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Allocation of risk factors for geodetic tasks in construction schedules

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Abstract: Road construction projects are characterized by multitasking and the influence of the correct implementation of one task on another. In the subject literature, we can encounter the analysis of risk factors throughout the project, and yet, we rarely find the distinction and characteristics of the impact of risk factors resulting from the implementation of planning and measurement tasks, the correctness and timeliness that have a huge impact on the performance of subsequent tasks, and the success of the project. Additionally, attention should be paid on the distinction between design work and the implementation of construction works, we are more capable of detecting errors faster at the initial stage than at the stage of performing measurements, which suggests the need to focus on minimizing the occurrence of risk factors at the initial stage. Therefore, two questions have been asked. How to quantify the risk factors of geodetic works in road construction projects? How to allocate quantified risk factors of

geodetic works in the schedule? The following article presents the description and the example of the practical use of the risk assessment procedure of geodetic works and risk allocation in the schedule based on the MORAG method (Method of Risk Analysis for Geodesy), which is the original method of risk analysis of geodetic works in road construction projects. As a result of these works, the risk values for the i -th risk factor and i -th geodetic task were determined, considering the increase in the duration of the work, the increase in the costs of the work, and all evaluation criteria. Then, the extension was described and calculated based on the data obtained from the actual implementation of the road construction project, the value, which in this case is 11.05 days, was entered into the modified schedule. The results of this study may help to better understand the scale of the impact of the correctness of the implementation of geodesy tasks on the implementation of construction tasks. Additionally, they may serve to increase the awareness of the scale of consequences of incorrectly performed measurement tasks (demolition is necessary) and greater attention on the cooperation between the entities implementing these activities.

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1 Introduction

A road construction project is a complex process consisting of various activities [1], which have a significant impact on the occurrence of many risk factors. These factors cause both delays and changes in the costs incurred.

The separation of elements threatening the proper implementation of constructed projects is the subject of articles on risk analysis processes [2–4]. The use of various methods and approaches to the risk analysis of road construction projects can be observed in the literature; yet, there are rarely any studies concerning risks in the area of geodetic works [5–10]. This fact determined the

Figure 1: Ideographic model of the MORAG (Method of Risk Analysis for Geodesy) method.

need to research in this field [11–13]. Therefore, a method of risk analysis of surveying works was developed [14]. The method is presented in Figure 1.

This method will increase the effectiveness of planning processes and should also increase the possibility of meeting the implementation deadlines, both for individual operations and for entire projects.

First, the risk assessment of geodetic works is presented. Then, the topic of the allocation of risk factors in geodetic tasks is undertaken, characterizing the manner of allocating the risk factors and the results. Section 3 describes the allocation of risks in the schedule with the description and the example of practical use. The work is concluded with a short summary.

2 Risk assessment of surveying works

In this work [14], the risk r_i of the occurrence of the i -th geodetic disturbance was identified using expression (1), i.e., as a product of the probability p_i of this disturbance occurrence and the consequences of its occurrence divided by the sum of these products for all n analyzed risk factors R_i for disruptions to geodetic works:

Table 1: Risk factors with specific risk values that may accompany their occurrence

