Project Duration Estimation for Road Construction in Developing Countries: An Empirical Analysis

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Abstract: The article examines the techniques used to determine the time required for the completion of road projects. It explores the approach to estimating the duration of road construction in developing countries. Regression analysis is put forward as a means of estimating the duration of road projects. The findings reveal that a 1% increase in project expense results in a 0.4% increase in project duration and that changes in the area also affect the project duration. Additionally, a 1% rise in gross national product per capita leads to a 0.05% decrease in project duration. It presents a thorough examination of the methodology used for estimating the duration of road projects in developing countries. The use of regression analysis as a method for determining project duration is proposed, and the results of the analysis indicate a strong correlation between project cost, area, gross national product per capita, and project duration.

Keywords: Duration of Road Projects, Project Cost and Duration, Regression Models, ROCKS, Developing Countries.

1. INTRODUCTION

The timing of construction projects is critical as it impacts both the cost and outcome of the project. The duration of a project can be influenced by various factors that arise during its execution, such as design errors, weather conditions, geological and hydrological factors, human-made issues, as well as economic and political considerations. Having an accurate estimate of the project's duration enables an approximation of the project's cost. It can also be used as a tool for evaluating bids and enables investors to plan their finances effectively. Additionally, by using a project duration estimation model, it is possible to pinpoint the reasons for delays and compare different projects. The assessment of the construction duration of buildings and structures begins with the pioneering studies carried out by a research organization representing Commonwealth countries (Australia) in the late 1960s. These studies provided an initial framework for evaluating construction duration and included data on construction duration, number of projects, and cost characteristics.

One of the most significant contributions to this field of research was made by Bromilow in 1969, with the publication of the results of his study on the relationship between project cost and duration. The study included 329 projects with a total cost of A$270 million and provided valuable insights into the correlation between project cost and duration.

Bromilow's study first compared the projected and actual duration of the projects, taking into account the types of buildings and their locations. The results revealed that only one out of eight projects were completed on schedule or ahead of the projected duration, with an average of 40% exceeding the expected duration. This highlighted the importance of accurate project duration estimation in order to properly plan and budget for construction projects. Bromilow's study also established the relationship between actual cost and construction duration, which he described using a specific formula. This formula provides a useful tool for evaluating the cost and duration of construction projects. He described this relationship with the following formula:

$$T = KC^{B} \tag{1}$$

where T is the duration of construction from the start of land ownership to the actual completion of construction, C is the final cost of construction in Australian dollars (indexed), K is a constant describing the overall level of duration for projects of 1 million Australian dollars (350 days), B is a constant describing how the duration depends on the size (cost) of the project.

2. LITERATURE REVIEW

One of the comprehensive review studies on construction delays in developing counties carried out by Islam and Trigunarsyah (2017). The study conducted a thorough literature review to identify the causes of delay and their effects. The authors found that the causes of delay are classified into 8 major groups and 53 frequent causes of delay are found under these groups as significant in developing countries. The most important and frequent factors that directly cause schedule delay in developing countries are financial issues such as contractor's cash flow problem, and delay in progress payment by owner, managerial issues such as poor site management, contractor-related factors, i.e., improper planning and scheduling, and owner-related factors like change order during construction. They also found that labor shortage is a severe factor of delay in Malaysia, Saudi Arabia, UAE, and Jordan. In addition, shortage of skilled labor is a significant factor in Afghanistan, Bangladesh, and India, and also some parts of Middle East and Africa. Change order in design or contract documents is identified as a major factor of delay mostly in Middle East and Africa and few countries in South Asia like India, and Indonesia. The delays have serious effects on project objectives such as schedule and cost overruns of the project. It also creates claims, disputes, litigation, and arbitration among project stakeholders, which sometimes causes the project to be abandoned. To reduce construction delays in developing countries, the authors suggest that owners should pay progress payments regularly and reduce change orders, and contractors should ensure cash flow throughout the project. In addition, improving managerial competency and ensuring timely procurement of equipment, materials, and labor with effective and efficient ways are also suggested for reducing delays. As a limitation, the study did not consider discussing the methodologies used in previous studies conducted in construction delays in developing countries. Therefore, reviewing various methodologies used in delay studies to find the most appropriate methods of prioritizing delay factors and facilitating decision-making processes in project management is a potential area for further study.

