The Bromilow Time-Cost model: a case study for the infrastructure projects in Romania

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Abstract. The Bromilow Time-Cost model is widely applied for estimating the duration of the construction works. The application of this model requires the estimation of different model’s parameters, which are capturing the economic, social and technological differences in projects’ implementation in different regions/countries. The paper aims to develop a mathematical Time-Cost model to be applied in Romania for the road infrastructure projects, grouped into four categories: highways, road rehabilitation, road modernization and by-pass. The research carried out by the authors has as objective to confirm the existence of the correlation between the project duration and costs, and to propose a procedure to be applied by the public decision authorities in order to estimate the duration of road infrastructure contracts. The estimation of the implementation time was done through three scenarios: optimistic, most likely and pessimistic. The parameters of the Bromilow Time-Cost model and the regression models were identified.

1. Introduction

Road infrastructure projects are characterized by high durations, high costs and significant impact on the economic development. They are tight associated with increased safety and quality of life. Both project owners and contractors need to consider an adequate project duration during bidding.

In Romania, there are no studies on the correlation between the duration of contracts for road infrastructure projects and their cost, which would improve the implementation of project tenders and make the contracted duration of works more predictable. The Romanian National Road Infrastructure Management Company (C.N.A.I.R.), the most important beneficiary of road infrastructure projects, has no procedures or at least public guidelines for estimating the duration of contracts. For this reason, the research presented in this paper, is intended on the one hand to highlight the correlation between the duration of projects and their cost and on the other hand, to provide decision-makers with a method for estimating the duration of road infrastructure contracts taking into account the specificities of our country.

The research conducted by the authors uses data from 89 road infrastructure projects executed between 2001 and 2018, of which 32 highway projects, 19 road rehabilitation projects, 12 road modernization projects and 27 bypass projects. The cumulative value of these projects is 4.577 billion Euros and the total length of the targeted roads is 2,026 km. The purpose of the regression analysis is to develop a mathematical model that allows the estimation of the execution duration of these categories of projects, taking into account their cost, from the stage of feasibility study and organization of tenders.
2. The Bromilow time-cost model for estimating the duration of road infrastructure projects

The duration of execution of construction works is directly proportional to their costs. This observation was analysed, detailed and translated into a mathematical forecasting model for the first time by Frank Bromilow [1] in a paper published in 1969 in the Building Forum, where he established a relationship between the size of a project and the time required to complete the construction, providing a quick and realistic estimate of the duration of construction without applying detailed planning techniques. The formula developed by Bromilow for time as a cost function has the form: \( T = KC^B \), where: \( T \) is the actual duration of the construction in working days from the actual start date of the works until their actual completion, \( C \) is the final cost of construction (of the beneficiary) in millions of dollars adjusted to the prices of labor and materials, \( K \) is a constant feature of execution performance for a $1 million project; the shorter \( K \), the shorter it will last (it is more efficient) and \( B \) is a constant indicator of the sensitivity of performance over time to cost.

One of the characteristics of the Time-Cost Bromilow model is the limitation of its application only to the research area, due to the differences of economic, social, administrative and technological nature between the countries.

Road infrastructure construction projects are of great importance for the development of a country's economy and as a result, researchers have sought to identify through various mathematical models the link between lead time and project cost. Czarmigowska and others [3] analysed 100 road infrastructure projects completed between 2003 and 2008 in Poland, of which 39 were road upgrades, 34 were upgrades and repairs and 27 were new road constructions. Data taken from the official publications of the Directorate-General for National Roads and Motorways were processed using regression analysis and the Bromilow model.

Similar studies were carried out on 41 state and local roads, 27 motorways, 25 roads (roads, tunnels, bridges, etc.) carried out between 1992 and 2003 in Croatia [2]. The sample for large road infrastructure projects comprises 27 road sections built between 2000 and 2010. In order to obtain feasible estimates, the authors propose introducing in the Bromilow model a series of parameters that take into account the magnitude of the orders of variation during the projects, their management capacity and the existence of financial problems faced by contractors in project implementation.

Choudhury [4] has studied the extent to which the Bromilow model can be applied in road infrastructure projects in India and to verify whether such a relationship is good for this sector of the Indian construction industry. For this, 50 infrastructure projects were identified for which the regression analysis based on the Bromilow model was applied. Tawiah [5] studied a set of 70 completed road projects completed between 2011 and 2012 in Ghana. The results of the analysis showed that the Bromilow Time-Cost model can be applied to these categories of projects. Kaka and Price [6] conducted similar research on projects in the UK, analysing a set of 140 road projects with a total value of over £120 million. For highway projects in Florida, Shr and Chen [7] investigated possible functional relationships between execution time and cost. Analysing 21 projects carried out by the US Department of Transportation (FDOT) in the United States between 1996 and 1999, Shr and Chen used nine different forms of regression models.

