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Influence of Technical Reasons on Cost Overruns of Infrastructural Projects: A Sustainable Development Perspective

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Abstract: Cost overruns are a significant issue in infrastructure projects, adversely affecting not only economic performance but also sustainability goals by straining resources and extending project timelines. There is consensus among researchers about the persistence of cost overruns and the importance of accurate estimates. However, there are significant differences in the explanation of the reasons for the overruns. While we recognize the importance of understanding the reasons for cost overruns at all stages of project development, we have focused on the reasons for cost overruns after contract award due to the rarely available real and valid data collected at the source of the information. We analyze the deviations between actual and contracted costs, as well as the dependence of cost deviations of individual project types on the size of the contract. For example, the size of the tunnel significantly affects relative cost deviations, while for standard viaducts or road sections this effect is minimal. The results confirmed that cost overruns are less frequent in standard facilities than in those where the experience factor has little influence on the final cost estimate. For example, deviations in the average value of the contracted costs for highway sections range between −12.1% and 27.9% of the contracted value, and for standardized viaduct projects they range between −16.73% and 6.27% of the contracted value. The type of distribution function of deviations between actual and contractually agreed costs was investigated, and a predictive model for estimating future cost deviations of project programs was presented. The goal is to improve economic sustainability and the related optimization of resources in the development of infrastructure, which contributes to the broader agenda of sustainable development. The results encourage the adoption of improved project documentation and forecasting tools, which are essential for sustainable project management.

Keywords: sustainability; cost overruns; infrastructure projects; technical errors; forecasting; sustainable development; economic efficiency; project management; resource optimization

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1. Introduction

Cost overruns in infrastructure projects can significantly burden resources, which, in addition to inefficient public spending and delayed benefits, produces effects contrary to the principles of sustainable development that could be avoided by more efficient management. Flyvbjerg et al. [1] conclude that 9 out of 10 projects experience cost overruns, while Love et al. [2] reported that 47% (i.e., ≈5 od 10) of transport projects deviate from their approved budget. Odeck [3] provides an overview of the literature on cost overruns, indicating an average cost overrun ranging from 4.5% to 86%. For example, Terrill et al. [4] reported AUD 34 billion in cost overruns of Australian transport infrastructure between 2001 and 2020, which is about one-fifth more than the initially expected costs.

There is a consensus among researchers regarding the ubiquity and negative impact of cost overruns; however, there is no unanimous explanation for the reasons behind these overruns in infrastructural projects. Siemiatycki [5] links the diversity of explanations

for cost overruns to the analyst's perspective. Conversely, Love and Ahiaga-Dagbui [6] summarized opposing views, identifying two schools of thought: (1) "Evolutionists" who suggest that overruns are a result of changes in scope and definition between the inception phase and the eventual project completion and (2) "Psycho-strategists" who attribute overruns to deception, planning fallacy, and unjustifiable optimism in the setting of initial cost targets. Through literature surveys, researchers, such as Adam et al. [7], Durdyev [8], and Herrera et al. [9], categorized the causes of overruns based on their frequency of occurrence, as shown in Table 1.

Table 1. Reasons for cost overruns according to Adam et al. [7], Durdyev [8], and Herrera et al. [9].

Adam et al. [7]	Durdyev [8]	Herrera et al. [9]
Communication Financial Management Material Organizational Projects Psychological Weather	Design problems and incomplete design Inaccurate estimation Poor planning Weather Poor communication Stakeholders' skill, experience, and competence Financial problems/poor financial management Price fluctuations Contract management issues Ground/soil conditions	Failures in design Price variations of material Inadequate project planning Project scope change Design changes Unrealistic contract duration Inadequate bidding method Poor site management and supervision Political situation Legal issues

The available literature includes research on the causes of cost overruns based on the identification and analysis of specific problems. For example, Tirataci and Yaman [10] highlight the impact of unrealistic contract duration on cost overruns. Ershadi et al. [11] and Catalão et al. [12] discuss the influence of the political situation, election years, and the pursuit of political gains [13] on costs escalation. Additionally, some authors link cost overruns to the complexity of large projects [6]. For instance, Cantarelli et al. [14] associate overruns with project size, Erol et al. [15] associate it with the inability to predict costs due to complex risk relationships, and Son and Rojas [16] associate it with poor decision-making resulting from limited knowledge and incomplete information. For example, the specificity of the location and the small possibilities of exact repetition of the performance process [17] reduce the influence of the experience or the applied method. Herrera et al. [9] concluded that the design and planning aspects significantly influence cost overruns and emphasized the need for changes and greater control in traditional processes during early project phases. This conclusion complements that of Adam et al. [7] who found factors related to communication and psychology to be ranked low. However, Adam et al. [7] emphasize that the low ranking of psychological reasons does not necessarily undermine their importance because it is possible that they are the root causes of other factors. Flyvbjerg [18] argues that we would expect a less biased error distribution if forecast errors were genuinely caused by technical shortcomings, simple mistakes, and inherent problems. Contrary to the conclusion of Adam et al. [7], Chen et al. [19] point to the acceptance of the optimism bias theory in the literature as the dominant cause of cost overruns in transport infrastructural projects. They provide an overview of the types of cognitive biases that appear in them but conclude that there are significant unanswered questions about the relationship between optimism bias in project cost estimation and cases of transportation infrastructure cost overruns [19]. Therefore, the differences in the explanations of the reasons for the overrun are evident. Osland and Strand [20] see the "strategic misrepresentation theory" as a major disagreement about the source of the overshoot. They believe that Flyvbjerg's [1] quantitative data and research design do not support his general conclusion of excluding technical explanations. While, according to Flyvbjerg [21], there is a matter of political bias in the assessment, for Eliasson and Fosgerau [22], this bias can be a random error, i.e.,

the result of the selection process. Such confrontational attitudes are explicitly expressed in the works of Flyvbjerg et al. [23] and Love & Ahiaga-Dagbui [6]. Flyvbjerg et al. [23] deny scope changes, complexity, geology, archaeology, bad weather, and business cycles as explanations for overruns. They see the root cause in human bias and underestimation of estimates, not errors. In contrast, Love & Ahiaga-Dagbui, p. 358, [6] reject this claim as being a result of ignorance and a neglect of the complexity of the nuances of the process of design and evaluation of transport infrastructure projects. They argue that there is no evidence to support deception and delusion as the main explanations for cost underestimation in transport infrastructure projects. To contribute to reaching a consensus on the reasons for the cost overruns in large infrastructural projects, contracts implemented during the construction of the road network in the Republic of Croatia were investigated. Such research was based on the conclusion of Adam et al. [7] who emphasize the importance of empirical data as a necessary step for understanding the magnitude of the various factors that cause cost overruns. They believe that data collected at the initial source, i.e., from strictly defined project documentation on cost overruns and delays at the time they occur, can be useful for gaining a clearer picture, in contrast to the retrospective views of respondents in surveys. Therefore, this research aims to present concrete data, specifically the deviations between the actual and contractually agreed costs of real projects. By focusing on the technical reasons for the overruns, we point out the importance of better understanding the sources of these overruns for a more accurate cost estimate. Infrastructure projects involve large resources in terms of energy consumption and environmental pollution. Any inefficient use of these resources represents an unnecessary burden on the environment in which they are realized. Understanding the reasons for overruns and accurate assessment through increasing project efficiency contributes to reducing pressure on the environment. Based on these data, we investigate the characteristics of the population to assess the possibility of using the results obtained for future forecasts. Following the introduction, the Section 2 outlines the research approach, materials, and methods. The Section 3 presents the research results. In the Section 4, we discuss the results obtained and limitations of the research. Finally, our conclusion is provided in the Section 5. The research samples are given in Appendix A.