Another interesting paper by Santoso and Soeng (2016), indicated 10 delay factors from the perspectives of contractors, consultants, and a combination of contractors and consultants in the construction industry. The top-10 lists from the perspectives of contractors, consultants, and a combination of contractors and consultants were dominated by delay factors from the contractor and project categories. According to the study, there was no significant difference in the perspectives of contractors and consultants. Therefore, the top-10 factors from the combined perspective can be used as a reference. The top 10 delay factors found in the study are: working during rainy season; flooding; impact on people's land; awarding the project to the lowest bidder; frequent equipment breakdowns; poor site arrangement, management, and supervision; poor ground condition and terrain; poor qualification of the contractor technical staff and project teams; late progress payment; low productivity labor.

The duration of road projects plays a vital role in the success of a project, as each day of delay affects the cost of the project, the cost to road users, and society as a whole. Factors influencing the delay of projects can be different, for example, downtime in the construction/repair of a road section due to late delivery of road construction materials when materials in a quarry run out. An important role is played by the transfer of communication, which can also affect the duration of the project. According to the report of the Transport Research Council (TRB), about 120 million US dollars are annually spent on resolving conflicts between road organizations and utilities (Transportation Research Board, 1984). Another report from the National Highway Cooperation Research Program (NCHRP) found that about 39% of road organization respondents reported that utilities always have an impact on city streets and road renovations, 30% very often and 22% often. When asked what public utilities influence the repair and reconstruction of roads, they answered the schedule of work (100%), cost (70%), and quality of work (30%) (National Academies of Sciences, Engineering, and Medicine, 2011).

For each project, there is an optimal point (T_0, C_0) for the cost and duration of the project, which can serve to determine the remuneration or penalties applied to the contractor (Figure 1).

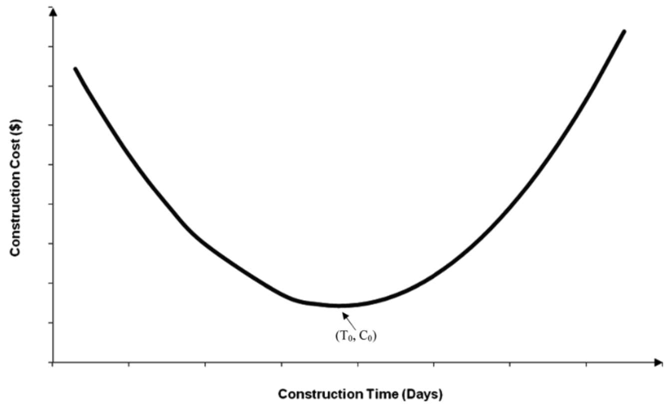

Figure 1. Cost-time relationship of highway construction project (Jiang et al., 2010).

At this point, the construction costs of the contractor are minimized, if changes in time begin from this point, then the construction costs of the contractor will probably increase. If construction time decreases, then direct costs will increase, but indirect costs will decrease (Shen et al., 1999). Additionally, it is worth noting that project duration estimation can also be affected by human factors, such as the skills and experience of the project managers and the workforce. Inaccuracies in the planning and scheduling of the project can also lead to delays. Therefore, it is important to have a clear and comprehensive project management plan in place to minimize the potential for delays.

The contractor is motivated to minimize the construction time as it leads to increased profits and improves the chances of winning the tender. This can be achieved by implementing strategies such as extending working hours, implementing multiple work shifts, and increasing the workforce. By accurately estimating the project duration, it is possible to calculate the potential rewards for finishing the project ahead of schedule, such as bonus days (Figure 2). However, it's important to note that this approach can also result in potential risks, such as overworking the workforce, increasing the potential for errors, or neglecting the safety measures, which can lead to accidents or delays. Therefore, it's important for the contractor to find a balance between minimizing the construction time and ensuring the safety and quality of the project. Additionally, advanced technologies such as project management software and digital tools can be used to optimize the project duration, monitor progress, and detect potential delays in real time.

