THE CONCEPTUAL FRAMEWORK FOR CONSTRUCTION PROJECT RISK ASSESSMENT

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ABSTRACT

The environment in which the project schedule will be executed is far from being static. Projects are subject to various uncertainties that have negative effect on activity durations. This is most apparent in the case of construction projects. The frequency and impact of risks depend on project-specific, contractor-specific and location-specific conditions. Identifying critical sources of risk is crucial to minimize disturbance in project development and assure success. The paper presents risk analysis and assessment framework. For the risk evaluation, the AHP was adopted in the paper. The proposed risk model is based on evaluating and weighting the particular project's characteristics and expected conditions. The method to assist planners in determining activity duration distribution parameters according to risk level is presented. This approach, combined with simulation technique, is argued to improve project planning and evaluation of risk mitigation alternatives.

1 INTRODUCTION

Construction projects are influenced by a variety of risk factors, e.g. weather, soil conditions, qualifications and productivity of the staff, crew and subcontractors, accidents, resource shortages, unreliable deliveries, defects. A schedule that is optimal with respect to project duration or cost may largely be affected by disruptions and uncontrollable factors. The available statistical knowledge of the uncertainties should be used while building the project schedule.

Risk in construction and engineering has been defined in various ways: the chance of injury, damage, or loss (Mehr & Cammack 1966), any exposure to the possibility of loss or damage (Papageorge 1988), the uncertainty and the result of uncertainty (Hertz & Thomas 1983), or the variation in the possible outcomes, a property of an entire probability distribution, whereas there is a separate probability for each outcome (Williams & Heins 1971). The risk factors have a significant impact on the outcome of a project especially in terms of duration and cause schedule delays.

To control the level of risk and mitigate its effects, risk management should be applied. The project risk management process requires risk identification, analysis and assessment, as the first steps for planning and implementing risk handling (response) strategies.

As a result of disturbances caused by risk factors, the activities' duration is a random variable. To determine a construction process' duration distribution types and parameters, a considerable number of time measurements would be necessary to make the results statistically sound. This might be too costly, time consuming and in some cases unjustified as, due to the unique character of construction projects and processes, statistical data from the past may be of little use in the future.

Many models have been proposed to describe and predict activity and project durations or work productivity on the basis of risk analysis: simple analytical, neural network based (e.g. Kog et al. 1999, Chua et al. 1997, Zayed & Halpin 2005, Shi 1999, AbouRizk et al. 2001, Sonmez & Rowings 1998), Bayesian belief network based (Nasir et al. 2003), fuzzy set besed (e.g. Lee &

Halpin 2003), regression (e.g. Hanna & Gunduz 2005, Jaselskis & Ashley 1991) and simulation models (e.g. Dawood 1997, Schatteman et al. 2008).

Most of the quantitative models assume that particular factors affect the processes independently. No model is considered to be superior as providing more reliable solutions than the other models. However, there is little evidence of extended practical use of the models developed to date.

2 PROJECT RISK ASSESSMENT FRAMEWORK

2.1 The proposed concept of project risk assessment

As a result of uncertainties, the project duration is a random variable. The probability density function of project duration reflects the project risk and enables to assess the probability of not meeting the contractual project due date. The proposed procedure for generate the pdf and predict the project risk consists of three main steps showed on Figure 1 and explained in the next paragraphs.

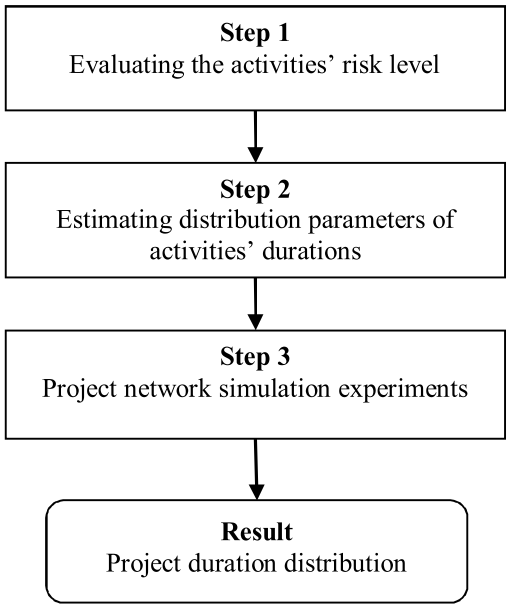

Figure 1. The proposed procedure of project risk assessment

2.2 Evaluating the activities' risk level

The precedence relationships between schedule activities, i.e. construction processes, are modeled by a unigraph directed, acyclic, in activity-on-node representation with single start and end nodes.

