WARSAW UNIVERSITY OF TECHNOLOGY Index 351733
FACULTY OF CIVIL ENGINEERING
COMMITTEE FOR CIVIL AND WATER ENGINEERING
POLISH ACADEMY OF SCIENCES ISSN 1230-2945

DOI: 10.24425/ace.2023.144191

ARCHIVES OF CIVIL ENGINEERING

Vol. LXIX ISSUE 1 2023

© 2023. Paulina Kostrzewa-Demczuk, Magdalena Rogalska. pp. 613 –626

This is an open-access article distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives License (CC BY-NC-ND 4.0, https://creativecommons.org/licenses/by-nc-nd/4.0/), which permits use, distribution, and reproduction in any medium, provided that the Article is properly cited, the use is non-commercial, and no modifications or adaptations are made.

Research paper

Planning of construction projects taking into account the design risk

Paulina Kostrzewa-Demczuk[1], Magdalena Rogalska[2]

Abstract: Complex construction projects require appropriate planning that allows for time and cost optimization, maximization of the use of available resources and appropriate investment control. Scheduling is a complicated process, due to the uncertainties and risks associated with construction works, the paper describes the development of the scheduling method traditionally used in Poland, based on data from KNR catalogs, by using the RiskyProject Professional program. In the RiskyProject Professional program, the risk and uncertainty with reference to a specific construction project were modeled, and the calculation results were compared with the real time of the project implementation. The conclusions from the work carried out confirm that the SRA (Schedule Risk Analysis) analysis of the base schedule allows for a more faithful representation of the actual conditions of a construction project. The probability of investment realization generated on the basis of the SRA analysis may be assumed at the level of 75÷90%.

Keywords: project delays, project management, risk, risk management, schedule, Schedule Risk Analysis

[1]PhD., Eng., Kielce University of Technology, Faculty of Civil Engineering and Architecture, Al. Tysiąclecia Państwa Polskiego 7, 25-314 Kielce, Poland, e-mail: pkostrzewa@tu.kielce.pl, ORCID: 0000-0002-8052-1214
[2]DSc., PhD., Eng., Lublin University of Technology, Faculty of Civil Engineering and Architecture, Nadbystrzycka St. 40, 20-618 Lublin, Poland, e-mail: m.rogalska@pollub.pl, ORCID: 0000-0001-8408-3242

1. Introduction

Complex construction projects require appropriate planning that allows for time and cost optimization, maximization of the use of available resources and appropriate investment control. In the process of negotiating construction contracts, it is required to specify the time of investment completion and the date of its completion. The result of failure to meet the agreed project implementation time for the Investor are financial losses (caused by a delay in obtaining revenues that were to be generated by the investment), and for the Contractor, an increase in overhead costs and the burden of contractual penalties [1].

Planning the implementation of construction projects is called scheduling. It is a complicated process due to the uncertainties and risks associated with construction works [2]. The schedule, like the construction cost estimate, is one of the most important design documents. Unfortunately, the construction practice shows that there are delays in relation to the adopted base plan when carrying out various types of investments. Many researchers around the world point to the discrepancies in the schedules of construction projects in relation to their actual course [3–5] and are looking for more effective scheduling methods [2, 6, 7].

Rhodes [8] and Flyvbjerg [9] indicate in their work that 9 out of 10 global mega-projects are delayed, which results in a significant increase in investment costs. Scientists emphasize that the time and cost of implementing public-private partnership (PPP) projects are often exceeded [10–12]. The literature on the construction of hydrotechnical facilities shows an increase in duration compared to the planned up to 50% [13–15]. San Cristóbal [16] analyzed a sample of 130 projects and indicated that 81.5% completed beyond the scheduled time. In contrast, Atkinson put forward the statement that construction projects are still described as unsuccessful [17].

In Poland and several other European countries, specially developed catalogs containing working time standards are used for costing and scheduling of construction projects. The work standard is a numerical description of the average productivity of the working brigade, which should be met if the employee works under standard working conditions and with medium intensity of effort. It turns out, however, that the Catalogs of Material Inputs (KNR) provide information on the average duration of the construction process, which sometimes differs significantly from the actual conditions [18–21]. The reasons for this are uncertainties and design risks that are difficult to reproduce by using KNR.

The PPP Guide differentiates project risk into risk related to design documentation defects and construction risk. Construction risks can be caused by defects or mistakes in design, a lack of appropriate planning, a lack of proper project and schedule management of the construction program, defects in the methods used, or other causes related to underperformance or even negligence by the private partner (or its contractors). This includes external factors that should have been anticipated, but were not. Therefore, the design risk discussed in this article should be related to the second of the above definitions – construction risk.

