RISK MANAGEMENT IN ROAD CONSTRUCTION WORKS

- QUANTITATIVE ANALYSIS OF COST DEVIATIONS FROM A PROJECT OWNER'S STANDPOINT -

João Ricardo Baptista Silva

Abstract

Construction projects are characterised by several uncertainties throughout the different various stages of their life cycle. Those uncertainties are especially relevant due to their impact on the project' performance, particularly in terms of costs. Considering the effects of such uncertainties on the goals set out for each project in terms of costs, these would fall within the definition of risks, as provided under standard ISO 31000. They must be accurately assessed, so they can be managed, in order to guarantee the success of the developments carried out by the project owners.

Due to the potential economic consequences arising from cost deviations, it is necessary to intervene and seek to minimise risks associated with positive cost deviations, particularly those arising from issues directly and easily controllable by those involved, and enhance negative cost deviations, especially through innovative and alternative solutions or by leveraging possible synergies. However, some particularities inherent to construction projects pose challenges to the application of the risk management techniques commonly used in other sectors.

This study aims to analyse and quantify cost deviations in road construction projects in order to provide a methodology and a basis to support the quantitative risk management of cost deviations. To this end, data from 738 road construction projects implemented in the State of Virginia, USA, in 1999 and 2000, were analysed. It was found that cost deviations are not explained by any of the factors commonly available in the projects' historical record databases and, therefore, it was concluded that they result from specific and particular aspects of each project or contract. Thus, cost deviation probabilistic distributions were proposed to help define amounts for contingency funds, both simplified and framed within the context of a quantitative risk management process to be implemented by the project owner.

Keywords: Risk management, construction, project owner, cost deviation, road construction projects.

Introduction

Most of the causes for cost deviations occur in the implementation and design stages, which are crucial for the good performance of projects. Cost deviations throughout the execution phase include several aspects which tend to affect the projects' performance, which is why so many studies have been conducted in this field (e.g., Maganlal, 2011; Hashimoto, 2008).

This work aims at contributing to the progress of risk management in the construction industry, and its research is focused on road infrastructure construction projects from a project owner's standpoint. The research work follows the principles of risk management proposed by Sousa (2012) and it aims mainly at analysing and quantifying the risk of cost deviation in road construction projects completed in the State of Virginia, United States of America (USA).

The research methodology comprised the following set of steps:

- review of knowledge on budgeting and causes for cost deviations;
- data collection from road infrastructure construction projects undertaken in the State of Virginia, USA, between 1999 and 2000;
- descriptive statistical analysis of cost deviations in the 738 contracts collected;
- inferential statistical analysis between cost deviations and the information available on the 738 contracts.

Considering the results obtained in the statistical analysis and following the approach proposed by Sousa (2012), statistical distributions of cost deviations were obtained and used as basis to support the implementation of quantitative risk management in road construction projects.

Cost deviations in construction

General considerations

In construction projects, goals are usually related to cost, time and compliance (Baker, 1997; Smith et. al., 2006). Deviations from the expected goals often have an effect on both cost and time, as these are practically inseparable, both depending on productivity. However, this study will only comprise a brief review on general cost deviations, as another study on the topic of time deviations is being presently carried out on the data from the same projects.

Cost Structure

The main components of a project's cost, in a very simplified way, are the cost of design, implementation, usage and monitoring. Figure 1 shows a diagram of the main elements that make up the cost of a project, detailing some of their components.

The distribution of the projects' total cost by each of the main elements identified depends on numerous factors, including the type and characteristics of the projects, their service life or aspects considering in costing.

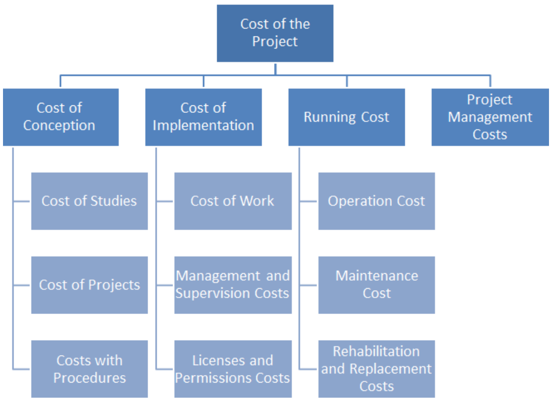

Figure 1 - Main elements of a project's cost (adapted from Sousa, 2012).

