ELSEVIER
Available online at www.sciencedirect.com
SciVerse ScienceDirect
Procedia - Social and Behavioral Sciences 74 (2013) 144 – 153
Procedia
Social and Behavioral Sciences

26th IPMA World Congress, Crete, Greece, 2012

Considerations on Project Quantitative Risk Analysis

Augustin Purnus[a,*], Constanta-Nicoleta Bodea[b]

[a]*Technical University of Civil Engineering, 124 Lacul Tei Blvd, Bucharest, Romania*
[b]*Academy of Economic Studies, 6 Pta Romana, Bucharest, Romania*

Abstract

The continuous growth of the challenges and the complexity of projects, lead to the development of new approaches to model and support uncertainties and risks. The experience gained in project planning shows that the probability of successful implementation of deterministic project schedules and budgets is very low. Therefore project planning technology should always include risk simulation to produce reliable results. The paper presents an analysis of the main risk management standards and guidelines, together with the main project risk quantitative analysis methods. A comparative analysis of the effectiveness of two quantitative risk analysis methods, Monte Carlo simulation and the Three Scenario Approach was made. Two experiments were designed in order to compare the effectiveness of both methods, basing on real projects implemented by the first author of the article. The experiments were performed using specific tools and techniques including the success probability trend as the best indicator of current project status during execution. The main conclusions of the effectiveness analysis are that though the Three Scenario Approach is a semi-probabilistic method and it is not as accurate as Monte Carlo, it is easy to be applied in practice and requires a very short time for computation.

Keywords: Project quantitative risk management; Monte Carlo; Three Scenario Approach; project scheduling

1. Introduction

While the financial and economical crisis is present at the global level and the competition in the market is more and more aggressive, the interest in project risk management increase. Effective risk management provides a solid basis for decision-making in projects, bringing important benefits, such as: reduced costs, increased engagement with stakeholders and better change management (Bayati *et al.*,

[*] Corresponding author. Tel.: +4-021-242-1208.
E-mail address: purnus@utcb.ro.

doi:10.1016/j.sbspro.2013.03.031

2011). Several approaches to project risks management were defined in standards and guidelines issued by professional association, which provide frameworks for managing project risks. Figure 1 presents a comparison of the structure of project risks management processes, as define in:

- ICB v3.0, International Competence Baseline, International Project Management Association (IPMA, 2006);
- AS/NZS 4360, Risk Management, Standards Australia/Standards New Zealand (AS/NZS, 2004);
- ISO 21500, Guidance on Project Management, STD v2, International Organization for Standardization (ISO, 2012);
- PMBOK Guide®, Guide to the Project Management Body of Knowledge, (PMI, 2008);
- SDPM, Success Driven Project Management, Spider Project Team, (Liberzon & Lobanov, 2000).

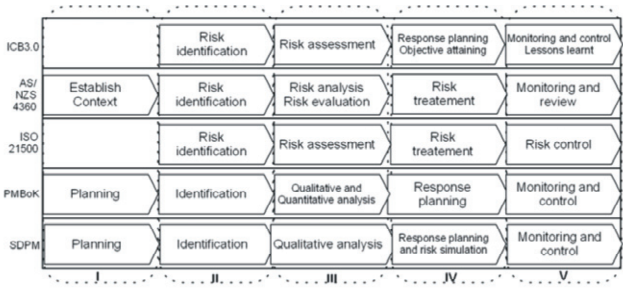

Fig. 1. Comparison of the structure of project risk management processes

Considering the process structures' homogeneity, as it is reveals by Figure 1, we can say that different project management standards and guidelines recommend a very similar framework for project risk management. What it is really relevant for differentiating risk management approaches is not the process structure as such, but how the integration of risk management with all other project management processes is reinforced. Chapman & Ward (2002) identify a lot of limitations and errors arising when the risks are managed in projects, even if the project manager has considerable experience in managing risks. The principal shortcomings relived by Chapman and Ward are the following: the initial activities for managing risks are too detailed and fails to underlay the connections with different projects elements in a balanced manner; the risk identification fails to provide a good structure of the sources of uncertainty, and to identify significant linkages and interdependences between issues; the risk estimates are highly dependent on the project scope hypothesis and not on other kind of assumptions; the risk estimations are costly, but not cost-effective; the risk evaluation fails to combine properly different source of uncertainty because crucial dependences are not captured and a weak implementation of the project plan. The majority of these limitations are linked to the integration of the risk management processes with each other and with the project management processes in large.