Decisions based on forecast rather than certain information are subject to uncertainty, limited resources [22] and risk [23]. The longer the implementation time, the greater the uncertainty of the course of the investment and the risk of not meeting its scheduled time. Consequently, the risks and uncertainties associated with the project schedule must be assessed in order to increase the success of the project [24]. Teixeria and his team [25] define:

– uncertainty, as an event characterized by a lack of information and the possibility of obtaining more than one result;
– risk, as a consequence of an event that is predicted on the basis of statistical probability and for which a decision can be expressed in terms of a range of possible outcomes.

Risk is usually defined as a negative event (eg risk of a fire, generating financial losses), although by definition it is an uncertain event or circumstance that leads to a negative or positive impact on the project objective [26]. In the case of scheduling, such a negative impact may be the time delay of the task completion. Risk analysis is part of every decision you make. It is also an extremely important element of scheduling. Risk analysis is the use of available information to determine the probability of certain events and their consequences. By examining the full range of possible outcomes in a given situation, a good risk analysis can both identify pitfalls and discover new opportunities [27]. The risk analysis can be done qualitatively or quantitatively.

Schedule Risk Analysis (SRA) and the ability to Multiskilled Resource Scheduling (MSRS) are strategies that enable scheduling taking into account the uncertainty and risk of projects [28]. An SRA is performed to assess the variability in the duration of activities and to estimate the likelihood of a project completing over the lifetime of the project [29]. Practitioners and researchers have developed several models, tools and techniques used in SRA [22, 30, 31]. One of the earliest methods used for SRA was the Program Assessment and Review Technique (PERT) [22]. Another model for SRA analysis, ERIC-S, identifies the optimistic and pessimistic duration of schedule activities based on project characteristics [30]. The CSRAM method [31] developed by Ökmen and Öztas assesses the correlations between the duration of activities and risk factors to determine the degree of uncertainty in the schedule. Most of the above-mentioned models are models based on CPM or PERT. The project implementation time risk analysis may also be carried out on the basis of the statistical method and Monte Carlo simulation. The following programs are used for this purpose: @Risk, RiskyProject Professional, Crystal Ball, Primavera Risk Analysis R8.x. The use of statistical methods and Monte Carlo simulations enables such designing of construction projects that take into account their risk and uncertainty in its approach, and will also generate information about possible delays [6, 32].

The aim of the work is to improve the traditionally used method of scheduling, based on data from KNR catalogs. The traditional planning method can be improved by using RiskyProject Professional. In the RiskyProject Professional program, the risk and uncertainty in relation to a specific construction project will be modeled, and the results of the calculations will be compared with the actual time of the project implementation.

2. Methodology

The study designed a schedule for a construction project described in detail in the case study. The schedule was developed on the basis of the implementation times of individual processes read from the Tangible Input Catalogs – specifying the standard times for the implementation of construction processes. The schedule has been extended to include the risk and uncertainty analysis conducted in the RiskyPro-ject Professional program in order to better reflect the actual conditions of work.

2.1. Sequential execution method

There are three main methods of work organization in construction: consecutive execution of works, parallel execution of works, even execution of works. Combinations of the above methods are also often used. In this work, the method of successive execution was used, which was dictated by the work organization adopted by the contractor.

The method of successive execution consists in the successive execution of objects according to the principle that the construction of a new object begins after the completion of works related to the preceding object.

Design-and-Build project delivery methods usually put the contractor in the lead role in the construction project. The opposite approach is IPD (Integrated project delivery), which is a return to the "master builder" concept, where the entire construction team, including the owner, architect, general contractor, structural engineers, manufacturers and subcontractors work together throughout the construction process. IPD allows you to maximize the efficiency of construction works and the time of investment implementation. Due to the size of the construction site, the scope of work and the contractor's resources, the method of organizing the works used in the discussed case was the Successive Execution Method, which is an inefficient method.

2.2. Catalogs of material expenses – KNR

Catalogs of Material Inputs (KNR) are normative documents that take into account the specificity of the implementation of construction works. KNR data is commonly used in Poland to prepare cost estimates and construction schedules. In its assumption, KNRs should allow for highly precise cost and time calculations of construction projects. The calculation of the consumption of materials and raw materials is not problematic, as opposed to determining the time-consuming construction processes. This is due to the dependence of the time-consuming construction processes on many influencing factors:

– type of tools and machines used and their way of use,
– the level of organization of working methods,
– surroundings,
– work ergonomics,
– the actual efficiency of employees' working time,
– the actual efficiency and use of the equipmen,
– and many other.

In the work, KNRs were used to forecast the implementation time of construction processes and on their basis a schedule for the considered construction case was developed. The schedule designed on the basis of KNR has been enriched with SRA. The SRA analysis was performed in the RiskyProject Professional program.

2.3. RiskyProject Professional

RiskyProject Professional is a program that allows you to run SRA construction projects. It makes it possible to define and introduce to the schedule various types of risks that pose threats to the timely conduct of the planned schedule. This is an approach that can be used in a schedule that does not include such uncertainties in its basic calculations.