Implementation and usage make up the most significant portion of costs in a project, in general terms, and of road construction projects, in particular. However, while the costs related to usage are distributed throughout an extended period of time (usually from 50 to 100 years), implementation costs are concentrated within a substantially shorter period (usually up to 5 years). Another important aspect is that the liability for the initial costs (design and implementation) of projects generally falls onto the project owner, whereas usage costs may be shared or fully supported by other interested parties (e.g. clients, end-users).

The present study will not take into account the various stages that comprise the life cycle of road construction projects, focusing only on the analysis of cost deviations related to the implementation stage and from a project owner's standpoint. The analysis will include contracts for new constructions, both rehabilitation and/or replacement, and various types of interventions carried out in the context of road infrastructure.

Cost deviations in road construction projects

Sample characterisation

The collected sample was divided, according to typology, into groups and subgroups, in order to clarify its identification and enable its analysis. Table 1 shows the distribution of the number of contracts in the sample by the groups and subgroups considered for each contract typology. It is observed that rehabilitation projects clearly dominate the sample, with a total of 600 contracts. Nevertheless, all of the considered subgroups contain over 30 contracts, which is the minimum number usually referred to for the application of the Central Limit Theorem.

Table 1 – Number of contracts by type of project.

Group	Subgroup	Data
New Construction Projects	New Roads (NRoa)	59
	New Artworks (NArtW)	37
Rehabilitation Projects	Roads Rehabilitation (RRoa)	417
	Roadsides and Gardens Rehabilitation (RRGar)	63
	Artworks Rehabilitation (RArtW)	120
Mixed/Other	Mixed/Other (M/O)	42
TOTAL		**738**

Regarding the categorisation by type of road, Table 2 shows the distribution of the number of contracts in the sample by the considered road categories.

Table 2 – Number of contracts by type of road.

Subgroup	Data
Interstate Roads (IS)	102
Primary Roads (P)	226
Secondary Roads (S)	313
Other (O)	97
TOTAL	**738**

Descriptive analysis

Table 3 presents a summary of the descriptive statistics of the total of contracts in the sample, in terms of initial amount, final amount and cost deviation. We can see that the average cost deviation is of 10.67%, with a standard deviation of 29.88%.

Table 3 - Descriptive statistics of the contracts.

Statistics	Parameter		
	Initial Amount [$]	Final Amount [$]	Cost Deviation [%]
Mean	1.753.495,01	1.966.788,75	10,67
Std. Error of Mean	261.283,33	291.668,80	1,10
Median	375.606,50	413.696,50	6,92
Std. Deviation	7.098.063,57	7.923.519,91	29,88
Skewness	10,51	10,50	2,69
Std. Error of Skewness	0,09	0,09	0,09
Kurtosis	138,63	139,07	24,68
Std. Error of Kurtosis	0,18	0,18	0,18
Minimum	19.500,00	8.281,00	-98,97
Maximum	117.397.948,00	129.874.621,00	298,35
Sum	1.294.079.314,00	1.451.490.096,00	-

Adopting a base 2 geometric scale and setting "0 - 200.000 $" as the limit for the first cost interval, the following is the distribution of the number of contracts and tenders in Figure 2. The ratio of tenders per contract varied between 3.8, for contracts with initial amounts falling within the “1.600.000 $ - 3.200.000 $” interval, and 6.7, for contracts with initial amounts falling within the “6.400.000 $ – 12.800.000 $” interval, so the global average of tenders per contract was of 4.8.

The number of contracts implemented in the respective intervals of initial and final amounts are shown in Figure 3. It is found that only one of the cost intervals suffered no change in the number of contracts based on the difference between initial and final amounts. This result was expected, since only 3 contracts did not record any cost deviation.

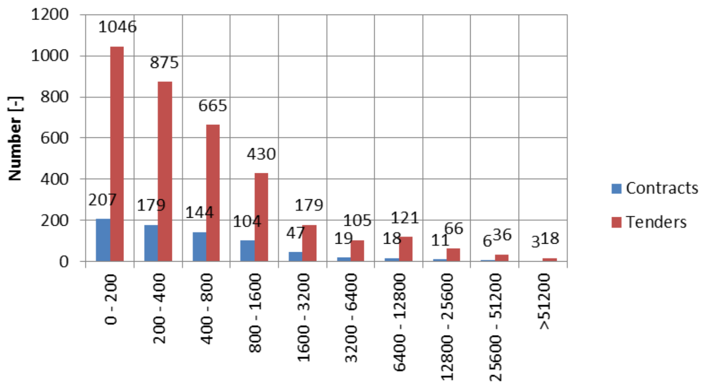

Figure 2 - Distribution of the number of contracts and tenders by initial amount interval.

