Abstract. This article deals with risk and uncertainties encountered during the appraisal process in construction, as well as with reasons of their origin. An analysis of three equal size buildings’ appraisal has been carried out at different stages of building implementation. Factors of different phases have been established and change tendencies of these factors have been identified. Methodology of risk and uncertainty minimization has been provided by means of stochastic programming and game theory methods. It has been done by the application of the multi-criterion decision making methods.

Keywords: 3D and 4D modelling, computer-aided evaluation in construction, uncertainty, risk, decision making.

1. Introduction

This article presents the analysis of uncertainty and risk due implementation of construction project. Theoretical part describes various definitions of uncertainty, risk both with there sources as calculation bias, information ambiguity and data inaccuracy in construction projects. Main analysis is connected with the project’s appraisal phase and its stages were the detailed information is the crucial factor for correct decision-making procedures under uncertainty and risk. Consequently this article is presenting various types risk what are undistinguishable from uncertainty circumstances in construction.

After the description of risk and uncertainty types list of solutions were prepared. Application of the suggested risk and uncertainty extenuating techniques in practise was shown as analysis of precision and bias dependence with available information at different stages of appraisal phase.

It is emphasized on uncertainty and risk management problem in the construction’s decision-making. Recently methods based on the utility theory, game theory, statistical distribution and probability, were improved and adjusted due to decision-making needs in construction. That is why the model with implemented multiple-criteria approaches is suggested both as a tool for dealing with the uncertainty and risk problems and to meet the needs of project managers in appraisal phase.

Insufficient attention to building stages and management of the chain processes is often encountered due implementation of construction projects. This is determined by imperfect laws and unclear contractual obligations which sometimes result into unsatisfactory quality of implemented chain works completed by unqualified project participants [1]. These facts, also, result into extra costs for a project and delays related to project’s realization. Moreover, it stimulates uncertainties and the risk increasing due to these indefinite situations.

This article is concentrated on the reduction of project’s risk and uncertainties as the process of making justified construction project’s decisions with estimated bias and known precision [2]. It is intended to explain the appraisal procedures for management of construction project’s phases with suggestions how, when and what actions can be taken to support project’s decision making process under conditions of risk and uncertainty.

Uncertainty is closely associated with uncertainty management, which is the process of integrating risk management and value management approaches of construction process [3].

This article deals with the part of construction process during which every possible solution is economically appraised and the most rational solution is chosen after this analysis. These processes are realized in appraisal phase under minimum of imprecise information and at a presence of the highest uncertainties. The researchers tend to underestimate the influence of suitability and precision of the evaluation data as well as the reliability of methods and means of their application [4]. The great variety of alternatives and criteria complicate the systemizing of data and decision making.
2. Risk and uncertainty in construction industry

2.1. Theoretical descriptions of risk and uncertainty

The term uncertainty is used in most of scientific literature concerning risk management. Theoretically, it can be defined as a lack of certainty involving variability and/or ambiguity. Alike uncertainty management is concerned as managing perceived threats and opportunities and their risk implications but also managing the various sources of uncertainty which give rise to and shape risk, threat and opportunity Chapman and Ward [4].

In risk situations, there are uncertain parameters controlled by probability distributions are known by the decision maker [2]. Whereas in uncertainty situations, parameters are uncertain, and furthermore, no information about probabilities is known. Problems in risk situations (stochastic optimization problems) intend to optimize the expected value of some objective function and problems under uncertainty (robust optimization problems) often attempt to optimize the worst-case performance of the system. However, goal of both stochastic and robust optimization is to find a solution that will perform well under any possible realization of the random parameters. In our case both describes uncertainties in construction project management.

It is clear that construction management organizations do not have exhaustive and precise information, especially regarding making long-term plans. It is possible to determine some parameter probability characteristics from experience or statistical data in certain situations of process’s research. But in other situations there is no data on which it would be possible to determine statistical peculiarities of parameters in risk-related and uncertain situations.