Individual risks predicted and generated in the RiskyProject Professional program can be assigned to individual project tasks or globally to the entire schedule. For each risk, the likelihood of its occurrence and its impact on the project implementation (e.g. what delay it may cause) are determined. Delays caused by individual project risks can be described as a percentage value (e.g. 5% of the project delay in relation to the base time) or a numerical value / range (e.g. 2 days delay; 1÷3 months delay). The software enables the detailed definition and description of the risk and the adoption of a response strategy (if it occurs). RiskyProject Professional suggests two risk response strategies by default:

– avoiding the risk (through actions that will reduce the probability of its occurrence);
– responses to risk, if it occurs (these are activities aimed at reducing the impact of a given risk on the value of project delay).

3. Case study

The implementation of renovation works of three residential, medium-rise, multi-family buildings, located at 9, 11 and 13 Wiśniowa Street in Kielce, was considered (Figure 1). The investment included 3 structures identical in terms of construction and technology, located in close proximity on plots with registration numbers 609, 610 and 611. The construction works were divided into three working plots. Each working plot (sector) corresponds to one object. The individual sectors are described as: building A (S1), building B (S2) and building C (S3). The same construction processes are carried out on individual buildings, from which five main works have been distinguished: preparatory works (P1), renovation of balconies and loggias (P2), thermal modernization (P3), facade painting (P4), construction of a plinth with waterproofing and thermal insulation of basement walls in the ground and the foundation of the building trim (P5).

In RiskyProject Professional, a basic schedule (S-Basic) was created for the case study presented in the thesis (Figure 2). The schedule was created based on the input data (process duration) based on the Catalogs of Material Inputs (KNR). In the case of sector S2, works P2 and P3 were not carried out due to the good technical condition of the existing elements and due to the limited budget. The execution time of processes P2 and P3 in sector 2 was assumed as 0 days.

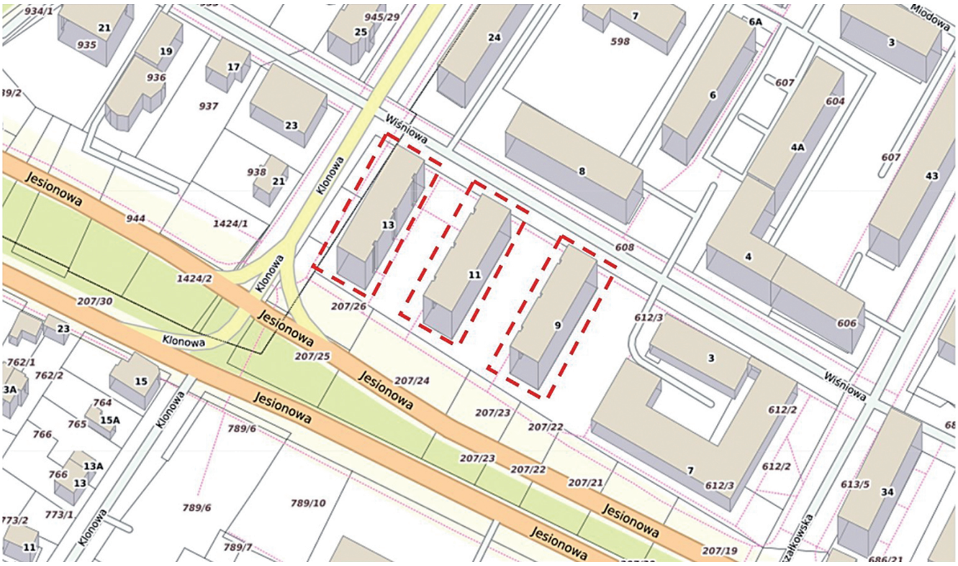

Fig. 1. Situation plan of the investment

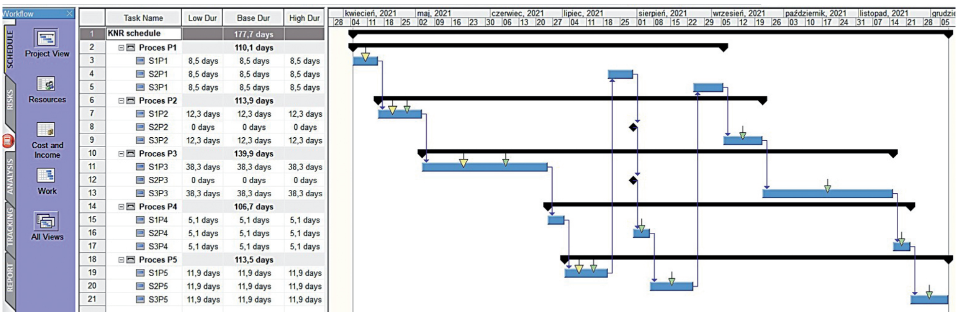

Fig. 2. Excerpt from the RiskyProject Professional spreadsheet for S-Basic

A number of project risks were introduced into the basic schedule made in RiskyProject Professional (S-Basic), creating a new schedule – schedule with risk (S-Risk). Both schedules were compared with each other and with the real time of the construction works – real schedule (S-Real), in order to determine the correctness of the calculations. The predicted risks were entered into the basic schedule based on data from KNR and assigned to the risk category related to the project implementation time. The individual risks were defined and described as (Table 1):

