

## RELIABILITY, RISK MANAGEMENT, AND CONTINGENCY OF CONSTRUCTION PROCESSES AND PROJECTS

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**Abstract.** The paper presents the evolution of concepts, an overview of research and applications pertaining to reliability in construction production, the use of reserves, robust itineraries, and contingency of time and cost. It describes areas of management advisory systems in relation to the cycle of risk analysis. The article also presents the main trends in different approaches to risk management in construction and construction project processes, such as reliability of production, discount methods, methods of reporting, integrated management together with trends towards standardisation of the investment process management. The discussion is embedded in the specific context: the achievements of trilateral academic colloquia, with participation of Lithuania, Germany and Poland, and a review of work by Professor Kapliński, the chair of the Polish delegation to the aforementioned colloquia.

**Keywords:** construction processes, construction projects, reliability, risk management, review.

### 1. Introduction

Risks that emerge from inability to keep deadlines and remain within the budget are important to all participants of an investment process. Recently, a vast number of researches and investigations were dedicated to this topic aiming to determine effective risk management measures.

In some cases, articles do not seem to consider the available research results. However, this could be explained by the complex nature of construction projects, which means that the focus of a research may depend on the type of a project, operational conditions, the particular phase of an investment project, the point of view (of the process subject), the manner of organisation, and etc.

Development of risk analysis methods reveals an interesting evolution of notions, methods and cases. This evolution can be traced back to the first results of the tripartite academic colloquia, which were comprised of academic centres of Vilnius (namely, VGTU, formerly known as VCEI), Leipzig (HTWK, formerly – THL) and Poznań (the University of Technology) since 1986. The meetings not only focused on such topics as selection, multicriteria optimisation and decision-making tools, but also discussed the issues of reliability of production and risk management in construction industry. Professor Oleg Kapliński has significantly contributed to the development and application of the latter. The paper briefly describes achievements of these colloquia and presents the overview of work by Professor Kapliński, the active member and the chair of the Polish delegation of the colloquia since 1989.

The colloquia were initiated by Professor Zavadskas, whose achievements have been described in a number of publications (e.g., Kapliński 2009a, b). Held biennially, the colloquia have left behind a trail of studies and summaries such as Zavadskas and Kaklauskas (2001), Kapliński *et al.* (2004), Kaklauskas *et al.* (2005), Peldschus *et al.* (2006), Zavadskas (2008), Peldschus (2009). As the result of the most recent colloquia (in 2009 and 2011), which stressed the issue of Operational Research in the context of sustainability, the *EURO Working Group OR in Sustainable Development and Civil Engineering (EWG-ORS DCE)* was established – c.f., Kapliński (2010) and Tamošaitienė *et al.* (2010). Furthermore, several joint colloquia resulted in dozens of jointly published books and articles in Germany, Poland and Lithuania. Besides, the meetings inspired a number of dissertations. Members to the colloquia also acted as reviewers of PhD theses.

The outstanding personality and contribution of Professor Oleg Kapliński (Fig. 1) to all colloquia has been invaluable. Born in Vilnius on 15 June 1942, he graduated from the Faculty of Civil Engineering of the Poznań University of Technology (PUT) in 1965. It is in this University that the Professor worked as the Head of the Department of Construction Engineering and Management for thirty years. Recently, he was re-elected as a member of the Committee on Civil Engineering and Hydroengineering of the Polish Academy of Sciences for the fifth term of office. For a number of years, the Professor has been in charge of the Section for Civil Engineering

Projects of the Committee. In the winter semester of 1985, he was a guest lecturer at the Vilnius Gediminas Technical University (known as Vilnius Civil Engineering Institute at the time), which awarded the Professor an honorary doctorate in 1996. At VGTU, he supervised nine PhDs. In addition, the Professor is an international member of the Building Academy in Kiev. Works by Professor Kapliński have been presented on several continents. 240 works including 11 books have been published. His areas of interest include construction industry production management, construction process modelling and theory of decision-making.