2. Materials and Methods

This research was conducted on a sample of completed contracts for which valid and reliable data on contractually agreed and realized costs are available. Contract titles, contractually agreed amounts, final amounts, and their relative deviations are presented in Appendix A. The contracts were collected according to the principle of availability [1,23] which means they were randomly selected without bias. This random selection does not favour any sample, and it is assumed that the selected contracts represent the average structure and characteristics of the entire population of infrastructure projects in the Republic of Croatia. In this sense, the sample is on average representative of general conclusions about cost deviations in specific types of infrastructure projects. Therefore, the working assumption is that there is a representative relationship between the 'Statistic', which describes the sample, and the 'Parameter', which describes the population as a reflection of reality. Furthermore, it is assumed that the available data are suitable for the application of the central limit theorem in forecasting deviations and for assessing the level of confidence in forecast for future projects. As stated in the literature review, psychological factors can represent significant reasons for deviations, but their impact after contracting is negligible, and we did not identify them in our samples. Therefore, the research is limited to technical reasons for cost overruns, and the assumption is that technical factors—such as project complexity, technical errors, and inaccurate estimates—are the primary reasons for deviations between actual and contractually agreed costs. The research focused on the following two hypotheses:

H1. *It is possible to determine the degree of confidence in the forecast of the impact of technical reasons on the assessment of discrepancies between the actual and the contractually agreed costs.*

H2. *The reasons for the discrepancy between the final costs and the contractually agreed costs are predominantly technical reasons, resulting from the complexity of the projects, errors, and incompleteness.*

The research took place in two parts. The first part covered the research of the "Cost Deviation" variable based on the contractually agreed and realized values, and the second part was an analysis of the structure of the reason for the overrun based on the contractor's claims for additional costs incurred during the realization phase. Three types of contracts were considered: contracts for individual highway sections ("Road Sections"), contracts for viaducts, standard bridges, and overpasses or underpasses ("Viaducts"), and contracts for tunnels ("Tunnels").

Our task was to determine the population parameter, i.e., a fixed number that describes the population reliably enough to make it possible to forecast deviations of future projects from the researched population of road projects in the Republic of Croatia with a certain probability. The sequence of research showed that forecasts of individual projects were unreliable. However, the researchers wanted to use valuable information for new knowledge and, furthermore, the mean value of the sampling distribution of the average cost deviation was monitored as a statistic. To model the behavior of a random variable in the population, the central limit theorem was applied to simulate many samples, with many random variables, based on the available data. This made it possible to forecast the mean value of any group of future projects. The data for the research were collected from the organizations that prepared and realized the projects, including contractual cost, final reports and completed calculations. Therefore, the recorded deviations represent real values that can be used in another research. In this research, it will be used to understand the population discrepancies between the actual and contractually agreed costs. Figure 1 shows the discrepancies between the actual and contractually agreed costs for the "Road Sections" sample.

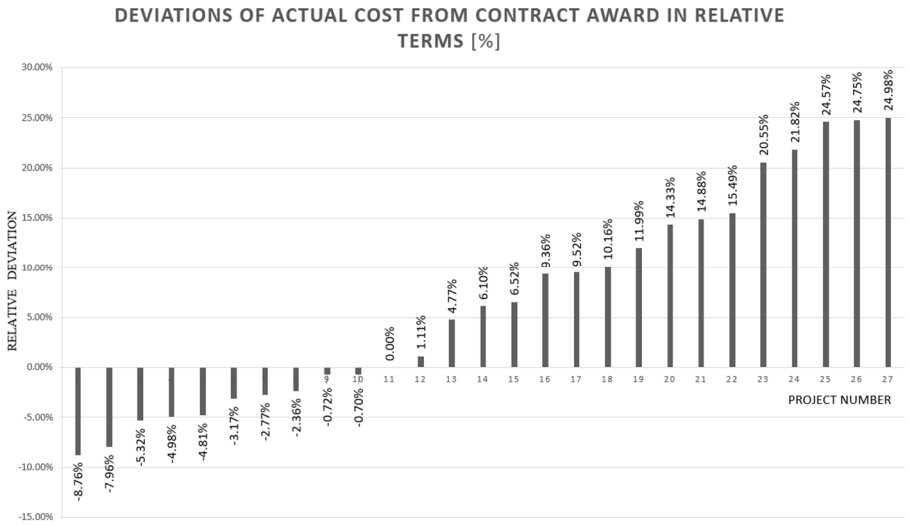


Figure 1. Discrepancies between the final costs and the contractually agreed costs for the "Road Sections" sample.

In a sample of 27 projects, 16 projects had cost overruns, and 10 projects were realized below the contractually agreed price. Furthermore, Figure 2 shows discrepancies between the actual costs and the contractually agreed costs for the "Viaducts" sample.

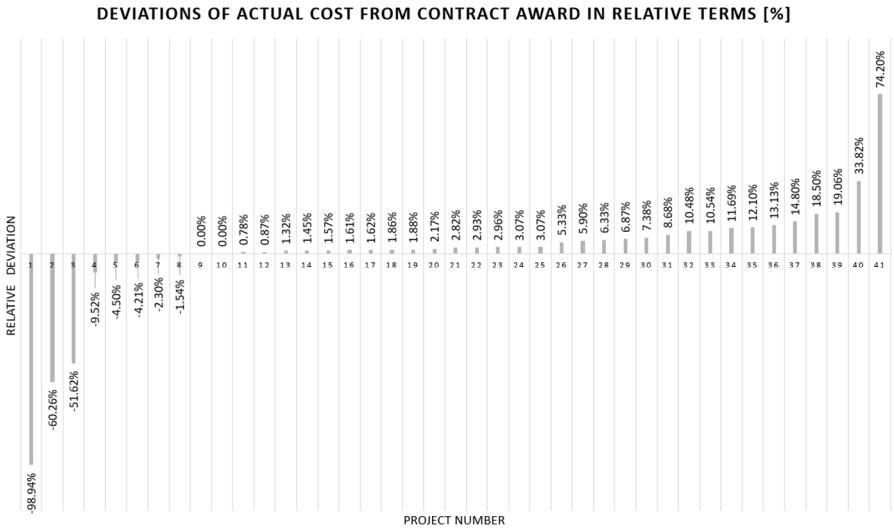


Figure 2. Discrepancies between the final costs and the contractually agreed costs for the "Viaducts" sample.

In a sample of 41 projects, 31 of them had cost overruns, and 8 projects were realized below the contractually agreed price, ranging between −98.94% and 74.2%. This sample clearly has certain anomalies that were explored in the research process. Figure 3 shows discrepancies between the actual costs and the contractually agreed costs for the "Tunnels" sample.

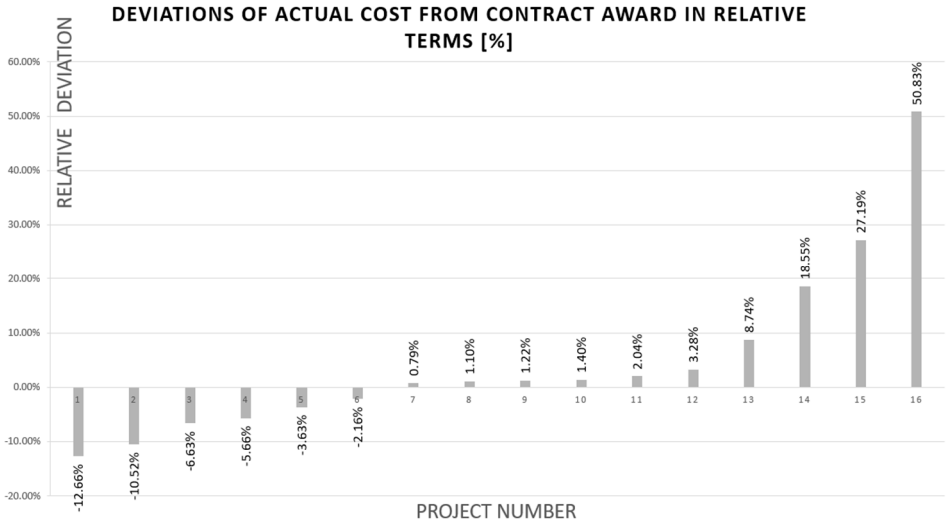


Figure 3. Discrepancies between the final costs and the contractually agreed costs for the "Tunnels" sample.