No.	Risk factors		Risk r_i of the i -th factor R_i		
	Symbol	Description	r_i	r_i^t	r_i^c
1	R_1	Incorrectly adopted horizontal layout	0.039	0.035	0.043
2	R_2	Incorrectly adopted altitude system for the development of data and the terrain elevation	0.049	0.046	0.052
3	R_3	No master plan draft and its later update	0.025	0.030	0.020
4	R_4	No GESUT (<i>Geodetic Register of Land Utilities Network</i>) information obtained from the PODGiK (<i>District Center for Geodetic and Cartographic Documentation</i>) resources	0.039	0.038	0.040
5	R_5	Incorrectly developed digital elevation model	0.049	0.048	0.051
6	R_6	Improper transport of geodetic instruments	0.043	0.036	0.051
7	R_7	No routine equipment inspection	0.065	0.060	0.070
8	R_8	No appropriate equipment selection	0.061	0.063	0.060
9	R_9	Erroneous height reference	0.064	0.068	0.060
10	R_{10}	Erroneous situational reference	0.058	0.062	0.055
11	R_{11}	No control over the stake-out performed	0.053	0.047	0.060
12	R_{12}	Incorrect stake-out made through the description on a stake of the elevation gain to the design level	0.043	0.040	0.046
13	R_{13}	Improper selection of the marking method for the points being staked	0.037	0.036	0.038
14	R_{14}	No staking of cubature objects on the banks	0.027	0.025	0.030
15	R_{15}	No inventory of existing elements intended for demolition	0.018	0.019	0.017
16	R_{16}	Incorrect location of control points, reference points	0.077	0.089	0.065
17	R_{17}	Incorrect location of implementation matrix points	0.077	0.082	0.072
18	R_{18}	No control of data from the PODGiK resources	0.037	0.036	0.038
19	R_{19}	A lack of communication with contractors of individual assortments	0.108	0.109	0.107
20	R_{20}	No proper generalization of measures	0.029	0.031	0.027

$$r_i = \frac{p_i \cdot c_i}{s}, \quad (1)$$

where

$$s = \sum_{i=1}^n (p_i c_i), \quad (2)$$

assuming that p_i is the value of probability and the consequence c_i is a number in the range from 0 to 1.

In ref. [14], calculations were made for 20 risk factors for surveying works, which were specified based on the literature review, experience, expert knowledge, available documentation, and case study analysis. These factors have been listed in refs [11–14]. Table 1 displays the risk factors together with specific risk values that may accompany their occurrence, where

- risk value r_i^t for the i -th risk factor, considering the increase in the duration of works,
- risk value r_i^c for the i -th risk factor, considering the cost increase of the work,
- risk value r_i for the i -th risk factor considering all assessment criteria.

3 Allocation of risk factors in surveying tasks

3.1 The method for allocation of risk factors

The analyses assumed that the risk r_i value for a given R_i factor was determined simultaneously for the entire construction project. Table 2 displays a scheme of the matrix for the allocation of risk R_i factors for specific surveying tasks G_i .

Hence, the value of the risk assigned to a given geodetic task g_i can be determined from the dependence

$$g_i = \sum_{i=1}^n r_i, \quad (3)$$

Table 2: Matrix of allocation of risk R_i factors for specific surveying tasks G_i . Source: own study

Specification	R_1	R_2	R_3	...	R_n
G_1	r_1	r_2	r_3	...	r_n
G_2	r_1	r_2	r_3	...	r_n
...	...	...	...	...	...
G_m	r_1	r_2	r_3	...	r_n

and if for a given surveying task G_i no risk R_i factor occurs, the risk value $r_i = 0$.

As in the case of the size of risk r_i of individual risk R_i factors, the risk g_i of individual surveying tasks G_i can also be identified with only one of the selected criteria, i.e., time or cost, considered.

For this reason, the following designations were adopted in the paper:

- g_i – the risk value for the i -th surveying task taking account of all assessment criteria,
- g_i^t – the risk value for the i -th geodetic task considering the extension of the duration of works,
- g_i^c – the risk value for the i -th geodetic task regarding the increase in the costs of these works.

3.2 Allocation of risk factors in surveying activities

Table 3 presents a cumulative scheme of the risk R_i factor allocation matrix for individual geodetic tasks G_i , while Figures 2–4 display graphically the results of calculations carried out from formula (3), due to which the risk values g_i^t , g_i^c , and g_i were obtained, respectively.

4 Risk allocation in the schedule

4.1 Method of risk allocation in the schedule

The method for the allocation of disruptions to schedules is presented below. The analyses assumed that the risk r_i value for the factor R_i was determined simultaneously for the entire construction project. If there is no risk R_i factor for the geodetic task G_i , the risk value $v = 0$. Table 4 displays the matrix for the allocation of risk R_i factors for individual geodetic tasks G_i .