Fig. 1. Professor Oleg Kapliński

In 1967, the first research by Professor Kapliński was devoted to application and development of network and mathematical methods for organisation and planning of a construction site. This later developed into two books (Kapliński, Stefański 1970; Kapliński, Skarzyński 1973). The book on network methods has three editions and countless citations. His PhD thesis was on the subject of transport and assembly of prefabricated elements. In the history of Poland, it was the first practical application of the theory of queues in construction industry. He defended his post-doctoral dissertation on balancing construction processes under stochastic conditions (Kapliński 1978) at the Krakow University of Technology.

His academic work focused on methodology of research, analysis and reasoning of the phenomena of expectation and balance; he researched the principles of balancing and concentration under stochastic and unspecified conditions. In further research, he developed the subjects of reliability of production, the use of expert systems and hybrid methods. Later, he researched issues of governance including risk management, integrated management and the use of information technology (IT); and finally, the standardisation of the management process in the investment process. Some of these topics are discussed below in the context of the above mentioned colloquia.

## 2. Reliability of production processes

The first cases of risk assessment discussed at the tripartite academic colloquia were based on reliability. Naturally, the methods evolved. Some elements of reliability theory are effectively used to analyse the time required for implementation of technological processes. Initiation

dates of processes were also studied, as well as buffering (introducing time reserves) (Borucka, Kapliński 1982; Kapliński 1997; Kapliński, Zavadskas 2002). Such issues as non-uniformity of production (Kapliński 1993a, 1997), material supplies (Kaklauskas *et al.* 2007), the impact of weather conditions on work technology (Pasałowski 2003, 2010), the accident rate in construction industry (Kapliński 2002a; Zavadskas, Vaidogas 2008, 2009), and selection of implementation options (Shevchenko *et al.* 2008; Vaidogas, Zavadskas 2007; Zavadskas 1996) were researched as well.

Although initially Professor Kapliński focused on methods of reserving or redundancy, later he also considered such issues as serious time-lag or inertia (Kapliński 2001a, b). Inertia is usually treated as elapsed time from the onset of a breakdown to the system's inability to work. The phenomenon of inertia often occurs in accessory production and is rarely recognised as an excellent tool for increasing reliability. In the course of further research under the supervision of Professor Kapliński, the risk analysis was extended to reliability of operation of systems (e.g., production systems). A simulator was built to consider the series structure. It allowed ascribing any structure and delay to every single element (phase) of the system. Every element worked in two states: work (ability) and disability. The method not only required defining the system structure, but also the types of distribution of those two states for each element of the system formatted in a dry way. As final effect, two distributions could be achieved: proper work of the system and breakdowns of the system. The idea of this extended method is presented in Fig. 2. The method is described in Kapliński (1985a, b, 1997), Kapliński and Miłosz (1996). Three stages of the modelling procedure (TMT) – which is consistent with the induction method much needed for research on production – are presented on the left side of Fig. 2.

## 3. Reliability and contingency

Kapliński (1974) proposed a method for determining time reserves – delays in the integration of successive sequences of processes within the Flow Line Method. His works were published much earlier than the Critical Chain Method (Goldratt 1997). Since then, the Theory of Constraints on the Reliability Theory prevails in applications for the organization of production. The way this subject matter was developed is presented in Fig. 3.

Prevention of disturbances in deadlines of scheduled work still relies on various types of reserves, mainly reserves of time. This is crucial for design of heterogeneous processes. These methods gained a greater status thanks to the development of heuristic methods and measures ensuring robustness of schedules.

The work on robustness continues, as exemplified by predictive/proactive scheduling and reactive scheduling. The most valuable direction of research in this area is predictive/proactive scheduling under a limited availability of resources. Resource-Constrained Project Scheduling Problems (Lambrechts *et al.* 2008) could be a good example of such work. In Poland, work by Klimek is noteworthy, including the PhD thesis (Klimek 2010).

In consequence, these approaches allow determining time contingency. This applies especially to time buffer allocation at the end of processes (the end of the project). The above mentioned direction of development results in contingency of resources, including – above all – costs. In the engineering practice (practical aspect of investment), contingencies have the following meanings:

- Contingency period means extension of the time of project implementation, which the contractor should accept at an assumed level of risk.
- Contingency amount means an amount of money which a contractor should have saved as a form of collateral in view of project implementation, assuming a certain level of risk.

