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Risk Based Budgeting of Infrastructure Projects

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Abstract

Determining the budget is a fundamental process for the development of infrastructure projects for three main reasons: a) it establishes a cost baseline that integrates project scope and quality requirements along with sponsor's funding limits, b) it constitutes a performance measure during the whole project's life-cycle, and c) it affects the competitiveness of the bid. Budgeting and cost estimation methods vary in terms of complexity and accuracy, but, most important, in the way they address contingency reserves in the total budget. The aim of this research is to explore the most applicable budgeting methods for infrastructure projects with regard to the inclusion of risks related costs to the overall budget and demonstrate the capacity of stochastic processes for optimizing overall budgets. Case-based reasoning, multiple regression analysis, Monte Carlo simulation and deterministic methods are briefly presented in terms of theoretical approach, requirements, accuracy and integration of risks. Two prevailing budgeting methods, namely the deterministic and Monte Carlo simulation are applied on a real case of reinforced concrete works for a building project; the comparison of the results highlights the two major findings of this research: a) stochastic processes provide more accurate justification of the contingency reserves required for inclusion of risks in budgets of infrastructure projects, and b) stochastic processes are optimum for the definition of realistic contingency reserves that, in turn, results to more competitive bids. The research concludes with the suggestion that stochastic processes should be used for risk based budgeting of infrastructure projects.

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1. Introduction

Budgeting of an infrastructure project, even from the very early stages of implementation, is a crucial project development process. Despite of the shortcomings of limited data and unidentified uncertainties

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and risks, an early budgeting is always required, in order to provide a range of costs for the development of the project in combination with the initial quality requirements set by the project sponsor (Tas & Yaman, 2005). The analytic and detailed cost estimate of project works is fundamental at the design phase where most of the activities and considerations with cost implications need to be decided and agreed between the project's stakeholders (Wen-der, 2006). Cost estimations and determination of budgeting requirements is an iterative process that takes place, also, in the rest of the phases in the project's life cycle, i.e. execution, monitoring and control, and ending of the project. As the project evolves, cost estimations become more accurate, since they are supported by a greater amount of reliable data.

The need of accurate and updated data is imperative, in order to assess realistically the project's costs performance and budgeting requirements, however data are not the only requirement for reliable cost estimations; appropriate data processing and a systematic consideration of several implications is required, in order to result to accurate cost estimations. According to Koo *et al.* (2010), this can be achieved either based on a team of experts that possesses high quality knowledge on the field or based on appropriate cost estimation methods that can substitute such a team. Common practice proves that the use of cost estimation methods is related to the project's importance and magnitude including the amount of money involved, rather than the requirement for accuracy in estimations. While infrastructure projects, which in the context of this research extend to any type and size of infrastructure, including public and private construction projects of any potential use (residential, industrial, utilities, etc.) are of significant importance for their sponsor, the application of systematic cost estimation methods is not introduced except from cases that may present particularities (e.g. public-private-partnership projects). Moreover, risk reserves are determined either on an empirical or a regulatory manner as fixed amounts that correspond to a certain percentage of the overall budget (Touran, 2003). In this way, there is no rational estimation of risk reserves, which may have a critical impact on the potential of success during the tendering process; over-estimated risk reserves may lead to non-competitive offers, while underestimated ones jeopardize the unhindered development of the project.

This paper briefly presents well-established budgeting methods, which are applicable to any type of infrastructure construction projects focusing on the way they address risk contingencies to the overall assessments. Then it clearly demonstrates the necessity for introducing new approaches for the determination of risk contingencies compared to the current practice. The usual deterministic estimation of risk contingencies is compared to a simple application of a Monte Carlo model on a real case of reinforced concrete works for a building project. The results clearly demonstrate the capacity of stochastic processes to contribute to more realistic budget estimations and more competitive bids for contractors.

2. Budgeting Methods for Infrastructure Projects

There are several budgeting methods applied in the construction industry, which present significant differences in terms of philosophy and approach to the problem of estimating the budget for a project. The most applied are the deterministic ones, however more complex methods such as Case-Based Reasoning (CBR), Regression analysis and Monte Carlo simulation are also met in practice. In this section a brief overview on those methods is presented, in terms of theoretical approach, requirements, accuracy and integration of risks.