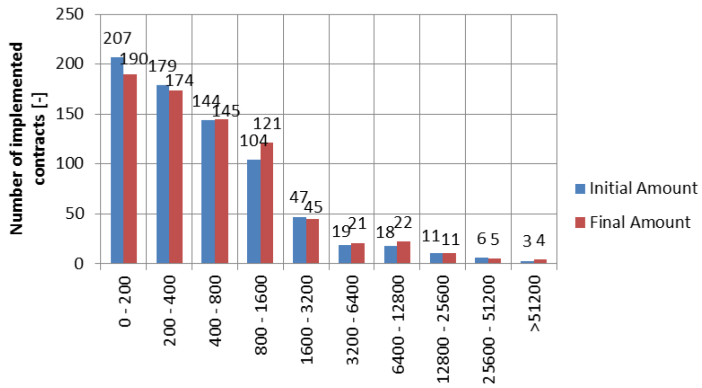

Figure 3 - Number of implemented contracts by amount interval.

The box graph shown in Figure 4 represents the dispersion of cost deviation for each of the considered intervals, for the initial amount and the entire sample (on the right). It should be noted that, except for a few intervals with fewer proposals, the median and the 1st and 3rd quartiles present similar amounts.

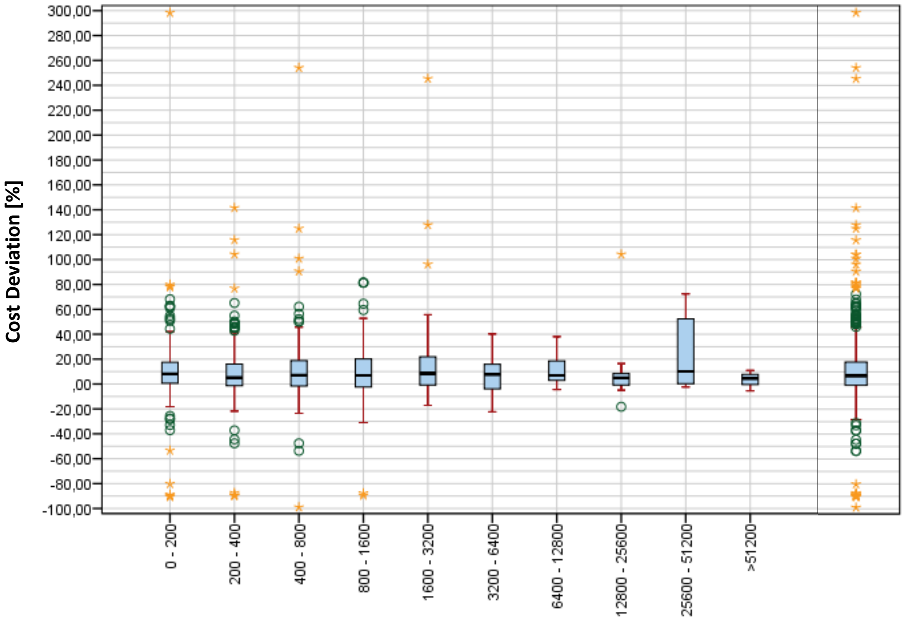

Figure 4 - Box graph of cost deviation by initial amount interval.

A detailed descriptive statistical analysis was also carried out on the contracts for each of the collected factors (year, location, type of road and type of project) for the initial amount, final amount and cost deviation. Using the non-parametric Kruskal-Wallis test for location, type of road and type of project, it was concluded that none of these factors are statistically significant for cost deviations.

As previously mentioned, the most implemented type of project was rehabilitation, which was well above new constructions and mixed/other projects, as shown in Figure 5. This results from the fact that the deficiencies in the United States road network are mostly related to the state of conservation of existing infrastructures and not as much to a shortage of such infrastructures. The American Society of Civil Engineers (ASCE) (1998) reports that about 59% of U.S. roads are in a mediocre state of conservation and about 31% of bridges are rated structurally deficient or functionally obsolete.

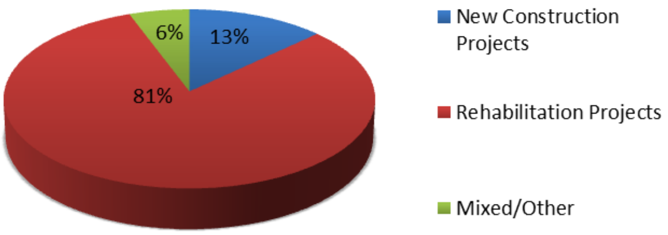

Figure 5 - Percentage of projects implemented in 1999 and 2000.