Contingency is given a slightly wider angle in the overall project risk management. In this case, other aspects are also taken into account, in accordance with the cycle of risk analysis, as shown in Fig. 3. Two concepts are utilised here: *contingency plan* and *contingency budget* (Kapliński 2010; Kapliński et al. 2011a, b). This line of research is promising and has an important practical aspect (Paślawski 2008a, b, 2009; Nassar 2002; Burger

2003; Barraza, Bueno 2007; Sonmez et al. 2007; Kasproicz 2004; Jaśkowski, Biruk 2011a, b).

#### 4. Management of construction projects

##### 4.1. Application of expert systems and hybrid methods

The publication by Kapliński and Hajdasz (1987) was an attempt to merge reliability with design work and expert systems. Collaboration with Lithuanian colleagues resulted in a number of joint publications, such as Kapliński and Zavadskas (1997), and Kapliński's book with co-authors (Zavadskas et al. 1995). It was the first book on applications of expert systems in construction industry in this part of Europe. At the same time, Professor O. Kapliński's team was working on combined methods, which were later identified as hybrid methods (Kapliński 1985a, b). They emerged in response to criticism regarding the "pure" expert systems, which were believed to have little utility in construction practice. Hybrid approach was proposed instead, as reflected in subsequent publications (Kapliński 1990, 1993b, 1997).