2.1. Deterministic Cost Estimation Methods

There are many deterministic methods that are being used currently, in order to estimate, with adequate precision, the budget of a project. Two of them, which are widely applied, are the Unit Quantity Method (UQM) and the Total Quantity Method (TQM).

In the context of UQM, the project is divided in measurable items, usually material, that constitute the project cost. For each item the cost per unit quantity is estimated by summing the individual costs of the constituent elements of the item required to produce a unit quantity. Once, the cost per unit quantity is estimated, it is multiplied by the overall quantity required for this item in the project's context. The overall project budget is assessed by summing all items costs, which are estimated according to the described procedure. Therefore, to provide an explanatory example, the cost of one cubic meter of reinforced concrete is estimated by summing the individual costs of the concrete, steel, and working hours required to produce the specific quantity. Then, this cost is multiplied by the quantity of cubic meters of reinforced concrete required for the whole project. The final budget of the whole project is estimated by adding the total costs of all identified items (e.g. painting, flooring, etc.), which are assessed as discussed above.

In the context of TQM, the application is following a reversed approach. In this case, the overall quantities of the individual constituent elements of all items are estimated and then multiplied by their unit cost. The overall budget for the project is assessed by summing the overall costs required for each project item.

Apart from their quite adequate precision, what makes deterministic methods so widely used is the simplicity of the calculations. No matter how large the scale of a project is, all the calculations are limited down to the four basic mathematical operations. Therefore, no sophisticated software, or special knowledge is needed, in order to estimate the budget of any project. Another advantage is that, the results are presented in a simple form, which enables immediate judgment on their credibility and acceptability, as well as updating of the final estimations, in cases of changes in the values of project items.

The major disadvantage that constitutes the fundamental difference between the deterministic and non-determinist methods is that they do not introduce uncertainty and risks to the estimations in an accurate manner. Risk contingencies may be addressed as additional costs to the anticipated ones, however without being able to change, in any case, unless a new estimation is performed from the beginning. The inaccuracy in the budget becomes greater upon consideration of the fact that in deterministic methods it is usual to introduce risk contingencies as fixed percentages of the overall budget, based on previous experience or regulatory provisions, instead of estimating reserves based on the specific requirements of the project in hand. This drawback renders deterministic methods inefficient for proper, accurate, and realistic budget estimation.

2.2. Stochastic Cost Estimation Methods

A different approach for budget estimations is introduced by the stochastic methods that differ from the deterministic ones in that uncertainty is introduced in the calculations in the form of probability distributions. Through these distributions, each cost item that presents uncertainty is assigned a value from a range of values for which a respective probability of occurrence is determined. The standard deviation of the probability distribution for a cost item expresses the risk for this item.

There are many stochastic methods that estimate the budget of a project (Öztas & Ökmen, 2004; Touran, 2003, etc.). The most applied ones are those based on simulation, particularly, Monte Carlo. This method simulates a very large number of possible outcomes for a given mathematical model that represents a physical problem. The values, which can be assigned to the problem's uncertain variables, as well as the final output of the model are given in the form of probabilistic distributions.

According to Evans and Olson (2002) Monte Carlo simulation presents the following advantages: a) it allows the descriptive representation and analysis of a studied system through an experimental process, yet without affecting the system at all, b) it allows better understanding of calculations compared to other analytical methods, and c) it quantifies the risk of a model in the form of a probabilistic distribution.

The main disadvantage of all simulation methods, including Monte Carlo, is the requirement for a large amount of data for the construction of realistic simulation models; such data are most of the times unavailable and require significant time to obtain, while, moreover, the unavoidable sample errors affect the precision of the results (Evans & Olson, 2002). Despite this major obstacle, simulation methods are among the most useful and practical tools for budget estimation.

