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Risks assessment model for the sustainable built environment of finishing construction works

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Abstract. Construction works are among the riskiest activities in Lithuania. To develop a sustainable environment at a construction site, risk factors must be first identified and then eliminated. Each case of a construction site, construction conditions and the project environment is unique. Thus, risks must be individually assessed considering distinguishing features of the construction works and the environmental conditions. Consequently, preconditions exist for the development of a new risk assessment model comprising risk assessment norms, the construction project and conditions of the construction processes. Expert evaluation and the TODIM method were used for the risk assessment of finishing works. Two construction sites were used to assess construction risks related to finishing works. The article presents risk assessment results based on the riskiest job at a construction site of finishing works as well as the line of priorities of the riskiest workplace.

Keywords: build environment, risks, assessment, finishing construction works, TODIM.

Introduction

In recent years, many scientific works were devoted to problems particular to engineering construction processes. Some of the studies and scientific research of the field dealt with the subject of occupational work safety in the construction industry.

1. Risk assessment model for the sustainable built environment of finishing construction works

Risk assessment model for the sustainable built environment of finishing construction works consist of:

- the analysis of mechanisms particular to accidents at work (Zavadskas, Turskis, & Tamošaitienė, 2010; Tamošaitienė, 2019);
- the analysis of the accident causes (Zavadskas, Turskis, & Tamošaitienė, 2008a; Chan & Wang, 2013; Tamošaitienė, Zavadskas, & Turskis, 2013);
- the identification of direct and indirect factors affecting the accident rate (Ghasemi, Sari, Yousefi, Falsafi, & Tamosaitiene, 2018; Environmental Protection Authority, 2009; Project Management Institute, 2012);
- the analysis of the accident rate with regards to factors that generate costs (Zavadskas, Turskis, & Tamošaitienė, 2008b; Kumar, Singh, & Gregory, 2016; Zeleňáková & Zvijáková, 2017);
- the developed mathematical model;
- results of the risk assessment calculations.

The developed risk assessment model for finishing works consist of six stages and presented in Figure 1.

The development of the list of risk criteria requires some detailed information from applicable regulatory documents, construction site conditions and specifications. In the case of finishing works, several regulatory documents must be considered, including Provisions for the protection of workers against the risks of vibration, Methodological guidelines for the investigation of ergonomic risk factors etc.

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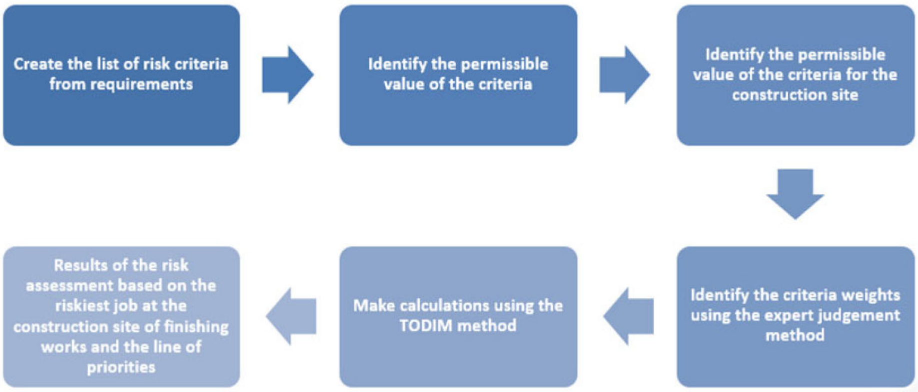

Figure 1. Risks assessment model for finishing works

Expert judgement and the TODIM method for problem-solving were used in the presented model. The TODIM method (the Portuguese acronym for interactive and multi-criteria decision-making), the current form of which was designed at the beginning of the nineties, is a discrete multi-criteria method based on the Prospect Theory. Thus, while practically all other multi-criteria methods start from the premise that the decision maker always looks for the solution corresponding to the maximum of some global measure of value – for example, the highest possible value of a multi-criteria utility function, in the case of MAUT – the TODIM method makes use of a global measurement of value calculable by the application of the paradigm of the Prospect Theory. This way, the method is based on a description, proved by empirical evidence, of how people make decisions effectively in the face of risk (Gomes & Rangel, 2009). The main steps, formulas and calculation processes of the TODIM method are presented in (Gomes & Rangel, 2009; Gomes, Rangel, & Maranhão, 2009; Moshkovich, Gomes, & Mechitov, 2011; Ruzgys, Volvačiovas, Ignatavičius, & Turskis, 2014).