- R1 – risk related to the variability of the availability of building materials;
- R2 – risk related to delays resulting from the lack of experience / qualifications of workers;
- R3 – risk related to the occurrence of unfavorable weather conditions;
- R4 – risk related to absenteeism of employees;

Table 1. Defined project risks

Risk name	Open or closed risk	Risk, problem or acquired knowledge	A threat or an opportunity for the project	The likelihood of the risk occurring	Type of risk score	Risk score (project delay)	Risk management strategy
R1	Open	Risk	Threat	10%	Relative latency	5%	Reaction
R2	Open	Risk	Threat	20%	Relative latency	5÷30%	Reaction
R3	Open	Risk	Threat	50%	Relative latency	20%	Reaction
R4	Open	Risk	Threat	20%	Relative latency	10%	Reaction
R5	Open	Risk	Threat	15%	Relative latency	15%	Reaction
R6	Open	Risk	Threat and opportunity	20%	Relative latency	−10÷10%	Reaction

– R5 – risk of exceptional situations (eg finding human remains, bombs);
– R6 – risk related to changes in the design documentation, changes in technology, changes initiated by the Investor.

Risks R1–R6 may include individual project tasks or the entire project globally. Global risk means that each task in the schedule may be at risk of delay due to the occurrence of a given risk. Risks R1 and R2 have been assigned to appropriate tasks and risks R3, R4, R5 and R6 globally to the entire project.

The risk R1 is related to the variability of building materials or their temporary lack, therefore it only applies to tasks in which building materials are used. Depending on the type of building material, different percentages of delays were assigned to the tasks (e.g. for paint, a possible 5% delay was specified, as it is a building material that is unlikely to be deficient or can be obtained from another supplier). Risk R2 is related to the inexperience of employees and has been assigned only to work performed in 1 sector. It is assumed that inexperienced employees will be trained to work in 1 sector and will gain some skill in their activity there, therefore, in other sectors, work will be carried out without major delays. The remaining risks (R3, R4, R5 and R6) are allocated globally, therefore they have an impact on each project task.

The program specifies whether the risk is open (it is taken into account in the current calculation) or closed (it is not included in the current calculation). In addition, project risk can be defined as the following types of events: risk, problem, conclusions drawn. Risks are events that may or may not occur and have a probability of 0÷100%. Problems are events that have already occurred and require a response. The conclusions drawn are events that happened in the past and have an associated history.

Project risk may have both negative and positive effects for the investment, therefore it may be defined as a threat (possibility of delay) or an opportunity (possibility of shortening the duration) for the project. The R6 risk is associated with possible changes to the project documentation, e.g. resulting from the Investor's needs or changes in the technology of work. The R6 risk can be both a threat and an opportunity to shorten the project (e.g. as a result of changes to certain works or speeding them up thanks to a new technology).

Should the risk occur, a risk response strategy has been adopted. For example, if there is a risk R4 (absenteeism of employees), a new employee will be hired in place of an employee who does not show up at work, or the resources of workers who have possible downtime will be used. This is a way of reducing the damage that occurs when a risk occurs.

4. Results and discussion

In RiskyProject Professional, a baseline schedule (S-Basic) was created in accordance with the Successive Execution Method and based on data read from KNRs. As a result of the works carried out, the estimated duration of the planned construction project was achieved, equal to 177.7 working days. The project risks described in the case study were introduced into the baseline schedule and the S-Risk schedule was designed. For the S-Risk schedule, a risk matrix was generated (Figure 3).