2.3. Case-Based Reasoning (CBR)

CBR is a popular method with several applications in project management including budget estimation. It is a method that provides solutions for problems based on the information and knowledge acquired from past similar situations. CBR systems and tools are actually implementing the expert judgment process, which, briefly, comprises the following steps (Kim *et al.*, 2004): a) observe the key features that describe the problem, b) identify these features in previous similar problems where they have appeared, and c) predict the evolution of the problem in hand, based on the experience from similar problems. CBR systems apply the same process in the following four steps (Kim *et al.*, 2004): a) storage in databases of old cases, which represent the experience of the system, b) restoration and reuse of stored old cases, based on the resemblance they present with the case in hand. Successful determination on the similarity between past experience and the situation in hand is based on the efficiency of the algorithms used by the case-based reasoner, c) review and adaptation of old cases to the case in hand, and d) storage of solved cases in the databases.

Huang and Tseng (2004) identified the following advantages of CBR methods: a) improvement in the knowledge gain process at the corporate level, b) leverage of existing knowledge, c) formalization of the knowledge, and d) facilitation in understanding new cases and registering them in the database. However, CBR, also, presents inefficiencies such as (Huang & Tseng, 2004): a) the preservation in the system of information of limited use, b) the shortage in identifying and evaluating data dependencies, and c) the reduced efficiency and applicability in large scale projects. Concerning the representation of risks, CBR cannot represent uncertainties or analyze data series to identify hidden data patterns. Therefore, a very important aspect in the budgeting process of an infrastructure project is actually not introduced in CBR, which prevents it from becoming a first choice as a method for budget estimation.

2.4. Regression Analysis

Regression analysis models have been applied in numerous fields including budget estimation, since they constitute a reliable statistical tool to identify dependencies between variables and justify predictions concerning the future evolution of a modeled problem. A typical regression analysis model can be represented in the form of equation 1:

$$y = k_1x_1+k_2x_2+ \dots +k_nx_n + q \tag{1}$$

where y is the overall budget, x_i, i=1…n are the cost items that constitute the overall budget, q is an estimated constant, and k_i, i=1…n are the regression coefficients of the cost items, which are derived from the statistical data.

While the mathematical model is easy to understand and regression analysis can be performed with common software tools that are easy to access and handle, Kim *et al.* (2004), have highlighted some disadvantages that they identified from the literature; these disadvantages are more analytically explained here:

- The mathematical modeling of budget estimation is not an easy task, since there is no specific approach that a designer or project manager should follow to develop it. Given the fact that the model should fit the available historical data, it is a matter of decision for the designer or the project manager, whether he will assume and test a model or accept the model that best fits to the data. In both cases he should be aware of the requirement to build certain types of equations for the regression analysis model and acquire certain type of data, which would be suitable to perform the analysis.

- The number of input variables cannot exceed some limits due to computational reasons. Therefore, several cost items may need to comprise a single set for the performance of the analysis. Apart from the appropriate grouping that is necessary, an important drawback in this case is that the impact of individual items to the overall budget is overlooked; therefore special considerations (e.g. risk-related) for these items cannot be taken.

Another issue of consideration is that the mathematical modeling in regression analysis considers a linear relationship between the cost items and the overall budget. This assumption is, generally, true provided that the model associates the overall budget to the variables that present this linearity with the overall project work. If, for example, the overall budget is related to material or, even, amount of work required, a linear relationship may be valid; however, if the overall budget is related to construction processes or project requirements, then this linearity may not exist and the method should not be applied.

Finally, with regard to the incorporation of uncertainty and risks to the estimations, these are obviously disregarded. The method identifies dependencies between variables based on statistical data; therefore the farther it can go is to indicate cost items, which present a weak relation to the budget. If the analyst considers such variables as critical then the indication of them as risky items is only indirect and, furthermore, there is no calculation of the range of values that these items could receive in the future.

3. Comparison Between Deterministic and Stochastic Methods: An Illustrative Example

In order to demonstrate the effectiveness of Monte Carlo simulation for budget estimation of infrastructure projects an illustrative example is developed. A four-story with basement building facility is selected and the analysis is focused on the construction of the bearing structure for which accurate data are readily available.