In practice probability parameters are considered to be known and equal to average of probable result. However, this substitution of probability processes with determined models is not always right. Stochastic programming is planning and management tasks which describe processes going under risk and uncertainty conditions, it examines tasks with random coefficients and finds solutions when the information on the task conditions is insufficient.

Due to the limitations chosen and lack of information the solution can be disastrous as rapid evaluation of possibilities might be misleading.

The aim of this article is to determine the way in which the choice of alternative solutions can differ if the volume of information is increasing and the accuracy of data is changing.

In compilation of stochastic problems and their analysis it is very important to know if it is necessary to get only one solution which cannot be changed or a solution which can be adjusted [7] according to newly obtained information (two-step and multi-step task).

Every construction project is unique, with unique data, environment and includes a high degree of information’s uncertainty. All construction projects experience the unexpected situations and uncertainties, due their implementation, what is why project managers must be ready for it. They must be supported by risk management to identify, analyze, control, and report risk.

[8] The project risk management explains this uncertainty phenomenon [9-10] using three basic sources [2, 4]:

- **Known-unknowns** are explicit assumptions or conditions which, if not valid, could have uncertain, significant consequences and can be analyzed and managed. Represent identified potential problems, such as possibility of a strike when a labour contract expires or enough rain to stall a construction project during winter. We don’t know exactly what will happen, but we do know it has a potential to damage our project and we can prepare for it;
- **Unknown-unknowns** are implicit assumptions or conditions which, if not valid, could have uncertain, significant consequences, i.e. the problems that arrive unexpectedly. These are “the ones you honestly couldn’t have seen coming”, but they can be expected and foreseen as a general contingency based on the project manager’s experience (competence and knowledge);
- **Bias** are systematic estimation errors which have significant consequences.

The bias are static risks, which will maintain their characteristics during their period of existence [6], but almost all other risks are dynamic and can change their probability and impact during the project life cycle [7]. Risks arise from uncertainty and are generally interpreted as factors which have an adverse effect on the achievement of the project objectives [3]. These are the reasons why project risk management must be a continuous process with feedback, from the beginning to the end of the project [2].

Many scientific works were completed analysing the classification of risk and uncertainties in construction [5, 11, 12]. Most of them emphasized, what risk classification process helps both to identify risks and to select the most appropriate risk management strategy [13, 14]. There are many different risks related to decision in construction, but most researchers agree with division of risks in either internal or external.

Smith [3] proposed to separate the more general risks which might influence a project but may be outside the control of the project parties from the risks associated with key project elements; these are referred to as global and elemental risks. Global risks [15] may be capable of being influenced by the principal or a part of government; political, legal, commercial and environmental risk. The
elemental risks are those risks associated with elements of the project, namely implementation and operational risks, and for some projects there will be financial and revenue risks [16]. These risks are more likely to be controllable or manageable by project parties.

2.2. Data precision tendencies and decision making in appraisal stage

Project appraisal is the early phase of the project cycle, and commences with the project inception and finishes at project sanction. Appraisal is an important stage in the evolution of any project because at the early stages of a project it is possible to make changes that are relatively cost-effective. It is important to consider alternatives, identify and assess risks, at a time when data are uncertain or unavailable [3] for further initiating of various projects to meet the overall objectives of the organization.

Appraisal phase can be subdivided into a concept viability and a project feasibility, both of which are determined under conditions of uncertainty (see figure 1). The initial viability decision requires the justification is the project realizable [17].

If the decision is that the project is not viable then there is no second decision to make, but if the project is found to be viable then the second decision is according to feasibility. The feasibility decision is to identify the particular form or appropriate option for the project out of all possible alternatives that is likely to be the most successful. The procedures in feasibility and design stages share the data used for specifying the calculations and reduce the bias of further calculations (like two-step or multi-step tasks in stochastic problem). As the project progresses through the appraisal phase the range of uncertainty is reduced as project options are either confirmed or eliminated, although at this stage the process still involves decision-making under conditions of uncertainty [18].