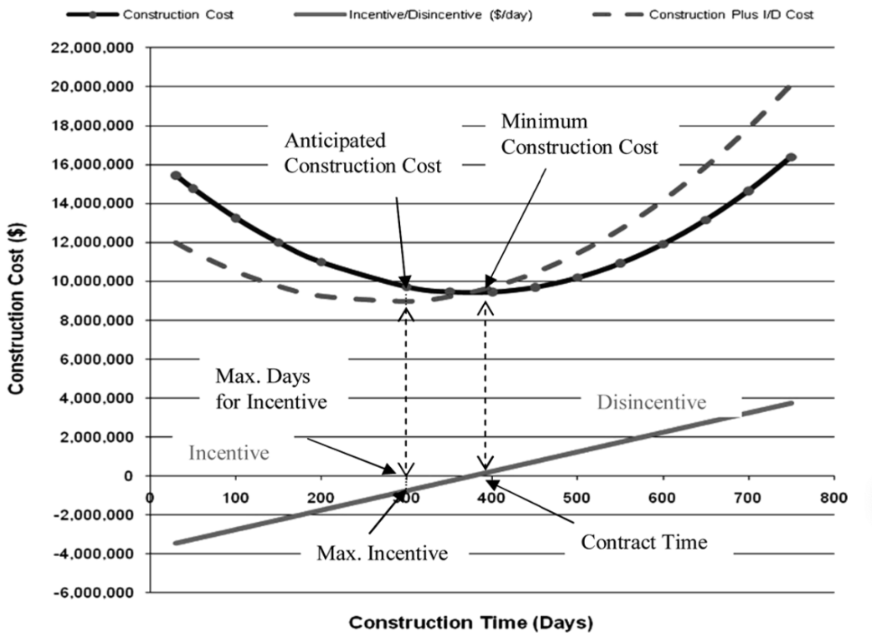

Figure 2. Determination of maximum incentive days and maximum incentive money amount (Jiang et al., 2010).

As shown in Figure 2, the optimal duration of a project tends to be skewed relative to the construction cost curve, which typically takes the form of parabolas for shorter construction times. In this example, the reward is approximately $1 million and the project duration has been reduced by 100 days. A review of the literature revealed that the relationship between the duration and cost of road projects can be linear or non-linear. Different studies have employed various methods such as regression equations (Chou, 2009; Choudhury and Rajan, 2003; Koźniewski and Orłowski, 2007; Wang and Gibson, 2010; Sodikov et al., 2010), neural network models (Wang and Gibson, 2010; Hoła and Schabowicz, 2010; Sodikov, 2005; Mensah et al., 2016a; Mensah et al., 2016b; Pewdum et al., 2009), fuzzy logic (Jaśkowski et al., 2010), and genetic algorithms (Rogalska et al., 2008) to analyze this relationship. Table 1 illustrates the regression equations that describe the duration (Y) and cost (X) of the project. These studies all consider the duration and cost of the project but differ in the relationship between these parameters (linear and non-linear). It is worth noting that the number of projects analyzed in these studies can also affect the outcome, with a smaller sample size leading to a higher coefficient of determination (R^2). The projects analyzed in these studies include asphalt paving, reconstruction, and new construction. There are various methods of data transformation (normalization) that have been applied, such as logarithmic and exponential transformations (Rogalska et al., 2008; Jin-Fang and Chen, 2006; Czarnigowskaa and Sobotkab, 2013). Additionally, it is important to consider other factors that can affect the duration of road projects, such as the level of complexity of the project, the availability of resources and materials, the quality of survey and design, and the regulations and permits required (Thanh and Hiep, 2011).

Table 1. Comparison of duration models - project costs

A source	Project type	Number of projects	Regression Equation	R^2
Jiang and Wu (2007)	1) Asphalt laying 2) New construction 3) Reconstruction	1) 139 2) 9 3) 9	1) $Y = 3 \times 10^{-5}X + 23.29$ 2) $Y = 39.89Ln(X) - 455.48$ 3) $Y = 1.25X^{0.31}$	1) 0.8 2) 0.9 3) 0.7
Jiang et al. (2010)	1) Asphalt laying 2) New construction 3) Reconstruction	-	1) $Y = 318.5X^2 - 41{,}6652.9X + 2{,}784{,}769.5$ 2) $Y = 358.1X^2 - 143{,}281.9X + 20{,}377{,}661.1$ 3) $Y = 289.5X^2 - 87{,}839.3X + 11{,}896{,}755.6$	1) 0.8 2) 0.7 3)0.8
Jin-Fang and Chen (2006)	Buildings	1) 13 2) 12 3) 11 4) 13 5) 13	1) $Y = 0.2 - 0.11X$ 2) $Y = 0.3 + 0.10X + 0.46X^2$ 3) $Y = 0.3 + 0.14X + 0.68X^2 + 0.28X^3$ 4) $Y = 0.22*0.8^X$ 5) $Y = 0.22*e^{-2.5X}$	1) 0.5 2) 0.7 3) 0.7 4) 0.5 5) 0.5
Czarnigowskaa and Sobotka (2013)	Buildings	100	$Ln(Y) = 1.2 + 0.46Ln(X)$	0.6