The common five phases of risk management can be set, according to Figure 1. The phase considered as critical for an effective risk management in projects is the risk assessment phase (Bayati *et al.*, 2011; Andersen, 2011). If we accept that risk management is all about identifying, measuring and minimizing uncertain events effecting projects, then the secret for a good risk management lies in the ability to quality and quantify the risk elements. This is why these professionals consider the qualitative and quantitative project risk analysis as the core processes in risk management.

The project quantitative risk analysis is considered the hardest part of risk management, because it is based on advanced statistics and mathematics methods. A lot of deterministic and probabilistic methods were developed over time and made available, especially through software implementation. But these methods are usually not properly applied, or not applied at all. The main reasons for this are lake of expertise, difficulties in collecting historical data, complexity of risk quantification methods, the absence of easy to use tools and also the computation effort. Only for a few project types, such as: research and development projects and public and military capital Investments in projects, the risk quantification is regularly performed. Many project team applies exclusively risk qualitative analysis. A study conducted by the Chartered Institute of Building between December 2007 and January 2008 highlight the fact that despite the development of sophisticated tools and techniques, a large number of construction projects are delayed and over budget and because the project quantitative risk analysis is missing (CIOB, 2008). The more complex the projects are, the less likely it is to achieve the success. The experience gain in a large number of projects reveal the fact that using only deterministic methods of scheduling leads to a low probability of success. For this reason project scheduling and monitoring must always include techniques for risk simulation in order to obtain feasible results.

Simulation is increasingly applied in business. As a project management method, simulation depends on two essential elements: a model for defining the project outcomes and outcome values and a technique that repeatedly generates scenarios (Schyler, 2001). The risk simulation methods can be semi-probabilistic and probabilistic ones. PERT (Program Evaluation and Review Technique), originally developed in the late 50s is one of the first project scheduling approach addressing the project risks (Pritchard, 2011; Kendrick, 2003). By the 1960s, Monte Carlo simulation is embedded in PERT, in order to avoid assuming that only one path may be critical and that the probability distribution of the project duration must be normal. In the same time, GERT (Graphical Evaluation and Review Technique) is defined, based on the decision trees embedded in Markov processes. GERT enhances the project manager’s ability to understand how the project is affected by the corrective actions, considered as repetitive processes, executed in a specific timeframe window. In 1970s, Chapman developed SCERT (Synergistic Contingency Planning and Review Technique) approach (Chapman & Ward, 2003), based on the fault tree and event tree concepts, for safety analysis.

The next two paragraphs will shortly introduce Monte Carlo simulation and the Three Scenario Approach. In the final part of the paper, we will compare the effectiveness of these two methods, by means of two experiments designed and ran by the authors.

2. Monte Carlo simulation

Recognized by the accuracy of its results, Monte Carlo method is part of the probabilistic methods used in risk simulation. The Monte Carlo method first generates artificial variable values, using a random number generator uniformly distributed in the interval [0, 1] and the associated cumulative distribution function. Then, the Monte Carlo method uses the obtained results to extract values from the probability distribution that describes the behavior of the stochastic variable.

2.1. Monte Carlo simulation with discrete stochastic variables

In the terminology of probability theory, one can note the stochastic variable as X, x_i being a particular value of the variable X. $P(X = x_i) = P(x_i)$ denotes the probability that X has the value x_i. The probability that the value of X exceeds a certain value xi is called the cumulative distribution function and it is denoted as $F(x_i)$. The most common theoretical discrete probability distributions are the discrete uniform distribution, the binomial distribution and the Poisson distribution.

The *discrete uniform distribution* describes variables with a small number of possible values, each with the same probability of realization. If the number of possible values is n, and set values possible is $\{x_1, x_2 \ldots x_n\}$, then the probability mass function is $P(X = x_i) = P(x_i) = 1/n$ for any value x_i, and the cumulative distribution function is $F(x_i) = P(X \le x_i) = i/n$, for i = 1, 2, ...,n.