3. Applying Bromilow's time-cost model in road infrastructure projects in Romania

3.1. Research methodology

In order to apply the Time-Cost model developed by Bromilow to the specific conditions of implementation of road infrastructure projects in Romania and to identify its characteristic parameters, 89 projects completed in the period 2001 - 2018 were selected, with a cumulative value of 4.577 billion Euro and totals 2,026 km, starting from data published by C.N.A.I.R. [8].

The following data was considered: year when the project works started, the contractual duration, the duration of the completion of the works, the initial costs of the works and the final costs. In order for the analysis to allow a consistent comparison of the data, the initial and final costs were expressed in Euro and adjusted for the inflation index.
3.2. Data collection
Data was grouped into the following categories: highways, road rehabilitation, road modernizations and bypasses, for the projects carried out between 2001 and 2018. From 31 highway projects, 25 projects were selected for the model development and 6 projects were kept for the model testing. 16 road rehabilitation projects were selected for building the model and all other projects being kept for the model testing. In the case of road modernization, 11 projects were selected for the model development, and one project was used for the model testing. For the bypass variants projects, 19 projects were selected for the model development and 7 projects were used for the model testing. Considering the specific features of each category of works, the regression analysis was performed separately for each project type.

3.3. Data analysis
Data was processed using statistical regression analysis, seeking as far as possible to obtain the highest possible degree of correlation between the duration of the contracts and their cost. Regression analysis and identification of Bromilow model parameters was performed using the JASP program [9] of the University of Amsterdam.

4. Research results
4.1. The results for the highway projects
The shape of the data cloud in the Cost - Duration diagram was drawn. As can be seen in figure 1, the dispersion of actual data is higher than for the contracted data. In addition, most contracted data have the same duration, even if the value of the contracts is significantly different.

![Figure 1. Data cloud distribution for contracted and actual cost and duration in the case of highways.](image.png)

Unlike the contracted indicators, the actual indicators highlight the correlation of the value of the works with the duration of execution. This fact is also confirmed by the correlation coefficient which for the contracted data is $R^2 = 0.0687$, while for the actual data, it is $R^2 = 0.2276$ (see figure 2).
The correlation $R^2$ for contracted and actual cost and duration in the case of highways.

In order to set the potential values of the parameters in the Bromilow model, the initial and actual durations and costs were transformed by logarithm (see figure 3).

The logarithm of the initial and actual data results in an improved correlation coefficient for the actual values at $R^2 = 0.3579$, while for the initial data the same non-correlation state is found. By interpreting these results, we can conclude that the contracted durations are not at all correlated with the volume of work, while the factual aspects contradict this state. Most contracts for the execution of motorway lots last for 24 calendar months.

In order to correlate the initial data, it was proposed to adjust the duration by defining not a single value, but three values that take into account the potential risks that may occur during execution. In this sense, the average initial and actual duration necessary to build a kilometre of highway was calculated, considering that in this time frame must be included the three durations that will correct the initial duration.

For the analysed data set, the average contracted duration is 20 working days per kilometre, while for the actual data, the average duration is 35 working days / kilometre. Under these conditions, for the optimistic scenario whose probability is usually zero, the duration of 12 working days was chosen, for the most probable scenario whose probability is greater than 50% the duration of 18 working days was chosen, and for the pessimistic scenario, duration of 25 days, corresponding to a probability of 100%. It was found that in this situation, the correlation coefficient $R^2$ varies between 0.51 for the optimistic scenario, 0.47 for the most likely scenario and 0.56 for the pessimistic scenario (see figure 4). Under...
these conditions, if we applied the Bromilow model, it could be validated for over 47% of contracts. To determine the model parameters, the values thus obtained are transformed by logarithm.

![Figure 4. Correlation for adjusted data for highways projects](image1)

In this situation, the correlation coefficient $R^2$ acquires much more acceptable values, ranging between 0.68 for the optimistic scenario, 0.68 for the most probable scenario, up to 0.70 for the pessimistic scenario (see figure 5).

