Quantitative risk analysis in investment projects in construction (advantages and disadvantages of selected methods)

Introduction
In the world of science, risk is regarded as a quantitative category. Due to the advancements in science and knowledge, in particular financial engineering, and the availability of financial IT applications, risk can be properly quantified. Appropriate methods, techniques and tools can be used to do this. Risk in investment projects executed in the construction industry can also be managed quantitatively. Risk estimation is a separate stage in the risk management process. In business practice, with the application of appropriate methods, we can estimate risks connected with project execution time and project-related costs. It’s generally assumed that these are the two most essential categories of risks related to investment and construction processes carried out by contractors. Investors are interested in risk quantification as well. They can use an array of methods and apply a number of practical solutions in order to quantify risks. Risk simulation may prove to be very helpful here. When estimating risks, however, one should always remember about the constraints in the use of some quantitative methods. A variety of methods employed in investment projects executed in the construction industry have their advantages and disadvantages. These issues are addressed in the paper, the principal aim of which is to discuss the selected quantitative methods used to quantify risks in investment projects carried out in the construction industry. The knowledge of these advantages and disadvantages may be valuable in business practice. The aim of the theoretical deliberations is to present the problems faced in quantitative risk management in the construction industry, which may be useful for entrepreneurs. It should be added that the issues discussed in the article are presented in the synthetic way and the author draws attention to practical aspects of the methods outlined in the paper. A review of literature and the technique of deduction are used in the paper. The subject of the paper is quite broadly described in the scholarly literature, but the empirical research conducted by the author may lead to a conclusion that there are numerous problems in the area of risk management in investment and construction activities, which should be explained by science in more detail.

* A Ph.D., Department of Investments and Real – Estate, Division of Investment Project Economics, Faculty of Finance and Insurance, Investments Economics Unit, University of Economics in Katowice, piotr.tworek@ue.katowice.pl
1. Methods of risk assessment in investment projects in construction – their advantages and disadvantages. Selected issues

As already mentioned in the introduction, domestic and international scholarly literature has broadly described the quantitative methods used to estimate risk in investment projects executed in the economy, including the construction industry\(^1\). It should be kept in mind, however - as emphasized by A. Zachorowska, that „(...) there is no single method, which would be appropriate in every case” [Zachorowska, 2006, p. 76]. This is mostly due to the fact that the profiles of projects executed in the economy differ. R. Mulcahy stresses out that a quantitative risk analysis is an attempt to identify risks carried by a project and predict where to dedicate time and commitment (highest risk areas), in order to minimise risk [Mulcahy, 2003, p. 133]. S.A. Burtonshaw-Gunn says that „(...) the quantitative risk analysis process aims to numerically analyze the probability of each risk and its consequences on the project objectives as well as the extent of overall project risk” [Burtonshaw – Gunn, 2009, p. 65]. In business practice, a number of methods are usually employed at the same time, in order to quantify risks in an investment project. The most essential risk measurement methods include simulation methods, the sensitivity analysis, operations research methods, probabilistic and statistical methods and expert judgement methods [Korombel, 2007, p. 94]. Apart from these, one can also use the function discrimination analysis, the Bayesian analysis, decision trees, the impact factor analysis, neural networks, a risk matrix and a risk register [Koller, 2005, p. 137]. From the theoretical point of view, also a number of other methods may be employed in quantitative analyses of investment projects executed in the construction industry. These methods, however, are not covered by the paper as their significance in business practice is much lower. The examples of such methods are given in international literature. Real options, for instance, may also be applied in the construction industry. According to the approach presented by the Project Management Institute in Newton, the USA, the basic methods for quantitative project risk analyses (project management) include the sensitivity analysis, decision trees and a risk simulation\(^2\). This approach, followed by economic entities in their quantitative project risk analyses, is generally regarded as the model approach. In the literature on the subject these methods are commented upon e.g. by B.T.

---


Barkley [Barkley, 2004, p. 82]. In general, the selection of a risk analysis method is affected by the following factors:

- a decision-maker’s attitude to risk,
- conditions in which the decision is made,
- scope of risk,
- availability and scope of information,
- investment conditions, including the economic life cycle of an investment project (long- and short-term risk analyses),
- the knowledge of risk analysis methods and an ability to use them in practical investment activities,
- the knowledge and experience in the estimation of risk levels and probability of events which may have impact on these risks,
- the decision-maker’s knowledge of time intensity and costs of applied methods [Rogowski, 2004, p. 190].