The *binomial distribution* is a discrete probability distribution that applies when there are only two possible outcomes: success or failure, admitted or rejected, passed or not passed, etc. For example, the stochastic variable is the number of experiments with "success". If *p*, the probability of "success" is the same for each of the n experiments, and experiments are independent, the probability mass function is defined by the probability that the number of successful experiments to be equal to a value x_i and can be calculated with the expression: $P(X = x_i) = P(x_i) = C_n^{x_i} p^{x_i} (1-p)^{n-x_i}$, for x_i = 0, 1, … , n, where n is the number of experiments. The cumulative distribution function is defined as: $F(x_i) = P(X \le x_i) = \sum_{v=0}^{x_i} P(v)$, for x_i = 0, 1, … , n. The average, μ has the value n*p, and the dispersion is define as: $\sigma^2 = np(1-p)$. The *Poisson distribution* is a discrete probability distribution that applies to independent random events. The stochastic variable is the number of events that can occur in a period of time. The probability mass function is the probability that the number of events occurring within a specified time to a value equal to x_i and can be calculated with the expression: $P(X = x_i) = P(x_i) = \frac{\lambda^{x_i} e^{-\lambda}}{x_i!}$, where λ is the average number of events in a time specified.

2.2. Monte Carlo simulation with continue stochastic variables

Unlike discrete probability distribution, it is not possible to define a continuous probability distribution in order to determine the probability for some particular value of continue stochastic variable. Since a continuous stochastic variable is a variable that can have any value a specified period, it has an infinite number of possible values in that interval and thus the probability that a continuous stochastic variable to have some particular value is zero. For a continuous stochastic variable, it is possible to defined probability as the variable value to be included in a specified interval. In this regards, the distribution is represented by a curve, and the probability is determined by evaluating the area under the curve between the interval margins on x-axis. Function f(x) which calculates the area is called by probability density and shall meet some conditions. In some cases the probability density function is quite difficult to calculate, but there are tables of values or software programs for continuous theoretical distributions, such as: continuous uniform distribution, triangular distribution, normal distribution, beta distribution and exponential distribution.

The continuous uniform distribution; If a stochastic variable uniformly distributed in [a, b], the probability density, f(x) is defined as follow: f (x) = 0 for x <a, f (x) = 1/(b-a) for a ≤ x ≤ b and f (x) = 0 for x> b. The cumulative distribution function, F is defined as follow: F(x) = 0 for x <a, F(x) = (x-a)/(b-a) for a ≤ x ≤ b, and F(x) = 1, for x> b. Media, μ is equals with (a + b)/2 and variance σ^2 is equals with $(b-a)^2/12$. *The triangular distribution;* It describes the probability values of a variable by three values: the minimum (a), the most likely (b) and maximum (c). It is assumed that the probability of achieving the minimum and maximum value is zero. The probability density function, f(x) is f(x) = 2 (x-a)/((b-a) (c-a)), for ≤ x ≤ b and f(x) = 2(c-x)/((c-a)(c-b)) for b <x ≤ c. The cumulative distribution function, F(x) is define as follow: F(x) = P(X ≤ x) = 0, for x <a, $F(x) = ((x-a)^2)/((b-a)(c-a))$, for a ≤ x ≤ b, $F(x) = 1 - ((c-x)^2)/((c-a)(c-b))$, for b <x ≤ c, F(x) = 1, for x>c. Mean μ is equals with (a + b + c)/3, and dispersion, σ^2 is equals with $(a^2 + b^2 + c^2 – a*b – a*c – b*c)/18$.

The normal distribution (Gaussian distribution); It describes the population characteristics or distributions of quantities that are sums of other sizes (according to the central limit theorem). Thus, the total duration of a project, the amount of probabilistic duration of activities on the critical path is a variable with normal distribution. Normal distribution is a symmetrical distribution as a bell. Function f(x) is a probability density function with two parameters, mean, μ and dispersion σ^2, having the form: $f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right)$. Since f(x), the probability density function of the normal distribution cannot be integrated exactly, it is not used directly. Calculation of areas needed to determine the probabilities $P(a \le x \le b)$ and the cumulative distribution function are based on the standard normal probability distribution, which is a normal distribution of a stochastic variable with mean $\mu = 0$, dispersion $\sigma^2 = 1$ and standard deviation $\sigma = 1$. To transform a stochastic variable X with normal distribution into a stochastic variable Z with the standard normal distribution, the following formula can be used: $Z = (x - \mu)/\sigma$. In the standard normal distribution tables, there are probabilities $P(0 \le Z \le z)$, which represents the value of the area under the curve of probability density function f(z) located between the average value, $\mu = 0$ and z. *The Beta distribution;* It has many shapes, by adjusting the following two parameters: a scaling coefficient, and an offset. A beta distribution can range from a symmetric, normal distribution to asymmetric one, with a long tail on the positive side. *The exponential distribution*; It is used to describe the time between events. It can be shown that if the number of arrivals can be described by a Poisson distribution, the interval between arrivals follows an exponential distribution.

