.28	
	Europe region model		7.80		Europe region model		8.42	
	North America region model		5.16		North America region model		7.44	
	South America region model		4.46		South America region model		5.28	
	Pacific region model		6.89		Pacific region model		6.98	

[a]0.90 level of confidence.

found to reduce the amount of cost overrun by 0.5% (on average). These relationships between the cost overrun and the planned duration, length, and engineer's cost estimate by PPP approach are depicted in Figs. 1–3. (It should be noted that nonlinear relationships between these variables and the cost overrun were tested; however, they did not yield statistically significant results.)

Table 3 also indicates that bridge-tunnel preservation has a propensity to generate a cost overrun of 19.4 and 15.3% (on average) for traditional rehabilitation and A + B + I/D contracts, respectively, all other factors remaining the same. Pavement repair is found to yield a 2.4, 9.6, and 11.2% cost overrun increase (on average) for the PBC, warranty, and A + B + I/D contracts, respectively. Shoulder repair is also found to increase the cost overrun of warranty and A + B + I/D contracts by 2.8 and 4.7% (on average), respectively. Alternatively, guardrail repair reduces the cost overrun of warranty contracts by 1.7% (on average). Culvert-gutters-drainage activities are also found to reduce the traditional rehabilitation, warranty, and A + B + I/D contract cost overrun

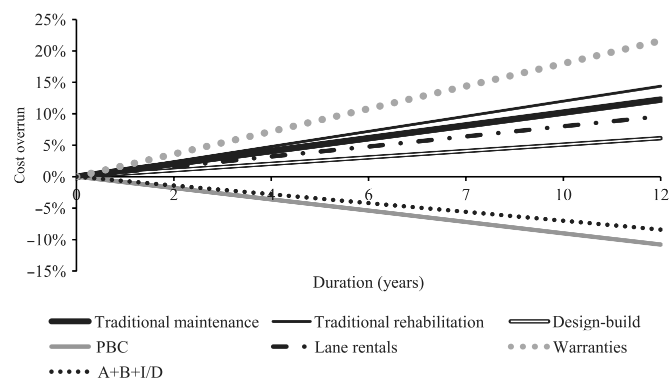

Fig. 1. Relationship of project planned duration and cost overrun by PPP approach

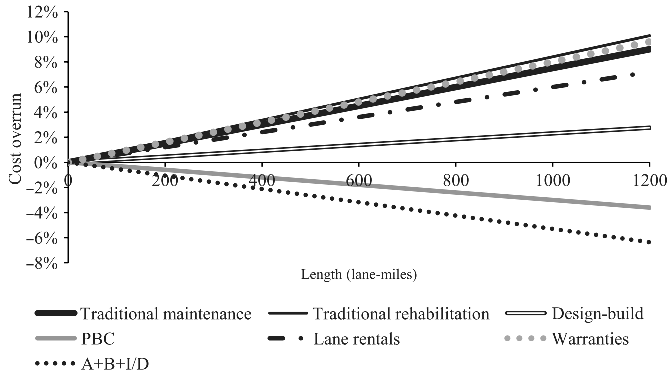

Fig. 2. Relationship of project length and cost overrun by PPP approach

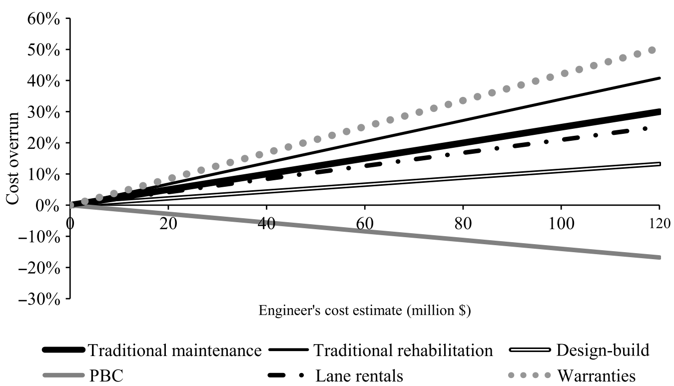

Fig. 3. Relationship of engineer's cost estimate and cost overrun by PPP approach [note that the cost estimate was not found to significantly affect the cost overrun of the cost-plus-time and incentives/disincentives ($A + B + I/D$) approach, so it is not illustrated in the figure]