The budget estimation model is based on equations (2) - (4), which were drawn from a previous work of Hofstadler (2010) and presented here with slight modifications for clarity reasons:

$$CP = [Q_C * (TCR * WA + c_{RCW}) * (1 + MU / 100\%)] * (1 + BU / 100\%) \quad (2)$$

$$TCR = RC_{FW} * FR + RC_{RW} * RR + RC_{CW} \quad (3)$$

$$c_{RCW} = c_{FW} * FR_{A,BD} + c_{RW} * RR + c_{CW} \quad (4)$$

In (2) - (4), the equations variables represent: CP, the total cost of the reinforced concrete works and materials, Q_C, the concrete quantity [m^3], TCR, the total labor consumption rate for reinforced concrete works, WA, the average wage for reinforced concrete works, c_{RCW}, the equipment and materials costs for reinforced concrete works, MU, the mark-up for overhead costs, BU, the buffer for costs, RC_{FW}, the average labor consumption rate for formwork-related activities [wh/m^2], FR, the average formwork ratio for the entire building [m^2/m^3], RC_{RW}, the average labor consumption rate for reinforcement works [wh/t], RR, the average reinforcement ratio for the entire building [t/m^3], RC_{CW}, the average labor consumption rate for concrete works [wh/m^3], c_{FW}, the average equipment and materials costs for formwork works [€/m^2], c_{RW}, the average equipment and materials costs for reinforcement works [€/m^2], and c_{CW}, the average equipment and materials costs for concrete works [€/m^3].

The above model, which is structured in accordance to TQM requires input of two types, namely quantities and costs. Concerning quantities it is easy to estimate the required values from the design plans of the building facility. Costs, on the other hand, may be estimated based on: a) labor laws for the minimum level of wages, b) market values for all types of required costs, i.e., equipment, material and labor, c) regulations and/or business policy for the overhead and buffer costs. It is easy to infer that all considered variables involve a certain degree of uncertainty: from the average consumption rates, which depend on the productivity of labor to the quantities, which always should be acquired considering losses of material for various reasons. Therefore, it is asserted that a deterministic approach to assess the values of these variables cannot create a sense of confidence for the project stakeholders. For this reason, the risk buffer for costs is playing an important role to the estimation of the budget. However, even that is often determined either by regulations in the case of public works or by "standard practice" in the case of private works.

Getting back to the example, Table 1 presents, in the first two columns, the budget estimation data that were drawn from the project's schedule and design plans, and the market values and history on wages and procurement costs, while in the last two columns, it presents the estimations of the values for the budget estimation variables that were determined by applying the deterministic approach.

Table 1. Data and budget estimations based on the deterministic approach

Budget estimation data	Values	Budget estimation variables		Estimated Values
Total duration [d]	44	FR	[m^2/m^3]	4.98
Total wages [€]	14784	RR	[t/m^3]	0.11
Total working hours [wh]	2112	c_{CW}	[€/m^3]	65
Number of workers	6	c_{RW}	[€/t]	709.09
Total concrete quantity [m^3]	261	c_{FW}	[€/m^2]	9
Total steel quantity [t]	28.71	c_{RCW}	[€/m^3]	187.909
Total formwork area [m^2]	1300	WA	[€/wh]	7
MU [%]	10	TCR	[wh/m^3]	8.09
BU_1 [%]	18	CP_1	[€]	82844.43
BU_2 [%]	14	CP_2	[€]	80036.13
BU_3 [%]	10	CP_3	[€]	77227.85

For the estimations of the values of the budget estimation variables, the following assumptions were made: a) the total labor consumption rate for reinforced concrete works was estimated based on the available data of total working hours and total concrete quantity, instead of introducing the average labor consumption rates, which were not available for the study, and b) the costs for concrete, steel and formwork were considered as 65€/m^3, 600€/t, and 45€/m^3 respectively.