3. Three Scenario Approach

Included in the Success Driven Project Management Methodology, the Three Scenario Approach is a semi-probabilistic method (Liberzon, 1996), used together with the management by trends (Archibald *et al.*, 2008). The risk events are selected and grouped using the regular approaches in qualitative risk analysis. Three estimations (optimistic, most probable and pessimistic) are obtained for all initial project data (duration, volume of work, productivity, calendars, resources) which will be used in rebuilding the probability curves for dates, costs and material requirement. Defining the desired target probabilities will allow us to obtain the desired dates for finishing the project, costs and material requirements (Liberzon & Archibald, 2003). The probabilities to meet the target dates are called success probabilities and they are used to measure the buffer penetration.

Probability Distribution Curve

Having the three scenarios we know the range of most frequent values for project duration, total cost, material requirements, resources etc.

In order to build the probability distribution curve we rely on the three points with the probabilities according to the three scenarios: the point with zero probability for the optimistic scenario, the point with 100 % probability for the pessimistic scenario and the point for which the probability distribution has the maximum value (Figure 2a).

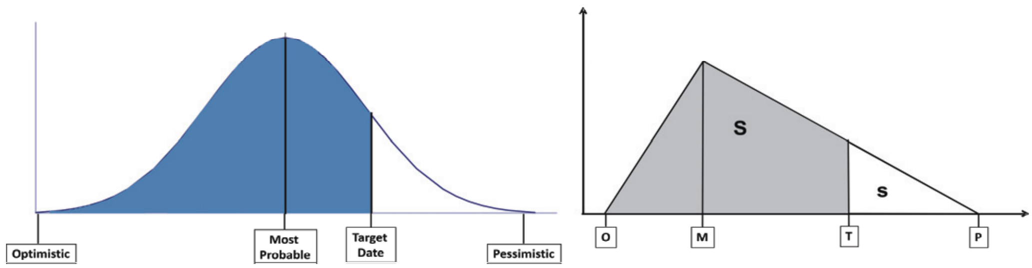

Fig. 2. (a) The probability distribution curve and (b) Triangular Distribution.

What we don't know is the shape of the probability distribution curve. This can be Beta, Normal or Triangular. In fact, in the Three Scenario Approach method the shape of the probability distribution curve is not so important. We know that the results are not accurate so they are not close to the exact value, but successive measurements will give results very close each other, being characterized by precision. During the project execution the same shape of the probability distribution curve will be used. In this way, even the shape is not the correct one, we will be able to establish if the probability will become greater or smaller as a result of risk events or the application of preventive or corrective measures (Liberzon & Souza Mello, 2011). To exemplify the probability computation for a certain target date we will use the triangular distribution (Figure 2b). The probability to achieve the target date is represented by the area under the probability distribution curve at the left side of the target date. $P = \frac{s}{S}$, where: P is the probability to achieve the target date, s - the area between the target date and the probabilistic date and S – the total area under the probability distribution curve.

Considering that X is the probability to achieve the target date, O is the optimistic scenario value, M is the most probable scenario value, P is the pessimistic scenario value and T is the target date value, the probability to achieve the target date will be: $X = 1 - \frac{(P-T)^2}{(P-O)\times(P-M)}$.

Let us consider the following project where the optimistic duration is 15 days, the most probable duration is 20 days and the pessimistic duration is 29 days, presented in Figure 3(a).

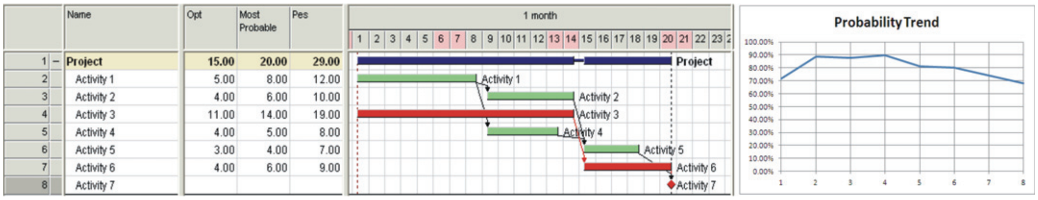

Fig. 3. (a) Numerical Example and (b) Probability Trend

If we define the desired target date as being the 23 days duration, the probability to achieve it based on the triangular distribution curve will be 71.43%. During the project execution the optimistic, most probable and pessimistic scenarios durations will change. For each update stage we computed the current probability to achieve the target date, in our example, 23 days. The results are presented in Table 1.

