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Correlation between time and cost in quantitative risk analysis in construction projects

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Abstract

The increasing constraints which construction companies face due to the prolonged financial crisis and the contracting construction market impose more and more realistic and efficient approaches related to the planning, scheduling and monitoring of their projects.
A project deterministic approach, with preset parameters of time and cost and with the decisions taken based on the independent analysis of time or cost, even they are interrelated, has a low likelihood to be successfully. Usually the construction projects are confronted with delays and over costs which reduce the company profit and leads to its bankruptcy. Therefore, a more efficient approach should take into account the risk events and uncertainties and the resources limitations in construction projects planning, scheduling and monitoring and also, the correlation between the parameters time, cost and the resources limitation.
The paper provides a practical approach of quantitative risk analysis using Monte Carlo Method and highlighting the correlation between the parameters time, cost and resources limitations in construction projects. The project execution is analyzed not only by the current probability to achieve the parameters time and cost together, but by the trends of their combination, integrating the scope, time, cost, resources and risks and providing a better tool in decision making. To demonstrate the advantages of this approach, a case study of a construction project is analyzed using Spider Project software.

Keywords: management by trends, Monte Carlo method, project planning and scheduling, quantitative risk analysis, risk index

1. Introduction

The construction projects are considered having high risks due to the numerous stakeholders, long production duration and open production systems (Taroun, 2013). The increasing constraints which construction companies face due to the prolonged financial crisis and the contracting construction market impose even more the application of structured approaches related to the planning, scheduling and monitoring of their projects. Unfortunately, the construction industry has a poor reputation in risk management comparing with other domains such as finance or insurance (Laryea, 2008), even if the risk management provides a solid basis for decision-making in projects and brings important benefits, such as: reduced costs, increased engagement with stakeholders and better change management (Bayati, Gharabaghi & Ebrahimi, 2011).

Different project risks management approaches were defined in standards and guidelines (ISO, 2012), (IPMA, 2006), (AS/NZS, 2004), (PMI, 2008), (Liberzon & Lobanov, 2000). In order to offer flexibility and space to manoeuvre for the application of different project risks processes, standards usually provide only a very generic description of the processes, focusing on the high level characteristics and not on the details on how it should be done. "Tailoring the process model should take into account the sector and organisation specific requirements as well as the requirements derived from the specific types and/or categories of projects performed in that organisation" (Wagner, 2012).

An efficient risk management lies in the ability to quality and quantifies the risk elements. *The project quantitative risk analysis* is usually considered as the hardest part of the risk management (Makait, 2011), (Andersen, 2011), mainly because it is based on advanced statistics and mathematics methods.

A project deterministic approach, with preset parameters of time and cost and with the decisions taken based on the independent analysis of time or cost, even they are interrelated, has a low likelihood to be successfully. Usually the construction projects are confronted with delays and over costs which reduce the company profit and leads to its bankruptcy. Therefore, a more efficient approach should take into account the risk events and

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uncertainties and the resources limitations in construction projects planning, scheduling and monitoring and also, the correlation between the parameters time, cost and the resources limitation.

Many probabilistic methods were developed over time and made available, especially through software implementation (Bodea & Purnuş, 2012a), (Purnuş & Bodea, 2013b), (Archibald, Liberzon, & Souza Mello, 2008). But these methods are usually not properly applied, or not applied at all. The main reasons for this are the complexity of methods, the lake of expertise, difficulties in collecting historical data and in communicating with the relevant stakeholders, especially line managers and/or resources from the functional departments. In (Galway, 2004) the results of several unstructured interviews with researchers and practitioners in the field of project risk analysis are presented. Regarding the general utility of quantitative project risk analysis, the answers were that it is clearly useful, mainly because it is so widely recommended, even if there was little empirical evidence of how useful these quantitative techniques really were. But the answers were followed by comments that project risk analysis is not well-understood, not well-integrated into project management, and not easily explainable to senior decision-makers.