Colligated figure 1 [3, 17] shows an influence of the effectiveness of changes to cost of the changes both with the precision of estimated building cost values during project implementation [18]. Parameters established from the architectural concept of a project are calculated in alternative analysis. Many uncertainties occur while calculation process and a calculation precision can be ±30%. A project should be arranged in accordance with certain design specifications, which meet the owner’s requirements. In this case the calculation precision is increased up to ±20%.

Planning of the risk and uncertainty analysis begins during the appraisal phase as each successive decision provides a more detailed view of the project. The decision process is further complicated by the fact that this must take place as soon as possible after the inception of the project, which usually coincides with the time of maximum uncertainty about the project.

While designing according to the data of a technical project the following questions are being solved:

- Local decisions for designing are being made (identification of missing information and supplementing the project with local decisions);
- A variance/variability designing is performed: it is being searched for a rational set of building’s constructional versions with alternative analysis.

Risk management operate throughout the project life cycle but a disproportionate part occurs during the appraisal phase. During appraisal, a relatively small amount of money is invested to fund the work of the project management team. However the solutions choose and decisions made in this stage have crucial influence to whole implementation of the project and need to be done by qualified person with high level of expertise and responsibility.

There is no standard method for making this decision, a wide range of tools and special techniques [19] are available to assist the project manager by providing better information. Ustinovičius [16],[20] stated what this is serious problem to decision support approaches, because it is not clear which method fits a particular construction problem better [21]. Scientists in their research noticed what it is important to choose right
normalization method and to follow up with this point it must be done according to the problem objectives, special requirements and with regard to possible inaccuracy or uncertainty threats [6]. At the end best computer techniques and the comprehensive analysis will be just support to the final decision has to be made by the project manager within the overall strategy of the company and goals of the project [3].

2.3. Need of reducing the risk and uncertainty

A traditional construction project can be described as a model covering all stages of its implementation [22], [23]: development and planning, design and economic assessment, tender and negotiations, construction and handover, maintenance and utilization. In these stages certain participants (Customer, costumer’s representative, department, designer, contractor, investor or owner) perform the appropriate actions. The information collected through earlier stages [24] is transferred to the next stages.

The lack of information exchange among the project participants negatively affects the implementation of the construction project [2]: increasing the execution times, being the reason for the demand of non-scheduled resources, including ruined human resource management (HRM) and planned resource supply chain.

It is possible to imagine technical, economical or a daily life situation where the consequences of not fulfilling of one or another restriction can be very unwelcoming or even tragic. In the model of such tasks it should be required that a set of variable parameters would satisfy all project’s limitations in a presence of any kind of fortuitous coefficients.

Kleim and Ludin [8] spotlighted several factors what can raise risk: team size; history and project similarity; staff expertise and experience; complexity; management stability; time compression; resource availability. Uncertainties often rise due to the lack of qualification and competence of the personnel from the project manager’s team. Qualification and competence of EU workers has been reviewed and the importance of appraisal and planning processes has been emphasised in The Leonardo Da Vinci project [1] “Recognition of needs and creation of the professional training in the area of the preparation and management of infrastructure construction projects financed by the European Union”.

So the uncertainty in undertaking a construction project comes from many sources and often involves many participants in the project [17]. Since each participant tries to minimize its own risk, the conflicts among various participants can be crucial to the project. Failure to recognize this responsibility by the client or project manager often leads to undesirable results. Uncertainties related with Force Major situations cannot be evaluated in project evaluation, because the factors of an influence can be disastrous and the project won’t be available to implement.

Estimation and evaluation of uncertainty are core tasks in any decision support process [19]. The greatest influence to construction cost estimation (appraisal procedures) occurs at the front end of the project (illustrated in Figure 1) [2].

Migilinskas, Ustinovičius and Popov noticed that sometimes assumptions made by designer during the conceptual and design phases may, restrict the best and most cost-effective solutions from being utilized [22]. Estimation can’t foresee all deflections from evaluated project especially changes of construction cost and implementation time. If the client can derive reasonable profits from the early operation of a completed facility, the project is considered a success even if construction costs far exceed the estimate based on an inadequate scope definition. However, inadequate planning and poor feasibility studies can lead to unsuccessful and abandoned projects.