Table 1. Duration for optimistic, most probable and pessimistic scenarios and the current probability to achieve the target date

	Optimistic duration	Most Probable duration	Pessimistic duration	Target Data	Current Probability
1	15	20	29	23	71.43%
2	13.9	15.9	21	23	88.95%
3	12.25	14.25	20.5	23	87.88%
4	11.7	13.7	20.5	23	89.56%
5	11.15	13.15	19.75	23	81.39%
6	10.6	12.6	19.5	23	80.05%
7	10.05	12.05	19	23	74.28%
8	9.5	11.5	18.5	23	67.86%

The probability trend is presented in the Figure 3(b).

If the probability trend is positive then no action should be taken. If on contrary, the probability trend is negative, then corrective actions are needed. Using such an approach allows us to identify as soon as possible the manifestation of the risk events and to take the proper decisions to.

4. A comparative analysis of the Monte Carlo and Three Scenario Approach methods

For the comparison of Monte Carlo and Three Scenario Approach methods we used the same software which has implemented both methods and has the same specific heuristics for resource constrained scheduling, Spider Project. It avoid us to obtain not valid results as time as different project management software use different algorithms for resource constrained scheduling than other software that has implemented Monte Carlo method.

Our analysis is based on the following two experiments:

- A small project consisted on 11 activities for which we analyzed and compared the results of both methods including success probability trends,
- A series of projects of different size and complexity for which we applied both of the methods, in order to identify the differences in terms of results and computation duration.

Experiment 1

The objective for the first numerical example is to analyze the differences of the results between Monte Carlo and Three Scenario Approach, especially during execution phase and to enhance the probability trends as a management tool for decision making. For this example we analyzed a simple network of activities presented in Figure 4.

In order to have compatible models, we established three durations for each activity: optimistic duration, most probable duration and pessimistic duration. As a remark, the Three Scenario Approach does not require this constraint.

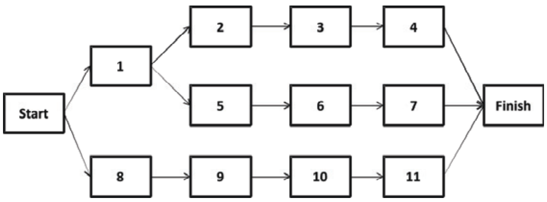

Fig. 4. Activity Network

In Table 2 are presented the phases and activities duration used in the experiment.

Table 2. Activities optimistic, most probable and pessimistic durations

Activity	Project	Start	1	2	3	4	5	6	7	8	9	10	11	Finish
Optimistic Duration	28	0	4	6	7	11	6	7	10	9	8	7	4	0
Most Probable Duration	35	0	6	8	9	12	7	10	10	11	10	8	6	0
Pessimistic Duration	49	0	9	11	14	15	9	12	15	16	12	11	10	0

We set as the target date the project duration 40 days.

For Monte Carlo method we used a Beta distribution of the probabilities, and 1000 iterations, while for the Three Scenario Approach, a Beta distribution. Running Monte Carlo method we obtain a probability of 98% for the target date in 29 seconds, while for the Three Scenario Approach method, the probability was 86.70% in 3 seconds computation duration.

The Figure 5 presents the probability curves, for Monte Carlo (a), Three Scenario Approach (b) and the probability trends resulted.

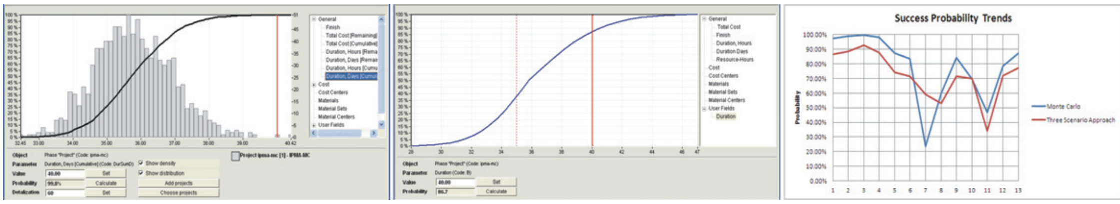

Fig. 5. Probability Curves in (a) Monte Carlo, in (b) Three Scenario Approach, and (c) the probability trends

The project execution phase was simulated taking into account 13 time frames for which we calculated the current probability to meet the target dates, focusing on the parameter Project Duration (Table 3).