The literature points out the difficulties that affect the ability of practitioners to carry out a project cost or schedule risk quantitative analysis (CIOB, 2008), (Bodea & Purnuş, 2012b), (Purnuş & Bodea, 2013a). Some of the most relevant are the following:

- Deciding the proper level of detail for the risk analysis (the level of aggregation of tasks or costs);
- Assuring relevant data in order to determine the probability distributions for task durations and the component costs. Particular distributions, such as the triangle one are usually used based on mean and variance estimation of the experts.
- Dealing with the correlations between task durations and costs. These correlations should be taken into account when specifying probability distributions. To elicit multivariate distributions is far a more difficult task than in the case of univariate one. In addition, the duration and cost random variables can only take positive values. The constraints on correlated positive random variables are more difficult and far less intuitive than in the case of normal distributions, where the correlations between an unlimited set of normal random variables can be specified arbitrarily.

The paper provides a practical approach of quantitative risk analysis using Monte Carlo Method and highlighting the correlation between the parameters time, cost and resources limitations in construction projects. The project execution is analyzed not only by the current probability to achieve the parameters time and cost together, but by the trends of their combination, integrating the scope, time, cost, resources and risks and providing a better tool in decision making. To demonstrate the advantages of this approach, a case study of a construction project is analyzed using Spider Project software.

2. A Project Risk Analysis Method considering duration and cost

Let us consider 5000 pairs of duration-cost values as a result of Monte Carlo simulation. If we consider the different order of magnitude of the two dimensions, it is necessary to normalize the values both for duration and cost, on the same interval, e.g. [0, 1]. Using this process, the pair of values (x, y) will become (x_n, y_n), applying the formulae (1) and (2):

$$x_n = \frac{x - x_{\min}}{x_{\max} - x_{\min}} \tag{1}$$

$$y_n = \frac{y - y_{\min}}{y_{\max} - y_{\min}} \tag{2}$$

After the normalization, the 5000 normalized values are represented as points in the space XoY, where X = duration and Y = cost.

All the 5000 points forms a cluster for which we compute the centroid C(x_c, y_c). The centroid coordinates may be considered as *the most probable values*, for duration (x_c) and cost (y_c).

Let us consider a point T(x_t, y_t), representing the target dates we want to analyze from the risk perspective. We compute the **euclidian distance** between C and T, $\mathbf{Dist_{C\text{-}T}}$ with (3):

$$Dist_{C-T} = \sqrt{(x_t - x_C)^2 + (y_T - y_C)^2} \tag{3}$$

In this case, the parameter $Dist_{C\text{-}T}$ indicates the deviation of the analyzed values relative to the most probable values.

For a correct interpretation of the parameter $Dist_{C\text{-}T}$, it is necessary to take into consideration the distance between the points which form the cluster. Therefore, we propose an index for risk analysis I_R, as a function of the ratio between the parameter $Dist_{C\text{-}T}$ and the position of target pair of values relative to the position of centroid, defined as following (4):

$$I_R = f\left(\frac{Dist_{C-T}}{Thr_p}\times 100, Position\right) \tag{4}$$

where: Thr_p is the upper limit (Threshold) of the distance to controid, with p% of the cluster points included while the position is a qualitative parameter.

Let us consider a parameter **p** which model the risk tolerance. If p value is set closed to 1, the risk tolerance is high. If p value is closed to 0, than the risk tolerance is low. The risk index I_R values which are higher than the p parameter values ($I_R > p$) will represent a high risk.

In order to exemplify the interpretation of risk index I_R, several experiments were made (table 1).

Table 1. Experiments with different T point coordinates and p parameter

Experiment	Coordinates of point T	Parameter p [%]	$\frac{Dist_{C-T}}{Thr_p}\times 100$	Risk Index I_R
1a	(50, 330000)	50%	61.9978	high risk
1b	(50, 330000)	75%	43.89951	low risk
1c	(50, 330000)	100%	14.16787	low risk
2a	(58, 340000)	50%	368.0186	high risk
2b	(58, 340000)	70%	260.5872	high risk
2c	(58, 340000)	100%	84.10038	low risk

The results of the experiments 1a and 2a are presented in Fig. 1and Fig. 2.