![Figure 5. Data correlation using the logarithmic transformation.](image2)

The parameters of the Bromilow model are presented in table 1.

| Scenario     | Regression equation | $R^2$ | K     | B  |
|--------------|---------------------|-------|-------|----|
| Optimistic   | $y = 0.3067x + 4.4749$ | 0.6867 | 87.7858 | 0.3067 |
| Most likely  | $y = 0.3904x + 4.2948$ | 0.6845 | 73.3175 | 0.3904 |
| Pessimistic  | $y = 0.4001x + 4.4874$ | 0.7047 | 88.8900 | 0.4001 |

By comparing the range of variation of the Bromilow model for the three scenarios, we found that it largely covers the variation resulting from contracted and actual data, allowing us to say that this model can be applied in estimating the execution times of highway projects (see figure 6).
Figure 6. The comparative variation of the duration with the project cost for highways.

Under these conditions, the Bromilow Time-Cost model will have not one, but three relations for estimating the duration of a highway project:

- For the optimistic scenario: \( T = 88C^{0.307} \)
- For the most likely scenario: \( T = 73C^{0.390} \)
- For the pessimistic scenario: \( T = 89C^{0.400} \)

in which the cost is expressed in millions of Euros.

4.2. The results for the road rehabilitation projects

From the analysis of the contracted data, it results that the average duration in working days for the accomplishment of a rehabilitation kilometre is 11 days, while the average duration corresponding to the actual data is 20 working days. The three scenarios lead to a significant correlation between the corrected realization time and the cost of the works. The correlation coefficient \( R^2 \) varies between 0.76 for the optimistic scenario, 0.75 for the most probable scenario and 0.77 for the pessimistic scenario.

Using the logarithm transformation, we obtained the regression equations corresponding for the three scenarios.

4.3. The results for the road modernization

From the verification of the degree of correlation between the pairs of values corresponding to the contracted and actual data, it is found that the contracted values - duration, cost - have an extremely low correlation coefficient \( R^2 = 0.1142 \), while the correlation coefficient for the actual data is a satisfactory one, it having a value of \( R^2 = 0.5487 \). However, the analyzed data show a high degree of heterogeneity in terms of the length of the modernized road sectors and the works of art that are included and that affect the accuracy of the Bromilow model. For this reason, from the available data series, 7 projects were selected that recorded similar lengths and costs. However, unlike the previous situations, there is a positive correlation with a correlation coefficient \( R^2 = 0.32 \) for the contracted data, while for the actual data, it is extremely low, practically non-existent, the correlation coefficient having the value \( R^2 = 0.004 \). The parameters of the Bromilow model were obtained for which it is found that they have a significant correlation coefficient, equal to \( R^2 = 0.77 \).

4.4. The results for the by-pass variant projects

Taking into account the high degree of heterogeneity of the data, we selected 15 contracts that have an average length of road sections of 8 kilometres and whose average contracted value is 15 million Euros. For the selected data set, the degree of correlation between the contracted and actual value pairs was analysed, finding that although the correlation is positive, it is insignificant. For the contracted data, three scenarios are proposed, optimistic, most likely and pessimistic, so as to obtain a range of values that allows us to forecast. By transforming the values by logarithm, the parameters of the Bromilow
model were obtained for which it is found that they have a correlation coefficient that varies between $R^2 = 0.45$ for the optimistic scenario, $R^2 = 0.42$ for the most probable scenario and $R^2 = 0.38$ for the pessimistic scenario.

5. Conclusions

The paper proposes a mathematical time-cost model which can be applied to the concrete conditions in Romania on road infrastructure projects. Considering the multiple risk events that accompany the complex road infrastructure projects, in the development of the Bromilow Time-Cost model, the estimation of the implementation time was done through three calculation options: optimistic, most likely and pessimistic, to cover extremely varied of the analyzed data.

The general conclusion of the research is that the existing durations of the contracts for the execution of road infrastructure projects must be reviewed by the C.N.A.I.R. to meet the specific conditions of Romania. The accuracy of the developed predictive model is higher the more accurate the processed data. Researching the correlation between execution time and cost requires detailed analysis of projects in the project portfolio of the C.N.A.I.R. for the application of a regression analysis whose results are closer to reality.

However, improving the forecast requires other steps that we recommend for further research:
- Detailed analysis of projects in the C.N.A.I.R. project portfolio for the application of a regression analysis whose results are closer to reality
- Analysis of the productivity of construction processes in the field of road infrastructure projects
- Development of a database with productivity corresponding to the capacity of construction companies operating in Romania and to be used in the realistic estimation of the duration of contracts
- Development of a guide for estimating the duration of contracts to be applied by C.N.A.I.R. in road infrastructure projects
- Using the Critical Path Analysis in the stage of preparation of the tender specifications to allow a realistic estimation of the duration of the contracts

If there are works of art on the road sectors, they will have to be analyzed separately, due to the particularities they involve.

6. References
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