In a sample of 16 projects, 10 of them had cost overruns, and 6 projects were realized below the contractually agreed price. In this sample, the cost deviations ranged between −12.66% and 50.83%. Although the data was collected from real documentation, the samples were expected to include unreliable and invalid information, and it was necessary to isolate and remove such data for representativeness purposes.

Samples Editing

The "Range" feature was used to edit the pattern. It shows the dispersion of cost deviations in the researched sample and is defined as the difference between the maximum and minimum cost deviations. Using a box plot diagram, we identified scattered data

points indicating inconsistencies in the collected results and excluded them as unreliable because they disrupted the average values, thereby affecting the accuracy of statistical indicators in further research. It is quite clear that the range is the simplest but also the least accurate measure of dispersion for a variable, and that it depends on the sample size. However, the fact that the data was collected randomly gives us confidence in its validity. Figure 4 shows the box plot of the "Road Sections" sample, in which no outliers were identified.

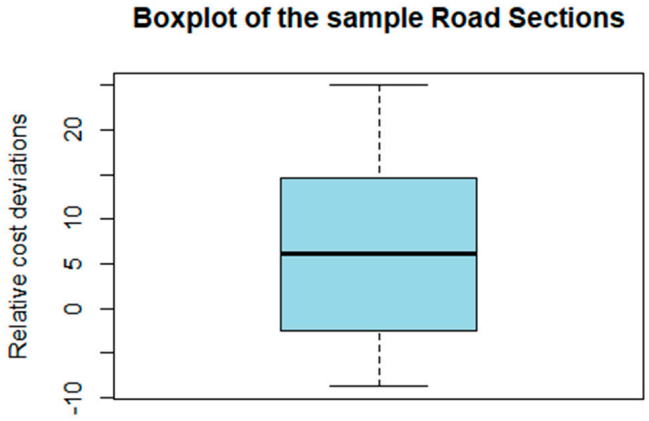


Figure 4. Box plot diagram for the "Range" variable of deviations in the "Road Sections" sample.

The sample is considered reliable in terms of data records at the source (for a range of cost deviations between −8.76% and 24.98%, with an average value of 6.6%, which represents a positive value and indicates cost overrun). Figure 5 shows the process of isolating and removing outliers from the "Viaducts" sample.

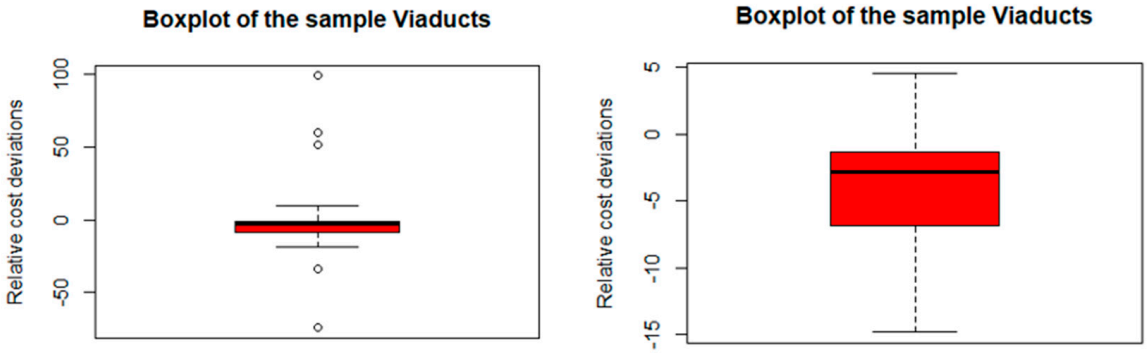


Figure 5. Box plot diagram for the "Range" variable of deviations in the "Viaducts" sample.

The initial sample deviation range between −98.94% and 74.20% is a result of the outliers. Eight projects were excluded from further research due to possibly incorrectly read or entered data in the database, a rare occurrence in the population or illogical cost records. Finally, the deviation range for the "Viaducts" sample is between −14.8% and 4.5%, or 19.3%. The mean value is a negative −3.94% and shows that construction costs tend to be overestimated in the contracting phase for this type of project. The projects were predominantly realized below the estimated price, and the reason lies in the standardization of the objects, due to which the bidders can better predict the prices and costs. Figure 6 shows the process of isolating and removing outliers from three projects in the "Tunnels" sample.

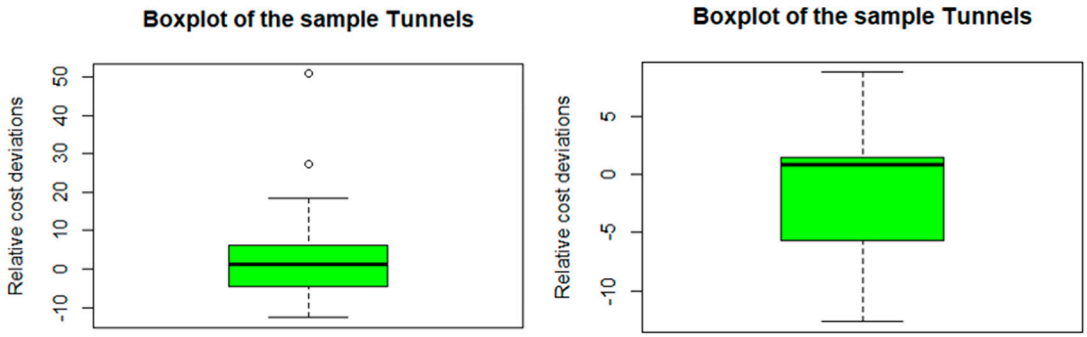


Figure 6. Box plot diagram for the "Range" variable of deviations in the "Tunnels" sample.

The initial range of deviations between −12.66% and 50.83% was reduced to a range between −12.66% and 8.74% after the elimination of outliers. The mean value is −1.7%, i.e., the construction costs were overestimated in the contracting phase for the sample of collected projects.

Through this procedure, we removed unreliable data from the samples at the source, but also determined the deviation ranges as a piece of data for continuing the research towards determining the population parameter. The sample statistics are represented by the random variable "Deviation of actual from contractually agreed costs" in the final phase of road infrastructure projects in the Republic of Croatia. The contractually agreed price is the final price before the start of construction, and the cost overrun is the difference between the actual costs at the end of the contract and the contractually agreed values. Therefore, a continuous numerical random variable X—"Deviation" (1) was investigated, which can take on any value x_i, as follows:

$$x = \frac{T_{Fin.} - T_{Contr.}}{T_{Contr.}} \quad (1)$$

where $T_{Fin.}$ Represents the final costs, and $T_{Contr...}$ represents the contractually agreed costs

The second part of the research analyzed the contractors' claims for compensation for additional costs incurred during construction. These claims were documented in writing and included descriptions of the reasons for cost overruns and justifications of financial claims, and they were not based on the opinions or impressions of respondents. After completing the process of agreeing upon the respective positions, undisputed claims were approved by the investor analysis department. This analysis was conducted on a population of road infrastructural projects in the Republic of Croatia, as described in Lovrinčević and Vukomanović [24].

3. Results

3.1. The Nature of the Random Variable

Understanding the nature of cost variances has become particularly interesting when using the "Reference Class Forecast" (RFC) method, which has become mandatory in Denmark, Great Britain, and Switzerland [25], p. 772. Love et al. [26] challenge Flyvbjerg's assumption that cost overruns follow a normal distribution, especially for road construction projects. According to them, the accuracy of the RFC is questionable due to the lack of a large sample of similar projects with accurate information, especially for relatively rare types of projects. They argue that the result of such an assumption can produce wrong probabilities, inaccurate assessments, and negative outcomes. To contribute to the discussion on probability distributions for data on cost overruns, this paper presents the distributions on investigated samples of road construction projects as of the contract award date. Figures 7–9 show the Q Q normality plots for the "Road Sections", "Viaducts" and "Tunnels" samples. The normal Q Q plot is an alternative graphical method for assessing the normality of a histogram and is simpler to use when there are small sample sizes. The

line on the graph represents the relationship in which the sample data comes from the same group of distribution functions as the theoretical, i.e., normal distribution. The axes show quantiles from the standard normal distribution with a mean of 0 and a standard deviation of 1. The scatter plot compares the data with a perfect normal distribution. The points on the scatter plot should lie as close as possible to the line, without any visible pattern deviating from the line, for the data to be considered normally distributed. If all the points fall on the line, we can assume a normal distribution of the variable "Relative cost deviation".