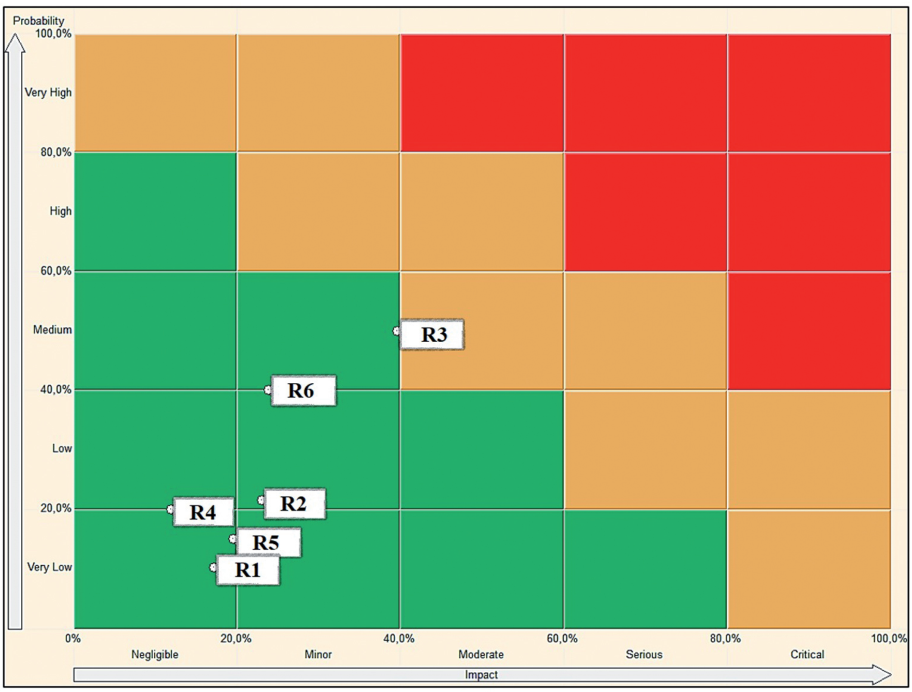

Fig. 3. Risk matrix

The risk matrix is a useful view that can be obtained in the program once all the data on the projected project risks have been entered. The risk matrix is a tool that allows you to determine the risk weight using the risk probability (y axis) and the calculated risk impact (x axis). Project risks modeled in the program were identified in the risk matrix as minor and moderate. This is partly due to the limited scope of construction work and the lack of complexity.

RiskyProject Professional specifies the probability of R1–R6 risks and their impact on the project. Based on the defined data, simulations were carried out and a probabilistic time for the completion of the assumed works within the planned period was calculated. The minimum and maximum possible duration of the project has been established. Figure 4 shows the frequency plot and Figure 5 shows the cumulative probability plot for the S–R schedule.

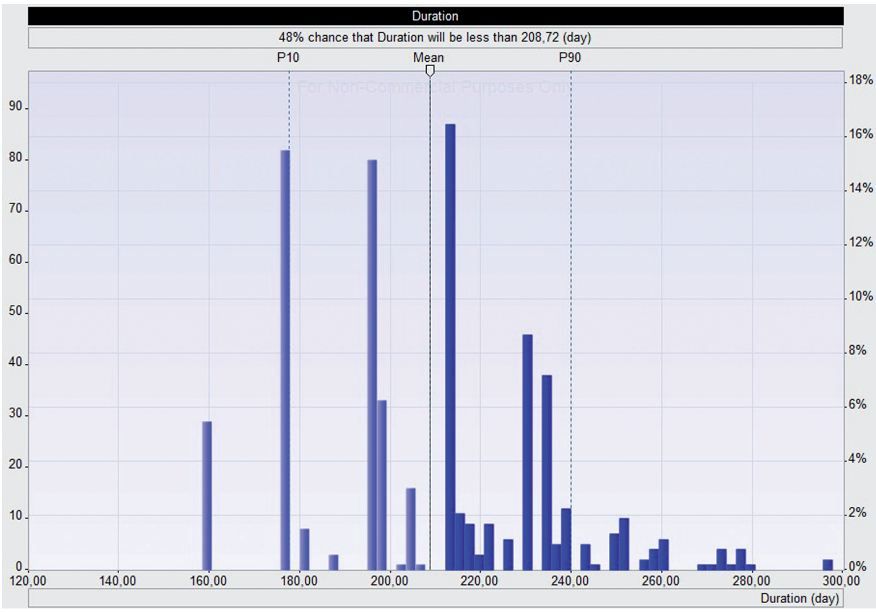

Fig. 4. Frequency graph

The schedule of project risks created in RiskyProject Professional forecasts the achievable times of realization of the considered construction project together with the probability of their occurrence. On the basis of research and experiments of various scientists, a triangular probability density distribution was adopted [33–36]. A summary of the results of the investment implementation time and their probabilities is given in Table 2.

The SRA results for the S-Risk schedule put the time with the lowest probability of realization at the level of 159.9 days. This is an optimistic time that can be obtained if none of the anticipated risks occur. The maximum duration of the investment was set at 296.8 days – the time takes into account the occurrence of all project risks and the related delays in the implementation of the project. The implementation time of the S-Basic schedule, based