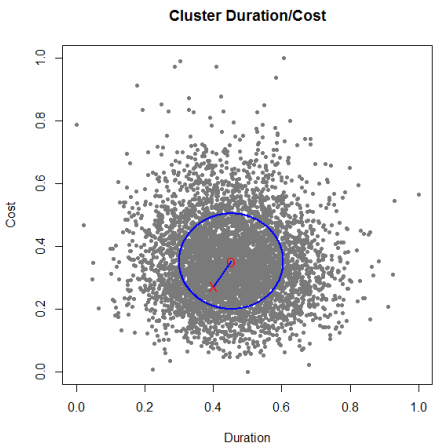

Figure 1. Experiment 1a - T(50, 330000), p=50%, I_R=high risk

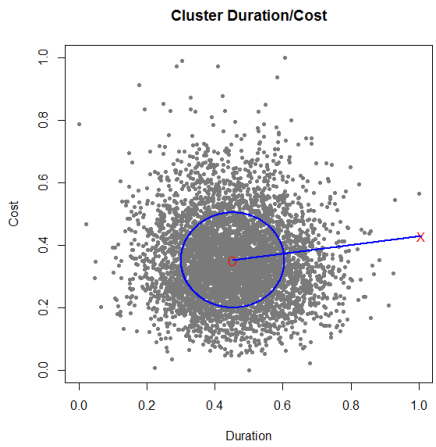

Figure 2: Experiment 2a - T(58, 340000), p=50%, I_R=high risk

3. A Case Study

The quantitative risk analysis was made for a construction project in the field of the implementation of new technologies for the recovery of recyclable materials from the contractor perspective. It consists in the construction of a technological warehouse, two reservoirs, fencing, access roads and platform. The project model was developed taking into account the execution level of detail of the activities, containing 643 activities, 46 resources (manpower and equipments), 124 multi-resources, 92 types of materials, 8 calendars, 15 cost components and 6 cost centers. The risk events and uncertainties were identified and prioritized according their potential impact on the project duration and cost using the regular approaches in qualitative risk analysis. As result, there were developed three scenarios: optimistic, most probable and pessimistic for the initial data

(duration, volume of work, productivity, calendars, resources), which were used in the risk analysis with Monte Carlo method. The optimistic scenario includes the risks with probabilities exceeding 90%, the most probable scenario includes the risk events with probabilities exceeding 50%, and all selected risk events were included in the pessimistic scenario (Liberzon, V., Souza Mello, B. P. 2011).

In the case of limited project resources, the probability curves for project duration, cost and other project parameters created using Monte Carlo method, are valid only if resource leveling heuristics that is used in risk simulation process is the same as used for project scheduling and management (Liberzon, V., Shavyrina, V., Makar-Limanov, O, 2012).

The quantitative risk analysis for the construction project was performed using the software Spider Project which has in place the module for Monte Carlo method. For the purpose of risk simulation, the project model was analyzed performing 5000 iterations, with resource constrained scheduling and the log-normal shape of probability distribution curve. The project execution phase was monitored with a 2 weeks frequency for 9 different stages in order to identify early signs of risk events occurrence and to take the best decision to mitigate their impact. The risk simulation was performed for each update, analyzing the trends of probabilities for project duration, project cost and the combined probability duration-cost.

In the initial stage the probabilities for both project duration and cost were computed. Based on the organization risk tolerance and the contractual terms, the target dates were set at 84.64% representing 206 days for project duration and 73.90% representing 2,702,000 Euro for project cost (Fig. 3, Fig. 4).