The frequency and impact of risk factors on a particular construction process depend on the project-specific, contractor-specific and location-specific conditions.

Table 1 lists ten construction project conditions considered to be of the greatest impact on risk and deviation in activities duration, identified on the basis of a survey among chartered engineers employed by construction companies in Poland.

Table 1. Construction project conditions affecting project risk level

No.	Condition
1	Season of the year
2	Human resources: skill and availability (concerns also subcontractors)
3	Quality and completeness of design documents
4	Quality of project and construction management systems
5	Labour conditions
6	Financial standing of project participants, project's finance conditions
7	Quality of the supply system
8	Site layout, site location
9	Project environment (economic, political, legal, geographic, labour market, suppliers etc.)
10	Equipment – quality and availability

The state of each condition was assumed to be scored using a five-point scale 0, 0.25, 0.5, 0.75, 1, where score 0 stands for ideal conditions, 0,5 – average conditions, and 1 – most adverse conditions. In the process of assigning scores, knowledge and experience of experts should be used. Group decision making involves aggregation of diverse individual preferences to obtain a single collective preference. To achieve consensus of the expert judgements, the authors propose the Delphi method.

The aggregated score for a project condition state is calculated according to the following formula:

$$PC = \sum_{j=1}^{n} pc_j \cdot w_j \,, \tag{1}$$

where: pc_j = evaluation of condition j state, w_j = weight of condition j, n = number of evaluated conditions (here, n=10).

The weights of particular project conditions should reflect their impact on extension of activities' duration (risk level). They can be found by means of Analytical Hierarchy Process. Let us consider a group of K experts involved in a decision making process. They compare, pairwisely, n criteria (project conditions) with respect to the project risk level. Each expert provides a set of $m = n(n-1)/2$ comparison judgments – assigns a numerical value of an importance ratio – using a fundamental scale: 1/9,1/7, 1/5, 1/3, 1, 3, 5, 7, 9. The scale may be extended by some intermediate values: 1/8, 1/6, 1/4, 1/2, 2, 4, 6, 8 if necessary.

As a result of the pairwise comparison that uses the above crisp ratios, a set of K matrices is created $A_k = \{a_{ijk}\}$, i = 1, 2, ..., n-1, j = 2, 3, ..., n, j > i, k = 1, 2, ..., K, where a_{ijk} stands for a relative preference of criterion i to j, as assessed by the expert k.

In the classical AHP method, Saaty proposed the geometric mean method of aggregating ratio judgments (Saaty & Vergas 2007). This is to assure satisfying the Pareto optimality axiom: the variant preferred by each expert or decision maker should be preferred by the whole group (Van Den Honert & Lootsma 1996).

Scoring the state of each project condition and determining each condition's weight for each particular construction process is not necessary, as construction processes can be divided into groups that are similarly affected by certain risk factors. For instance, in the case of housing projects, six activities groups were identified by authors to represent all the types of activities in project schedule. These groups are Mobilization, Foundations, Structural works, Internal and External finishing, and Services.

2.3 Estimating distributions parameters of activities' durations

As a result of disturbances caused by risk factors, the duration of a activity j is a random variable. Its actual distribution is unknown. If there is only a limited number of sample data, the continuous triangular distribution (with lower limit a_j, mode m_i and upper limit b_i) is often used for a proxy of actual distribution (Johnson 1997). Similarly to PERT, the lower and upper limits can be evaluated properly as optimistic and pessimistic (or 5% and 10% fractiles) estimates of activity j duration. Instead, they could be derived from the planner's database of past experience, if such was available.

The duration's mode m_i can be calculated on the basis of median duration estimate based on a unit production time. As unit production times are established for average states of project conditions, the distribution function formulated this way would reflect the variability of activity duration only in the case of PC=0.5.