2. Case study: the new risks assessment model for the sustainable built environment of finishing construction works

Each concrete-handling workplace is represented using physical, ergonomic and work-related factors as well as described using 13 occupational risk criteria:

$x_{1.1.}$ Exposure to hand-arm vibration
$x_{2.1.}$ Single-load lifting and carrying constantly during a shift
$x_{2.2.}$ The distance of the mass of a hand-held load from the torso of a worker
$x_{2.3}$. Multiple strained bending at the waist
$x_{2.4.}$ Repeated motions involving hand and finger muscles
$x_{2.5.}$ Repeated motions involving hand, finger and shoulder muscles
$x_{2.6.}$ Working posture: Neck, shoulders
$x_{2.7.}$ Working posture: Elbow, wrist
$x_{2.8.}$ Working posture: Back
$x_{2.9.}$ Working posture: Hips, legs
$x_{3.1.}$ Risk of a worker falling from a height
$x_{3.2.}$ Risk of an object falling from a height on people working below
$x_{3.3.}$ Risk of falling due to slipping or tripping

The expert judgement was used to assess the sustainable build environment of finishing construction works. It was based on a scale used to establish the importance of risk assessment criteria. The “relative overall values”, ranging from 1 to 13, were used to rank order of alternatives.

Various finishing works were considered, including those performed indoors, outdoors, under various weather conditions and at different heights. Functions of a worker performing finishing works comprise the storage of finishing materials and equipment, the preparation and arrangement of the workplace, the fixing of thermal insulation boards, the installation of finishing panels on facades and in the premises, the installation of ventilated facades, and the handling of required equipment and tools.

The risk assessment was made in four different construction projects in Vilnius city (Figure 2).

To determine the most rational alternative for the sustainable built environment of finishing construction works, calculations of the TODIM method described above were performed using the data presented in Tables 1 and 2. A normalised decision-making matrix is given in Table 3. Table 4 shows the calculation processes with a small part of single-criterion dominance and relative dominance data. The global dominance and the relative overall value are presented in Table 5.

a) b) c)

Figure 2. Some examples from the risk assessment of finishing construction works at different construction projects: a) finishing construction workers at a height; b) uncomfortable posture causing hand tension of finishing construction workers; c) finishing construction workers at a height

Table 1. Calculation of the individual weight of a criterion using the expert judgement method

Experts	Risk criteria												
	$x_{1.1.}$	$x_{2.1.}$	$x_{2.2}$	$x_{2.3.}$	$x_{2.4}$	$x_{2.5}$	$x_{2.6}$	$x_{2.7}$	$x_{2.8}$	$x_{2.9}$	$x_{3.1.}$	$x_{3.2.}$	$x_{3.3.}$
Expert 1	1	9	10	4	2	3	7	8	11	6	13	12	5
Expert 2	1	10	9	4	2	3	6	7	8	5	13	11	12
Expert 3	2	10	8	4	1	3	6	7	9	5	13	12	11
Expert 4	1	10	9	3	2	4	7	5	8	6	12	13	11
Expert 5	1	10	9	4	2	3	6	7	8	5	13	11	12
Expert 6	2	10	8	4	1	3	6	7	9	5	13	12	11
Expert 7	1	10	8	4	2	3	6	7	9	5	13	12	11
t	1.29	9.86	8.71	3.86	1.71	3.14	6.29	6.86	8.86	5.29	12.86	11.86	10.43
q	0.01	0.11	0.10	0.04	0.02	0.03	0.07	0.08	0.10	0.06	0.14	0.13	0.11
Concordance coef., W	0.95												
Sum of the Rank	9	69	61	27	12	22	44	48	62	37	90	83	73
Average of the sum	49												
Sum of squared squares S	8478.00												
No. of experts r	7												
No. of the criteria n	13												
Significance of the concordance coef., χ	79.86												

Table 2. Initial data for the risk assessment model for the sustainable build environment of finishing construction works