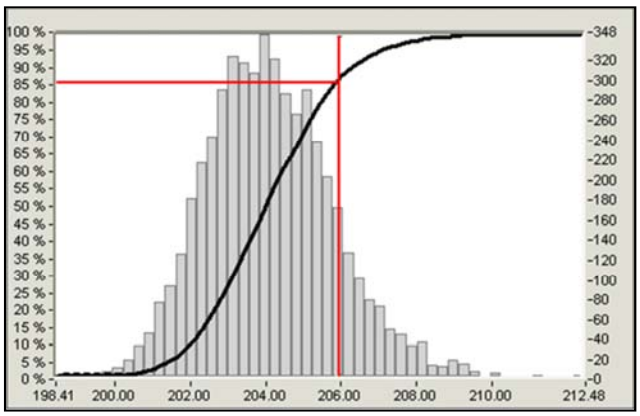

Figure 3. Probability curve and target date for project duration

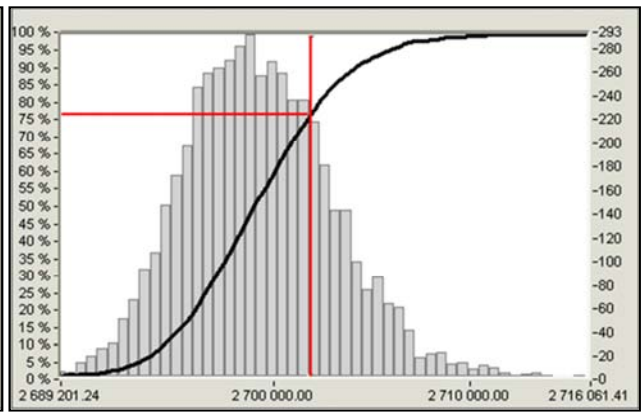

Figure 4. Probability curve and target date for project cost

If we consider that activity duration and cost estimates do not depend on each other the probability to meet both targets will be the multiplication of the probabilities to achieve the targets. However these parameters are correlated and setting multiple project targets will require multidimensional risk analysis. For this reason, our analysis took into consideration the following parameters variation during execution: the duration and cost buffers, the position of the pair of values representing the target duration and cost related to the centroid of the iterations results, the distance between the centroid and the target dates, the correlation between the project duration and cost and the proposed risk index (Fig. 5).

During the project execution, risks events like delays due to the lack of resources, weather, over costs and unforeseeable events occurs, impacting the current probability to achieve the target duration and cost. The variation of probabilities for target duration, cost and combined probability duration-cost is presented in the table 2.

Table 2. Probabilities of targets parameters in different stages of the project execution

Probabilities	0	1	2	3	4	5	6	7	8	9
Duration	84.64%	0.04%	0.22%	3.14%	32.76%	88.40%	94.96%	34.20%	56.90%	70.56%
Cost	73.90%	29.28%	42.00%	45.20%	47.36%	51.64%	53.30%	55.82%	58.92%	27.42%
Duration-Cost	70.20%	0.04%	0.22%	3.04%	28.18%	51.36%	53.28%	31.02%	48.76%	27.34%

While the duration and cost buffers are in a descendent trend as the result of the risk events impact (table 3), an important aspect of the risk simulation was to identify the position of the target dates relative to the position of centroid. It resulted that in different stages of the project execution, the position of the target dates may belongs to one or another quadrant relative to the position of centroid (Fig. 6).

Table 3. Variation of the duration and cost buffer

Buffer	0	1	2	3	4	5	6	7	8	9
Duration	100.00%	90.58%	85.61%	80.50%	75.97%	71.14%	65.94%	64.57%	59.64%	54.68%
Cost	100.00%	38.22%	50.77%	50.77%	50.77%	51.14%	50.83%	48.95%	44.53%	8.51%