Table 1 presents, in the last three rows, three different scenarios for the risk buffer cost. The first scenario for BU = 18% is based on the governing regulation for considering risk contingencies in the budget of public works in Greece. Since there is no provision for private works, this is the only valid, official value in the legislation that the analyst may consider for risk contingencies, if he does not want to use an arbitrary value based on his attitude towards risks and current practice in the market. The other two scenarios, though arbitrary, are realistic and were chosen to highlight the importance of the risk contingency to the competitiveness of the bid. As table 1 shows, a reduction of the risk buffer by 22% results to a reduction of the overall budget by 3.4%, while in the case of doubling the reduction of the risk buffer (44%), the reduction to the overall budget is also doubled (6.8%). These results clearly show two things: a) in the deterministic approach the relation of the risks contingencies costs to the overall budget is linear due to the mathematical modeling of the budget estimation process, and b) the impact of the risks contingencies is very important for the competitiveness of the bid; this importance is further increased considering that if the risk buffer is not determined through regulations, it becomes a criterion of differentiation between competing bids, because its estimation is rather based on the bidder's risk attitude and on his expected capacity to effectively manage risks throughout the project's life cycle.

In order to demonstrate the capacity of the stochastic methods against the deterministic ones for risk based budgeting of infrastructure projects, the same mathematical model was applied in the context of a Monte Carlo simulation that was performed by using the software tool @RISK (v5.5) developed by Palisade Corporation.

The first and most important step in the stochastic estimation of a project's budget is the determination of appropriate and representative probability distributions for all the estimation variables that may be considered as probabilistic; however, this is not an easy task. The methodological approaches for determining probability distributions for a project's cost items are: a) the use of historical or statistical data, and b) the use of subjective or expert judgment. For the illustrative example, both approaches were adopted depending on the variable under study. Therefore:

- For the average equipment and materials costs for reinforcement works (c_{RW}), the probability distribution for the cost of steel was determined based on historical data for the period 2003-2011 (alpha6, 2011a). The normal probability distribution as presented in Figure 1(a) was the best fit to the data with the respective P-P plot presented in Figure 1(b).
- For the average equipment and materials costs for concrete works (c_{CW}), the probability distribution for the cost of concrete was determined based on historical data for the period 2004-2011 (alpha6, 2011b). The log-logistic probability distribution as presented in Figure 2(a) was the best fit to the data with the respective P-P plot presented in Figure 2(b).
- For the concrete quantity (Q_C), the average formwork ratio for the entire building (FR), the average reinforcement ratio for the entire building (RR), and the average equipment and materials costs for formwork works (c_{FW}), a three-point estimate based on expert judgment was made due to lack of historical data. For all variables the optimistic and the pessimistic scenarios were considered as equal deviations from the expected value; therefore, the derived probability functions were in all cases isobaric triangulars as presented in Figures 3 and 4.

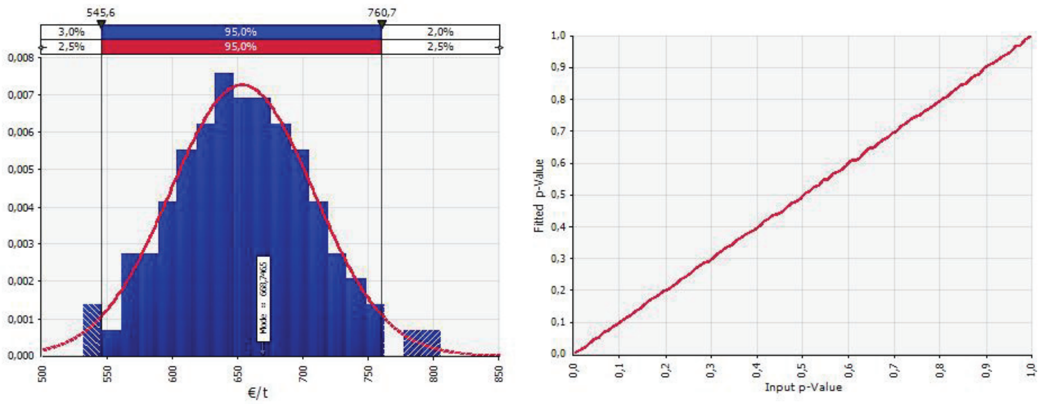

Fig. 1. (a) Probability distribution for the cost of steel; (b) P-P plot for the normal distribution

