ESTIMATING DISTRIBUTION PARAMETERS OF SCHEDULE ACTIVITY DURATION ON THE BASIS OF RISK RELATED TO EXPECTED PROJECT CONDITIONS

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─**Abstract**─

The paper focuses on handling schedule risks. For each schedule activity, a statistical distribution of its duration is to be defined. Therefore, a research was undertaken to develop a method to assist planners in determining activity duration distribution parameters according to risk level. A triangular distribution was assumed, and its parameters estimated on the basis of three input values (the most likely, pessimistic and optimistic durations). In contrast to the Program Evaluation and Review Technique, the approach proposed in the paper assumes that these input values should be evaluated independently of the particular project's conditions and could be derived from the planner's database of past experience. For the risk evaluation, the AHP was adopted. The proposed risk model – considering the diversity of activity types – was based on evaluating and weighting the particular project's characteristics and expected conditions. This approach, combined with simulation technique, is argued to improve project planning and evaluation of risk mitigation alternatives.

Key Words: *Project scheduling, Project risk assessment, Project management*
JEL Classification: M11

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. These factors are stochastic in nature and, as such, they cannot be exactly predicted. Their variation results in uncertainty and risk in the final cost, duration and quality of the project.

Risk in construction and engineering has been defined in various ways: the chance of injury, damage, or loss (Mehr and Cammack, 1966:18), any exposure to the possibility of loss or damage (Papageorge, 1988:5), the uncertainty and the result of uncertainty (Hertz and Thomas, 1983:1-5), or the variation in the possible outcomes, a property of an entire pobability distribution, whereas there is a separate probability for each outcome (Williams and Heins, 1971:5). The risk factors have a significant impact on the outcome of a project especially in terms of duration and cause schedule delays.

Unrealistic completion dates put a burden on various parties of the contract, especially the contractor. Risk should be incorporated into the schedule to make the milestones and project completion dates achievable. To control the level of risk and mitigate its effects, risk management should be applied. The project risk management process requires risk indentification, analysis and assessment, as the first steps for planning and implementing risk handling (response) strategies.

Unit production times / unit productivity rates, being often the basis for planning duration of construction processes, are usually expressed by single values – medians or means corresponding to average conditions. To determine a 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. According to the way of describing the risk factors' impact on activity duration, two groups of methods can be distinguished: quantitative and qualitative. The qualitative models use a verbal description of the impact. The quantitative models base on analytical or numerical relations. There exist a number of such models to choose from: simple analytical, neural network (e.g. Kog et al., 1999; Chua et al., 1997; Zayed and Halpin, 2005; Shi, 1999; AbouRizk et al., 2001; Sonmez and Rowings, 1998),

Bayesian belief network (Nasir et al., 2003), fuzzy set (e.g. Lee and Halpin, 2003), regression (e.g. Hanna and Gunduz, 2005; Jaselskis and 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. PROPOSED METHOD OF ESTMATING DISTRIBUTION PARAMETERS OF ACTIVITIES' DURATIONS

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.

The state of each condition was assumed to be scored by assigning a numerical value from the interval $\langle 0, 1 \rangle$ (e.g. using a five-point scale), 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:

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

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

Table 1. Construction project conditions affecting project risk level

No.	Condition	Related risk factors (examples)
1	Season of the year	Sub-zero or very high temperatures, precipitation, strong winds
2	Human resources: skill and availability (concerns also subcontractors)	Employing unqualified local or seasonal workers, ineffective coordination of subcontractors, unreliable subcontractors, possibility of rework due to bad workmanship.
3	Quality and completeness of design documents	Variations of scope, quantity, or sequence of works, delays with design information (esp. in the case of design being delivered in stages), unforeseen soil conditions leading to variations, inadequate work

		programme
4	Quality of project and construction management systems	Ineffective operations management (bad communication between project participants, delayed decisions), insufficient number of superintendence staff, inadequate IT by creating and updating construction programmes, great number of workers to be managed, lack of work progress control, inexperienced engineering staff
5	Labour conditions	Demotivating wage and salary system, fluctuation of employees due to low pay or bad working conditions, difficult/unhealthy working conditions, productivity drop due to working overtime, work suspension by occupational health and safety or other authorities, accidents on site, inadequate welfare facilities on site.
6	Financial standing of project participants, project's finance conditions	Delayed payment to general contractor, the contractor's insolvency, no delay penalties, no bonuses for early delivery, delayed payment to subcontractors, insufficiency of the accepted contract amount, delayed payment to material suppliers, delayed payment to machinery suppliers.
7	Quality of the supply system	Poor quality of materials, incorrect planning of deliveries.
8	Site layout, site location	Too small building site, difficulties in the site's power/water supply, adverse topography of the site hindering rational location of site facilities (limited crane working zone, longer internal transport routes). Particular requirements for external transportation (oversize load permits, night deliveries, limitations of access roads)
9	Project environment (economic, political, legal, geographic, labour market, suppliers etc.)	Inflation consuming contractor's profits; Protests of green organisations/ local people that suspend works; Random occurrences (fire, flood, theft); Delayed delivery of construction machinery; Difficulty in hiring machinery of particular parameters due to underestimated budget; Difficulty in finding qualified subcontractors or crews.
10	Equipment – quality and availability	Machinery breakdowns; Inadequate machinery parameters; Relying on hired machinery (keeping hire times to minimum to save money)

The weights of particular project conditions should reflect their impact on extension of process 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. 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 and Lootsma, 1996). The geometric mean can be calculating using the following formula:

$$m_{ij} = \left(\prod_{k=1}^{K} a_{ijk} \right)^{1/K}.$$

The geometric mean expresses a certain group consensus but it does not fully reflect the discrepancy between the experts' preferences. It can be used as the representative preference judgment of the entire group in the case that the dispersion of the group judgments is not unusually large (Saaty and Vargas, 2007). Otherwise, in order to determine values of criteria weights $w = [w_1, w_2, ..., w_n]^T$, one may refer to the procedure presented in the paper of Jaskowski et. al (Jaskowski et al., 2010).