To construct a project schedule, one needs to assume fixed activities' duration estimates t_j. The risk connected with these decisions can be described using following formula:

$$r^{PC}\left(t_j\right)=\int_{t_j}^{b_j^{PC}}\left(x-t_j\right)\cdot f_j^{PC}(x)\,dx, \qquad (2)$$

where:
$r^{PC}\left(t_i\right)$ = risk associated with expressing the duration of activity j, as a fixed value t_j, when the state of project conditions is assessed as PC; it is the expected value of extension of duration over the estimate t_j,
$f_j^{PC}(x)$ = activity j duration's distribution function when the state of project conditions is assessed as PC (with parameters a_j^{PC}, m_j^{PC}, b_j^{PC}).

The analytical formula to calculate the approximate risk value that bases on the assumption of a triangular distribution takes the following form:

$$r^{PC}\left(t_j\right)=$$
$$=\begin{cases}\dfrac{\frac{1}{3}t_j^3-a_j^{PC}t_j^2-\left(m_j^{PC}\right)^2t_j+2a_j^{PC}m_j^{PC}t_j+\frac{2}{3}\left(m_j^{PC}\right)^3-a_j^{PC}\left(m_j^{PC}\right)^2}{\left(b_j^{PC}-a_j^{PC}\right)\cdot\left(m_j^{PC}-a_j^{PC}\right)}+ \\ +\dfrac{-\left(m_j^{PC}\right)^2t_j+2b_j^{PC}m_j^{PC}t_j+\frac{2}{3}\left(m_j^{PC}\right)^3-b_j^{PC}\left(m_j^{PC}\right)^2-\left(b_j^{PC}\right)^2t_j+\frac{1}{3}\left(b_j^{PC}\right)^3}{\left(b_j^{PC}-a_j^{PC}\right)\cdot\left(b_j^{PC}-m_j^{PC}\right)}, \\ t_i\in\left[a_j^{PC},m_j^{PC}\right] \\ \dfrac{-t_j^3+3b_j^{PC}t_j^2-\left(b_j^{PC}\right)^2t_j+\left(b_j^{PC}\right)^3}{3\left(b_j^{PC}-a_j^{PC}\right)\cdot\left(b_j^{PC}-m_j^{PC}\right)}, t_j\in\left[m_j^{PC},b_j^{PC}\right]\end{cases} \qquad (3)$$

Figure 2 presents the results of using this formula: the risk curve of fixed activity duration estimate for a activity of the following parameters of triangular distribution function: $a_j^{0,5}=0$, $m_j^{0,5}=0,3$, $b_j^{0,5}=1$ and PC=0.5.

To find the parameters of the distribution function for other states of project conditions ($PC\neq 0.5$), the authors propose using the least squares technique and fitting the risk curve under the following assumptions:

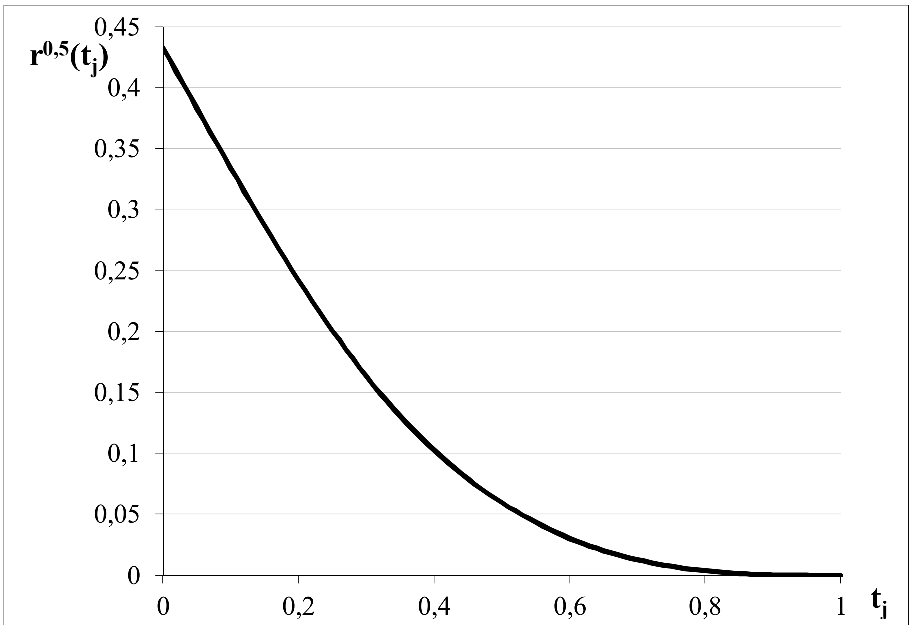

Figure 2. Risk curve of fixed activity duration estimate (example)

1. The risk associated with fixed duration estimate t_j of activity j is linearly dependent on the state of the project conditions:
   $$r^{PC}(t_j) = r^{0,5}(t_j) \cdot \frac{PC}{0,5}, \quad \forall t_j \in \left[a_j^{PC}, b_j^{PC}\right].$$
2. If PC>0.5 then lower limit and the mode of the distribution function can be increased.
3. If PC<0.5 then the upper limit and the mode of the distribution function can be reduced.