In 1999 and 2000, 600 rehabilitation contracts, 96 contracts for new infrastructure and 42 mixed/other contracts were implemented, amounting to a total of 738 executed projects.

Figure 6, shows that, out of the rehabilitation projects implemented, road rehabilitation was the type of project with the highest number of implementations, followed by the rehabilitation of artworks and, finally, the rehabilitation of roadsides and gardens.

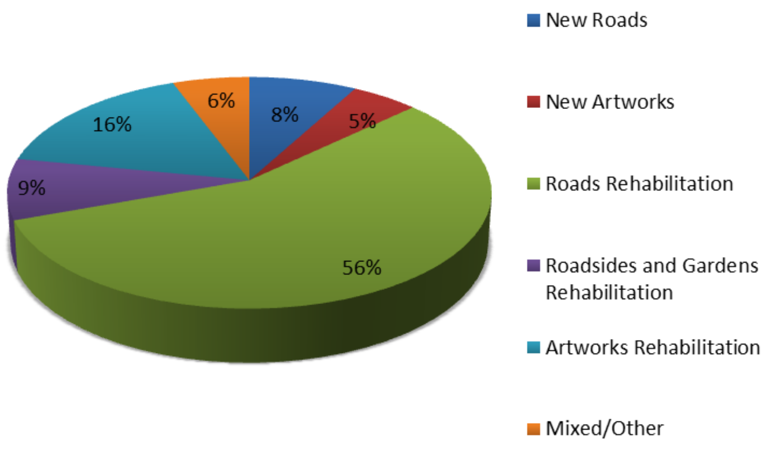

Figure 6 - Percentage of types of projects implemented in 1999 and 2000.

Contracts for the construction of new roads have been reduced, accounting for only 8% of the 738 projects (59 contracts for construction of new roads in 1999 and 2000). Regarding contracts for "mixed/other" and artworks, these were the least implemented - respectively, 5% and 6% of all contracts implemented in 1999 and 2000.

Despite the differences between the awarding amount and the final amount (cost deviation), there are three contracts in which the cost deviation was zero, i.e. the difference between the initial and final amounts is null. Table 4 presents the data referring to those three contracts, where no deviation costs were verified.

Table 4 - Data relating to contracts with no cost deviation.

Data	Contract Code		
	MA1115939744B	CM18518A39560B	CM399BRR705
Year	1999	1999	2000
Month	May	November	January
Type of Project	RArtW	RArtW	RRoa
Type of Road	S	P	P
Location	Northern Virginia	Bristol	Lynchburg
Awarding Amount	$ 62.436,00	$ 27.900,00	$ 82.500,00
Number of Tenders	6	6	10
Max. Amount of Tenders	$ 125.856,00	$ 98.750,00	$ 317.760,00
Min. Amount of Tenders	$ 62.436,14	$ 27.900,00	$ 82.500,00
Average Amount of Tenders	$ 103.086,71	$ 49.052,02	$ 158.886,90
Standard Deviation	$ 25.909,99	$ 31.482,98	$ 74.249,81

Inferential analysis

The inferential statistical analysis essentially sought to determine whether any of the factors with information in the database presents correlation with cost deviations. In this sense, the following were considered as possible explanatory factors for cost deviations: type of contract, type of road, location (see descriptive analysis) and size of the contract, number of tenders, minimum, average and maximum amount of tenders and the interval and standard deviation of tender amounts (see Table 5).

Table 5 - Correlations between the factors analysed and cost deviations.

CORRELATION		Cost Deviation	
		Pearson	Spearman's rho
Initial amount	Coef.	0,012	0,145**
	Sig. (2-tailed)	0,737	0,000
Number of tenders	Coef.	0,065	0,086*
	Sig. (2-tailed)	0,078	0,020
Maximum amount of tenders	Coef.	0,011	0,135**
	Sig. (2-tailed)	0,764	0,000
Minimum amount of tenders	Coef.	0,012	0,145**
	Sig. (2-tailed)	0,737	0,000
Average amount of tenders	Coef.	0,012	0,142**
	Sig. (2-tailed)	0,750	0,000
Standard deviation of tender amounts	Coef.	-0,001	0,100**
	Sig. (2-tailed)	0,972	0,008
Interval of tender amounts	Coef.	0,006	0,119**
	Sig. (2-tailed)	0,871	0,001

*Correlation is significant at the 0,05 level
**Correlation is significant at the 0,01 level

In the analysis conducted, it was possible to *observe* the existence of outliers, i.e. contracts with clearly anomalous cost deviations, when compared to the rest. Those contracts were, therefore, removed from the sample before the inferential statistical analysis. It should be noted that the criterion *for* the identification of an outlier was based on standardised amounts greater than 3,00.