No	Risk criteria	Unit	Optimality direction	q	Alternative					S
					A_1	A_2	A_3	A_4	A_5	
$x_{1.1.}$	Exposure to hand-arm vibration	m/s^2	min	0.01	1.64	1.02	0.44	0.45	1.08	4.63
$x_{2.1.}$	Single-load lifting and carrying constantly during a shift	kg	min	0.11	10	25	30	30	15	110
$x_{2.2.}$	The distance of the mass of a hand-held load from the torso of a worker	cm	min	0.10	30	50	50	45	25	200
$x_{2.3.}$	Multiple strained bending at the waist	degrees	min	0.04	30	45	20	20	30	145
$x_{2.4.}$	Repeated motions involving hand and finger muscles	no./relay	min	0.02	2154	3451	1664	1600	7682	16551
$x_{2.5.}$	Repeated motions involving hand, finger and shoulder muscles	no./relay	min	0.03	1542	2145	2560	2336	7542	16125
$x_{2.6.}$	Working posture: Neck, shoulders	point	min	0.07	3	3	2	3	4	15
$x_{2.7.}$	Working posture: Elbow, wrist	point	min	0.08	4	4	3	4	4	19
$x_{2.8.}$	Working posture: Back	point	min	0.10	4	4	3	3	4	18
$x_{2.9.}$	Working posture: Hips, legs	point	min	0.06	2	3	2	3	3	13
$x_{3.1.}$	Risk of a worker falling from a height	point	max	0.14	3	1	1	1	1	7
$x_{3.2.}$	Risk of an object falling from a height on people working below	point	max	0.13	2	1	2	2	2	9
$x_{3.3.}$	Risk of falling due to slipping or tripping	point	max	0.11	3	2	3	3	2	13

Table 3. Normalised decision-making matrix

No	Alternatives				
	A_1	A_2	A_3	A_4	A_5
$x_{1.1.}$	0.0870	0.1398	0.3242	0.3170	0.1321
$x_{2.1.}$	0.3659	0.1463	0.1220	0.1220	0.2439
$x_{2.2.}$	0.2459	0.1475	0.1475	0.1639	0.2951
$x_{2.3.}$	0.1765	0.1176	0.2647	0.2647	0.1765
$x_{2.4.}$	0.2200	0.1373	0.2848	0.2962	0.0617
$x_{2.5.}$	0.3139	0.2257	0.1891	0.2072	0.0642
$x_{2.6.}$	0.1905	0.1905	0.2857	0.1905	0.1429
$x_{2.7.}$	0.1875	0.1875	0.2500	0.1875	0.1875
$x_{2.8.}$	0.1765	0.1765	0.2353	0.2353	0.1765
$x_{2.9.}$	0.2500	0.1667	0.2500	0.1667	0.1667
$x_{3.1.}$	0.4286	0.1429	0.1429	0.1429	0.1429
$x_{3.2.}$	0.2222	0.1111	0.2222	0.2222	0.2222
$x_{3.3.}$	0.2308	0.1538	0.2308	0.2308	0.1538

Table 4. Single-criterion dominance and relative dominance

Ψ_1 x_{ij}-x_{ik}	A_1	A_2	A_3	A_4	A_5	
A_1	0.0000	–0.0529	–0.2372	–0.2300	–0.0451	
A_2	0.0529	0.0000	–0.1843	–0.1771	0.0078	
A_3	0.2372	0.1843	0.0000	0.0072	0.1921	
A_4	0.2300	0.1771	–0.0072	0.0000	0.1849	
A_5	0.0451	–0.0078	–0.1921	–0.1849	0.0000	
Y_1	A_1	A_2	A_3	A_4	A_5	S
A_1	0.0000	–0.3219	–0.6818	–0.6714	–0.2973	–1.9724
A_2	0.1642	0.0000	–0.6011	–0.5892	0.0630	–0.9631
A_3	0.3479	0.3067	0.0000	0.0606	0.3131	1.0282
A_4	0.3426	0.3006	–0.1188	0.0000	0.3071	0.8315
A_5	0.1517	–0.1234	–0.6136	–0.6020	0.0000	–1.1873
Ψ_2 x_{ij}–x_{ik}	A_1	A_2	A_3	A_4	A_5	
A_1	0.0000	0.2195	0.2439	0.2439	0.1220	
A_2	–0.2195	0.0000	0.0244	0.0244	–0.0976	
A_3	–0.2439	–0.0244	0.0000	0.0000	–0.1220	
A_4	–0.2439	–0.0244	0.0000	0.0000	–0.1220	
A_5	–0.1220	0.0976	0.1220	0.1220	0.0000	
Ψ_2	A_1	A_2	A_3	A_4	A_5	S
A_1	0.0000	1.1099	1.1700	1.1700	0.8273	4.2772
A_2	–0.1978	0.0000	0.3700	0.3700	–0.1318	0.4103
A_3	–0.2085	–0.0659	0.0000	0.0000	–0.1474	–0.4218
A_4	–0.2085	–0.0659	0.0000	0.0000	–0.1474	–0.4218
A_5	–0.1474	0.7400	0.8273	0.8273	0.0000	2.2471
Ψ_3 x_{ij}–x_{ik}	A_1	A_2	A_3	A_4	A_5	
A_1	0.0000	0.0984	0.0984	0.0820	–0.0492	
A_2	–0.0984	0.0000	0.0000	–0.0164	–0.1475	
A_3	–0.0984	0.0000	0.0000	–0.0164	–0.1475	
A_4	–0.0820	0.0164	0.0164	0.0000	–0.1311	
A_5	0.0492	0.1475	0.1475	0.1311	0.0000	