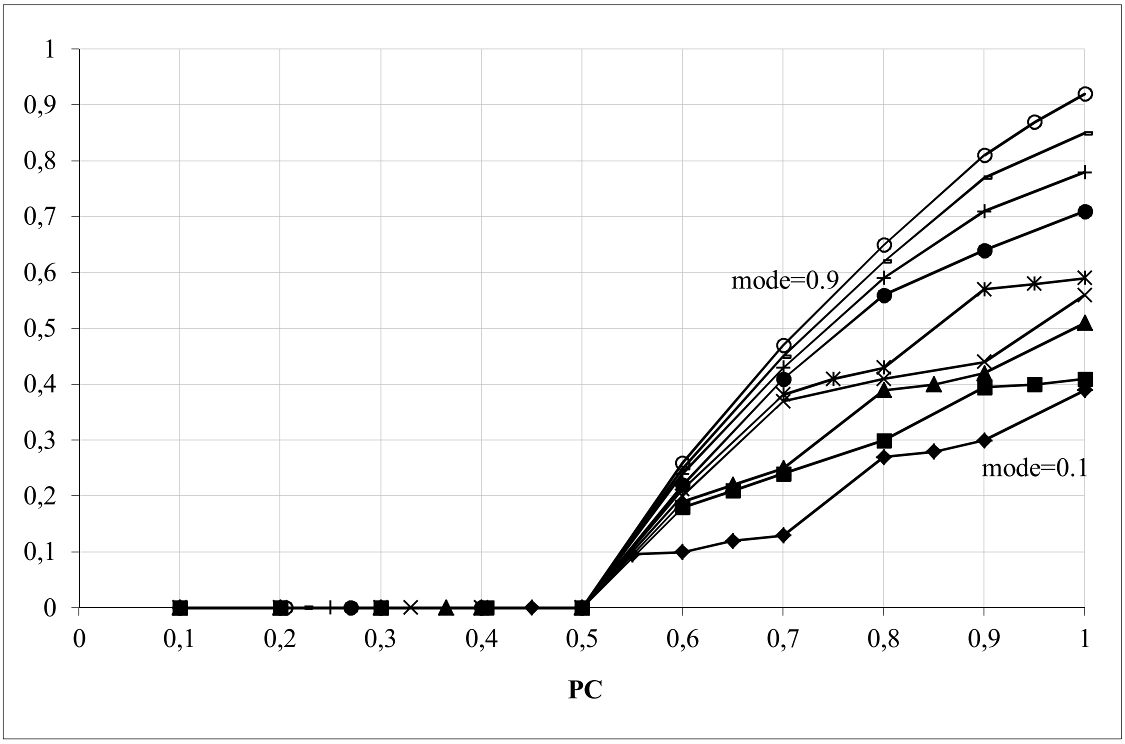

Figure 3. Effect of the state of project conditions on the a_{sj}^{PC} parameter

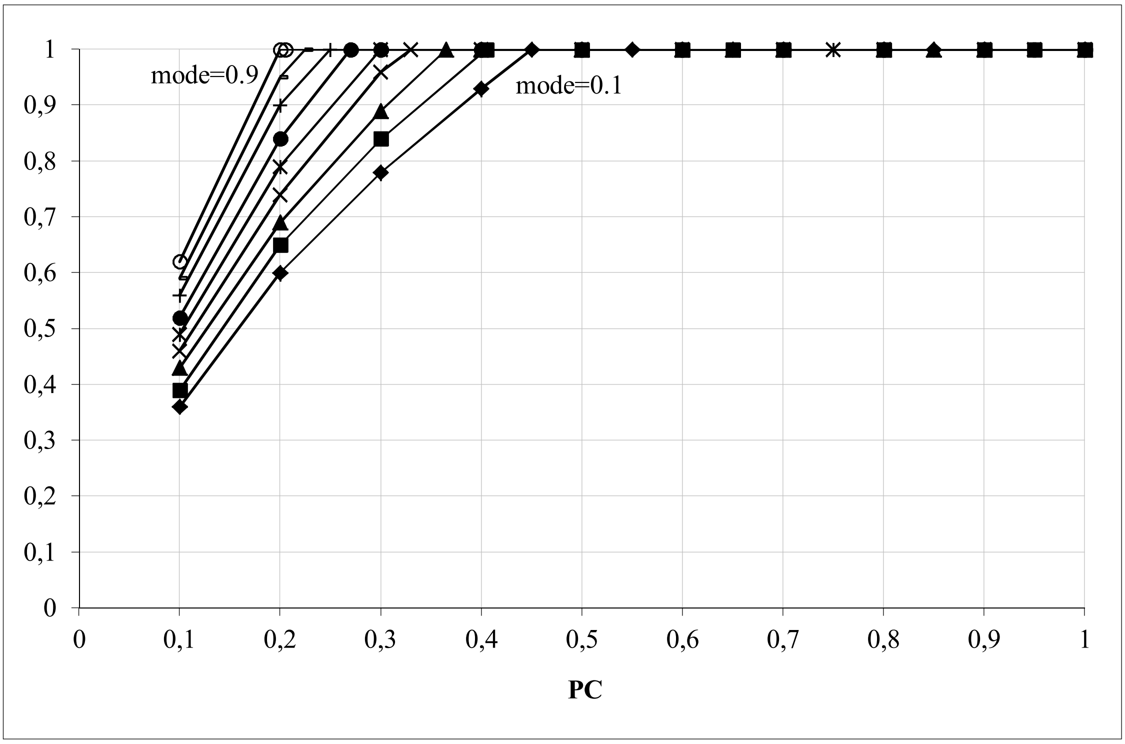

Figure 4. Effect of the state of project conditions on the b_{sj}^{PC} parameter

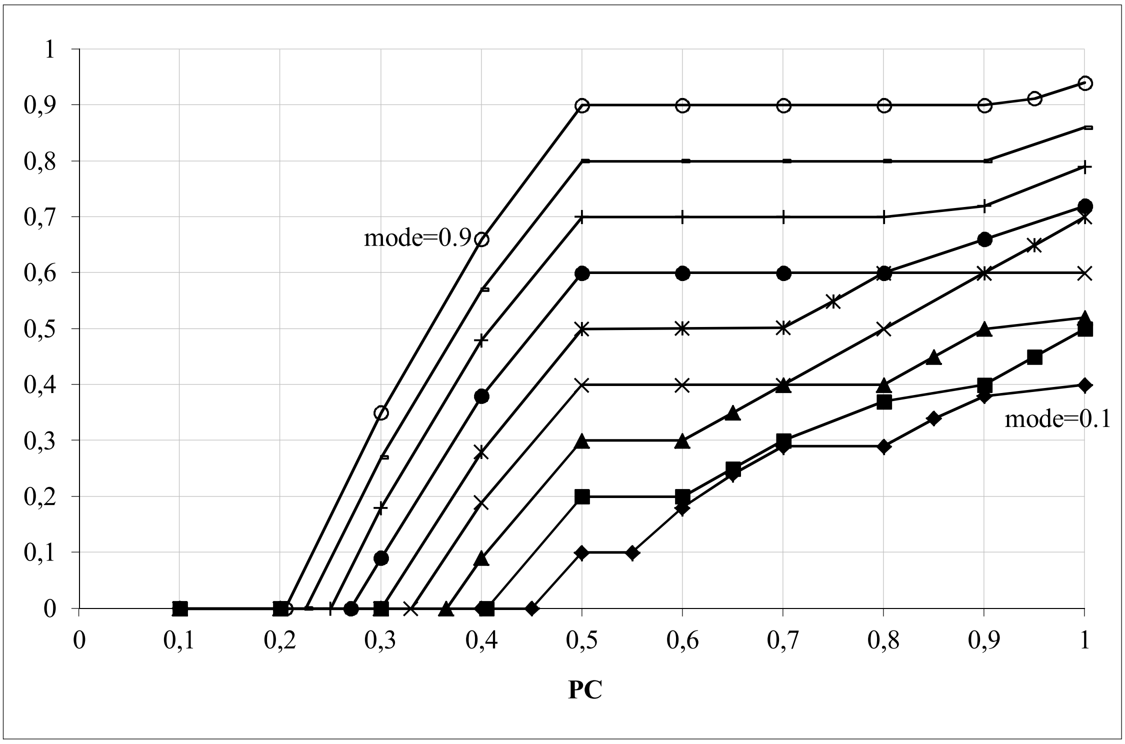

Figure 4. Effect of the state of project conditions on the m_{sj}^{PC} parameter

The sum of the squares of the errors was minimised for limited number of t_j values. Figures 3–5 present the relationship between the state of project conditions *PC* and the parameters of the standardized triangular distribution function for the activity j with original standardized parameters a_{sj}=0, m_{sj}=mode, b_{sj}=1 for PC=0.5; coefficient of determination R^2 takes values 0.77–0.96.

Parameters of the distribution function can be determined using graphs on Figures 3–5 and the following equations:

$$a_j^{PC} = a_j^{0,5} + a_{sj}^{PC} \cdot \left(b_j^{0,5} - a_j^{0,5}\right), \tag{4}$$

$$m_j^{PC} = a_j^{0,5} + m_{sj}^{PC} \cdot \left(b_j^{0,5} - a_j^{0,5}\right), \tag{5}$$

$$b_j^{PC} = a_j^{0,5} + b_{sj}^{PC} \cdot \left(b_j^{0,5} - a_j^{0,5}\right). \tag{6}$$

2.4 Project network simulation experiments

There are a number of methods that allow the planner to consider the effect of random occurrences on the project performance and to assess the chances of meeting the deadlines defined by the contract. The first attempt to allow for risks in project planning was made by the inventors of *PERT* (Program Evaluation and Review Technique).

The assumptions of *PERT* made it possible to reduce the complexity of network model analyses but, at the same time, affected the accuracy of time estimates of individual project events and the project as a whole (Biruk & Jaskowski 2010). Therefore, project networks are often analysed by means of the *Monte Carlo* simulation.

The Monte Carlo method simulates the project network many times, each time randomly choosing a value for activities' duration from their probability distribution. The outcome is a probability distribution of the project duration, evaluated on the basis of project durations calculated in consecutive iterations of the network. Monte Carlo simulation may be applied to quantify the confidence in the target project completion date or total project duration. The project manager is able to report the probability of completing the project at any particular date, which allows him to set a schedule reserve for the project.

The simulation experiments can be conducted using standard project management software, such as Microsoft Project or Primavera, along with Monte Carlo simulation add-ins, such as @Risk or Risk + (Kwak & Ingall 2007).

To illustrate the impact of project conditions on its duration, the following example is introduced. Figure 5 presents a simple construction project network model. The estimates of process durations (random variables of triangular distribution) are presented in Table 2. The Monte Carlo simulation was conducted using Minuteman GPSS World software.

The cumulative distributions of project duration for three PC scores (0.5 – for average and 0.7 – expected conditions also 0.4 – for project risk level after planned mitigation actions) and are shown in Figure 6. Let us assume that the project manager determines the reliability of the contractual project due date at the level of 0.6. The planned risk mitigation actions allow to reduce the project duration in this simple example from about 20 to 18 days (c.a. 10 %).