by 2.9, 3.1, and 2.3% (on average), respectively. In the traditional maintenance and PBC models, landscape maintenance and litter removal are found to reduce the corresponding cost overrun by 4.0 and 4.7% (on average), respectively. And rest areas and vegetation/tree maintenance are found to reduce the cost overrun of traditional maintenance contracts by 4.6% (on average). Finally, in the PBC model, it is found that illumination repair/maintenance and mowing reduce the amount of cost overrun by 4.0 and 4.6% (on average), respectively.

Conclusions and Recommendations

Over the past decade, there has been considerable effort focusing on finding new ways of contracting for highway maintenance and rehabilitation programs, motivated increasingly by widening funding gaps. To that end, public-private partnerships have been formed to provide sustainable highway preservation solutions by cutting costs and retaining an acceptable level of service for the infrastructure asset, without harming the environment and exhausting natural resources. When compared with in-house practices, many PPP approaches produce cost savings. However, the questions as to whether, and under what conditions, different PPP contracting approaches result in cost overrun have previously not been systematically addressed. Past research has comprehensively analyzed the problem of cost overrun without segregating the analysis by PPP approach, typically due to data limitations. Such efforts inevitably assume that all PPP contracting approaches share similar characteristics, and that the potential of cost overrun depends on the same (or similar) factors. This study explores the problem of cost overrun by investigating its likelihood and amount separately for seven popular PPP contracting approaches.

The results show that a number of project characteristics (planned project duration, length, engineer's cost estimate, and number of work activities included in the contract) affect both the likelihood and amount of cost overrun for most of the PPP approaches. Also, specific work types are found to affect the likelihood and amount of cost overrun, such as bridge-tunnel preservation, pavement repair, guardrail repair, culvert-gutter-drainage repair, electrical systems maintenance, landscape maintenance, litter removal, vegetation/tree maintenance, emergency facilities maintenance/response, shoulder repair, rest areas maintenance, illumination repair/maintenance, and mowing.

The analysis provides important insights that can be generalized for developing cost-effective contracting strategies in the PPP context. It is evidenced that large-sized projects, in terms of duration, length, and cost (and number of activities included, for the case of PBC), are generally more likely to have cost overrun. However, the opposite holds for PBC and $A + B + I/D$, as these contracting approaches favor large-sized projects, and can therefore be adopted as a sustainable solution in long-term preservation programs.

Moreover, work types that typically have high costs or a high level of implementation risk are more likely to result in cost overrun, regardless of the PPP approach. And relatively low-cost work types with typically low level of implementation risk are less likely to result in cost overrun, irrespective of the PPP approach.

Finally, warranties are found to be more sensitive to changes in almost all factors that increase the likelihood and amount of cost overrun, whereas PBC and $A + B + I/D$ are more sensitive to changes in most of the factors that reduce the cost overrun likelihood and amount. Warranties traditionally have high cost overrun and life-cycle costs as their primary focus to provide a very high level of service. PBC and $A + B + I/D$ have low life-cycle costs and traditionally have low cost overrun, as they aim at both retaining a high level of service and cutting costs, and typically offer incentives towards these goals. This is another indication that PBC and $A + B + I/D$ can contribute towards the sustainability of highway preservation.

Although the nature of this study is primarily exploratory, the research findings can help transportation agencies and related organizations facilitate decision-making processes regarding the adoption of appropriate PPP for different maintenance and rehabilitation work types, which in turn has the potential to lead to sustainable highway preservation. However, as always, final recommendations should also include other considerations such as local site conditions and the social and political contexts. Further analysis using information that was not readily available herein, as for example project characteristics such as change orders, road functional classes, or more detailed work types, along with an exploratory spatial analysis to account for regulations and contractual conditions among different countries or regions, could shed additional light on the problem of cost overrun across different PPP contracting approaches.

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