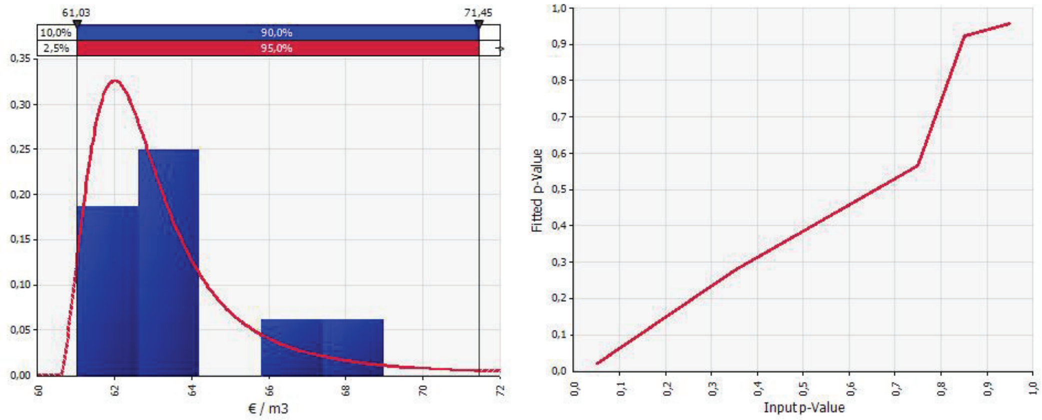

Fig. 2. (a) Probability distribution for the cost of concrete; (b) P-P plot for the normal distribution

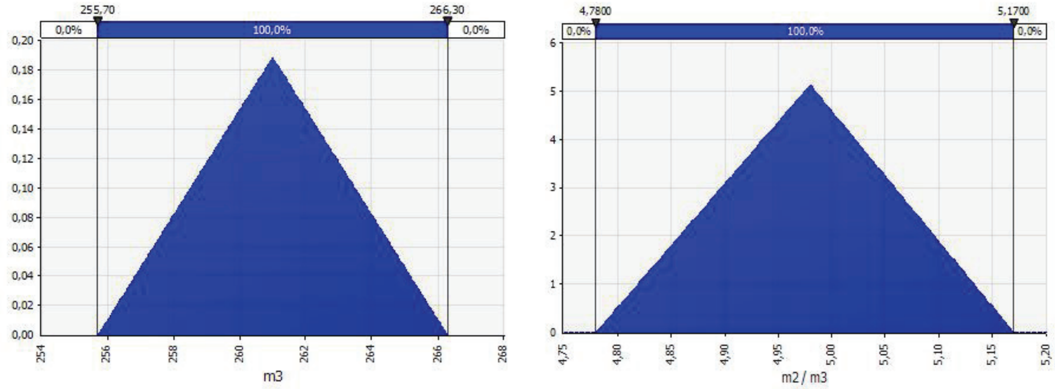

Fig. 3. Probability distributions for: (a) the concrete quantity; (b) the average formwork ratio for the entire building

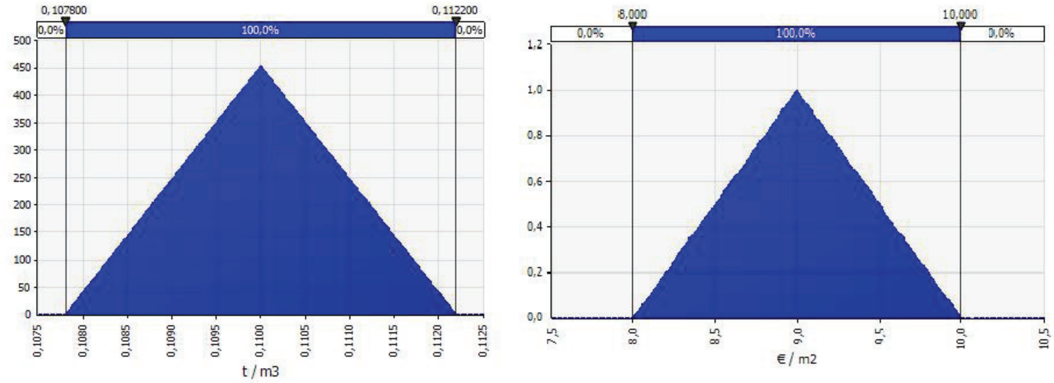

Fig. 4. Probability distributions for: (a) the average reinforcement ratio for the entire building; (b) the average equipment and materials costs for formwork works

Since all the basic variables have been assigned a probabilistic distribution, the Monte Carlo simulation is performed for the intermediate and the final output of the mathematical model (i.e., equations (2)-(4)). Figures 5 and 6 present the results for the three different scenarios concerning the risk buffer value.