2.4. Solutions to reduce an influence of the risk and uncertainty

Construction project can be described as a unique set of co-ordinated activities, with a definite start and finish, performed by an individual or organisation to meet specific objectives with defined schedule, cost and performance parameters. It is dynamical process constantly influenced by various factors and treats. Risk management is the systematic practice of identifying and reducing the uncertainty threats that exist in the project and the project’s environment [10] during whole project life cycle. Risk management is to make better decisions on a real project under conditions of uncertainty. It is a continuous and dynamic process which is necessary from project initiation until project conclusion, although what tends to be thought of as conventional risk management is undertaken in the early stages of a project [3],[12]. Furthermore, the concept of risk taken into account is as an uncertain event that, if it occurs, has a positive (opportunities) or negative (threats) effect on a project objective. The origin of risk is the uncertainty inherent to any project, and every risk is associated with (at least) a cause, a consequence (if it occurs), and the probability or likelihood of the event occurring [9].

What is why risk management is the means by which uncertainty is systematically managed to increase the likelihood of meeting project objectives. The key word is systematic, because the more disciplined the approach, the more we are able to control and reduce the risks [10]. This type of risk management approach can be implemented using unambiguous contractual obligations with risk divided between client and contractor.

Building management realization according to traditional Construction contract (described in FIDIC RED book) only partially can solve the issues mentioned above [25]. This can be done on condition that the General contactor (or a costumer representative – a technical supervisor) takes all the responsibility for the organization and control of those who perform the work, which should be done according to a documentation prepared by designers and approved by the costumer. It is a more positive situation when a building project is
realized in accordance with Design-Build (described in FIDIC YELLOW book) or Turn-Key (described in FIDIC SILVER book) contracts. In these cases project stages, chain processes, responsibility for the work performed, and the management are clearly defined by contractual obligations and are exercised by a responsible contracting organization. Only Turn-Key contract describe obligations to the Contractor to accept all the project’s risks. Alternative analysis and decision making before the work phase is most often met while performing according to Design-Build and Turn-Key contracts [25].

During the period of the realization of these projects the alternatives should be analyzed, rational and effective decisions upon building project should be made in accordance with customer’s requirements and design conditions. Automated and prepared-in-advance means for making these decisions should be applied.

One of the solutions to solve problem of uncertainty is the development of a construction execution plan preparation is very much analogous to the development of a good facility design. The planner must weigh the costs and reliability of different options while at the same time ensuring technical feasibility and make a decision [17]. Construction planning is more difficult in some ways since the building process is dynamic as the site and the physical facility change over time as construction proceeds.

The development of formal risk management processes has been main subject of much interest recently. The Association of Project Managers (APM) have developed Project Risk Analysis and Management (PRAM) [4, 8, 17]. Prepared using typical pattern for risk management systems, PRAM defines a number of phases of risk process description. The Institution of Civil Engineers and the Faculty and Institute of Actuaries [2, 26] prepared comprehensive process of Risk Analysis and Management for Projects (RAMP), designed to cover the complete project lifecycle. The architecture for RAMP follows a more complex multi-level breakdown structure. Scientists and authors of article generate a specific attitude on the processes of project management under risk and uncertainty [3, 17, 22, 27]:

- The "life cycle" of costs and benefits from initial planning through operation and disposal of a facility are relevant to decision making. Construction costs represent only one portion of overall life cycle costs.
- In corporate business can be several alternative projects competing for available resources. A choice or prioritisation of projects according organisation priorities and strategic goals has to be made.
- Optimizing performance at one stage of the process may not be beneficial overall if additional costs or delays occur elsewhere, the analysis of all scope of project is advisable.
- Fragmentation of project management among different specialists is necessary, but good communication and coordination among the participants is essential to accomplish the overall goals of the project.
- Productivity improvements are always of importance and value. As a result, introducing new materials and automated construction processes is always desirable.
- Quality of work and performance are critically important to project’s success (especially for owner).