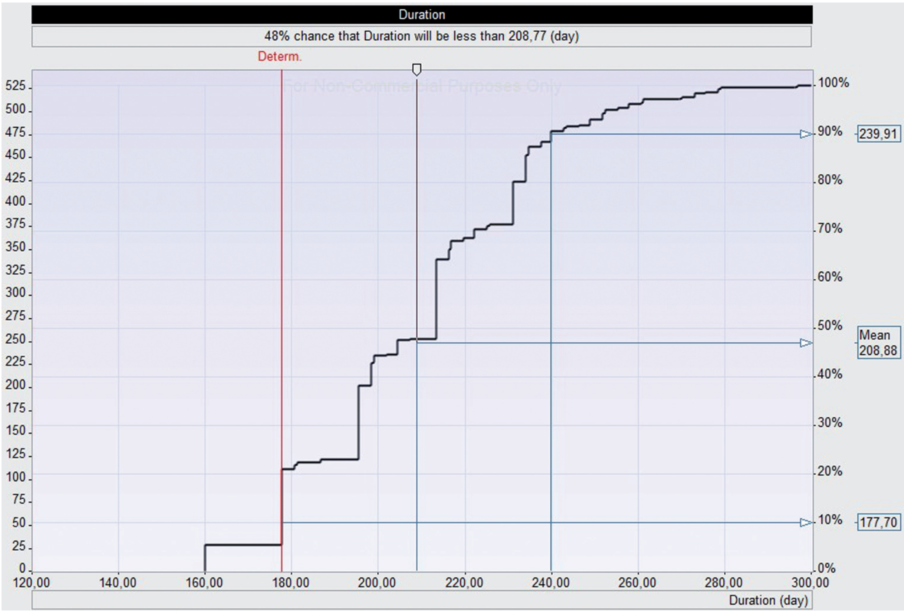

Fig. 5. Cumulative Probability Chart

on the traditional approach of investment planning, was 177.7 business days – deterministic time. By comparing the time of the S-Basic schedule with the S-Risk schedule, we obtain the probability of execution at the level of 10÷20%.

The real time that was experimentally tested during the implementation of the investment described in the case study was 238.5 man-days. This means that assuming a schedule designed in a traditional way, taking into account the average times of work completion included in the KNR, a delay of 60 man-days would be achieved. Comparing the real time of the S-Real investment implementation with the time forecast in the S-Risk schedule (taking into account the project risk), the probability of completion of works at the level of 90% is obtained.

By assuming a minimum project completion time, the contractor assumes a high risk of failure to complete the work on schedule, which may result in low profits. Assuming the maximum investment implementation time – safe time, the contractor can count on high returns on the investment, but there is a high probability that his offer will not be attractive compared to the others that participate in the tender procedure. Practice shows that the minimum and maximum investment realization times are not accepted. Usually, when using the SRA analysis, the probability of completion of works is assumed at the level of about 70-80%. This is due to the profit and loss analysis.

The S-Risk schedule, taking into account project risks, shows a much better representation of the real time of investment implementation than the schedule based on deterministic data – S-Basic. By reading the probability of the work being completed in 238.5 working days from Figure 5, the probability of completion is 88%.

Table 2. Percentage probability of the investment being completed within a specified period of time

Percentage probability [%]	Project completion time [days]
Min	159.9
5	159.9
10	177.7
15	177.7
20	177.7
25	195.5
30	195.5
35	195.5
40	198.4
45	204.4
50	213.3
55	213.3
60	213.3
65	216.2
70	222.1
75	231.0
80	231.0
85	234.0
90	234.0
95	252.3
Max	296.8

5. Conclusions

In the sequential execution method, the work is carried out sequentially (from start to finish) on the individual sectors. After completing the work in sector 1, move on to sector 2, etc. RiskyProject Professional allows you to design a schedule that takes into account the appropriate linkages of work tasks and sectors as required by the sequential execution method. Input data – implementation times of individual construction processes were determined on the basis of Catalogs of Material Inputs (KNR). Due to the apparent trend of delays in construction projects carried out in everyday life, an SRA analysis was carried out in the RiskyPro-ject Professional program. The SRA analysis showed higher investment execution times compared to the baseline schedule. The verification of the correctness of the calculations was carried out on the basis of a comparison of the research results with the real time of investment implementation. The investment described in the present work was carried out during 238.5 working days using the Successive Execution Method. A much better representation of the real time (S-Real) was obtained in the S-Risk schedule. Conclusions from the work carried out):

- The traditional method of designing construction schedules using KNR input data is a method that can generate significant design delays;
- An additional schedule risk analysis is necessary in relation to individual implementation conditions. Baseline SRA analysis enables a more faithful representation of the actual conditions of a construction project;
- The probability of investment realization generated on the basis of the SRA analysis may be assumed at the level of 75÷90%. This will ensure a very good representation of the implementation of construction works compared to the actual time of their course.

Further research should focus on the search for better methods of predicting input data – construction process completion times. Another direction for further research may be the search for methods of designing schedules that will ensure the maximization of resource use and optimization of investment implementation time.

References

[1] S.A. Assaf and S. Al-Hejji, "Causes of delay in large construction projects", *International Journal of Project Management*, vol. 24, no. 4, pp. 349–357, 2006, DOI: 10.1016/j.ijproman.2005.11.010.