For all the analysed factors, either including or *removing outliers*, the correlation with cost deviations is non-existent or very poor and regression trends cannot be considered representative or significant. The slight trends observed in some minor factors are probably conditioned by ranges of amounts in which the sample is smaller.

Regarding the average for the sample, the ratio between the awarding and final amounts was obtained and is presented in Figure 7. The ratio between the two figures is linear and presents a coefficient of determination (R^2) of 0.995. For the contracts analysed, for each increment in the Initial Cost, the Final Cost increases, on average, by $ 1,114.

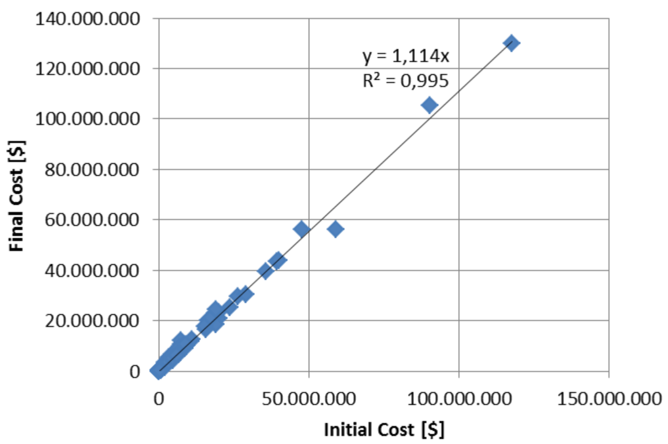

Figure 7 - Ratio between initial and final costs.

Risk of cost deviations

General considerations

The analysed data confirm that cost deviations in road construction projects in the State of Virginia, USA, are frequent and can take on significant proportions. To address this reality, it is common practice, in many countries and several organisations, to allocate contingency funds. According to the *Project Management Institute* (PMI 2004), contingency funds are the "amount of funds, budget, or time required above the estimated to reduce the risk of slippage in project goals to a level considered acceptable to the organisation". The need and size of the contingency fund reflect the existing uncertainty and the corresponding level of risk (Thompson & Perry 1992).

Proposed approach

The approach adopted was that proposed by Sousa (2012), which is based on the assumption that cost deviations during the implementation stage may be motivated by numerous factors, which are specific to each particular project. This implies that, for projects of the same type, the distribution of cost and time deviations, regarding aspects that are common to all of them, does not follow a particular overall pattern, external to the nature of the works involved (e.g. location and type of contract; year of execution; number of tenders submitted and their amounts; awarding amount).

The analyses conducted point out the hypothesis that cost deviations during the implementation stage are not explained by factors common to projects of a particular nature. Thus, the distribution of the contracts cost deviations, with the respective probabilistic distribution duly adjusted, is shown below. (Figure 8).

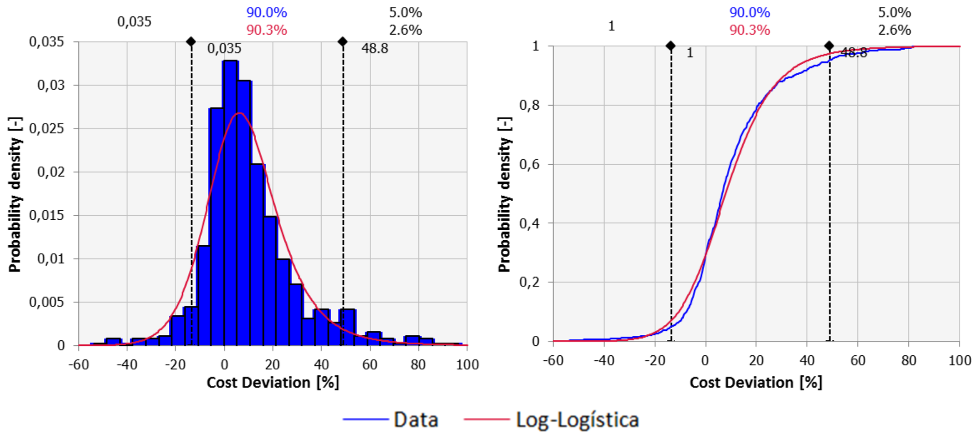

Figure 8 - Statistical adjustment of cost deviations in all contracts, without *outliers*.

