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Road and Rail Infrastructure II

Stjepan Lakušić – EDITOR



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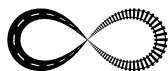
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PREDICTION MODEL FOR THE COST OF ROAD REHABILITATION AND RECONSTRUCTION WORKS

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Abstract

Maintenance of existing road network represents a challenge for public road authorities who seek a balance between available budgets and the need for maintaining level of service at a satisfactory level on existing road sections. For this reason, prediction of cost for road rehabilitation and reconstruction works represents one of key inputs for the objective analysis of projects and available budgets and optimization of road maintenance alternatives.

However, the average unit costs of road rehabilitation and reconstruction vary substantially between countries, and even between projects in the same country, due to a number of factors. In this paper an effort is made to develop a prediction model that could be applied for a wide range of conditions in different countries. A specialized dataset is used, which was generated under a World Bank study for a sample of road works contracts from 14 countries in Europe and Central Asia, signed between the years 2000 and 2010. The data sample for the analysis covers 94 projects of rehabilitation and reconstruction of flexible pavements. A multivariate regression analysis is used to evaluate the determinants of the cost per kilometer of the road rehabilitation or reconstruction.

The explanatory variables that are tested in the model are divided in three groups:

- a Variables related to oil prices
- b Variables that are country specific
- c Variables that are project specific

The variables included in the analyses were chosen in view of their potential explanatory power. The resulting regression model is expected to be useful in the strategic analysis of road networks, including the optimization of road maintenance alternatives.

Keywords: Road rehabilitation and reconstruction works, cost prediction model, multivariate linear regression analysis

1 Introduction

Public road authorities are facing a challenge of finding a balance between available funds and a need for maintaining existing road networks at a satisfactory level of service. For this reason, prediction of cost for road rehabilitation and reconstruction (RRR) works, as one of most common type of works, represents one of key inputs for the objective analysis of projects and available budgets and optimization of road maintenance alternatives.

However, the project cost for RRR works vary substantially across countries and over time, but variation also exists within the country in the same year due to a number of reasons. Thus, accurate cost estimations of RRR projects at the early stages of the road planning and maintenance programs are challenging and difficult to obtain.

During project implementation, as more detailed information become available, it is possible to derive accurate project costs. However, developing models that could estimate costs of RRR works at an early stage of project development, with minimum project information, is crucial in planning road maintenance programs. Relatively precise cost prediction models would ensure better allocation of resources and successful delivery of such programs.

This paper presents a model that can be applied for the early cost estimations of RRR works in European and Central Asia (ECA) countries where only limited project information is available. Multiple regression analysis (MRA) is used for the model development since this technique is adequate for examining potential variables, their suitability and contribution to the model.

2 Input dataset

The World Bank has recently performed two studies to establish a framework for cross-country comparative assessment of the procurement and implementation processes of RRR works contracts [1,2]. A specialized dataset was generated covering projects in 14 countries of Europe and Central Asia (ECA): Albania, Armenia, Azerbaijan, Bosnia and Herzegovina, Bulgaria, Croatia, Estonia, Georgia, Kazakhstan, Macedonia, Poland, Romania, Serbia, and Ukraine [2]. The data sample covered 94 completed or on-going RRR works contracts signed between 2000 and 2010 and included data for contracts above a threshold value of U.S. \$1 million. All contract amounts in local currency were converted into U.S. dollars using the exchange rate at the bid opening date [3,4]. The cost per km of RRR works did not include the cost of structures. The above mentioned study made it possible to do cross country comparison of the costs of RRR works, and inspired the idea to develop a general cost prediction model that could be used in the ECA countries for strategic planning of RRR works at the network level.

The dependent variable in the analysis was the actual cost of RRR works per kilometer, for a two-lane (7-m wide) road equivalent. The initial set of the explanatory variables included 18 variables in total. These variables can be grouped in the following three categories:

- variables related to oil price
- variables that are country specific
- variables that are project specific
- The oil price related variables included:
 - the crude oil price per barrel
 - the diesel and gasoline fuel price per liter in the country
 - whether the country is a net oil exporter or importer (a dummy variable)

The prices of gasoline and diesel fuel per liter were added to the original database. It was anticipated that these variables could be significant for the model as their price variation may affect the price of RRR works. As most of the maintenance works were performed on asphalt concrete pavements, it was expected that the price of bitumen would affect the price of RRR works. The prices of crude oil, gasoline and diesel are publicly available for all the countries and therefore were used as a proxy for the cost of bitumen [5,6,7].

Also, a dummy variable indicating whether the country was an oil exporter or importer was tested in the model for its significance (a dummy variable which took value 0 if the country was oil exporter, and value 1 if the country was oil importer). It was anticipated that the costs of RRR works should be lower in the countries that were oil exporters. This variable can be obtained from the World Bank's World Development Indicators database (WDI), which is publicly available [8]. Variables that are country specific included:

- the country's Gross National Income (GNI) per capita
- inflation
- Gross domestic product growth rate
- climate conditions
- road sector gasoline fuel consumption

- the Transparency International Corruption Perceptions Index (CPI)
- World Governance Index (WGI).