3. DATA SOURCE AND METHODOLOGY

Statistical models are widely used for estimating the duration of road projects as they offer several advantages such as the interpretation of the relationship between dependent and independent variables, the representation of results in the form of an equation, and the evaluation of variables and their correlation. However, there are certain factors that can affect the final outcome of the model. The number of variables and observations plays a crucial role, and the data preprocessing stage is important to consider outliers and data transformation. For this study, the initial design data was obtained from the ROCKS database created by the World Bank (ROCKS, 2000). This database is significant because it covers road projects from around the world, of which the World Bank was a donor. The number of projects is over 3,000 and the number of countries is 92. Pre-processing of the data showed that only 662 projects had project duration data. After removing all missing data and outliers, 276 projects remained. Tables 2 and 3 show the number of projects in the countries studied, as well as the number of projects by type of road repair.

Table 2. A number of projects across countries

No.	Country	Projects	Percentage
1	Uganda	145	52.5%
2	Poland	48	17.4%
3	Armenia	25	9.1%

4	Thailand	14	5.1%
5	Dominican Republic	11	4.0%
6	Import	9	3.3%
7	Laos	8	2.9%
8	Cameroon	5	1.8%
9	Uruguay	3	1.1%
10	Bolivia	2	0.7%
11	Nigeria	2	0.7%
12	Cambodia	1	0.4%
13	Ghana	1	0.4%
14	Panama	1	0.4%
15	Senegal	1	0.4%

Table 3. Type of road work activities

No.	Road activities	Quantity	Percentage
1	Maintenance of unpaved roads	90	32.6%
2	Reconstruction of the asphalt concrete road	61	22.1%
3	Gravel road repair	37	13.4%
4	Asphalt paving > 99 mm	20	7.2%
5	Surface finishing	14	5.1%
6	Reconstruction of the highway for 2	12	4.3%
7	Asphalt paving from 80 to 99 mm	10	3.6%
8	Maintenance of 2-lane asphalt concrete road	9	3.3%
9	Partial widening and reconstruction of a/b	7	2.5%
10	Double surface treatment	4	1.4%
11	Asphalt paving from 40 to 59 mm	3	1.1%
12	Surface treatment (bitumen emulsion only)	3	1.1%
13	Asphalt paving from 60 to 79 mm	2	0.7%
14	Widening and reconstruction of the asphalt concrete road	2	0.7%
15	Construction of a new 2-lane a/b	1	0.4%
16	Construction of a 2-lane gravel road	1	0.4%

Logarithmic transformation of variables was used in this study to normalize the data and interpret the regression coefficients in percentage terms. The results showed that after the logarithmic transformation, the data smoothed out, and the number of projects and countries studied were also reported in the study. While statistical models offer several advantages, it is also important to consider other factors that can affect the duration of road projects such as human factors, the level of complexity of the project, the availability of resources and materials, and the regulations and permits required.

Regression analysis is a statistical method that was used to create a project duration-cost estimation model in this study. The linear model of multiple regression is a statistical method that is used to examine the relationship between two or more independent variables and a dependent variable. The linear model of multiple regression used in this study has the following form:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_n X_n \tag{2}$$

Where Y is the dependent variable (project duration), X_1, X_2, ..., X_n are independent variables (cost, GDP per capita, etc.) and β_0, β_1, β_2, … β_n are the coefficients to be estimated. The goal of this model is to find the best-fit line through the data points by minimizing the sum of the squared residuals. The goal of this model is to estimate the project duration based on the cost and other independent variables. However, it is noted that this model assumes the relationship between the independent and dependent variables that is linear, which may not always be the case. In some cases, non-linear models or other statistical methods may be more appropriate to estimate the project duration. Additionally, the accuracy of the model also depends on the quality and representativeness of the data used to estimate the model.