1.1. Sensitivity analysis

When looking at this method, attention should be drawn to the fact that the sensitivity analysis is, in principle, a simple simulation. This method helps us to find out which risk factors (variables) have the biggest impact on an investment project. In particular, “(...) the analysis of an investment project’s sensitivity to changes in decision-making conditions, which determine the outcome of the investment profitability calculation for the project, is carried out in case when only one input variable changes or in case, when two or more input variables (investment events and their environment, which are uncertain) change” [Ostrowska, 2002, p. 118]. In practical terms, it’s particularly useful for investors in the construction industry as they are able to identify the key risk factors for their projects, which may, for example, concern the most important types of costs relating to the execution of the projects, and then use appropriate calculations to obtain the results, which show the deviations from the expected values e.g. NPV. Therefore, the method is aimed to find out what deviations of the key project variables from the initially planned (assumed) values can be expected in the future. In particular, “(...) the sensitivity analysis is employed to evaluate how sensitive the investment project is to changes in specific factors used to calculate the break-even point” [Towarnicka, 2000, p. 96]. In practical economic activities - as mentioned above - it’s used to find out how the NPV value actually achieved by the project is going to differ from the NPV value expected from the investor. Another practical example may concern the situation when in the analysed period the operating costs of the investment project increase, income stays at the same level and, consequently, the positive NPV result for the investment deteriorates. The sensitivity analysis can also give an answer to a different question, i.e. how can the selling price of a product be reduced to still keep the project financially viable [Marcinek, 2004, p. 126]. Just like in case of any other method, the sensitivity analysis has its advantages and disadvantages, which are presented in Tab. 1.
### Table 1. The sensitivity analysis - advantages and disadvantages

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>– is used to identify risk, indicating areas, which should be subject to a more in-depth analysis,</td>
<td>– simplified assumption, often inconsistent with the reality, about a steady level of other independent explanatory variables, when examining changes in a given explanatory variable; this fault can be removed by using a scenario analysis,</td>
</tr>
<tr>
<td>– is mainly useful for development projects, for which risk has not been analyzed yet (there is no experience from any similar investment projects performed in the past),</td>
<td>– project risk depends both on the sensitivity of a decision-making criterion to changes in independent explanatory variables and on the scope of probable values of these variables, reflected in their probability distribution; as the sensitivity analysis takes into account only the former factor, it’s incomplete; this fault can be removed by using a simulation analysis,</td>
</tr>
<tr>
<td>– its results, i.e. the knowledge about the impact of specific explanatory variables on an explained variable may be used in other risk analysis methods,</td>
<td></td>
</tr>
<tr>
<td>– it presents all the sensitivity curves on one graph, which may facilitate direct comparison of risks dependent on various explanatory variables,</td>
<td></td>
</tr>
<tr>
<td>– sensitivity curves give useful information about boundary points, where a decision-making criterion changes, and can be used to calculate safety margins.</td>
<td></td>
</tr>
</tbody>
</table>

Source: [Rogowski, 2004, p. 200].

### 1.2. Decisions Tree Analysis

The decision tree analysis is a very simply method used in the risk quantification process and its feature is a relatively high clarity. This method takes into account risk probabilities and costs or rewards of each logical path of events and future decisions [Kompendium wiedzy…, 2000, p. 184]. This method supports the process of decision-making in enterprises. As emphasised by R.M. Wideman „(...) the method is well suited to project risk analysis and has been applied extensively, with additional efforts made to resolve the problem of interrelated risks” [Wideman, 1992, p. C-4]. Using the method, a number of decision alternatives can be considered, taking into account the probability of a given scenario of events. The bottom line here is the fact that we can choose one out of many possible alternatives. With regard to investment activities carried out by companies, a typical decision tree describes an action, its outcome and probability of achieving possible results. Its structure is composed of four types of elements, namely:

– decision points, i.e. moments at which the decision-maker has to choose from among possible alternatives of further courses of action (from every decision point, specific courses of action have their own paths (branches) leading to specific events),
result points, i.e. these are points at which any possible results caused by the chosen course of action are identified,
possible results i.e. potential results of specific courses of action,
probabilities of occurrence of future events, which have impact on the results [Marcinek, 2000, p. 148].