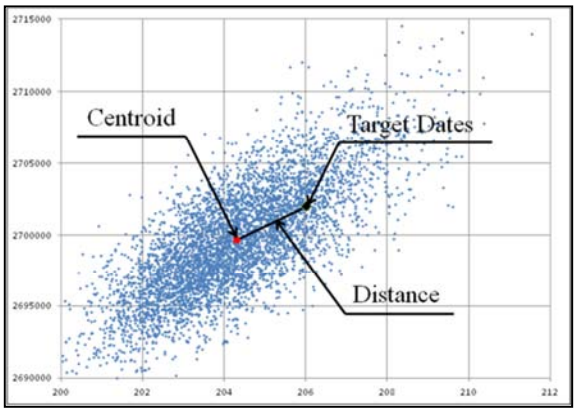

Figure 5. Scatter diagram for the initial stage

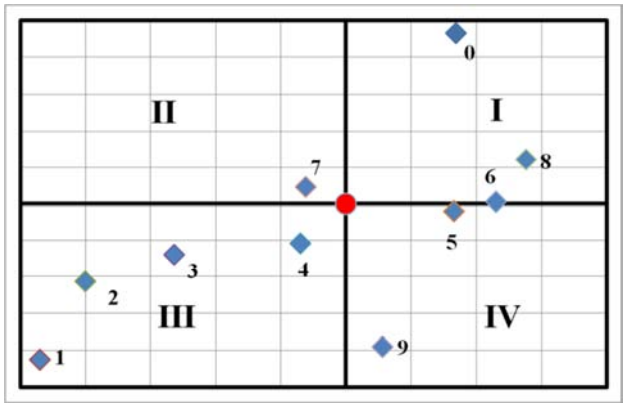

Figure 6. Relative position of the target dates to the centroid

The risk index I_R variation as a direct function of distance $Dist_{C\text{-}T}$ has to be correlated with the target dates position relative to the centroid position (table 4).

Table 4. Variation of the distance and the position of target dates in different quadrants

	0	1	2	3	4	5	6	7	8	9
Distance	36.09%	100.00%	85.04%	56.19%	14.92%	35.27%	48.99%	13.08%	61.68%	11.84%
I_R	medium	high	high	medium	low	medium	medium	high	low	high
Quadrant position	I	III	III	III	III	IV	I	II	I	IV

As time as the position of the target dates is in the 3rd quadrant, the trend of risk index I_R will be opposite to the trend of combined probability duration-cost. If the position the target dates is in the other quadrants, than the trend of risk index will be in accordance with the trend of the combined probability duration-cost, providing an additional tool for decision taking.

4. Conclusions

The quantitative risk analysis with applications in construction projects represents an important asset for the construction companies which are facing with continuous delays and cost overruns. The paper provides a practical approach of quantitative risk analysis using Monte Carlo method and highlighting the correlation between the parameters time, cost and resources limitations in construction projects. The project execution is analyzed not only by the current probability to achieve the parameters time and cost together, but by the trends of their combination, integrating the scope, time, cost, resources and risks and providing a better tool in decision making.

The application of quantitative risk analysis using Monte Carlo method becomes increasingly easy due to the development of software solutions. However, a special attention should be given to the limited project resource which is typical for most of the construction projects. In this case, the probability curves for project duration, cost and other project parameters created using Monte Carlo method, are valid only if resource leveling heuristics that is used in risk simulation process is the same as used for project scheduling and management.

A risk index taking into account the distance between the target dates (duration-cost) and the centroid of the solutions cluster resulted from Monte Carlo simulation, together with their relative position as a combined qualitative-quantitative index was proposed. Its trend variation become an additional tool for decision taking, as time as the quality of input data in the Monte Carlo simulation is never good enough.

References

Andersen D.L. (2011), "Project Risk management – Inside Out: How to cope with complexity generated risk", in: *Future Trends in Project, Programme and Portfolio Management, Proceedings International Expert Seminar*, IPMA, Zurich.

Archibald, R., Liberzon, V., & de Souza Mello, B. P. (2008), "The Application of Success Probabilities, Success Driven Project Management/SDPM, and Some Critical Chain Concepts to the Oil & Gas Industry in Brazil", The Annual PMI College of Scheduling Conference, Chicago.