Continued Table 4

Ψ_3	A_1	A_2	A_3	A_4	A_5	S
A_1	0.0000	0.7084	0.7084	0.6467	–0.0982	1.9653
A_2	–0.1388	0.0000	0.0000	–0.0567	–0.1701	–0.3656
A_3	–0.1388	0.0000	0.0000	–0.0567	–0.1701	–0.3656
A_4	–0.1268	0.2892	0.2892	0.0000	–0.1603	0.2913
A_5	0.5009	0.8676	0.8676	0.8180	0.0000	3.0542
Ψ_4 $x_{ij}–x_{ik}$	A_1	A_2	A_3	A_4	A_5	
A_1	0.0000	0.0588	–0.0882	–0.0882	0.0000	
A_2	–0.0588	0.0000	–0.1471	–0.1471	–0.0588	
A_3	0.0882	0.1471	0.0000	0.0000	0.0882	
A_4	0.0882	0.1471	0.0000	0.0000	0.0882	
A_5	0.0000	0.0588	–0.0882	–0.0882	0.0000	
Ψ_4	A_1	A_2	A_3	A_4	A_5	S
A_1	0.0000	0.5746	–0.2079	–0.2079	0.0000	0.1587
A_2	–0.1698	0.0000	–0.2684	–0.2684	–0.1698	–0.8764
A_3	0.4243	0.5478	0.0000	0.0000	0.4243	1.3965
A_4	0.3001	0.3874	0.0000	0.0000	0.3001	0.9875
A_5	0.0000	0.3001	–0.2079	–0.2079	0.0000	–0.1158
Ψ_5 $x_{ij}–x_{ik}$	A_1	A_2	A_3	A_4	A_5	
A_1	0.0000	0.0827	–0.0648	–0.0762	0.1583	
A_2	–0.0827	0.0000	–0.1475	–0.1589	0.0756	
A_3	0.0648	0.1475	0.0000	–0.0114	0.2231	
A_4	0.0762	0.1589	0.0114	0.0000	0.2345	
A_5	–0.1583	–0.0756	–0.2231	–0.2345	0.0000	
Ψ_5	A_1	A_2	A_3	A_4	A_5	S
A_1	0.0000	0.2905	–0.2520	–0.2732	0.4019	0.1672
A_2	–0.2847	0.0000	–0.3802	–0.3946	0.2778	–0.7816
A_3	0.2571	0.3879	0.0000	–0.1057	0.4771	1.0165
A_4	0.2788	0.4026	0.1078	0.0000	0.4892	1.2784
A_5	–0.3939	–0.2722	–0.4676	–0.4794	0.0000	–1.6131
Ψ_6 $x_{ij}–x_{ik}$	A_1	A_2	A_3	A_4	A_5	
A_1	0.0000	0.0882	0.1248	0.1067	0.2497	
A_2	–0.0882	0.0000	0.0366	0.0185	0.1615	
A_3	–0.1248	–0.0366	0.0000	–0.0181	0.1249	
A_4	–0.1067	–0.0185	0.0181	0.0000	0.1430	
A_5	–0.2497	–0.1615	–0.1249	–0.1430	0.0000	
Ψ_6	A_1	A_2	A_3	A_4	A_5	S
A_1	0.0000	0.3675	0.4371	0.4041	0.6182	1.8270
A_2	–0.2401	0.0000	0.2366	0.1680	0.4971	0.6617
A_3	–0.2856	–0.1546	0.0000	–0.1088	0.4372	–0.1118
A_4	–0.2640	–0.1098	0.1666	0.0000	0.4679	0.2607
A_5	–0.4039	–0.3248	–0.2857	–0.3057	0.0000	–1.3201