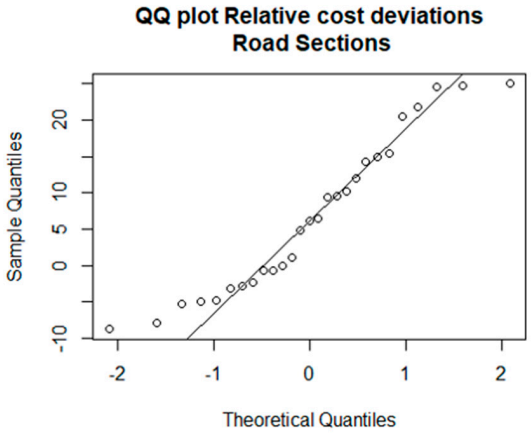


Figure 7. Comparison function with a normal distribution for the "Road Sections" sample.

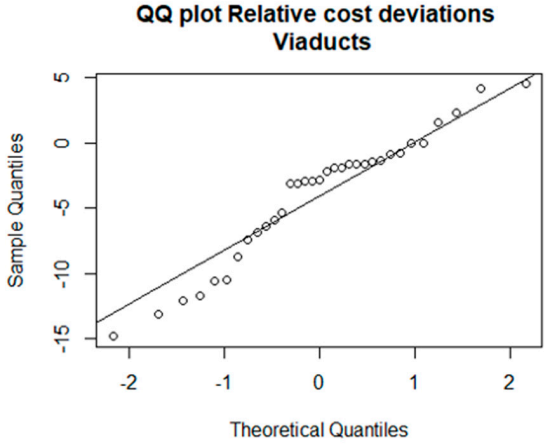


Figure 8. Comparison function with a normal distribution for the "Viaducts" sample.

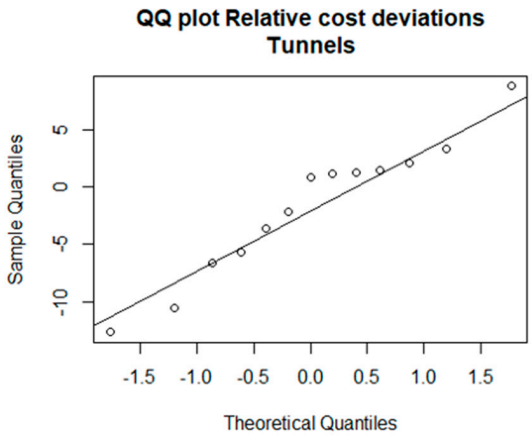


Figure 9. Comparison function with a normal distribution for the "Tunnels" sample.

The "Road Sections" sample indicates a significant deviation in the marginal results. The points from the central part of the sample do not fall on the line, but they are very close to the line, and their deviation has no functional regularity or recognizable pattern. For the "Viaducts" sample, a significant deviation and irregularity were observed to the left of zero. In the case of the "Tunnels" sample, the deviation from the line is significant, but symmetrical and relatively balanced. Due to the insufficiently strong approach to the normality line, the Kolmogorov–Smirnov (K-S) and Shapiro–Wilk normality tests were conducted. The null hypothesis of these tests is that the "sample distribution is normal" if the test is significant. Table 2 shows *p*-values for all three samples.

Table 2. Shapiro–Wilk and Kolmogorov–Smirnov test results.

Sample	Shapiro–Wilk Test *p*-Value	Kolmogorov–Smirnov Test *p*-Value
"Road Sections"	0.07284	0.6008
"Viaducts"	0.07799	0.1145
"Tunnels"	0.6638	0.5823

The *p*-values are greater than 0.05, which confirms the null hypothesis, that is, the samples come from a population that follows a normal distribution. By connecting the information of the Q Q diagram and normality tests, we conclude that all three samples meet the condition of normality at the 95% significance level, which means that the variable "Deviation" comes from the family of normal curves.

3.2. Results of Normalizing Classes by the Ratio of Contract Value to Cost Deviations

The sample classes for the research were formed based on the fact proven in the literature that cost deviations depend on the types of projects [27]. However, some studies have found a connection between the size or complexity of projects and cost deviations [28]. For this reason, we want to determine whether, in this sense, the projects from the sample belong to the same class of projects defined by the relationship between the "Contractually agreed value" and "Relative cost deviation" variables. We monitor whether or not cost deviations depend on the level of the contractually agreed amount and whether or not future projects need to be classified into classes according to the contract financial size criterion. For modeling purposes, we used the linear regression method, for which the variable normality requirement had been satisfied. We wanted to understand the functional relationship between the non-random variable X (contractually agreed value) and the random variable Y (relative deviation) of contractually agreed vs. actual costs. Figures 10–12 represent the properties of sample distribution because of the linear regression model.

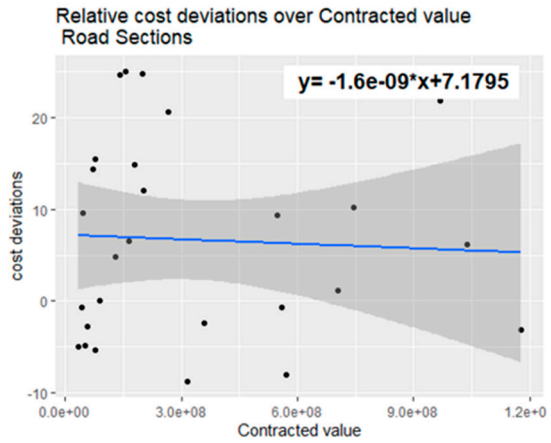


Figure 10. Regression model for the "Road Section" sample.

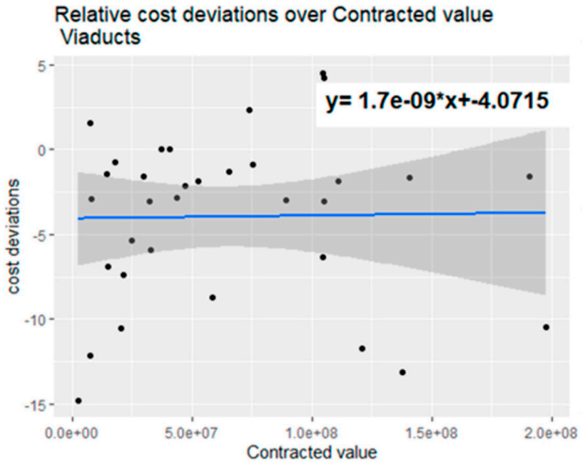


Figure 11. Regression model for the "Viaducts" sample.

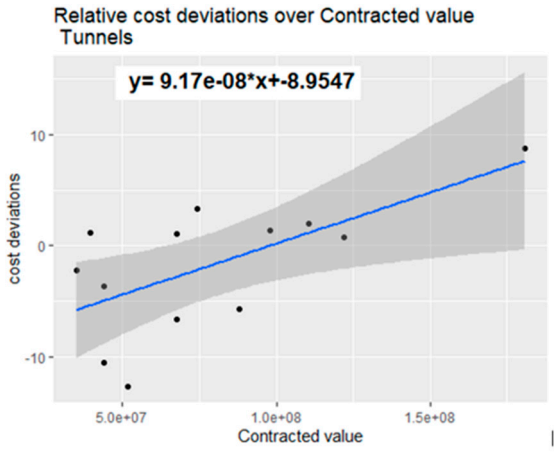


Figure 12. Regression model for the "Tunnels" sample.