A constructively simple approach to estimating [28] uses a decision support modelling paradigm based on project risk management and operational research concepts [4]. It employs probability models selected from a set of alternative stochastic models of uncertainty with a view to maximizing the insight provided, given an appropriate level of complexity [2]. Ranking of alternatives under uncertainty is fundamentally important in decision-making process [11], especially at the multiple criteria decision-making situations. To compare the construction projects and to select the most economically effective project implementation alternative [16] advisable to use the multiple criteria decision support software [5]. Decision making problems have always been especially significant for any state, company or individual at any level of management, either strategic or functional [16]. Therefore, much time and energy have been expended in investigating these problems all over the world [29].

Project management techniques are methods for reducing uncertainty and, therefore, improving our odds of success [10],[19]. Project management techniques reduce risk in three fundamental ways:

- Active planning and future simulation (when you can see the future, you improve your odds dramatically).
- Early problem recognition (structured tools of project management recognize problem earlier).
- Improved communication (common cause of project failure is communication breakdowns).

3. Methodology, analysis and implementation

Construction consulting and contracting company can fill the information lack ensuring coordination works and information feedback in development, design and construction stages [30]. In order to determine theoretical values of the project’s parameters during appraisal phase as precisely as possible and to reduce errors in the field of construction, the use of Product Lifecycle Management (PLM) [28, 31, 32] or the so-called four-dimensional (4D) concept [22] is recommended. The feedback from the participants is ensured by using a 4D concept for the management of construction projects combined information flows inside enterprise [27].

The exact demand for project resources can be established due a thorough calculation of the project-related quantities. In most cases this manual work is time-consuming. To reduce the time needed for this the calculation of the required quantities and to avoid mistakes and inaccuracies caused by manual calculation, the 4D concept model can be used. Main conclusion of the previous research of Migilinskas and Ustinovichius is
– the time saved to complete calculation procedures using 4D concept, compared to calculation procedures made in ordinary way, can be used for managing a larger amount of construction project tenders with a possibility to perform a more thorough analysis and a comparison of more alternative solutions for each construction project [22], [27].

Matching of building component selection and the choice of building component is met in every process of design [29]. The selection of building component parts can be performed by choosing several suitable composition alternatives from the available solutions of structural elements from “tree” shape database. The generation of these variants is called synthesis of alternatives. This type of solution for the evaluation of alternatives is used for analysis in this article.

The object of the analysis is the main constructive elements of a six-storey social-administrative building (entire building area is 1440 m²). Three different versions of frame structure are designed for the analysis of architectural building conception: 1) masonry brick structure with hollow core prefabricated slabs; 2) Cast on site monolithic frame; 3) prefabricated ferro-concrete structure.

The first frame building model construction contains prefab ferro-concrete foundation, supporting constructions (brick wall of silicate bricks), hollow core prefabricated concrete slabs, and gable roof with tin cover. The second frame building model construction contains monolithic pile foundations and monolithic grillage, supporting reinforced ferro-concrete monolithic constructions (round section columns, walls of staircases and slabs) and a flat roof with bituminous cover. The third frame building model construction contains prefabricated cup-type foundation and grillage joists, the supporting prefabricated reinforced ferro-concrete constructions (square section columns, beams, walls of staircases, hollow core slabs) and a flat roof with bituminous cover.

As shown in figure 2 manually gathered data is collected by a general calculation pattern from conceptual building schemes. Data for analysis a pre-generated automatically from 3D format building models’ technical specifications, which were created by Bentley Structural. Work amounts are obtained and estimated values of building model are calculated from the established specifications. Labour expenditures, payment, material and machinery demand are brought to attention in the analysis of economic parameters of a project. Also, a work process timetable is designed and the building duration is established. Site expenditures are determined for every building according to its building duration and other parameters.

By an application of multi-criterion synthesis an opportunity to make a right decision is given to decision maker. It is done when several different possibilities need to be evaluated [33]. In general, it is not possible to determine a solution which would be the most rational in all aspects while dealing with this kind of tasks.