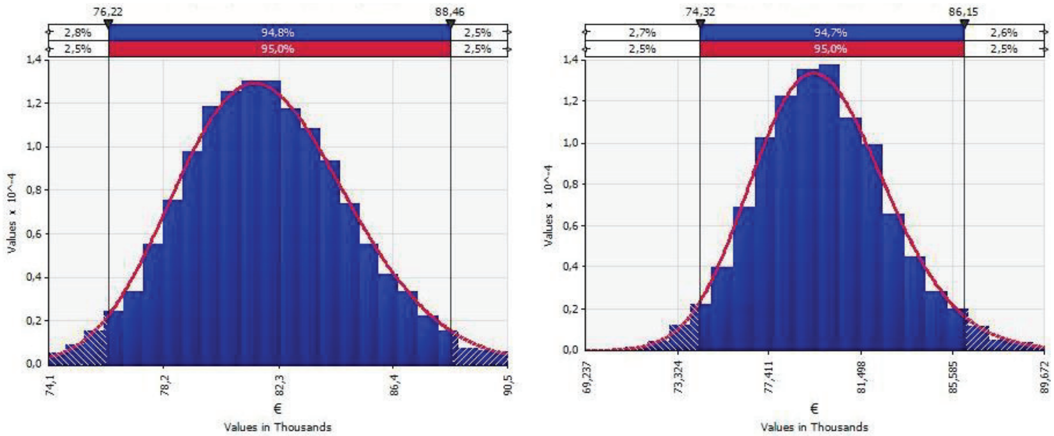

Fig. 5. (a) Total costs for risk buffer 18%; (b) Total costs for risk buffer 14%

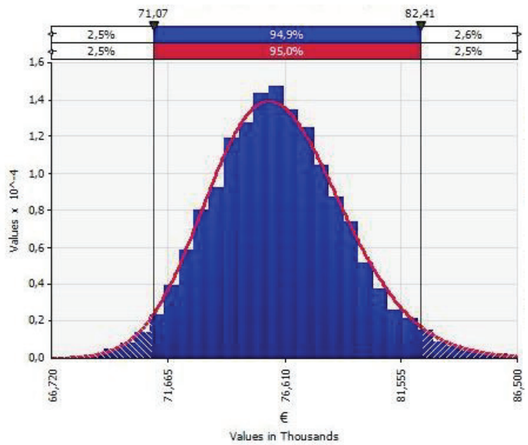

Fig. 6. Total costs for risk buffer 10%

The results for the total costs as derived from the respective probability distributions are 81906.49€, 79824.19€, and 76353.23€ for the three different scenarios of risk contingencies, i.e. for 18%, 14%, and 10% respectively. Compared to the respective results through the implementation of the deterministic method these are quite similar; therefore, the two methods yield approximately the same predictions for the overall costs. However, the great difference between the two methods lies in the estimation of risks. While, the assumption in the estimations is for several risk buffers, the distributions in Figures 5-6 reveal that with a level of confidence of 95%, the overall losses will not exceed an amount of, approximately, 7%, for all three scenarios. This means that by applying the stochastic method it is possible to estimate more accurately the expected cost risk and, consequently, use it as the risk buffer in the budgeting process. The obvious advantage compared to the deterministic method is that an important parameter, which affects the final bid is addressed realistically in the calculations, hence helping to achieve a more competitive and more pragmatic budget.

4. Conclusions

Budgeting for infrastructure projects is performed based on methods that fail to address effectively uncertainties and risks. Even though a risk buffer is included to any budget estimation, its value is either empirical or standard based on regulations and common practices; however, it is inaccurate and unreal. Proper risk based budgeting of infrastructure projects is feasible by implementing a simple Monte Carlo simulation with the help of appropriate software tools. The accurate estimation of risk contingencies results to more competitive bids and more realistic budgets that create a more effective framework for the development of infrastructure projects.

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