On the *x*-axis, the contractually agreed values of the projects included in the sample are presented, whereas the relative post-construction cost deviation are presented on the *y*-axis. The linear regression graphs for the "Road Sections" and "Viaducts" samples show negligible deviation from the horizontal line. For the "Road Sections" sample, the *p*-value is 0.8016, and for the "Viaducts" sample, it is 0.91824. As the *p*-values for both samples are greater than 0.05, there is no statistically significant relationship between the size of the contractually agreed amount and the relative cost deviation. In other words, at the 0.05 significance level, we cannot argue that changes in the value of the independent variable reflect changes in the expectation of the dependent variable. The amount of cost deviation does not depend on the contract value, and the obtained functional relationship cannot be used for future estimates. For the "Tunnels" sample, there is a pronounced dynamic relationship between the increase in cost deviation and the growth of the contractually agreed financial value, and the *p*-value of 0.01806 is below the threshold of 0.05. For this sample, it is justified at the level of significance to reject the null hypothesis in favor of the alternative and to accept that, at the level of significance, there is a justified link between the size of the contract and the cost overrun. Please note that these regression models cannot be used to forecast cost deviations, as there is no variability for the "Viaducts" and "Road Sections" samples. In contrast, for the "Tunnels" sample, there is variability in the deviations, but the recorded functional relationship between contract size and deviation is not reliable. This result shows that the cost deviations in this sample significantly depend on the length of the tunnel and increase along with the length of the tunnel. Namely, all tunnels are in the same geological environment and the works were carried out using

the same method, so the only difference is their lengths. Therefore, increasing the length increases the contractors' demands for additional work due to unforeseen circumstances.

It can be concluded that contracts for viaducts and contracts for road sections, regardless of the contract size, can be classified into their respective reference classes, which does not apply to tunnels. In fact, for tunnels, a statistically significant correlation of deviations between the actual and contractually agreed costs was confirmed, which means that the contracts from the sample do not belong in the same class. It would be necessary to form classes based on the contract size from one sample, which would result in several smaller classes created from an already small sample. Thus, this sample becomes unusable for further analysis, and we continue to analyze only two samples, namely "Road Sections" and "Viaducts".

3.3. Statistical Characteristics of Discrepancies Between the Actual and Contractually Agreed Costs

The sample research showed that the discrepancies between the actual costs and the contractually agreed values follow a normal distribution. This fact aligns with Flyvbjerg's [29], p. 6, expectation, which predicts that technical explanations should have a normal or almost normal distribution of inaccuracies. To visualize the discrepancies between the actual and contractually agreed costs of the samples, probability density functions (PDFs) were modeled. First, histograms of discrete values were formed, which were then transformed into continuous density function curves using kernel density estimation (KDE). Figure 13 shows an approximation of the probability density functions for the "Road section" sample, and Figure 14 show smoothed probability density functions for samples from the "Viaducts".

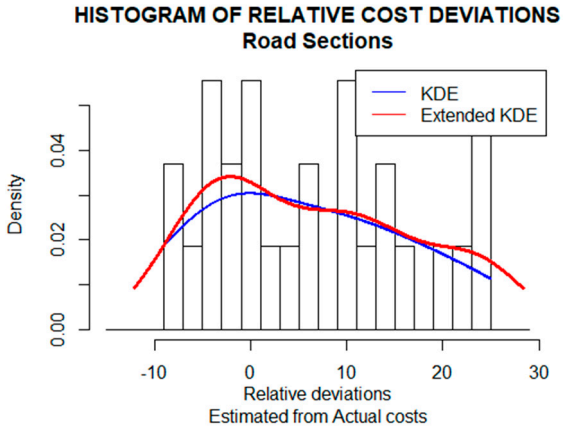


Figure 13. Approximation of the probability density functions for the "Road section" sample.

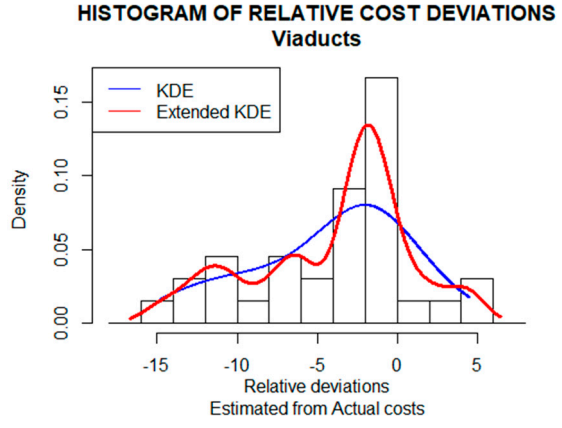


Figure 14. Approximation of the probability density functions for the "Viaducts" sample.

To provide clarification of the graphs, a descriptive overview of distributions is presented. Table 3 provides a descriptive overview of the density distribution function's features for the "Road Sections" sample, whereas Table 4 provides it for the "Viaducts" sample.

Table 3. Descriptive presentation of the density distribution function for the "Road section" sample.

Min.	Mean	Max	σ	Lower	Upper	Skew
−12.134	8.110	28.354	11.70502	3.694841	12.52516	0.340

Table 4. Descriptive presentation of the density distribution function for the "Viaducts" sample.

Min.	Mean	Max.	σ	Lower	Upper	Skew
−16.73	−5.23	6.27	6.69552	−9.143662	−1.156338	0.498

Considering that the samples are randomly drawn from the relevant population and are, thus, unbiased and representative, the results can be used for comparison with the findings of other studies. However, the wide confidence interval hinders confidence in estimates of deviations for future individual projects. In other words, descriptive indicators of the sample depict the characteristics of a specific sample, but not of the population, indicating insufficient sample sizes. Love et al. [26,28] note that causes of cost overruns, which may not have been considered during contract awarding and which typically arise during construction, as well as changes that will occur due to insights gained during construction, should somehow be included in estimates of actual costs, as this remains crucial information. Therefore, by applying the central limit theorem, the "average deviation of sample costs" random variable $\bar{x}$ was used as an unbiased estimator of the population mean μ of road project costs. This possibility is based on the fact that the sampling distribution tends to assume a normal form even if the population distribution does not have a normal form. Based on the mean, the range of values, and standard deviation of the obtained sample distributions, a sampling distribution of means of the investigated populations was formed using kernel estimation, which has a normal shape. Figure 15 shows the probability density function, and Table 5 presents the characteristics of the probability density distribution function for the mean deviation of the "Road Sections" population contracts for the highest-ranking roads.

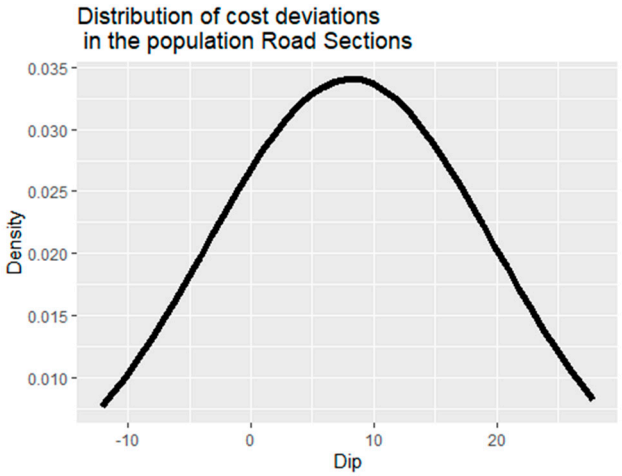


Figure 15. Probability density function for the "Road Sections" population.

Table 5. Descriptive view PDF for the "Road section" population.

Min.	1st Qu.	Median	Mean	3rd Qu	Max.
−12.134	−2.134	7.866	7.866	17.866	27.866

Figure 16 shows the probability density distribution function, and Table 6 displays the characteristics of the probability density distribution function for the mean deviation of the "Viaducts" population contracts for the highest-ranking road sections.