The study includes density distribution graphs of the initial data (Cost, Duration, Area, GDP) and the data after logarithmic transformation (LCost, LDuration, LArea, LGDP). These graphs are used to visualize the distribution of the data before and after the logarithmic transformation. The logarithmic transformation is applied to normalize the data and improve the interpretability of the results. The density distribution graphs of the initial data before and after logarithmic transformation allow researchers to observe the changes in the distribution of the data and to identify any outliers or skewness in the data before and after the logarithmic transformation. The logarithmic transformation of variables has a number of advantages, such as data normalization, interpretation of regression coefficients in percentage terms, and others. Figure 3 shows the change in distribution density before and after the logarithmic transformation of the data. And, the data after the transformation was smoothed out a bit as illustrated in Figure 3.

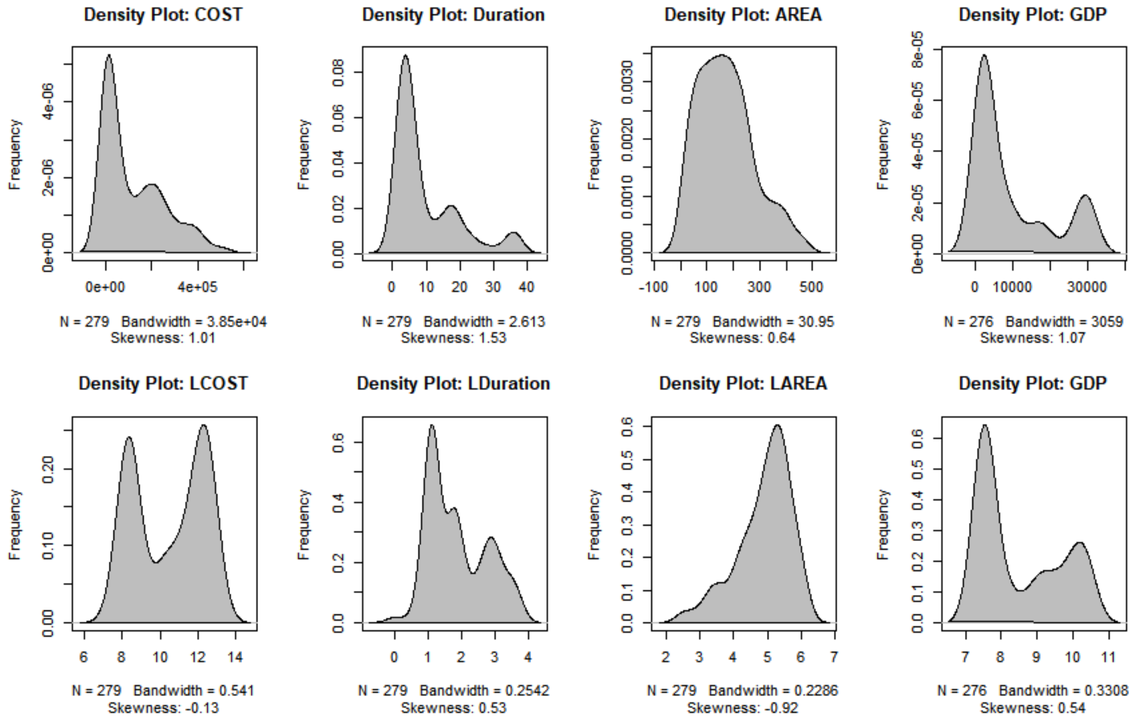

Figure 3. Density distribution graphs of the initial data (Cost, Duration, Area, GDP) and the data after logarithmic transformation (LCost, LDuration, LArea, LGDP).

In this study, we employed a stepwise regression method to select the variables included in each of the four regression models. The stepwise regression approach is a variable selection technique that iteratively adds or removes variables from the model based on their statistical significance.