Continued Table 4

Ψ_7 x_{ij}–x_{ik}	A_1	A_2	A_3	A_4	A_5	
A_1	0.0000	0.0000	–0.0952	0.0000	0.0476	
A_2	0.0000	0.0000	–0.0952	0.0000	0.0476	
A_3	0.0952	0.0952	0.0000	0.0952	0.1429	
A_4	0.0000	0.0000	–0.0952	0.0000	0.0476	
A_5	–0.0476	–0.0476	–0.1429	–0.0476	0.0000	
Ψ_7	A_1	A_2	A_3	A_4	A_5	S
A_1	0.0000	0.0000	–0.1633	0.0000	0.4124	0.2491
A_2	0.0000	0.0000	–0.1633	0.0000	0.4124	0.2491
A_3	0.5832	0.5832	0.0000	0.5832	0.7143	2.4639
A_4	0.0000	0.0000	–0.1633	0.0000	0.4124	0.2491
A_5	–0.1155	–0.1155	–0.2000	–0.1155	0.0000	–0.5464
Ψ_8 x_{ij}–x_{ik}	A_1	A_2	A_3	A_4	A_5	
A_1	0.0000	0.0000	–0.0625	0.0000	0.0000	
A_2	0.0000	0.0000	–0.0625	0.0000	0.0000	
A_3	0.0625	0.0625	0.0000	0.0625	0.0625	
A_4	0.0000	0.0000	–0.0625	0.0000	0.0000	
A_5	0.0000	0.0000	–0.0625	0.0000	0.0000	
Ψ_8	A_1	A_2	A_3	A_4	A_5	S
A_1	0.0000	0.0000	–0.1323	0.0000	0.0000	–0.1323
A_2	0.0000	0.0000	–0.1323	0.0000	0.0000	–0.1323
A_3	0.4725	0.4725	0.0000	0.4725	0.4725	1.8898
A_4	0.0000	0.0000	–0.1323	0.0000	0.0000	–0.1323
A_5	0.0000	0.0000	–0.1323	0.0000	0.0000	–0.1323
Ψ_9 x_{ij}–x_{ik}	A_1	A_2	A_3	A_4	A_5	
A_1	0.0000	0.0000	–0.0588	–0.0588	0.0000	
A_2	0.0000	0.0000	–0.0588	–0.0588	0.0000	
A_3	0.0588	0.0588	0.0000	0.0000	0.0588	
A_4	0.0588	0.0588	0.0000	0.0000	0.0588	
A_5	0.0000	0.0000	–0.0588	–0.0588	0.0000	
Ψ_9	A_1	A_2	A_3	A_4	A_5	S
A_1	0.0000	0.0000	–0.1074	–0.1074	0.0000	–0.2148
A_2	0.0000	0.0000	–0.1074	–0.1074	0.0000	–0.2148
A_3	0.5478	0.5478	0.0000	0.0000	0.5478	1.6435
A_4	0.5478	0.5478	0.0000	0.0000	0.5478	1.6435
A_5	0.0000	0.0000	–0.1074	–0.1074	0.0000	–0.2148
Ψ_{10} x_{ij}–x_{ik}	A_1	A_2	A_3	A_4	A_5	
A_1	0.0000	0.0833	0.0000	0.0833	0.0833	
A_2	–0.0833	0.0000	–0.0833	0.0000	0.0000	
A_3	0.0000	0.0833	0.0000	0.0833	0.0833	
A_4	–0.0833	0.0000	–0.0833	0.0000	0.0000	
A_5	–0.0833	0.0000	–0.0833	0.0000	0.0000	