[2] I. Mahamid, A. Bruland, and N. Dmaidi, "Causes of delay in road construction projects", *Journal of Management in* Engineering, vol. 28, pp. 300–310, 2011, DOI: 10.1061/(ASCE)ME.1943-5479.0000096.

[3] F.D. Fugar and A.B. Agyakwah-Baah, "Delays in building construction projects in Ghana", *Australasian Journal of Construction Economics and Building*, vol. 10, no. 1-2, pp. 103–116, 2010, DOI: 10.5130/AJCEB.v10i1-2.1592.

[4] R.F. Aziz, "Ranking of delay factors in construction projects after Egyptian revolution", *Alexandria Engineering Journal*, vol. 52, no. 3, pp. 387–406, 2013, DOI: 10.1016/j.aej.2013.03.002.

[5] W. Jing, et al., "System dynamics modeling strategy for civil construction projects: the concept of successive legislation periods", *Symmetry*, vol. 11, no. 5, 2019, DOI: 10.3390/sym11050677.

[6] A. Gondia, et al., "Machine learning algorithms for construction projects delay risk prediction", *Journal of Construction Engineering and Management*, vol. 146, no. 1, 2020, DOI: 10.1061/(ASCE)CO.1943-7862.0001736.

[7] N. Kokkaew and W. Wipulanusat, "Completion delay risk management: A dynamic risk insurance approach", *KSCE Journal of Civil Engineering*, vol. 18, pp. 1599–1608, 2014, DOI: 10.1007/s12205-014-1128-4.

[8] C. Rhodes, "Construction industry: statistics and policy", House of Commons Library. [Online]. Available: https://commonslibrary.parliament.uk/research-briefings/sn01432/. [Accessed: 01.12.2022].

[9] B. Flyvbjerg, "What you should know about megaprojects and why: An overview", *Project Management Journal*, vol. 45, no. 2, pp. 6–19, 2014, DOI: 10.1002/pmj.21409.

[10] Y. Liang and H. Wang, "Sustainable performance measurements for public–private partnership projects: empirical evidence from China", *Sustainability*, vol. 11, no. 13, 2019, DOI: 10.3390/su11133653.

[11] X. Jiang, K. Lu, B. Xia, Y. Liu, and C. Cui, "Identifying significant risks and analyzing risk relationship for construction PPP projects in China using integrated FISM-MICMAC approach", *Sustainability*, vol. 11, no. 19, art. no. 5206, 2019, DOI: 10.3390/su11195206.

[12] Y. Li and X.Y. Wang, "Using fuzzy analytic network process and ISM methods for risk assessment of public-private partnership: A China perspective", *Journal of Civil Engineering and Management*, vol. 25, no. 2, pp. 168–183, 2019.

[13] B.K. Sovacool, A. Gilbert, and D. Nugent, "An international comparative assessment of construction cost overruns for electricity infrastructure", *Energy Research and Social Science*, vol. 3, pp. 152–160, 2014, DOI: 10.1016/j.erss.2014.07.016.

[14] O. Awojobi and G.P. Jenkins, "Were the hydro dams financed by the World Bank from 1976 to 2005 worthwhile?", *Energy Policy*, vol. 86, pp. 222–232, 2015, DOI: 10.1016/J.ENPOL.2015.06.040.

[15] A. Ansar, et al., "Should we build more large dams? The actual costs of hydropower megaproject development", *Energy Policy*, vol. 69, pp. 43–56, 2014, DOI: 10.1016/j.enpol.2013.10.069.

[16] J.R.S. Cristóbal, "The S-curve envelope as a tool for monitoring and control of projects", *Procedia Computer Science*, vol. 121, pp. 756–761, 2017, DOI: 10.1016/j.procs.2017.11.097.

[17] R. Atkinson, "Project Management: cost, time and quality, two best guesses and a phenomenon, it's [its] time to accept other success criteria", *International Journal of Project Management*, vol. 17, no. 6, pp. 337–342, 1999, DOI: 10.1016/S0263-7863(98)00069-6.

[18] M. Rogalska, *Wieloczynnikowe modele w prognozowaniu czasu procesów budowlanych*. Lublin, Poland: Wydawnistwo Politechniki Lubelskiej, 2016.

[19] P. Kostrzewa-Demczuk and M. Rogalska, "Anticipating the length of employees' working time", *Symmetry*, vol. 12, no. 3, art. no. 413, 2020, DOI: 10.3390/sym12030413.

[20] P. Kostrzewa and M. Rogalska, "Scheduling construction processes using the probabilistic time coupling method III", *IOP Conference Series: Materials Science and Engineering*, vol. 471, art. no. 11207, 2019, DOI: 10.1088/1757-899X/471/11/112072.

[21] S. Bolotin, et al., "Harmonogramowanie przedsięwzięć budowlanych z uwzględnieniem modelu czasowo przestrzennego", *Przegląd Budowlany*, no. 11, pp. 24–28, 2014.