The advantages of using the stepwise regression method in this study are as follows:

1. *Automated variable selection*: Stepwise regression automates the process of variable selection by considering the statistical significance of variables. It sequentially adds or removes variables based on their contribution to the model's explanatory power. This approach reduces subjectivity in the variable selection process and ensures that only relevant variables are included in the final models.
2. *Efficient use of computational resources*: Stepwise regression allows for efficient utilization of computational resources by considering a subset of variables rather than examining all possible combinations. This can be particularly advantageous when dealing with large datasets or a high number of potential predictors.
3. *Exploration of complex relationships*: By iteratively adding and removing variables, the stepwise method enables the exploration of complex relationships between the independent variables and the dependent variable (project duration, in this case). It provides insights into which variables have the most significant impact on the duration of road projects in developing countries.
4. *Improved interpretability*: By selecting a subset of variables that contribute the most to the model's explanatory power, stepwise regression enhances the interpretability of the results. The final models include the most relevant variables, allowing for a clearer understanding of their individual effects on project duration.

In this study, we have considered four different regression models to estimate the duration of road projects in developing countries using stepwise method. These models aim to capture the relationships between project duration and various factors, including project cost, project area, and the Gross Domestic Product (GDP) of the country. The first model incorporates three variables: project cost, project area, and GDP per capita. The second model focuses on project cost and GDP per capita. The third model examines project area and GDP per capita, while the fourth model solely considers GDP per capita. To ensure data normalization and enhance interpretability, all models employ a natural logarithm transformation. It is important to note that these models are not mutually exclusive, and the choice of which model to utilize depends on the specific research question and the available data. By comparing and analyzing the results of these models, we aim to identify the best model that effectively estimates project duration based on the variables of cost, area, and GDP of the country. It is worth acknowledging that this study does not account for potential variations in factors affecting project duration across different types of projects, which can be a limitation. Nevertheless, the regression analysis serves as an initial step in understanding the relationships between the chosen variables and project duration in the context of road construction projects in developing countries. It provides a quantitative assessment and generates insights for further investigation and refinement of project duration estimation methods.

$$\text{Model 1: } Ln(dur) = b_0 + \beta_1 Ln(cost) + \beta_2 Ln(area) + \beta_3 Ln(gdp) \quad (3)$$
$$\text{Model 2: } Ln(dur) = b_0 + \beta_1 Ln(cost) + \beta_2 Ln(gdp) \quad (4)$$
$$\text{Model 3: } Ln(dur) = b_0 + \beta_1 Ln(area) + \beta_3 Ln(gdp) \quad (5)$$
$$\text{Model 4: } Ln(dur) = b_0 + \beta_1 Ln(gdp) \quad (6)$$

where $Ln(dur)$ – duration of the project (months); $Ln(cost)$ – Project cost (1 km in USD);$Ln(area)$ - area (width of the carriageway * for the length of the road, m^2); $Ln(gdp)$ – GDP per capita (World Bank, 2017)

In this study, various models were used to estimate the duration of road projects. These models were chosen to explore the relationship between the duration and cost of the project, taking into account the characteristics of the project such as the geometric parameters (area) and the economic indicator (Gross Domestic Product per capita, GDP). The data were transformed using a natural logarithm to normalize the data and improve the interpretability of the results. Table 4 in the study shows the results of the regression analysis and the regression coefficients have significant values ($p<0.01$). This means that the relationship between the independent and dependent variables is statistically significant and that the model can be used to make predictions about the duration of road projects. The results of the regression analysis can be used to identify the most important predictors of the project duration and to estimate the project duration based on the cost, area, and GDP of the country.

Table 4. Regression models performance

Items	Dependent variables			
	Ln(major)			
	(1)	(2)	(3)	(4)
Ln(cost)	0.445^{***}	0.399^{***}		
	(0.022)	(0.028)		

Ln(area)	0.438^{***}		0.330^{***}	
	(0.034)		(0.053)	
Ln(gdp)	-0.048^{***}	-0.082^{*}	0.496^{***}	0.427^{***}
	(0.036)	(0.045)	(0.037)	(0.038)
A constant	-4.515^{***}	-1.605^{***}	-3.962^{***}	-1.755^{***}
	(0.295)	(0.243)	(0.463)	(0.322)
Number of observations	276	276	276	276
R^2	0.761	0.614	0.406	0.320
Adjusted R^2	0.759	0.611	0.402	0.318
Residual Std. Error	0.419 (df = 272)	0.532 (df = 273)	0.660 (df = 273)	0.705 (df = 274)
F criterion	289.249^{***} (df = 3; 272)	217.206^{***} (df = 2; 273)	93.384^{***} (df = 2; 273)	129.165^{***} (df = 1; 274)