Similarly to the sensitivity analysis mentioned above, the decision tree analysis has its pros and cons as well. This is illustrated in Tab. 2.

Table 2. Decision Tree Analysis - strengths and weaknesses

<table>
<thead>
<tr>
<th>Strength</th>
<th>Weakness</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Causes the organization to structure the costs and benefits of decisions when the results are determined in part by uncertainty and risk.</td>
<td>- It is sometimes difficult to create the decision structure.</td>
</tr>
<tr>
<td>- Solution of the decision tree helps select the decision that provides the highest Expected Monetary Value or expected utility to the organization.</td>
<td>- Probabilities of occurrences can be difficult to quantify in the absence of historical data.</td>
</tr>
<tr>
<td></td>
<td>- The best decision may change with relatively plausible changes in the input data, meaning that the answer may not be stable.</td>
</tr>
<tr>
<td></td>
<td>- The organization may not make decisions based on a linear Expected Monetary Value basis but rather on a non-linear utility function; utility functions are difficult to specify.</td>
</tr>
<tr>
<td></td>
<td>- Decision tree analysis of complicated situations requires specialized (though available) software.</td>
</tr>
<tr>
<td></td>
<td>- There may be some resistance to using technical approaches to decision-making.</td>
</tr>
</tbody>
</table>

Source: Based on: [Practice Standard for Project Risk Management, 2009, pp. 91-92].

Summing up, the decision tree method helps us to identify the possible courses of action, taking into account percentage probabilities and, consequently, risks [Marcinek, 2000, p. 148]. The method works perfectly in the construction industry, when employed e.g. by contractors in their practical activities [Dallas, 2006, p. 318]. A general contractor may, for example, use the method to evaluate the risk related to the choice of one or more subcontractors, i.e. to decide whether it’s more profitable (in terms of risk) to cooperate with the existing subcontractor or to take a risk and hire a new subcontractor, taking into account a number of assumptions, such as the long duration of the construction period, the cooperating party’s reliability, the project profile etc.
1.3. Risk simulation

A very popular risk simulation method used in economic activities all over the world is the stochastic method of Monte Carlo risk simulation [Marcinek, Foltyn – Zarychta, Pera, Saluga, Tworek, 2010, pp. 129-133]. In particular, this method helps to analyse cost and schedule risks not only for specific actions but also for the entire project [Pritchard, 2002, p. 227.] Just like the two methods mentioned before, also the Monte Carlo method has its advantages and disadvantages. Its strengths and weaknesses are listed in Tab. 3.

Table 3. Monte Carlo simulation - strengths and weaknesses

<table>
<thead>
<tr>
<th>Strength</th>
<th>Weakness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stochastic - easier to compute for multiple inputs.</td>
<td>Probability distributions are assumed based on previous experience.</td>
</tr>
<tr>
<td>Allows a probability distribution to be used avoiding single point estimations.</td>
<td>Risk profiles are often underestimated, due to excluding the tails of the distributions.</td>
</tr>
<tr>
<td>Provides a more representative prediction of risk, provided initial assumptions are reasonable.</td>
<td>Most Monte Carlo packages, with the exception of the high end ones, do not allow for interdependence of input variables.</td>
</tr>
<tr>
<td>Relatively fast with modern computing technology, brute force approach to calculation.</td>
<td>Use of historical data can propagate previous erroneous assumptions.</td>
</tr>
<tr>
<td></td>
<td>Subjective judgement is typically used to come up with starting points.</td>
</tr>
<tr>
<td></td>
<td>Can become too complex and unwieldy.</td>
</tr>
</tbody>
</table>

Source: [Merna, Al-Thani, 2010, p. 80].