Table 3. Probabilities to achieve the target date with Monte Carlo and Three Scenario Approach

Update	1	2	3	4	5	6	7	8	9	10	11	12	13
Monte Carlo	97.6	98.9	99.9	98.3	87.5	83.4	23.6	60.0	84.4	69.5	46.8	78.6	87.5
Three Scenario Approach	86.7	88.5	92.6	87.6	74.3	71.6	59.3	52.8	71.4	69.9	34.1	71.9	77.2

The probabilities shows lower values for the Three Scenario Approach than Monte Carlo method, but the trends for both methods are similar. That means Three Scenario Approach can replace successfully Monte Carlo method for medium and large projects were the computation effort become an issue.

Experiment 2

In order to highlight the advantages of using one or another risk simulation method, we applied them in several real construction projects of medium and large size and we calculated the probabilities to achieve the target dates (for the finish date and total cost).

The analysis was performed with a computer having a processor of 2.7 GHz Intel Core I7, with RAM of 4 GB at 1333 MHz DDR3. The probability distribution curve used in computation was the Beta distribution and the number of iterations for Monte Carlo method was 1000. The first project consists of 211 activities with 54 resources (manpower and equipments), 95 materials and 12 cost components. The second project consists of 698 activities with 21 resources (manpower and equipments), 3 materials and one cost components. The results are presented in Table 4.

The probabilities obtained using Monte Carlo are higher than Three Scenario Approach. This is due the fact the Three Scenario Approach allow to take into consideration the unknown unknowns.

The computation duration is variable taking into account the number of activities, the number of allocated resources and materials and the number of cost components. For the first project the computation duration in Monte Carlo method is 225 times more than the Three Scenario Approach, while for the second project is 168 times more.

Table 4. Probabilities to achieve the target date with Monte Carlo and Three Scenario Approach for medium and large projects

Project	Method	Parameter		Computation Duration (seconds)
		Duration	Total Cost	
1	Monte Carlo	86.90%	100.00%	675
	Three Scenario Approach	82.20%	84.90%	3
2	Monte Carlo	84.70%	97.20%	840
	Three Scenario Approach	82.50%	83.50%	5

5. Conclusions

Project risk management represents a significant area in project management. The authors analyzed several risk management standards and guidelines and concluded that what it is really relevant for differentiating risk management approaches is not the process structure as such, but how the integration of risk management with all other project management processes is reinforced. The authors focused on risk simulation methods recommended and used in project quantitative risk analysis, investigating theoretical and in practice two methods, Monte Carlo and the Three Scenario Approach. In order to compare the effectiveness of the methods, two experiments were designed based on real projects.

Even if the Monte Carlo method is very accurate, its practical application is not feasible because of the iterations which require effort and time for computation. The application of Monte Carlo needs a great amount of time for the preparation of input data when the projects are of medium and large size, with hundreds and thousands activities, resources, materials and cost components. As time as the project environment is in continuous changing the accuracy of the results using Monte Carlo method does not help the project managers too much in decision making.

Though the Three Scenario Approach is a semi-probabilistic method and it is not as accurate as Monte Carlo, the use of the same shape of the probability distribution curve gives it stability in results. It is easy to be applied in practice and requires a very short time for computation. Time and cost buffers are set by defining reliable targets that have reasonable probabilities to meet. The application of management by trends of the probability to achieve the target dates which is in fact the management of buffers penetration allows project managers to identify timely the risk events and to react properly. Trends of probabilities to meet project targets (success probabilities) are most valuable and integrated project performance indicators. They depend not only on project performance but also on project environment.

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 in Zurich*, IPMA, ISBN 978-3-9523891-2-6.

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.

Chapman, C., & Ward, S. (2002). *Managing Project Risk and Uncertainty - A Constructively Simple Approach to Decision Making*. Chichester, John Wiley & Sons Ltd.

Chapman, C., & Ward, S. (2003). *Project Risk Management, Processes, Techniques and Insights*, Second edition, John Wiley & Sons Ltd.

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

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.

Kendrick ,T. (2003). *Identifying and Managing Project Risk*, AMACON

Liberzon, V. (1996). Resource Management and PMBOK, in: *Proceedings of the 27th Annual PMI 1996 Seminars & Symposium*, Boston.

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

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

Pritchard, C. L. (2011). *Risk Management-Concept and Guidance*. (2nd ed.). ESI International.

Schyler, J. (2001). *Risk and Decision Analysis in Projects*. (2nd ed.). PMI, Inc.