It was assumed in the analyses that the risk value for the i -th geodetic task regarding the extended duration of works g_i^t was calculated from formula (4):

$$g_i^t = \sum_{i=1}^n r_i^t \leq 1, \quad (4)$$

for

$$r_i^t = p_i \times c_i^t, \quad (5)$$

where p_i is the probability of the risk R_i factor occurrence and c_i^t is a consequence of the risk R_i factor occurrence

Table 3: Matrix of allocation of risk R_i factors for individual geodetic tasks G_i

Specification	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9	R_{10}	R_{11}	R_{12}	R_{13}	R_{14}	R_{15}	R_{16}	R_{17}	R_{18}	R_{19}	R_{20}
Determination and measurement of the geodetic control network	G_1	x	x	x	x	x	x	x	x	x						x	x	x	x	
Staking construction objects in the field	G_2	x	x	x		x	x	x	x	x	x					x	x	x	x	
Inventory of the existing land	G_3	x	x	x	x	x	x	x	x	x	x				x	x	x	x	x	x
Execution of cross sections (trenches, embankments)	G_4	x	x	x	x	x	x	x	x	x	x					x	x	x	x	
Performing control measurements together with preparing the measurement documentation	G_5	x	x	x	x	x	x	x	x	x	x					x	x	x	x	x
Current stocktaking of the works performed together with as-built documentation of earthworks	G_6	x	x	x	x	x	x	x	x	x	x					x		x	x	x
Situational and height determination of substructure and surface layers	G_7	x	x	x		x	x	x	x	x	x		x			x		x	x	x
Control measurements of the execution of works according to the technical specification and preparation of the as-built documentation of the substructure and surface	G_8	x	x	x		x	x	x	x	x	x					x		x	x	x
Drainage of the road structure by performing culverts, stormwater drainage, sanitary sewer system or cleaning devices by means of delineation, installation of benchmarks as well as control measurements and preparation of documentation	G_9	x	x	x	x	x	x	x	x	x	x					x		x		
Finishing works: strengthening of escarpments, roadsides, ditches, gabions, and sewage	G_{10}	x	x	x		x	x	x	x	x	x					x		x	x	x
Determination of the axes of designed devices, control measurement, and the preparation of as-built dimensional documentation according to the technical specification of traffic safety devices	G_{11}	x	x	x		x	x	x	x	x	x		x			x		x		
Staking prefabricated and monolithic elements of road greenery or reconstruction of tracks	G_{12}	x	x	x		x	x	x	x	x	x		x			x		x		
Staking and inventory of other cubature objects such as sheds, arbors, and bus bays	G_{13}	x		x		x	x	x		x	x		x			x		x		
Measurement of technical infrastructure equipment	G_{14}	x	x	x	x	x	x	x	x	x	x					x		x		

The symbol x denotes the allocation of risk factors R_i in individual geodetic tasks G_i .

Figure 2: The risk value for the i -th geodetic task considering the extended duration of works.

concerning the higher duration of the construction project.

Then, assume that the surveying error is detected in the first few construction activities B_i following the surveying task and that there is a direct causal link between them and the surveying task in question.

The allocation of the risk factor takes place by extending the duration of the surveying task and the duration of construction tasks directly related to the discussed surveying task. The pattern has been created, as a result of these analyses:

$$W_i = \left(\sum_{j=1}^n r_j^t \right) \left(\sum_{k=1}^m (y_k T_k^B) + T_i^G \right) = g_i^t \left(\sum_{k=1}^m (y_k T_k^B) + T_i^G \right), \quad (6)$$

where W_i is the extension, T_i^G the duration of the geodetic task, T_k^B the duration of the construction task, G_i the geodetic task, g_i^t the risk value for the i -th geodetic task,

n the number of risk R_j factors, m the number of construction tasks B completed until a wrongly performed surveying task B is detected, y a coefficient regarding the time of both the re-performance of the construction task T_i^B and the time of its demolition, with $1.0 \leq y$.