There are a big number of computer programs and IT tools, which can be used to run risk simulations. Since such simulations involve a big number of calculations, they help to accurately estimate risk in cases, when it cannot be done manually. A computer is able to perform a several dozen thousand or million simulations at the same time. For example, from the contractor’s point of view, a risk simulation is particularly useful to calculate the deviations in project costs, which need to be incurred throughout a longer period of investment project execution (in the construction industry some projects may even take several years to complete, i.e. big infrastructural projects) in changeable conditions. In order to calculate risk of the project executed in the construction industry one should first build a construction system model, divided into a number of subcomponents, to take into account all processes (execution stages with specific activities and tasks needed to complete the...
investment project), which tend to take place within a project [Będkowski, 2001, p. 50]. Based on that, a simulation should be created and then the risk simulation should be carried out [Będkowski, 2001, p. 50]. A simplified model of such a system for the Monte Carlo risk simulation is presented in Fig. 1.

**Figure 1. Simulation model**

```
Identification of factors
(input variables)  Mathematical model
F(i)=...

Description of variables using
distribution of probability

Correlation matrix

Monte Carlo simulation
method

1 - iterations

Set of results
(output variables)

Empirical distribution of
values

Source: [Minansowicz, Surowiec, 2002, p. 47].
```

In case when the simulation is used in the NPV analysis of the investment project and its risk, the simplest mathematical model is the formula for NPV calculation, which is often supplemented with the equations describing dependencies between the variables that affect the cash flow value, e.g. volume of sales, cost level, price [Pluta, 2000, p. 167].

**Conclusion**

Every quantitative method referred to in the paper may find its practical application in risk management in investment projects carried out in the construction industry. They are, however, used by participants of the investment and construction process to a various extent. More specifically, the popular methods include the sensitivity analysis, the decision tree analysis and a risk simulation, which are the subjects of the paper. In order to apply these methods in specific projects and then interpret the obtained results, people responsible for risk management in enterprises need to have appropriate knowledge in this field and, most of all, have to be aware of the advantages and disadvantages offered by the methods. As emphasized in the paper, there are many different investment projects and they are executed in different conditions. Different
profiles and characters of investment projects require different methodology for quantitative risk management. Some methods are better for some projects, other methods for other projects. Therefore, people responsible for risk quantification must specialise in a given area, possess specific knowledge and constantly improve and update this knowledge. In the construction industry, for example, risk is managed differently in civil engineering projects, water engineering projects, tunnel construction or manufacturing of construction products and prefabricated elements. Consequently, there are certain problems in the application of quantitative methods in business practice and these problems have to be analysed and explained by science. These issues are addressed in the paper, which focuses on the strengths and weaknesses of the methods mentioned above, i.e. the sensitivity analysis, the decision tree analysis and the Monte Carlo simulation method.

References

Summary
The practical application of quantitative methods in risk management in investment projects carried out in the construction industry requires specialised knowledge in this field. In particular, it’s necessary to know the advantages and disadvantages of the methods. As different investment projects are carried out in the economy, including the construction industry, every time different methods, techniques and tools need to be used to estimate risks. These issues are addressed in the paper, the aim of which is to discuss the selected methods used to estimate risk in investment projects in the construction industry, focusing on their advantages and disadvantages. The problems are discussed theoretically and presented in a synthetic way.

Key words
Risk assessment, investment projects, construction

Ilościowa analiza ryzyka w projektach inwestycyjnych w budownictwie: zalety i wady wybranych metod – ujęcie teoretyczne (Streszczenie)
Zastosowanie w praktyce metod ilościowych w zarządzaniu ryzykiem w projektach inwestycyjnych realizowanych w budownictwie wymaga specjalistycznej wiedzy z tego zakresu. W szczególności konieczna jest znajomość zalet i wad tych metod. Odmienny charakter inwestycji realizowanych w praktyce gospodarczej, w tym
w budownictwie sprawia, że za każdym razem w celu oszacowania ryzyka należy stosować inne metody, techniki i narzędzia. Kwestiom tym poświęcony jest niniejszy artykuł, którego głównym celem jest omówienie wybranych metod szacowania ryzyka w praktyce znajdujących zastosowanie w projektach inwestycyjnych realizowanych w budownictwie ze szczególnym uwzględnieniem ich zalet i wad. Problematyka została omówiona w sposób teoretyczny i przedstawiona w syntetycznej formie.

**Słowa kluczowe**
ryzyko, metody ilościowe, projekty inwestycyjne, budownictwo