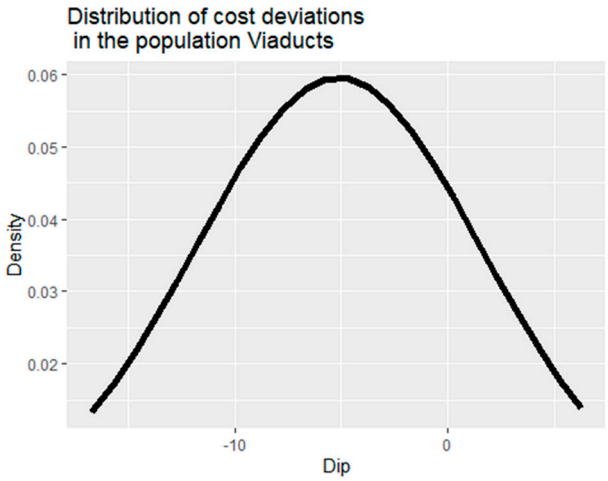


Figure 16. Probability density function for the "Viaducts" population.

Table 6. Descriptive view PDF for the "Viaducts "population.

Min.	1st Qu.	Median	Mean	3rd Qu	Max.
−16.73	−10.98	−5.23	−5.23	0.52	6.27

The displayed functions provide us with information about the populations of such contracts, including the mean value (μ) and the standard deviation (σ). As we are dealing with a normal distribution, the use of known distribution features, namely the z-score, allows us to forecast the values of average cost deviations for project programs in the same population. Therefore, the average discrepancy between the actual costs and the estimated costs for future projects in the selected probability is calculated as follows:

$$\overline{x} = z * \sigma_{\overline{x}} + \mu_{\overline{x}} \quad (2)$$

The obtained value numerically represents the percentage deviation that will not be exceeded, subject to the selected probability using the z-score. In other words, if we increase the average value of a future project program by a coefficient reflecting the obtained percentage with the chosen probability, we can know that the average deviation of actual costs from contractually agreed costs of those projects will not be greater than the average value obtained in this way. For example, for a probability of 95%, the z-value is 1.96, so we can calculate the cost deviation as a percentage. Therefore, if we increase the average value of the contractually agreed costs of project programs by the obtained percentage, we can confidently state, with a probability of 95%, that the budget thus increased will not be exceeded. Following the same principle, we can determine the probability interval, with the probability being less or greater than the selected value. The standard deviation of the average cost deviations of future project programs $\sigma_{\overline{x}}$ is calculated as follows:

$$\sigma_{\overline{x}} = \frac{\sigma}{\sqrt{n}} \quad (3)$$

where n is the number of projects in the program for which the forecast is made

The H1 hypothesis was, thus, confirmed. By modeling the statistical characteristics of the population as a normal distribution, we were able to forecast deviations from the estimated average construction costs of the project program based on the known properties of the function and sample characteristics. By systematically monitoring the development

of projects, it is possible to increase the sample size and improve the accuracy of forecasting deviations for individual projects. Furthermore, the data presented by Lovrinčević and Vukomanović [24] describe the reasons for recorded cost overruns, which can be expected in the implementation of future project programs based on the presented probabilities. Based on 562 contractor claims totaling €Eur 187 million, it was found that technical reasons accounted for 55.5% of the claims by number, with a financial share of 74% of all claims. Risks related to natural conditions, with a share of 30% in the number of claims, had a financial share of 16%. Additionally, there were risks associated with management, accounting for 8.36% of the number of claims and a financial share of 2%, as well as contractual reasons, with a 5.3% occurrence share and an 8% financial share. As the claims were submitted and approved by individuals responsible solely for technical monitoring of actual and contractually agreed costs who were not involved in the selection among alternative options and who were not financially or organizationally related, it is unlikely that there was deceit or bias at the root of the claims. Love et al. [28] p. 321, refer to factors contributing to cost overruns as of the contract award date, including material and labor shortages, price inflation, rework, change orders, site access, unexpected site conditions, and unforeseen events. Research on specific claims for increased contract costs from a representative sample, which showed an absolute dominance of reasons related to project complexity, errors, and incompleteness, is in line with the conclusions of Love et al. [28], p. 321, that confirm the H2 hypothesis. This conclusion is supported by studies that attribute reasons for cost overruns related to psychology and bias to project phases much earlier than in this research. Son & Rojas [16] state that the delusion of success is very prevalent during the construction planning phase [30], where planners are likely to have an optimism bias. Andersen, Samset, & Welde [31] also locate strategic misrepresentation between the "initial assessment" and the "first realistic assessment", or the contract award date. Love et al. [26,28] make a distinction between costs before and after contract award, using the term construction uncertainty for any unresolved design issues at the time of contract award that will cause deviations from estimated costs. Love et al. [6] p. 364, found a sample of 16 railway projects where cost increases were attributed to changes in scope in all of the sampled projects. Based on these studies and using inductive reasoning, it was adopted as a fact that the share of psychological and political–economic reasons for relative deviations of the investigated projects after contracting is negligible, and the investigated cost deviations are predominantly due to technical reasons. The inaccuracy of technical data essentially reflects an incomplete understanding of technical features, which is reflected in the inaccuracy of quantity and activity estimation. For large infrastructural projects, it is objectively impossible to foresee all circumstances, and what we do not "see" cannot be processed in project documentation as a basis for cost estimation.

4. Discussion

The backbone of this research comprises understanding the characteristics of discrepancies between the actual and contractually agreed construction costs of road projects. Love and Dahbui [6] argue that cost overruns relative to the timing of contracting reflect the efficiency measure of the contractor. While this is true from the contractor's perspective, in terms of cost deviations, it is not the case from the client's perspective, and the investigated cost deviations are not a result of contractor inefficiency. The contracts examined are awarded to the lowest bidder based on public tendering. Contracts are performed based on the actual versus projected quantities with fixed unit prices for specific works, and any inefficiency of the contractor is not reflected in the recorded final costs for the investor. The risk of additional costs due to the potential inefficiency of the contractor is borne solely by the contractor, just as increasing efficiency will yield benefits. In this sense, the final cost amount aligns with the contractually agreed costs, increased, or decreased for changes in executed quantities and the cost of works necessary to complete the project, which were not covered by the contract due to oversights. The research encompasses such reasons and the cost deviations they induce. It is acknowledged, based on the data available in

the literature [3,23], that for many projects, the largest cost overruns occur in the early stages of the project lifecycle, and by studying costs at the contracting phase, a significant portion of overruns is captured [27]. However, this does not mean that deviations occurring after contract award should be disregarded. In our research, the contract size was not functionally related to the amounts of cost overruns for two out of three samples, aligning with the conclusion of Love et al. [28] and Love et al. [32], who did not find any significant differences in cost overruns among procurement methods, project types, or contract sizes.

Using the contract award as a reference point, the calculated average deviations of road contracts' costs were 7.866%, matching Odeck's [33] results of 7.9%. Love et al. [26], on the other hand, found an average cost overrun of 13.55% for road projects. However, it should be noted that we are referring to average sample deviations, not population-based ones. Comparing results can only be indicative as sample statistical features heavily depend on sample size, data quality, extreme values, and other similar factors. Randomly selecting other potential samples would likely yield different results. For indicative comparison purposes, Love et al. [32] found an average cost overrun of 13.28% for transportation infrastructure projects; however, specifically for rework costs during construction due to design changes, errors, and omissions, the deviations were 11.21%. Even closer results were found by Terrilla [4], who identified an average cost overrun of 9% during the construction phase. For a more diverse sample composed of construction and engineering projects, Love et al. [28] calculated an average cost overrun of 12.22%. Based on the foregoing, it can be stated that the cost deviations for the investigated sample are of the same order of magnitude as in similar studies, which in a way confirms the sample's quality. In addition to the road sample, we singled out a sample for standard viaducts and highway structures as an interesting group of projects, as they are projects that do not significantly differ in their characteristics, except possibly in length. These are contracts where a semi-modular construction system was used, and bidders had previous experience. The average deviation value of the sample's costs is negative, i.e., −5.23%, indicating a slight caution in price bidding but also implementation below the contractually agreed amount.