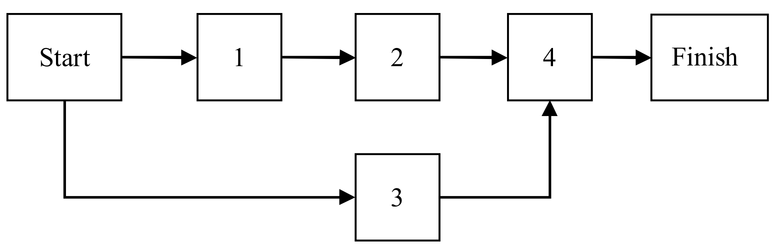

Figure 5. Precedence relationships among processes of the example

Table 2. Estimates of processes durations (example) [days]

Activity	*PC* = 0.4			*PC* = 0.5			*PC* = 0.7		
j	a_j	b_j	m_j	a_j	b_j	m_j	a_j	b_j	m_j
Start	0	0	0	0	0	0	0	0	0
1	5	10	5.95	5	10	7	6.85	10	7
2	4	8.99	5	4	9	5	5.20	9	5.50
3	8	14	9.68	8	14	11	10.29	14	11
4	3	7	4.12	3	7	5	4.53	7	5
Finish	0	0	0	0	0	0	0	0	0

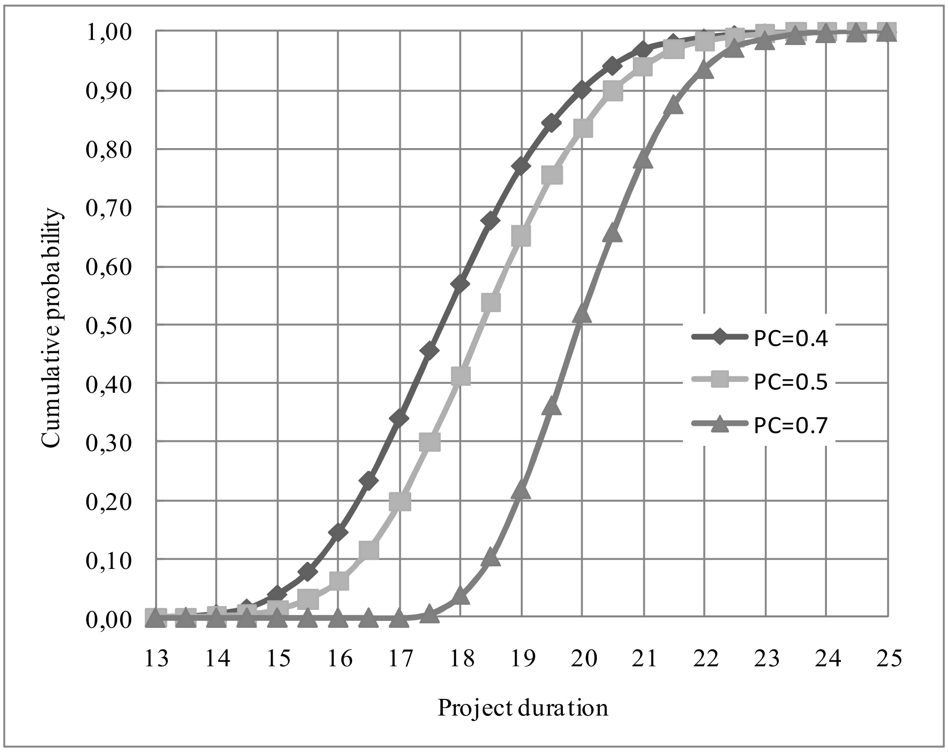

Figure 6. Cumulative distribution function of project duration realized for different conditions scores

3 CONCLUSIONS

The paper presents the framework for construction project risk assessment. The approach enables the planner to estimate the probability distribution of project duration on the basis of the project conditions' evaluation and Monte Carlo simulation technique. The input needed for the analysis should be stored in a contractor database (i.a. the weights of particular project conditions for groups of processes, upper and lower limits per unit, unit production times). A considerable advantage of this approach is seen in the possibility of automated assessment of the impact of risk mitigation actions on the duration of the project.

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