Using the graphs shown in Figure 8, it is possible to manage cost deviations in three different ways:

- establishing a safety margin, which shall be ensured in the budget, from which one can determine the corresponding probabilistic amount of the cost deviation (e.g. for a safety margin of 80%, which corresponds to considering that there is only a 20% probability of the cost deviation being higher than the contingency, the contingency fund must be around 20%);
- matching the qualitative scale used in qualitative cost deviation risk analyses with a cost deviation probability (e.g. considering that a project with a very high cost deviation risk corresponds to a 90% probability, which means that the expected cost deviation amounts to about 30%);
- validating the results of the quantitative cost deviation risk analyses using the distribution obtained to assess whether the estimated amount is consistent with the characteristics of the project and previous cost deviations.

Although the statistical analyses carried out have not identified any statistically significant differences in cost deviations for the different types of projects, in practice, each type of project is characterised by substantially different construction operations, which are associated with specific hazards and opportunities. Accordingly, this approach was applied to the following subgroups of contract types in the sample (Figure 9 to Figure 14):

- New Construction Projects
    - Roads (NRoa);
    - Artworks (NArtW);
- Rehabilitation Projects
    - Roads (RRoa);
    - Artworks (RArtW);
    - Roadsides and Gardens (RRGar);
- Mixed/Other (M/O).

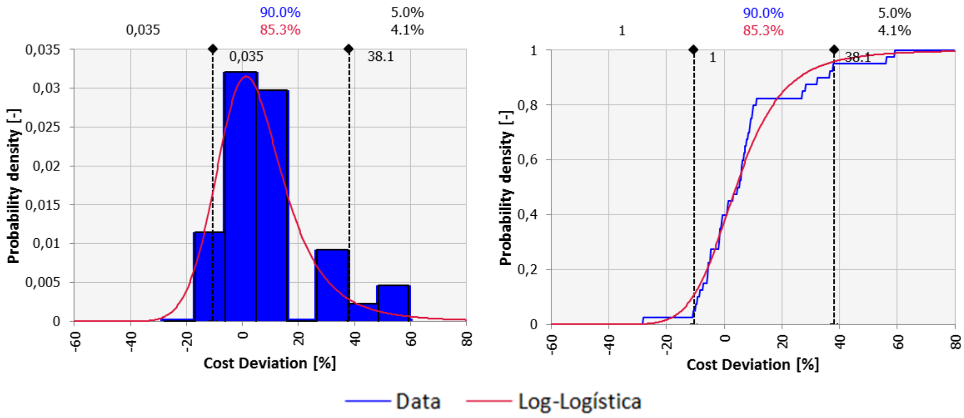

Figure 9 - Statistical adjustment of cost deviations in M/O projects without *outliers*.

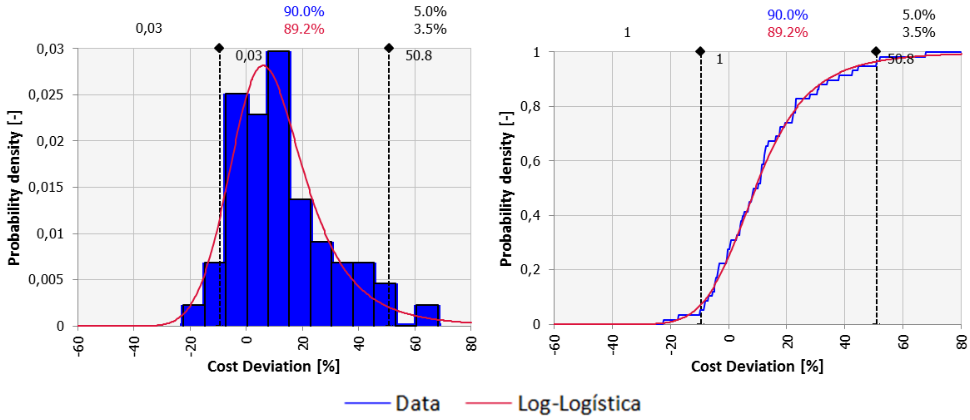

Figure 10 - Statistical adjustment of cost deviations in NRoa projects without *outliers*.