[22] R.M. Choudhry, et al., "Cost and schedule risk analysis of bridge construction in Pakistan: establishing risk guidelines", *Journal of Construction Engineering and Management*, 2014, vol. 140, no. 7, 2014, DOI: 10.1061/(ASCE)CO.1943-7862.0000857.

[23] *PMI. A guide to the project management body of knowledge*. PA, USA: Project Management Institute, Inc, 2017.

[24] P. Jaśkowski, S. Biruk, and M. Krzemiński, "Proactive scheduling of repetitive construction processes to reduce crews idle times and delays", *Archives of Civil Engineering*, vol. 67, no. 4, pp. 287–302, 2021, DOI: 10.24425/ace.2021.138500.

[25] J.C. Teixeria, et al., *Zarządzanie ryzykiem w budownictwie*. Warszawa, Polska: Wydawnictwo: Guimaraes, 2011.

[26] *PMBOK guide. A guide to the project management body of knowledge*. Pennsylvania, USA: Project Management Institute, PMI, 2000.

[27] P. Jaśkowski, S. Biruk, and M. Krzemiński, "Planning repetitive construction processes to improve robustness of schedules in risk environment", *Archives of Civil Engineering*, vol. 66, no. 3, pp. 643–657, 2020, DOI: 10.24425/ace.2020.134418.

[28] M. Vanhoucke, *Project management with dynamic scheduling: baseline scheduling, risk analysis and project control*. Ghent, Belgium: Springer Science & Business Media, 2013.

[29] S. Sackey and B.S. Kim, "Schedule risk analysis using a proposed modified variance and mean of the original program evaluation and review technique model", *KSCE Journal of Civil Engineering*, vol. 23, pp. 1484–1492, 2019, DOI: 10.1007/s12205-019-1826-z.

[30] D. Nasir, B. Mccabe, and L. Hartono, "Evaluating risk in construction–schedule model (ERIC–S): construction schedule risk model", *Journal of Construction Engineering and Management*, vol. 129, no. 5, pp. 518–527, 2003, DOI: 10.1061/(ASCE)0733-9364(2003)129:5(518).

[31] Ö. Ökmen and O. Öztas, "Construction project network evaluation with correlated schedule risk analysis model", *Journal of Construction Engineering and Management*, vol. 134, no. 1, pp. 49–63, 2008, DOI: 10.1061/(ASCE)0733-9364(2008)134:1(49).

[32] Z.M. Yaseen, et al., "Prediction of risk delay in construction projects using a hybrid artificial intelligence model", *Sustainability*, vol. 12, no. 4, art. no. 1514, 2020, DOI: 10.3390/su12041514.

[33] T.S. Glickman and F. Xu, "The distribution of the product of two triangular random variables", *Statistics and Probability Letters*, vol. 78, pp. 2821–2826, 2008.

[34] K.E. Fairchild, L. Misra, and Y. Shi, "Using triangular distribution for business and finance simulations in Excel", *Journal of Financial Education,* vol. 42, pp. 313–336, 2016.

[35] D. Johnson, "Triangular approximations for continuous random variables in risk analysis", *Journal of the Operational Research Society*, vol. 53, no. 4, pp. 457–467, 2002, DOI: 10.1057/palgrave.jors.2601330.

[36] I.T. Yang, "Impact of budget uncertainty on project time-cost kradeoff", *IEEE Transactions on Engineering Management*, vol. 52, no. 2, pp. 167–174, 2005, DOI: 10.1109/TEM.2005.844924.

Planowanie realizacji przedsięwzięć budowlanych z uwzględnieniem ryzyka projektowego

Słowa kluczowe: opóźnienia projektu, zarządzanie projektem, ryzyko, zarządzanie ryzykiem, harmonogram, Schedule Risk Analisys

Streszczenie:

Złożone przedsięwzięcia budowlane wymagają odpowiedniego planowania, które umożliwia optymalizację czasowo-kosztową, maksymalizację wykorzystania dostępnych zasobów i odpowiednią kontrolę inwestycji. W pracy opisano rozwinięcie tradycyjnie stosowanej w Polsce metody harmonogramowania, opartej na danych pochodzących z katalogów KNR, poprzez wykorzystanie programu RiskyProject Professional. W programie RiskyProject Professional zamodelowano ryzyko i niepewność w nawiązaniu do konkretnego projektu budowlanego, a wyniki obliczeń porównano z czasem rzeczywistym realizacji przedsięwzięcia. Wnioski z przeprowadzonych prac potwierdzają, że analiza SRA bazowego harmonogramu umożliwia wierniejsze odwzorowanie warunków rzeczywistych przedsięwzięcia budowlanego. Prawdopodobieństwo realizacji inwestycji wygenerowane na podstawie analizy SRA, może być przyjmowane na poziomie 75÷90%.

Received: 2022-10-10, Revised: 2022-12-16