The country's Gross National Income per capita, inflation and Gross domestic product growth rate are variables used as indications of the specific economic conditions in the country in which the RRR project was implemented. Values for these indicators can be obtained from the World Bank's World Development Indicators database (WDI), which is publicly available [8]. Climate conditions were included in the analysis through a dummy variable which took the value 0 if the climate was mild and the value 1 if severe climate conditions are prevailing in the country. The variable expressing the road sector gasoline fuel consumption is added to the initial set of variables because it could be indicative, and it is easily obtained from the World Bank's WDI database [8].

Transparency International (TI) defines corruption as the abuse of entrusted power for private gain [9]. This definition encompasses corrupt practices in both public and private sectors. The CPI ranks countries according to the perception of corruption in the public sector and the score goes from 0 (highly corrupt) to 10 (very clean). The WGI measures the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as 'capture' of the state by elites and private interests [8].

These country specific variables were chosen to be able to identify the link between the strength of the country's economy and the possible influence of corrupted and nepotistic governments to the costs of RRR works. Variables that are project specific included:

- price of asphalt concrete (us \$ per m³)
- total number of bidders
- number of foreign bidders
- number of local bidders
- percent of local bidders
- terrain type
- expected RRR works duration (in months)
- length of the RRR works (7-m wide two lane road equivalent).

The number of bidders was used as a proxy for the level of competition in a specific contract, the rational being that costs would tend to be lower with a higher degree of competition. Percent of local bidders was calculated as a percent of local contractors compared to the total number of firms that participated in the tender.

It was anticipated that performing the RRR works of any type on difficult terrain conditions would increase the costs of the RRR works. A dummy variable was used that takes value 0 if the terrain is flat and value 1 if terrain is hilly or mountainous. The length of RRR works was expressed as the equivalent length of a 7-meter wide two lane road. The expected duration of RRR works was expressed in months, and it was expected that the cost of RRR works per kilometer in the projects with longer expected duration would be higher because those works were anticipated to be more complex and therefore more expensive.

The values for all variables were obtained, to the extent possible, at the time of bidding.

3 Methodology

In order to find a model which would be relatively simple for further use, multiple linear regression analysis is chosen as a method for model development and for the analysis of selected variables. The cost of RRR works per kilometer was set as the dependent variable and it was transformed using natural logarithm in order to obtain a better fit of the model. Thus, in this analysis, the regression equation was formulated as:

$$Y = e^{(\beta_0 + \sum_{i=1}^p (\beta_i \times x_i) + \epsilon)}$$

where y is the dependent variable, X_i are independent variables, p is the number of independent variables, ϵ is the residual error, β_i are regression coefficients and β_0 is a constant. Before model development, several engineering assumptions were made regarding the sign of regression coefficients. These assumptions served as the benchmark for the logical testing of the model and its results. For example, it was expected that higher prices of crude oil and its derivatives would increase the price of RRR works, as well as the severe climate and terrain conditions and the fact that the country is an oil importer. On the other hand, the costs of RRR works would decline as the level of competition, expressed through the number of bidders, increases.

Furthermore, during the preliminary analysis of the data set, the correlation between independent variables was tested, as well as the sign of regression coefficient of each independent variable. For example, after initial analysis of data, it was observed that there was a positive correlation between the crude oil and oil derivative prices and the costs of RRR works.

Four diagnostic methods were used for testing the dataset for outliers:

- Analyses of the (square) residuals
- Standardized residuals
- Cook's distance
- Leverage matrix.

The threshold value for recognizing an outlier, based on the standardized residual, was set to be ± 3 standard deviations. For the Cook's distance, the 'suspicious' points are the points with significantly different value of Cook's coefficient compared to the values in the other points (critical value is 1, as a general rule), and as for the Leverage distances, critical value is calculated as $2.5 \cdot p/n$, p being the number of explanatory variables, and n being the sample size. In the selected data sample, there were no outliers identified.

The backward analysis method was used as a starting point for the analysis of variables which should be included in the model. Backward analysis is based on the removal of the variable that has the highest p -value (because its contribution to the model is the least significant). However, in this study slightly altered backward analysis was used. Variables were removed from the model if they had p -value higher than 0.1 (threshold value set in this study). Additionally, the satisfaction of engineering assumptions previously mentioned was checked in terms of logical judgment.

Also, before the final decision about the next step was made, the effect of the deletion of the selected variable on the model was reviewed by comparing the coefficient of determination R^2 and adjusted coefficient of determination R_2 , F -statistic, and standard error of the estimate to their values from the previous model. Therefore, developed models include variables that have regression coefficient with p -values lower than 0.1 and that are in accordance with the earlier established assumptions.

During the model development, the motivation was also to use a data sample as large as possible. For example, it was found that the terrain conditions were unknown for most contracts. Using this variable in the model could greatly reduce the size of the data sample, thus such variable was not included in the model development.

Standard regression assumptions were checked for developed models. It was confirmed that the relationship between independent variables and the dependent variable is linear. Also, the residuals follow normal distribution, have zero mean and a constant variance and are independent of each other, i.e., residuals are independently and identically distributed (iid) normal random variables [10].