Furthermore, it is a known fact that determining the probability distribution of deviations between the actual and estimated costs can help estimate the real value of actual costs. The same applies to estimates of discrepancies between the actual costs and costs at contract award. Since Flyvbjerg et al. [1] presented their paper, there have been disagreements about the type of statistical distribution of cost deviations. These are evident in the comparisons between Flyvbjerg et al. [23] and Love et al. [6]. Love et al. argued that Flyvbjerg assumes a normal distribution without relevant grounds for such claims. Love et al. [28] provided a three-parameter Frechet probability function for construction and engineering projects, which is not a normal function, as the best one for calculating cost overrun probabilities. For average costs due to modifications during implementation and average cost overruns in transportation infrastructure projects, Love et al. [32] provide a generalized logistic function for calculating the probability of cost overruns of alterations, and a Johnson SB distribution for the overall distribution for calculating the probability of cost overruns. For road projects comparable to the results presented here, Love et al. [26] found that the log logistic (3P) probability function provided the best overall distribution for calculating cost overrun probabilities. However, our sample showed that the discrepancies between the actual costs and the contractually agreed values show a normal distribution pattern, contrary to the results of Love et al. [26,28]. However, this difference does not affect the cost estimation model of project programs presented here, as normality is not a requirement for using the central limit theorem. As a result of its application, the average cost deviation of the sample costs represents the mean value of the sampling distribution of average cost deviations of all samples from the population, opening the possibility of estimating the average costs of any project program from the described population.

5. Conclusions

The working assumption that project complexity, technical errors, and inaccurate estimates are the primary reasons for deviations between actual and contractually agreed costs is confirmed by the fact that we did not identify psychological reasons for cost deviations in the collected samples. Therefore, the obtained results regarding the characteristics of the deviations pertain to the technical reasons for cost overruns. In this research, we managed to prove that discrepancies between the actual costs and the contractually agreed ones result from technical reasons, and we have demonstrated how we can incorporate their impact into forecasting the discrepancies between the actual costs and the contractually agreed ones in the average costs of project programs. The samples we investigated were formed based on empirical data collected from strictly defined project documentation, disregarding the subjective attitudes of the respondents. Samples were classified based on contract types into reference classes, and statistical features describing them were presented. The fact that samples of construction projects with a focus on three categories (road sections, viaducts, and tunnels) were analysed to investigate deviations between contractually agreed costs and actual costs, represents a limitation in terms of generalizing to other types of projects. However, the applied methodology and methods can certainly be used to study other types of projects. Similarly, certain features highlighted by the research can be compared and used in evaluating other types of projects. For example, the sample of tunnel contracts showed that the contracts in the sample do not belong to the same class of projects because cost deviations depend on the agreed price and the length of the tunnel. This is expected given the significant impact of uncertainties that arise during excavation (changes in soil categories during excavation, underground water, or hidden caves and pits). Such risks increase with greater tunnel length, making it logical that due to varying tunnel lengths, the contracts studied do not belong to the same class. In contrast, with standard viaducts, the unknowns are fewer and their classification within the same category based on contract size is understandable. Accordingly, in other types of projects we can expect similar results regarding classification when dealing with projects that are closer to standardized production, as opposed to those that face greater unknowns during their execution. Furthermore, the research is limited to technical reasons for cost overruns, as psychological reasons were not identified in our samples. This does not mean that we diminish the importance of psychological reasons for overruns, which have been recognized in the literature presented, but rather that we believe their impact after contract signing is negligible. We calculated the discrepancies between the actual costs and the contractually agreed costs and the structure of reasons that caused these discrepancies. The results show that cost overruns are dominant in the population of contracts for individual highway sections, unlike contracts for standard structures. Deviations in the mean values of contractually agreed costs for individual highway sections range between −12.1% and 27.9% of the contractually agreed value, while for standardized viaduct projects, they range between −16.73% and 6.27% of the contractually agreed value. These discrepancies, given the nature of the sample, can be considered a consequence of technical reasons, confirming the reality of their share in cost overruns in general. It has been shown that the distribution functions of the discrepancies between the actual costs and the contractually agreed costs, i.e., the technical reasons for the deviations, belong to the family of normal distributions. The obtained distributions of actual deviations from the contractually agreed costs in the samples were used to determine the mean values of discrepancies between the actual and contractually agreed costs for the population of certain types of projects. We demonstrated how the average deviation value of the sample costs can be used to forecast the average deviations for any sample of projects from the population of such projects. The presented analysis of the reasons for the overrun and the statistical model contributes to a more accurate prediction of costs as an essential component that encourages a holistic approach to sustainability in infrastructure development.

The displayed values refer to project implementation circumstances in the Republic of Croatia, but the principle is applicable to any country or type of project. Reducing cost overruns by reducing the negative impact of technical reasons is linked to the preservation of environmental resources and the reduction of emissions caused by unnecessary activities.

The insights presented in the article highlight the significant impact that the accuracy of documentation has on the deviations between actual and contractually agreed costs. The research has potential policy implications by providing a framework for insisting on improving the accuracy of assessments through sustainability policies to optimize the use of public funds and resources in relation to project sustainability impacts. Governments and agencies can apply these insights to revise project management regulations, contract design, and procurement policies to improve long-term sustainability goals. It promotes the use of methods, solutions, and technologies aimed at improving project designs to achieve greater accuracy, which is a prerequisite for high-quality forecasting and planning in infrastructure project management. The results confirm that the relative simplicity and standardization of project solutions due to repetition and learning from experience contribute to the accuracy of the estimated contract price. A method for estimating program project costs is proposed, along with the establishment of unified data collection systems to increase sample sizes, allowing more accurate predictions of the final costs of individual projects.

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Conflicts of Interest: Author Marijo Lovrinčević was employed by the company Ariozo d.o.o., Author Romano Perić was employed by the company BIM Projekt d.o.o. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Appendix A

Table A1. The "Road Sections" sample.

No.	SECTIONS	Contractually Agreed Costs (T_{Contr})	Final Costs (T_{Fin})	Relative Cost Deviation $(T_{Contr} - T_{Fin})/T_{Contr}$
1	Čvor Sv. Rok—tunel Sv. Rok	20,632,526.67 €Eur	25,786,531.85 €Eur	0.2498
2	Tunel Sv. Rok—Maslinica	26,364,944.93 €Eur	32,891,254.26 €Eur	0.2475
3	Maslinica—Zadar 1	11,849,363.43 €Eur	11,849,363.43 €Eur	0
4	Zadar 1—Zadar 2	9,733,622.39 €Eur	11,128,867.00 €Eur	0.1433
5	Zadar 2—Benkovac	17,302,716.,30 €Eur	18,128,062.88 €Eur	0.0477
6	Benkovac—Pirovac	23,965,583.96 €Eur	27,532,802.97 €Eur	0.1488
7	Pirovac—Skradin	10,236,890.31 €Eur	11,822,927.87 €Eur	0.1549
8	Skradin—Šibenik	18,912,329.26 €Eur	23,558,525.77 €Eur	0.2457
9	Šibenik—Vrpolje	21,892,760.42 €Eur	23,319,323.76 €Eur	0.0652
10	Prgomet—Dugopolje	35,514,005.82 €Eur	42,812,117.55 €Eur	0.2055
11	Dugopolje—Bisko	72,869,393.,20 €Eur	79,687,235.37 €Eur	0.0936
12	Bisko—Šestanovac	137,771,.341.79 €Eur	146,174,528.21 €Eur	0.061
13	Šestanovac—Zagvozd	93,392,.451.,41 €Eur	94,427,796.05 €Eur	0.0111
14	Zagvozd—Ravča	128,658,460.,96 €Eur	156,732,160.31 €Eur	0.2182
15	Čvor Ploče—Luka Ploče	98,680,769.14 €Eur	108,708,836.74 €Eur	0.1016
16	Spojna za grad i luku Ploče	7,551,553.54 €Eur	7,342,490.94 €Eur	−0.0277
17	Čvor Ploče—granica BiH	6,855,725.36 €Eur	6,525,857.44 €Eur	−0.0481
18	Spojna cesta i tunel Sv. Ilija	41,987,604.48 €Eur	38,307,961.73 €Eur	−0.0876
19	Zabok—Krapina, 1. dio	5,799,559.62 €Eur	5,758,836.45 €Eur	−0.007