End of Table 4

Ψ_{10}	A_1	A_2	A_3	A_4	A_5	S
A_1	0.0000	0.5051	0.0000	0.5051	0.5051	1.5152
A_2	–0.1650	0.0000	–0.1650	0.0000	0.0000	–0.3300
A_3	0.0000	0.5051	0.0000	0.5051	0.5051	1.5152
A_4	–0.1650	0.0000	–0.1650	0.0000	0.0000	–0.3300
A_5	–0.1650	0.0000	–0.1650	0.0000	0.0000	–0.3300
Ψ_{11} x_{ij}–x_{ik}	A_1	A_2	A_3	A_4	A_5	
A_1	0.0000	0.2857	0.2857	0.2857	0.2857	
A_2	–0.2857	0.0000	0.0000	0.0000	0.0000	
A_3	–0.2857	0.0000	0.0000	0.0000	0.0000	
A_4	–0.2857	0.0000	0.0000	0.0000	0.0000	
A_5	–0.2857	0.0000	0.0000	0.0000	0.0000	
Ψ_{11}	A_1	A_2	A_3	A_4	A_5	S
A_1	0.0000	0.9352	0.9352	0.9352	0.9352	3.7409
A_2	–0.3055	0.0000	0.0000	0.0000	0.0000	–0.3055
A_3	–0.3055	0.0000	0.0000	0.0000	0.0000	0.0000
A_4	–0.3055	0.0000	0.0000	0.0000	0.0000	0.0000
A_5	–0.3055	0.0000	0.0000	0.0000	0.0000	–0.3055
Ψ_{12} x_{ij}–x_{ik}	A_1	A_2	A_3	A_4	A_5	
A_1	0.0000	0.1111	0.0000	0.0000	0.0000	
A_2	–0.1111	0.0000	–0.1111	–0.1111	–0.1111	
A_3	0.0000	0.1111	0.0000	0.0000	0.0000	
A_4	0.0000	0.1111	0.0000	0.0000	0.0000	
A_5	0.0000	0.1111	0.0000	0.0000	0.0000	
Ψ_{12}	A_1	A_2	A_3	A_4	A_5	S
A_1	0.0000	0.8585	0.0000	0.0000	0.0000	0.8585
A_2	–0.1905	0.0000	–0.1905	–0.1905	–0.1905	–0.7621
A_3	0.0000	0.8585	0.0000	0.0000	0.0000	0.0000
A_4	0.0000	0.8585	0.0000	0.0000	0.0000	0.0000
A_5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ψ_{13} x_{ij}–x_{ik}	A_1	A_2	A_3	A_4	A_5	
A_1	0.0000	0.0769	0.0000	0.0000	0.0769	
A_2	–0.0769	0.0000	–0.0769	–0.0769	0.0000	
A_3	0.0000	0.0769	0.0000	0.0000	0.0769	
A_4	0.0000	0.0769	0.0000	0.0000	0.0769	
A_5	–0.0769	0.0000	–0.0769	–0.0769	0.0000	
Ψ_{13}	A_1	A_2	A_3	A_4	A_5	S
A_1	0.0000	0.7143	0.0000	0.0000	0.7143	1.4286
A_2	–0.1171	0.0000	–0.1171	–0.1171	0.0000	–0.3512
A_3	0.0000	0.7143	0.0000	0.0000	0.7143	1.4286
A_4	0.0000	0.7143	0.0000	0.0000	0.7143	1.4286
A_5	–0.1171	0.0000	–0.1171	–0.1171	0.0000	–0.3512

Table 5. Global dominance and the relative overall value

Alternative		Calculation results					
		d	***G***	G_{max}	G_{min}	***V***	***Rank***
A_1	A_1, A_1	0	13.8681			1.000	1
	A_1, A_2	5.7420					
	A_1, A_3	1.7060					
	A_1, A_4	2.4011					
	A_1, A_5	4.0190					
A_2	A_2, A_1	–1.6450	–3.7614			0.000	5
	A_2, A_2	0					
	A_2, A_3	–1.5186					
	A_2, A_4	–1.1858					
	A_2, A_5	0.5881					
A_3	A_3, A_1	1.6944	12.0361			0.896	2
	A_3, A_2	4.7032					
	A_3, A_3	0		13.87	–3.76		
	A_3, A_4	1.3502					
	A_3, A_5	4.2882					
A_4	A_4, A_1	0.3995	6.6394			0.590	3
	A_4, A_2	3.3247					
	A_4, A_3	–0.0158					
	A_4, A_4	0					
	A_4, A_5	2.9310					
A_5	A_5, A_1	–0.9957	–0.8152			0.167	4
	A_5, A_2	1.0717					
	A_5, A_3	–0.6016					
	A_5, A_4	–0.2896					
	A_5, A_5	0					

Alternatives according to problem solution results are ranked as follows: $A_1 \succ A_5 \succ A_2 \succ A_3 \succ A_4$.

Conclusions

The risk assessment results are presented in the article based on the riskiest job at the construction site of the finishing works, with the priority line $A_1 \succ A_5 \succ A_2 \succ A_3 \succ A_4$.

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