4 Resulting regression models

In total, seven variables were selected as most significant variables when estimating the expected cost of RRR works in a country, namely: the Transparency International Corruption Perceptions Index, climate conditions of the project's country, country Gross National Income, expected participation of local contractors on the tender, expected duration of RRR works, the length of the RRR works (as the equivalent length of a 7-meter wide two lane road), and the price of asphalt concrete.

Two models were developed, each with the use of six independent variables with sample size of 43 (table 1).

Table 1 Table 1
Regression coefficients for model 1 and model 2.

	Independent Variable	Coefficient	Model 1	Model 2
	constant	β_o	9.912009*	11.08770*
Country specific variables	TICPI	β_{TICPI}	0.2555876*	
	Climate	β_c	0.6063567*	0.6389887*
	GNI	β_{GNI}		1.406455x10 ⁻⁴ *
Project specific variable	% of local bidders	β_{LB}	-7.814582x10 ⁻³ *	-6.6619297x10 ⁻³ *
	Duration	β_{DUR}	0.06392160*	0.04442844*
	Ln (road length eq)	β_{RL}	-0.3673852*	-0.2677805**
	asphalt	β_{ASPH}	0.4254832*	0.2210973***
Dependent variable	Ln (cost/km)			

*p-value less than 0.01, **p-value less than 0.05, ***p-value less than 0.1

Both models are highly statistically significant with coefficients of correlation 0.831 (model 1) and 0.835 (model 2), and adjusted coefficients of correlation of 0.803 (model 1) and 0.807 (model 2). Standard error of the estimate is 0.2782 (model 1) and 0.2753 (model 2). In order to compare the two models it is usual practice to calculate the F value that evaluates goodness of fit, taking in consideration degrees of freedom and the size of the sample. As the size of the data sample was 43 for both models, and the same number of independent variables was used in both models, F values were almost the same for both models (29.506 for model 1 and 30.258 for model 2).

The negative sign of the variable 'ln (road length eq)' regression coefficient is in accordance with the assumptions earlier established, i.e., it was expected that if the RRR work was performed on a longer section, the price per kilometer of such works would be lower. Furthermore, the price was expected to be higher if the estimated duration of the RRR works was relatively long due to more complex type of works. Also, the costs per kilometer of RRR works tend to be lower in case most of the firms on the tender are local contractors.

Figure 1 represents the comparison of actual and predicted costs. The X-axis represents natural logarithm of actual costs, i.e., contract values from the WB database, and the Y-axis represents natural logarithm of calculated costs using the equation obtained for final models.

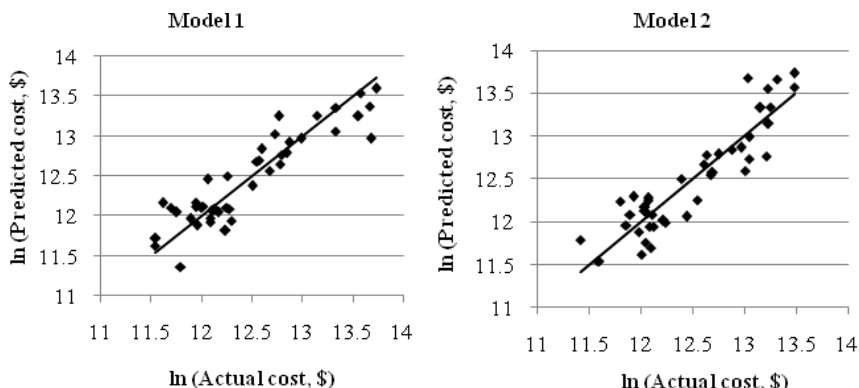


Figure 1 Comparison of actual and predicted costs for both models.

Developed models make error in estimate within the range of $\pm 5\%$. It should be noted that variables related to the oil price are not included in final models. However, it could be assumed that the price of asphalt concrete would reflect, to some extent, the crude oil price on the market and price of its derivatives, i.e., price of bitumen. Considering that only six values are needed as input data for the RRR cost estimates, the developed models provide a reasonable estimates for projects when only limited information is available. In other words, one can estimate the expected costs of RRR works knowing only two input parameters about the country and four input parameters about the project.

5 Conclusions

This paper explores the parameters based on which it is possible to estimate the unit cost of RRR works at the strategic level, i.e., when only limited information is available about a project at the planning stage.

Seven variables were found to be the most significant variables when estimating the cost of the RRR works in a particular country. Based on these variables, two models were developed and both are found to be highly statistically significant. Both models are general, covering broad spectrum of RRR works in different countries. Such models are a useful tool which allows reasonably accurate first estimates about the expected costs of the RRR works based on limited basic country and project information.

The resulting regression equations are expected to be particularly useful at the strategic level, for planning and optimization of RRR works in road networks in countries of Europe and Central Asia. Further research is recommended to focus on the analysis of contracts for RRR works in road networks in other regions, the results of which could be pooled together with the results with this research.

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