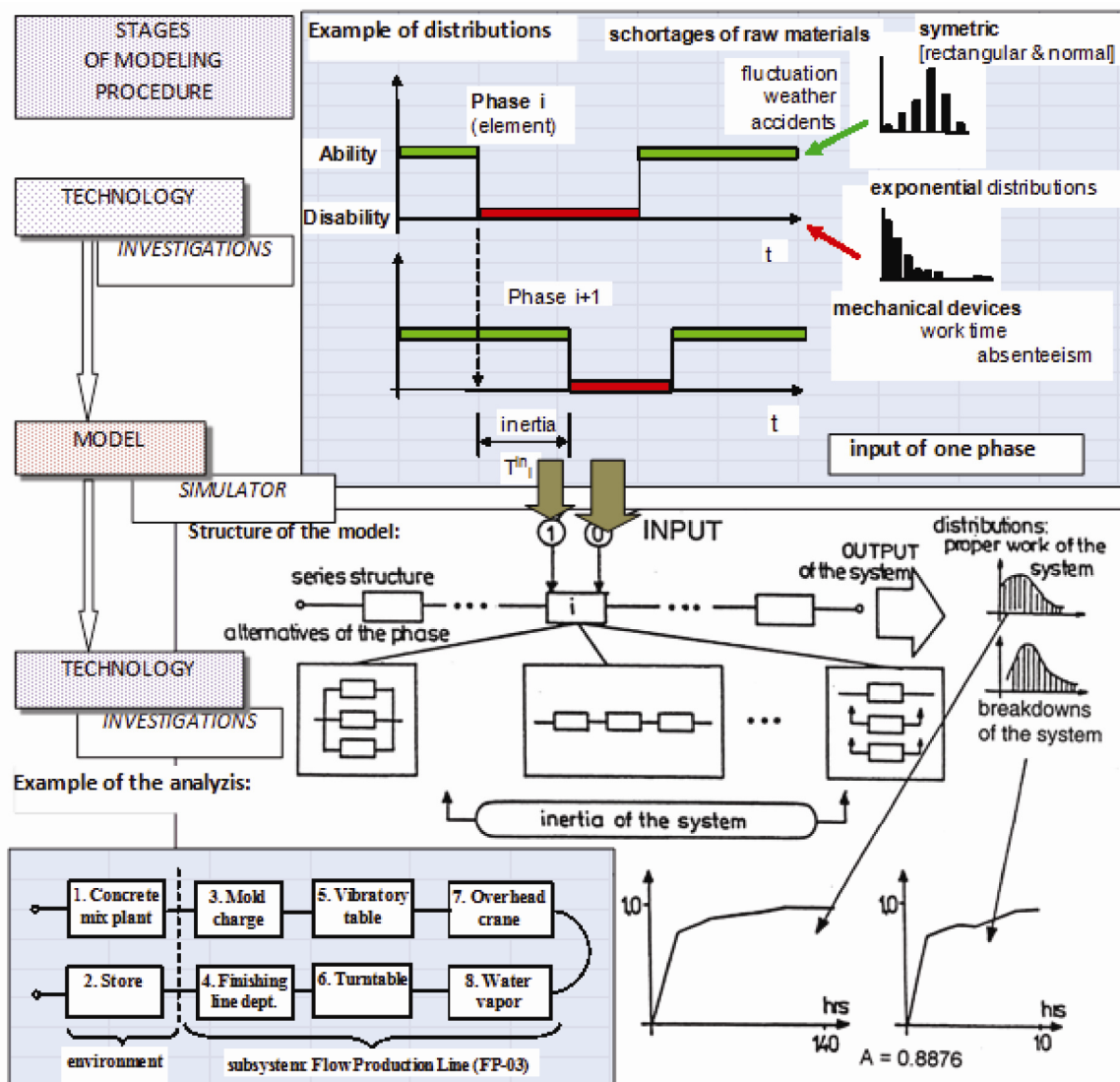


Fig. 2. Synthesis of the extended method of testing reliability and operation of production systems (Kapliński 1978)