AS/NZS (2004). "AS/NZS 4360: Risk Management", Standards Australia/Standards New Zealand, available at: http://www.ucop.edu/riskmgt/erm/documents/as_stdrds4360_2004.pdf.

Bayati, A., Gharabaghi, A. A, & Ebrahimi, M. (2011), "Practical risk management in petrochemical industries: an NPC case study", in: *Future Trends in Project, Programme and Portfolio Management, Proceedings International Expert Seminar in Zurich*, IPMA, ISBN 978-3-9523891-2-6.

Bodea C., Purnuş A. (2012a), Project Risk Simulation Methods - a Comparative Analysis, Management & Marketing, Challenges for Knowledge Society, volum 7, nr. 4/2012, pp.565-580, ISSN 1842-0206, Editura Economică, Bucureşti.

Bodea C., Purnuş A. (2012b). A comparative Analysis of Project Risk Simulation Approaches, in: C. Bratianu, G. Brătucu, D. Lixandroiu, N. Pop, S. Văduva (eds): Business Excellence, Challenges during the Economic Crisis, Proceedings of the 7th International Conference on Business Excellence, vol 1, 12-13 October 2012, ISBN 978-606-19-0103-6, (vol 1), Editura Universităţii "Transilvania", Braşov, 2012, pp. 55-60.

CIOB (2008). "Managing Risk of Delayed Completion in the 21st Century", Chartered Institute of Building, pp.52-53.

Galway L. (2004) Quantitative Risk Analysis for Project Management A Critical Review, WR-112-RC, RAND Corporation working paper series

IPMA (2006), "IPMA Competence Baseline (ICB 3.0)", International Project Management Association (IPMA), ISBN 0-9553213-0-1.

ISO (2012), "Guidance on Project Management, ISO 21500", STD v2, International Organization for Standardization.

Laryea, S.(2008). Risk pricing practices in finance, insurance, and construction, COBRA 2008. The construction and building research conference of the Royal Institution of Chartered Surveyors, Dublin.

Liberzon, V., & Lobanov, I. (2000), "Advanced Features of Russian Project Management Software", The 3rd PMI Europe Conference Proceedings, Jerusalem, Israel, 12-14 June.

Liberzon, V., Souza Mello, B. P. (2011). Success Driven Project Management (SDPM) Approach to Project Planning and Performance Analysis, The 8th Annual PMI College of Scheduling, San Francisco

Liberzon, V., Shavyrina, V., Makar-Limanov, O, (2012), Advanced Project Scheduling - What is necessary for creating adequate project model and is absent in most scheduling tools, The 9th Annual PMI College of Scheduling, New York

Makait T. (2011), "Qualitative and quantitative: EPC Project Risk Management is no gamble", in: *Future Trends in Project, Programme and Portfolio Management, Proceedings International Expert Seminar in Zurich*, IPMA, ISBN 978-3-9523891-2-6.

PMI (2008), "PMBOK® Guide: A Guide to the Project Management Body of Knowledge", Newtown, PA: Project Management Institute.

Purnuş A., Bodea C. (2013a). Considerations on Project Quantitative Risk Analysis, Procedia - Social and Behavioral Sciences, vol. 74 March 2013, pp. 271–280, DOI: 10.1016/j.sbspro.2013.03.03, ISSN: 1877-0428, Elsevier Ltd, 2013.

Purnuş A., Bodea C. (2013b), Project Prioritization and Portfolio Performance Measurement in Project Oriented Organizations, 27th IPMA World Congress, Dubrovnik, Croatia.

Taroun, A. (2013), Towards a better modelling and assessment of construction risk: Insights from a literature review, International Journal of Project Management http://dx.doi.org/10.1016/j.ijproman.2013.03.004

Wagner R. (2012), Processes of ISO 21500, in Grau N., Bodea C (eds), ISO 21500 Project management Standard, Shaker Verlag GmbH, ISBN 978-3-8440-2493-7