Note: $^{*}p^{**}p^{***}p<0.01$

The best model in terms of reliability (adjusted coefficient of determination R^2) showed Model 1, which has $R^2 = 0.76$ (adjusted) and the model has following form:

$$Ln(dur) = 0.4Ln(cost) + 0.4Ln(area) - 005Ln(gdp) - 45 \quad (7)$$

Or by simplifying:

$$Ln(dur) = 0.4Ln(cost * area) - 005Ln(gdp) - 45 \quad (8)$$

The results of the study (7) – (8) show the relationship between the duration of road projects and the cost, area, and GDP per capita. The results can be interpreted as follows:

- With an increase in the cost of the project by 1%, the duration of the project increases by 0.4%.
- Similarly, the area changes in relation to the duration of the project, with a larger area resulting in a longer project duration.
- But with a 1% increase in GDP per capita, the duration of the project is reduced by 0.05%. This suggests that the more developed the country, the shorter the construction time.
- The regression equation has a strong relationship between the project duration variable and other parameters as p-value is less than 0.01.

It is important to note that the results of the study are based on the data that was used to estimate the model, and may not be generalizable to other data sets or contexts. The results of the study can be used to identify the most important predictors of the project duration and to estimate the project duration based on the cost, area, and GDP of the country.

It is worth mentioning the limitation of the research as follows:

1. *Variable selection*: The stepwise method used for variable selection has limitations. It may lead to potential omitted variables if important factors influencing project duration were not included in the models. Possibility of other relevant variables, such as project complexity, contractor experience, or government regulations, that were not considered in the analysis.
2. *Generalizability*: The study focuses on road projects in developing countries, which may limit the generalizability of the findings to other contexts. The factors influencing project duration could differ in developed countries or in other types of construction projects. Caution should be exercised when extrapolating the results to different settings.
3. *Model assumptions*: Assumptions of linear regression, such as linearity, independence of errors, and absence of multicollinearity.

4. CONCLUSION

A review of the literature on estimating the duration of road projects in developing countries showed that there is no widely accepted methodology. There are regulatory documents that establish the normalized time for the execution of design, survey, and construction work. The absence of a methodology for assessing the duration of road projects in developing countries is due to the fact that the profitability of road projects does not play a significant role, as most of the funding comes from the state. Evaluation and determination of the optimal timing for the implementation of road repair work will allow the customer to apply remuneration when performing road repair work earlier than the time specified in the project stage, and to apply penalties with an increase in construction time. When choosing a project duration-cost estimation model, geometric parameters and economic indicators should also be taken into account. Transformation (logarithmic) of the original data allows interpreting the regression coefficients in percentage terms, therefore, it is possible to characterize the relationship between the independent and dependent variables. It is important to note that when assessing the duration of road projects, a comprehensive approach should be used, taking into account all factors that may affect the duration of the project. Furthermore, it is crucial to consider other factors that affect the duration of the project, such as project complexity, weather conditions, and human factors. Having a proper estimation of the duration of road projects will allow for better budgeting and planning for investors, as well as identifying causes of delays, and comparing existing projects. The future research focus should shed light on the following aspects:

- How the model can be used for decision-making, for example, by identifying the most important predictors of the project duration and using that information to allocate resources and manage risks more effectively.
- Furthermore, it is important to consider how the model can be adapted and updated over time as new data becomes available, to ensure its continued relevance and accuracy.
- It is crucial to consider the ethical and social implications of the study, such as the potential impact on different stakeholders, including road users, local communities, and the environment.
- Another important aspect to consider would be the impact of any external factors that can affect the duration of the project, such as natural disasters, political instability, or economic downturns.
- It would also be beneficial to gather more data on different types of road projects, such as highways, bridges, and tunnels, to see if any differences exist in terms of project duration and cost.

In conclusion, the use of statistical models and logarithmic transformation of data in this research can provide a useful framework for estimating the duration of road projects in developing countries. The findings show that a 1.0% increase in project cost results in a 0.4% increase in project duration and that changes in the area also affect the project duration. In addition, an increase of 1.0% rise in GDP per capita leads to a 0.05% decrease in project duration. However, it is necessary to consider a comprehensive approach and gather more data from different regions and countries to improve the generalizability of the findings.

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