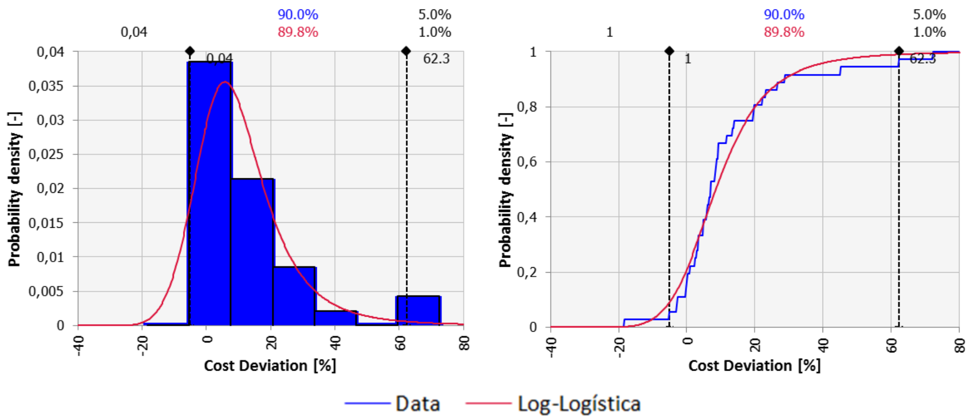

Figure 11 - Statistical adjustment of cost deviations in NArtW projects without *outliers*.

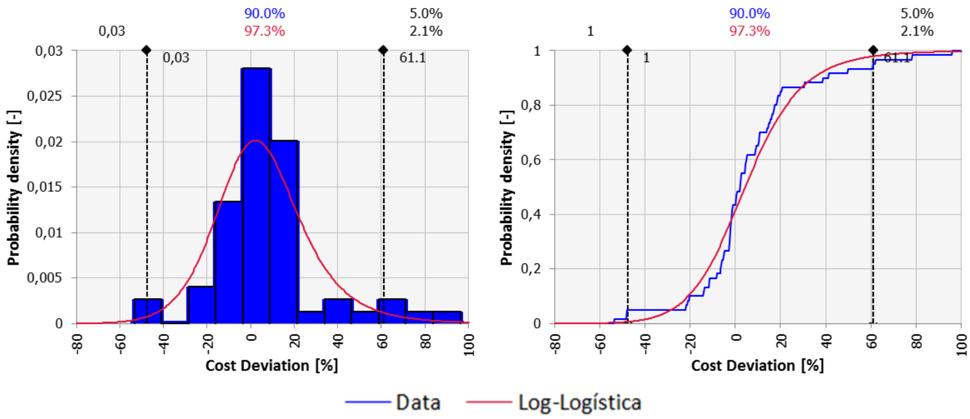

Figure 12 - Statistical adjustment of cost deviations in RRGar projects without *outliers*.

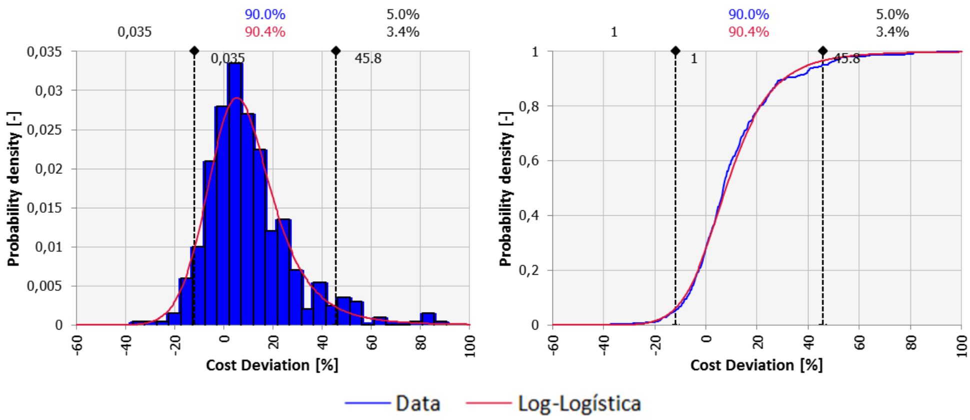

Figure 13 - Statistical adjustment of cost deviations in RRoa projects without *outliers*.

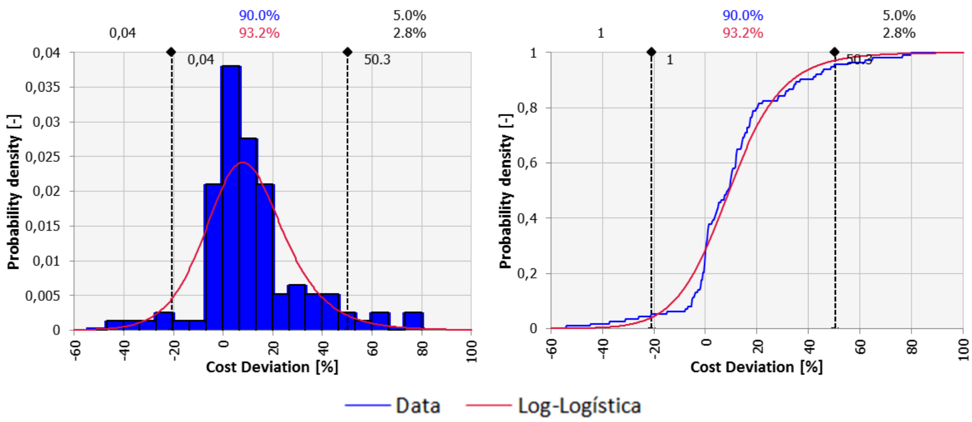

Figure 14 - Statistical adjustment of cost deviations in RArtW projects without *outliers*.