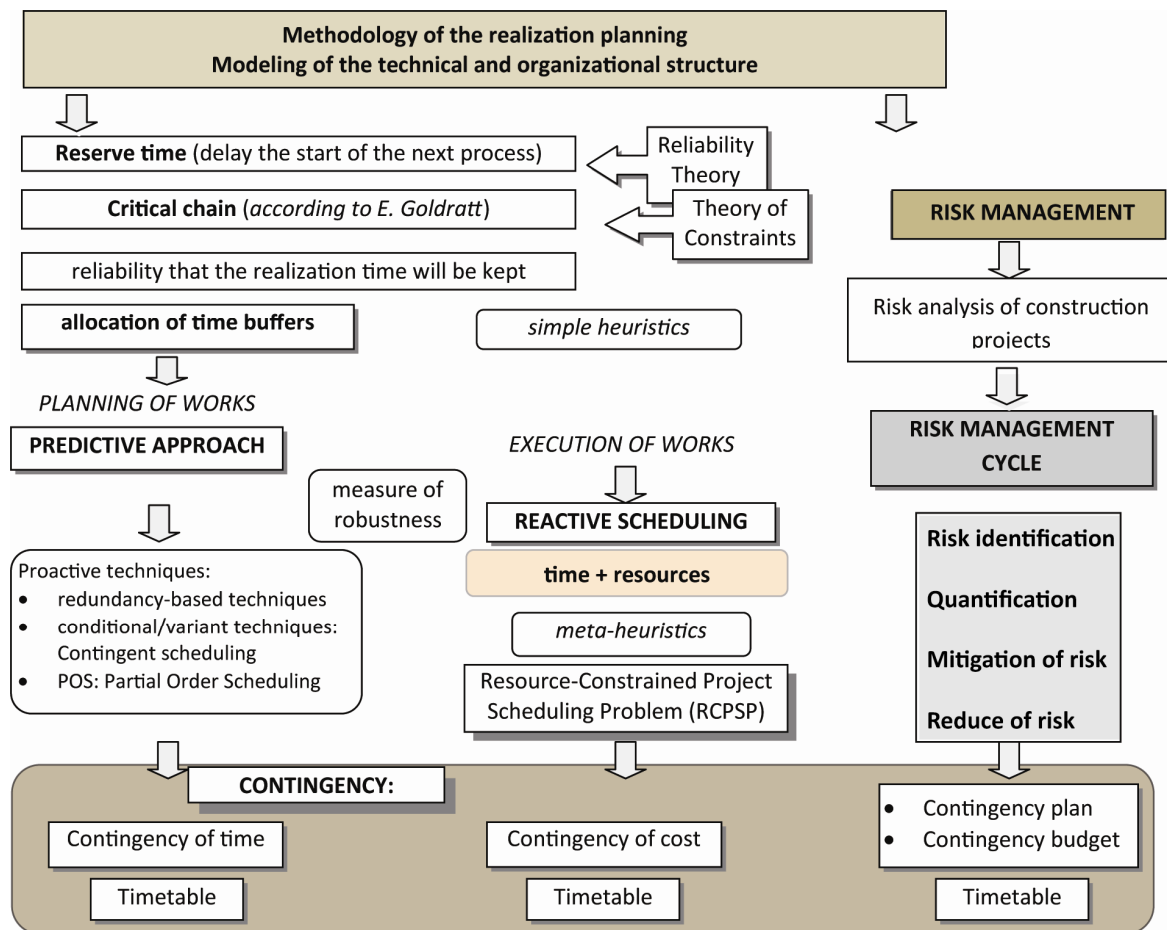


Fig. 3. The evolutionary path between reliability and contingency (Kapliński 2007)

Further research focused on advisory systems. An advisory system is a developed and specialised form of an expert system. Such systems are usually hybrids by nature. The team built a hybrid advisory system for the purpose of repairing concrete industrial floors (HASRICF) (Gajzler 2008a, b). The system, basing on answers provided by the user during a dialogue, generates conclusions and informs about the possible material and technological solutions, as well as costs and corrective algorithms. The HASRICF advisory system is based on system modules. The most important of those are: a knowledge base (in the form of fuzzy, rule base), a database, an inferential mechanism that uses ANN, and a dialogue interface. While the inferential mechanism in the form of ANN has proved to be an effective solution, the knowledge acquisition form requires amelioration. At present, a solution is sought for in the group of automatic acquisition methods (data/text mining, induction of rules from decision trees) (see Gajzler 2010).

The hybrid approach allows incorporating a wide range of Multiple Criteria Decision Making (MCDM) methods. Review of the applications of these methods was given by Zavadskas and Turskis (2011).

#### 4.2. Risk management

The tripartite academic colloquia especially focused on the risk management topic. In view of project management, different approaches were presented (i.e., Kapliński

*et al.* 2002; Kapliński 2002b; Dziadosz, Kapliński 2008; Dziadosz 2010; Zavadskas *et al.* 2010; Meszek, Dziadosz 2011). The team constantly worked on devising various risk management instruments (i.e., Kapliński, Thiel 1990; Kapliński, Meszek 1992; Paslawski 2003).

Identification of the so-called risk factors is of major importance in risk analysis. The risk factors and relationships between them are significant concepts in risk management. COMPASS (prepared in U.S., 1996) was one of the first methods for early identification and control of risk factors. It was a type of Decision Support System that covered four modules (Hastak *et al.* 1996). The year 2000 brought further interesting methods, such as RAMP and ICRAM. RAMP is a systematised process of identification, assessment and risk management in investment processes (RAMP 2005). ICRAM is used to analyse risk at international construction markets. Three risk levels were introduced, i.e. macro, market and project levels (Hastak, Shaked 2000). MOCRA (Method of Construction Risk Assessment) was developed in Poland (Skorupka 2005). It uses an idea suggested in the ICRAM method. This method is accompanied by two tables:

- correlation of construction project operations with risk factors,
- hierarchy of risk factors (AHP).

In consequence, the analysis allows defining the differences between forecasted time and costs and real time

and costs. Two alternative schedules are then offered. Sometimes, such solutions are controversial, particularly in cooperation with subcontractors. The evaluation of alternative schedules was presented in Kapliński (2010).

The following concepts are related to the notion of *risk management*:

- *the risk of bankruptcy*, for example of a building company. An assessment of such a risk using scoring methods was presented in (Kapliński 2008b);
- *the approach to risk (aversion or disposition to risk)*. The use of utility theory and conditional probabilities in this regard is also presented in the last work by Kapliński (2012).

The above presented issues belong to a separate area of research and apply not only to the area of economic evaluation, but also to the psychology of a decision making.

#### 4.3. An attempt at a comprehensive approach

Experience suggests the need of an extended project risk analysis. This analysis arises in an evolutionary way. A number of trends can be identified here. First of all, the above discussed production reliability trend. Discount methods provide a different outlook, i.e., *Net Present Value* or *Value at Risk*.