Table A1. *Cont.*

No.	SECTIONS	Contractually Agreed Costs (T_{Contr})	Final Costs (T_{Fin})	Relative Cost Deviation ($T_{Contr} - T_{Fin}$)/T_{Contr}
20	Zlatar Bistr.—Andreševac, 1. faza	4,504,239.51 €Eur	4,279,732.59 €Eur	−0.0498
21	Zlatar Bistr.—Andreševac, 2. faza	10,515,896.19 €Eur	9,956,165.61 €Eur	−0.0532
22	Dubovo—Kapja	5,994,243.31 €Eur	6,564,939.57 €Eur	0.0952
23	Sredanci—Đakovo	74,296,614.63 €Eur	73,762,642.00 €Eur	−0.0072
24	Osijek—Đakovo	156,374,043.98 €Eur	151,413,514.31 €Eur	−0.0317
25	Jakuševac—V. Gorica, 0–6,3 km	75,774,286.13 €Eur	69,743,224.39 €Eur	−0.0796
26	Jakuševac—V. Gorica, 6,3–8,4 km	26,796,178.51 €Eur	30,009,197.24 €Eur	0.1199
27	Buševec—Lekenik	47,840,327.92 €Eur	46,710,938.79 €Eur	−0.0236

Table A2. The "Viaducts" sample.

No.	VIADUCTS	Contractually Agreed Costs (T_{Contr})	Final Costs (T_{Fin})	Relative Cost Deviation ($T_{Contr} - T_{Fin}$)/T_{Contr}
1	Krpani	3,012,643.36 €Eur	3,570,079.16 €Eur	−0.185
2	T. Sv. Rok—Maslinica (objekti)	18,693,745.28 €Eur	18,996,450.24 €Eur	−0.0162
3	Maslinica—Zadar 1 (prolazi)	3,418,518.37 €Eur	4,574,522.26 €Eur	−0.3382
4	Zadar 1—Zadar 2 (objekti)	1,023,981.90 €Eur	1,147,862.55 €Eur	−0.121
5	Zadar 1—Zadar 2 (prijelazi)	1,068,784.68 €Eur	1,861,841.56 €Eur	−0.742
6	Zadar 2—Benkovac (objekti)	5,376,048.35 €Eur	5,376,048.35 €Eur	0
7	Zadar 2—Benkovac (prijelazi)	4,336,762.41 €Eur	4,592,727.12 €Eur	−0.059
8	Pirovac—Skradin (vijadukti)	18,309,862.04 €Eur	20,714,210.35 €Eur	−0.1313
9	Pirovac—Skradin (nadvožnjaci)	2,824,215.06 €Eur	3,032,608.24 €Eur	−0.0738
10	Skradin—Šibenik (most Krka)	11,839,699.73 €Eur	12,190,129.61 €Eur	−0.0296
11	Skradin—Šibenik (vijadukti)	9,987,614.92 €Eur	10,074,.106.22 €Eur	−0.0087
12	Skradin—Šibenik (nadvožnjaci)	4,973,923.24 €Eur	4,973,923.24 €Eur	0
13	Šibenik—Vrpolje (vijadukti)	15,922,631.98 €Eur	18,957,424.89 €Eur	−0.1906
14	Prgomet—Dugopolje (objekti)	16,042,218.21 €Eur	17,917,153.04 €Eur	−0.1169
15	Most Cetina	9,786,025.51 €Eur	9,560,550.90 €Eur	0.023
16	Rašćane	13,967,342.74 €Eur	13,379,288.93 €Eur	0.0421
17	Biakuše	5,773,195.41 €Eur	5,935,946.60 €Eur	−0.0282
18	Prosike	1,066,549.16 €Eur	1,097,821.14 €Eur	−0.0293
19	Perići	4,275,187.98 €Eur	4,406,483.14 €Eur	−0.0307
20	Bulati	3,310,234.21 €Eur	3,486,709.38 €Eur	−0.0533
21	Akrapi	2,380,835.00 €Eur	2,399,423.14 €Eur	−0.0078
22	Kotezi	26,268,788.97 €Eur	29,020,839.41 €Eur	−0.1048
23	Radonjić	6,240,615.02 €Eur	6,375,982.01 €Eur	−0.0217
24	Dračevac 1	3,586,603.90 €Eur	38,144.55 €Eur	0.9894
25	Dračevac 2	1,992,447.12 €Eur	2,129,247.31 €Eur	−0.0687
26	Vrila	2,720,203.83 €Eur	3,006,821.68 €Eur	−0.1054
27	Vijadukt u osi 11	4,437,310.49 €Eur	2,146,934.79 €Eur	0.5162
28	Vijadukt u osi 14	5,527,656.35 €Eur	2,196,649.39 €Eur	0.6026
29	Crna Rijeka	7,746,520.11 €Eur	8,418,610.04 €Eur	−0.0868
30	Crip	3,985,458.16 €Eur	4,049,608.15 €Eur	−0.0161
31	Gradina	14,763,830.46 €Eur	15,040,717.53 €Eur	−0.0188
32	Paklina	1,954,240.29 €Eur	1,982,595.72 €Eur	−0.0145
33	Lučka	6,963,092.77 €Eur	7,092,919.85 €Eur	−0.0186
34	Veliki Prolog	8,716,916.79 €Eur	8,831,.695.27 €Eur	−0.0132
35	Mali Prolog	1,002,983.36 €Eur	987,584.72 €Eur	0.0154
36	Krapinica	331,700.79 €Eur	380,786.73 €Eur	−0.148
37	Đakovo Sredanci (objekti)	13,897,290.67 €Eur	13,271,661.66 €Eur	0.045
38	Đakovo Sredanci (nadvožnjaci)	13,920,569.54 €Eur	14,347,299.90 €Eur	−0.0307
39	Đakovo Sredanci (vijadukti)	13,907,908.49 €Eur	14,787,836.01 €Eur	−0.0633
40	Jošava, Topolinka i Hrastinka	25,294,642.94 €Eur	25,692,811.37 €Eur	−0.0157
41	Buševec Lekenik (objekti)	19,050,051.74 €Eur	17,236,859.09 €Eur	0.0952

Table A3. The "Tunnels" sample.

No.	TUNNELS	Contractually Agreed Costs (T_{Contr})	Final Costs (T_{Fin})	Relative Cost Deviation ($T_{Contr} - T_{Fin}$)/T_{Contr}
1	Krpani	2,984,935.96 €Eur	3,538,724.73 €Eur	0.1855
2	Sv. Rok	54,808,956.67 €Eur	82,669,246.49 €Eur	0.5083
3	Čelinka, Ledenik i Bristovac	24,020,320.55 €Eur	26,120,644.90 €Eur	0.0874
4	Dubrava	9,848,213.18 €Eur	10,170,756.60 €Eur	0.0328
5	Zaranač i Bisko	16,187,747.11 €Eur	16,315,776.96 €Eur	0.0079
6	Sv. Ilija	27,049,266.41 €Eur	34,402,808.52 €Eur	0.2719
7	Umac	5,257,408.48 €Eur	5,321,491.98 €Eur	0.0122
8	Šubir	14,685,832.95 €Eur	14,986,058.55 €Eur	0.0204
9	Mali Prolog	12,976,806.73 €Eur	13,158,346.82 €Eur	0.014
10	Kobiljača	11,678,082.63 €Eur	11,016,875.75 €Eur	−0.0566
11	Puljani	4,638,079.08 €Eur	4,537,868.23 €Eur	−0.0216
12	Crna Brda	5,844,625.04 €Eur	5,229,730.89 €Eur	−0.1052
13	Stražina	8,957,034.30 €Eur	9,055,351.28 €Eur	0.011
14	Zmijarević	8,984,025.60 €Eur	8,388,274.57 €Eur	−0.0663
15	Petrovac	5,805,759.34 €Eur	5,594,887.11 €Eur	−0.0363
16	Međak	6,836,106.44 €Eur	5,970,779.93 €Eur	−0.1266

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