![Fig 2. Creation of building models by using regular (manually) and automated (computer aided) procedures.](image)

Thus, those multi-criterion methods which do not require the objectively best solutions (if they exist at all) have been selected. The main task of the multi-criteria synthesis is to link various tasks into a general project.

In the case of uncertainty and risk the appropriate methods and rules are used to find optimal strategies. Some works [5, 21] describe these main decision support stages: the formation of a matrix of alternatives, the selection of criteria, the selection of optimum criteria, the validation of criteria compatibility estimated by experts, decision matrix normalization, evaluation of alternatives rationality, multicriteria evaluation and the final decision.

Current software packages cannot handle the inherent subjectivity in risk assessment effectively, nevertheless decision-making process must be supported with developed software for multiple criteria evaluation of alternatives in construction.

4. Evaluation of alternatives and analysis results

In this paper, the research is focused on the integration of multiple criteria decisions into computer-aided modelling-management-evaluation systems as well as using the algorithm of the synthesis methods [29], for combining several construction projects or a few phases of design stages into a joint system [24] (see figure 3).

The researchers Peldschus, Zavadskas, Ustinovichius developed decision support software LEVI 3.0 [5]. Using this software, it is possible to find solutions to problems by different methods, to compare the
construction projects and to select the most economically effective project implementation alternative in construction industry [30, 34]. LEVI 3.0 can evaluate the effects of the application of different methods of transformation on the numerical results and improve the quality of transformation as well as ensuring precise solving of technological and organizational problems (tasks). This application with usage of the appropriate transformation methods allows avoiding inaccuracies in assessing the alternatives of construction projects [6]. Therefore, all the information should be accumulated in the building databases for further construction and facility management.

After completion of the analysis the following results were obtained (in both cases calculations done by competent executor and no influence of human factors were under consideration in made analysis):

1. From figure 4 compared specifications for 3D building models created with Bentley Structural and the same building model specifications created manually (for building models with different mainframe solutions):
   a) Countable labour expenditure values of building model differ from -3,998% to +10,192%;
   b) Countable payment values of building model differ from -4,08% to +10,193%;
   c) Countable material expenditure values of building model differ from -8,839% to +10,200%;
   d) Countable machinery expenditure values of building model differ from -10,191% to +1,171%;
   e) Countable site expenditure values of building model differ from -3,069% to +10,197%;
   f) Countable building model construction leghts differ from -18,180% to +25,000%.

2. Approximately, 35% of time for calculation is saved in creation of quantity specifications.

3. Calculation of construction amounts during appraisal phase additionally requires 5-10% of reserve for estimated direct costs. Whereas having amounts of work generated from 3D model may be taken without additional reserve.

4. In the diagram the intermediate values (except extreme values <1% and >8%) are varying from -5% to +5%. The average of absolute values is about 2,8-3,5%.

5. Summary and conclusions

Uncertainty and risk management is still a problem area in the construction industry. In article, it was explained the appraisal procedures and solutions for decision making in construction under the conditions of risk and uncertainty. The following solutions were made to manage risk and uncertainty in construction during appraisal phase:

1. Categorizing and classification of risks can help to determine the source, relative importance, and their impact to the project [8].

2. It is advisable to use the computer-aided design systems (according to 4D concept) [22] and simulation of construction process to foresee and reduce both risks and uncertainties related with project’s cost and time;

3. The discipline of project management can help to reduce required costs and amend the quality of the result.

4. Project communication systems [26] must be improved and built upon common terminology, standards, defined metrics of measurement and consistent knowledge of processes and procedures.

5. It is advisable to use the multiple criteria decision support software LEVI 3.0 as a powerful tool for choosing the effective construction project alternatives.

Suggested solutions for dealing with the risk and uncertainty problems can fail to meet the needs of project managers. That is why an essential aspect of project evaluation is the reduction of risk to a level which is acceptable to the investor (client). This process starts with a realistic assessment of all uncertainties associated with the data generated during appraisal phase. Therefore uncertainty management must be made on thorough preparation from very beginning of project and last for whole project life cycle.
References