Another interesting trend is based on the analysis of current network models, together with the *Earned Value* (EV) and *Earned Schedule* (ES) models. While discount methods are more useful to investors, EV and ES methods are more useful to contractors. These aspects are also presented in publications (Kapliński 2010; Kapliński et al. 2011b). It is significant that there is a need to extend this approach with the introduction of integrated management, including such systems as *Enterprise Resource Planning* (ERP) and *Business Intelligence*. However, it may take a long time before building companies will fully implement such systems (Kapliński 2008a, 2009c, d).

#### 4.4. Standardisation in investment process management

Investment process is mainly affected by current legal regulations. Due to randomness of events and a desire to unify procedures, there has been a shift towards standardisation and clear, simple guidelines and rules of conduct. There is a tendency to disseminate knowledge in the following areas: project management, use of PMBOK®/PMI and PRINCE2 – methods for controlling work progress, standard contract conditions (including FIDIC), which leads to integrated management.

The new management paradigm (based on process management) fosters identification and quantification of risk. Nonetheless, it has become necessary to simultaneously manage the company and risk itself.

Terms of contract – which are a part of international standards – not only necessitate adoption of an appropriate organisational structure, but also indicate the areas of responsibility and the way risk is shared. The most recent

research results in this area are provided in the publications (Kapliński 2011; Kapliński et al. 2011 b).

#### 5. Final remarks

The review of achievements by Professor Kapliński should be supplemented by publications synthesising knowledge and achievements of other participants of the colloquia. The most significant are the articles and books on processes and construction project modelling (Kapliński 1997, 2005, 2007; Kapliński et al. 2002). In addition to articles evaluating the colloquia, there are publications focusing on assessment of the academic community working in this area, including evaluations of promotional work (Kapliński, Zavadskas 2002). The syntheses of academic heritage of other prominent colloquia members were also presented in Kapliński (2009a, b), Kapliński and Peldschus (2011a, b), Kapliński and Tamošaitienė (2010), Kapliński and Tupenaite (2011). These publications reveal the evolution of concepts and methods aimed at resolving the risk management problem in construction industry.

This overview shows that the risk can be analysed depending on a context. Risk should be treated as a state, in which there is a possibility of a loss. One of the most relevant concepts of risk is the dispersion of actual and expected results. This concept leaves room for contingency.

Processes in construction industry, as well as implementation of construction projects are governed by specific laws. The need to standardise legislation results from international cooperation in the execution of contracts and requirements of banks. This promotes standardisation, especially at the stage of preparation for and implementation of investments.

Efforts to create standards in planning and implementation of construction project activities allowed for elimination of such phenomena as instability of processes, unreliability, decrease in quality, unpredictability of events, and etc. Further research should be continued in this direction.

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## STATYBOS PROCESŲ IR PROJEKTŲ PATIKIMUMAS, RIZIKOS IR ATSITIKTINUMŲ VALDYMAS

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Santrauka

Straipsnyje pateikiama koncepcijų raida, mokslinių tyrimų ir taikomųjų programų, susijusių su statybos produkcijos patikimumu, atsargų, patikimų maršrutų bei laiko ir lėšų naudojimo nenumatytais atvejais, apžvalga. Aprašomos valdymo konsultavimo sistemų sritys, atsižvelgiant į rizikos analizės ciklą. Straipsnyje taip pat apžvelgiamos pagrindinės skirtingų požiūrių į rizikos valdymą statybos ir statybos projektavimo procesų metu tendencijos, pavyzdžiui, gamybos patikimumo, diskonto metodai, atskaitomybės metodai, integruotas valdymas bei investicinio proceso valdymo standartizavimo tendencijos. Diskusija pateikiama specifiniame trišalio akademinio bendradarbiavimo, dalyvaujant Lietuvai, Vokietijai ir Lenkijai, bei Lenkijos delegacijos pirmininko profesoriaus Kapliński pasiekimų kontekste.

**Reikšminiai žodžiai:** statybos procesai, statybos projektai, patikimumas, rizikos valdymas, apžvalga.



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