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, five activities groups were indentified by authors to represent all the types of activities in project schedule. These groups are Mobilization, Foundations, Structural works, Internal and External finishings, and Services.

As a result of disturbances caused by risk factors, the duration of a process i 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_i, mode m_i and upper limit b_i) is often used for a proxy of actual distribution. Similarly to PERT, the lower and upper limits can be evaluated properly as optimistic and pessimistic estimates of process 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 averange states of project conditions, the distribution function formulated this way would reflect the variability of process duration only in the case of $PC=0.5$.

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

$$r^{PC}(t_i) = \int_{ti}^{bi} (x - t_i) \cdot f_i(x)\, dx,$$

where:

$r^{PC}(t_i)$ – risk associated with expressing the duration of process i, as a fixed fixed value t_i, when the state of project conditions is assessed as PC; it is the expected value of extention of duration over the estimate t_i,

$f_i(x)$ – process i duration's distribution function.

The analytical formula to calculate the approximate risk value that bases on the assumption of a triangular distribution is complex so it is not presented in the paper. Figure 1 presents the results of using this formula: the risk curve of fixed process duration estimate for a process of the following normalised parameters of triangular distribution function: a_i=0, m_i=0.3, b_i=1 and PC=0.5.
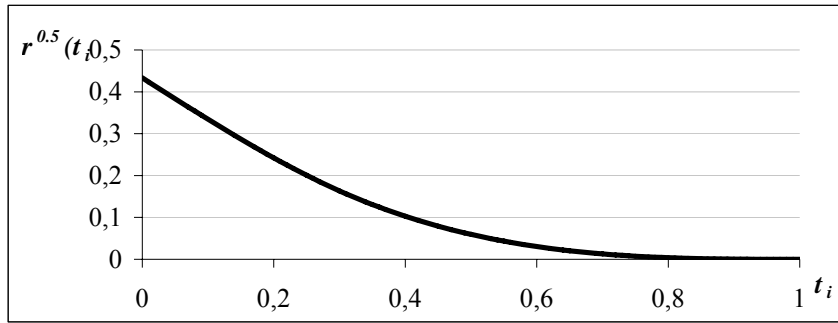
To find the parameters of the distribution function for other states of project conditions ($PC \neq 0.5$), the authors propose using the least squares technique and fitting the $r^{PC}(t_i) = \int_{ti}^{bi} (x - t_i) \cdot f_i(x)\, dx$ – curve under the following assumptions:

- The risk associated with fixed duration estimate t_i of process i is linearly dependent on the state of the project conditions:

$$r^{PC}(t_i) = r^{0.5}(t_i) \cdot \frac{PC}{0.5}, \quad \forall t_i \in \langle a_i, b_i \rangle.$$

- If PC>0.5 then lower limit and the mode of the distribution function can be increased.

- If PC<0.5 then the upper limit and the mode of the distribution function can be reduced.

Figure-1: **Risk Curve of Fixed Process Duration Estimate (Example)**
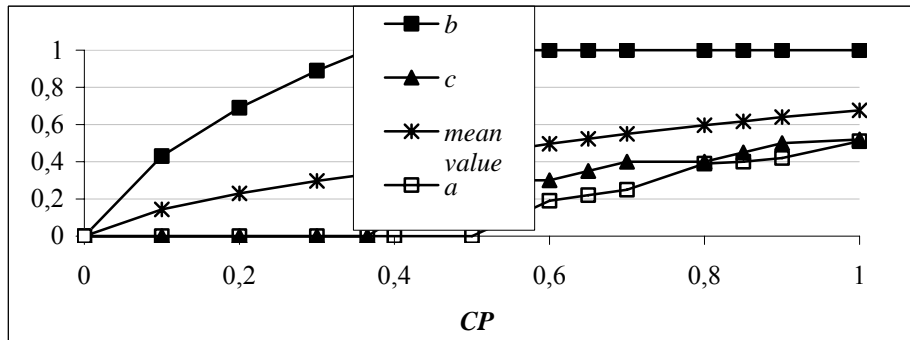

The sum of the squares of the errors was minimised for limited number of t_i values by means of standard MS Excel functions (e.g. scenario toolbar). Figure 2 presents the relationship between the state of project conditions *PC* and the parameters of the triangular distribution function. For the process *i* with original parameters a_i=0, m_i=0.3, b_i=1 for *PC*=0.5; coefficient of determination R^2 takes values 0.77–0.96.

CONCLUSIONS

The approach to estimating distribution parameters of schedule activity duration presented in the paper is the basis for assessing the risk of the entire project by means of Monte Carlo simulation technique. The input needed for the analysis can be found 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 assessing the effect of risk mitigation actions on the duration of the project.

Figure-2: Effect of the State of Project Conditions on the Parameters of Tringular Distribution Function (Example)

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