Findings

Cost deviations affect the different stages of construction projects, with direct or indirect consequences for all stakeholders. Such deviations are, in most cases, the most reliable indicator to evaluate the success, or even the viability of the projects. It is, therefore, necessary to control costs, making estimates as accurate as possible, to ensure both the quality and the deadlines of such projects.

This study falls within the field of construction management in general, and risk management in particular, and is focused on road infrastructure construction projects. This study followed the approach proposed by Sousa (2012) and aimed at analysing and quantifying cost deviations in road construction projects implemented in the State of Virginia, USA, in 1999 and 2000, from a project owner's standpoint.

Through a descriptive analysis it was concluded that, out of the 738 contracts included in the sample, only three presented no cost deviation. It can, therefore, be said that the study and the analysis of cost deviations is currently a highly relevant topic for all those involved.

It was also found that there is no statistically significant correlation between the various factors that characterise each contract (year; location; type of road; type of contract; number of tenders submitted and their amounts; awarding amount) and cost deviation. However, due to the fact that the analysis comprised only two years (1999 and 2000) it is not possible to draw definitive conclusions on the correlation between the "year" factor and cost deviation. Thus, it was found that cost deviations in the analysed projects are not explained by the factors available in the historical record databases, i.e., cost deviations during the implementation stage of projects can be triggered by many factors, which are specific to each particular case. This means that, for the sample of road construction projects analysed, the distribution of cost deviations in relation to the common aspects, external to the nature of the works involved does not follow any particular overall pattern.

Although there were no statistical relationships between the different factors and cost deviations, we propose that it is possible to use the cost deviation history to define contingency funds for future contracts, within the context of risk management implementation in road construction projects. Thus, it is possible to define contingency funds proportionate to the risk of failing the project's goals, while having a historical statistical basis as reference.

Thus, statistical distributions of cost deviations were obtained in order to allow the definition of differentiated contingency funds for future contracts, based on the estimated level of risk and/or desired confidence level for budgeting (Figure 8 is a visual representation of the description). From a risk management standpoint, cost deviation distributions allow for the following alternative practical applications:

- converting qualitative risk analyses into statistically representative quantitative amounts for each type of project by matching each level of the qualitative scale used to a cost deviation distribution probability (the amount of the contingency fund corresponding to the probability is obtained from the cost deviation distribution);
- validating results of quantitative risk analyses, by analysing whether the percentile of the cost deviation distribution, in which the amount of cost deviation is estimated in the risk analysis, is consistent with the specific characteristics of the contract (the cost deviation distribution allows assessing the amount estimated in the risk analysis against historical records).

This research follows an approach that provides a tool to assist in the implementation of quantitative risk management in road construction projects. This approach can be used proactively, as early as the budgeting stage, or even during the implementation stage, thus providing an objective reference to perform cost-benefit analyses on the measures used to address any identified risks. Thus, it is possible to establish a clearer and more objective common ground among the different stakeholders in construction projects, enabling the decision making process while explicitly taking into account the underlying uncertainties, and contributing for the optimisation of the projects' performance.

Bibliographic References

ASCE. (2009). *America´s Infrastructure G.P.A.* USA: American Society of Civil Engineers.

Baker, S. W. (1997). *Risk management in major projects.* Edinburgh: Ameada Hess Ltd.

Hashimoto, L. F. (2008). *Major technical factors that cause deviations in the cost of construction of commercial and residential buildings.* São Paulo, Brazil: Anhembi Morumbi University. (in portuguese)

Maganlal, M. H. (2011). *Modeling risk in the management of large projects.* Lisbon: IST. (in portuguese)

PMI. (2004). *PMBOK guide.* USA: Project Management Institute.

Smith, N. J., Merna, T., & Jobling, P. (2006). *Managing risk in construction projects.* UK: Blackwell Publishing.

Sousa, V. (2012). *Risk management in construction - Application to urban drainage systems.* Lisbon: Instituto Superior Técnico. (in portuguese)

Thompson, P., & Perry, J. (1992). *Engineering construction risks: A guide to project risk analysis and risk management.* London: Thomas Telford.