4.2 Exemplary risk allocation in a schedule

In order to illustrate the risk allocation in the schedule, a fragment of the actual road construction schedule was used, as shown in Figure 5.

In this case, the geodetic task G_1 is to “retrace the route and mark elevation points”. The analyses assumed that an error in the performance of this surveying task could be detected after the first construction activity following it, namely “humus layer removal” (B_1).

Figure 3: The risk value for the i -th geodetic task considering the increased costs of works.

Figure 4: The risk value for the i -th geodetic task taking account of all criteria.

Table 4: Matrix of allocation of risk R_i factors for individual surveying tasks G_i

Specification	R_1	R_2	R_3	...	R_n
G_1	r_1^t	r_2^t	r_3^t	...	r_n^t
G_2	r_1^t	r_2^t	r_3^t	...	r_n^t
...	...	...	...	...	...
G_m	r_1^t	r_2^t	r_3^t	...	r_n^t

According to the presented schedule, the geodetic task duration $T_1^G = 4$ days, while the construction task duration $T_1^C = 3$ days. Following Figure 1, it was assumed that the risk value taking into account the increase in the duration of works g_1^t is 0.801 for the geodetic task G_2 , i.e., “retrace the route and mark elevation points”. The task Z_1 was treated as equivalent to the geodetic task “staking construction objects in the field”. The values of the coefficient γ considering the time of both the re-performance of the construction task T_i^B and the time of its demolition $\gamma_1 = 1.6$ (for the construction task “humus layer removal”) were taken for calculations.

Thus, the extension W_1 of the whole construction project related to incorrectly performed geodetic task G_1 is 7.05 days, as

$$\begin{aligned}
 W_1 &= g_1^t((\gamma_1 T_1^B) + T_1^G) \\
 &= 0.801((1.6 \times 3) + 4) \\
 &= 7.05 \text{ days.}
 \end{aligned} \tag{7}$$

The calculations made indicate that the duration of the corrected schedule regarding the possibility of a wrongly performed surveying task Z_1 should be assumed as $T_1^G = 4 + 7.05 = 11.05$ days.

5 Summary and conclusions

The presented results are the effect of using the acquired data and do not constitute unambiguous information, but a visualization of the method and an indication of its development directions. A failure to perform the surveying activity or its incorrect execution may lead to substantial financial losses, the extension of the project duration to an unacceptable level, or a failure to meet

Figure 5: The risk value for the i -th surveying task considering all criteria.

the quality standards. As can be easily seen, the necessity to perform this type of analysis, broaden the knowledge, even about the elements which at first glance are not essential, and pay attention to elementary activities are even necessary to limit the risk and failures.

The advantages of the presented method are largely its simplicity, transparent procedure, targeting specific risk factors, and the possibility of its practical use.

The disadvantage of this method is the necessity to collect a large database on the basis of which the risk value is determined and further analysis is performed.

The limitations related to the conducted research are related to the long period of data collection due to the limited number of projects of this type.

The application of this method is characterized by the need to build an expert database of risk factors. Nevertheless, the presented method enables the determination of the impact of the identified risk factors on the time of schedule implementation, and thus, to determine the impact of these factors on the improvement of construction tasks. In the next stage, the expansion of the database is planned, which will increase the accuracy of the research.

This work constitutes a further step to understanding how to construct an optimal schedule that can enhance the capability to verify and reduce the impact of risk factors on the time and cost of the construction project when developing and building up the database. As technology and new technologies evolve, it should be borne in mind that it is impossible to create ideal solutions in a changing environment. On the other hand, it is feasible to use the knowledge and try, as in the case of the method presented in this paper, to create an expert system that, based on a teaching sequence of correctly identified objects, will support the decision-making process.

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