Normalisation in the selection of construction alternatives

Article in International Journal of Management and Decision Making · January 2007

DOI: 10.1504/IJMDM.2007.013422

Darius Migilinskas
Vilnius Gediminas Technical University

Normalisation in the selection of construction alternatives

Darius Migilinskas* and Leonas Ustinovichius

Department of Construction Technology and Management,
Vilnius Gediminas Technical University,
Saulėtekio al. 11, LT-10223 Vilnius, Lithuania,
E-mail: dariusmg@mail.lt
E-mail: leonasu@st.vtu.lt
*Corresponding author

Abstract: In construction, the selection of effective construction alternatives is based on decision according to technological and economical analysis. The choice and analysis must be made independent of any preferences or interests and must be supported by a precise calculation of significant criteria such as economic benefit, workability of alternatives and investments. The comparison of normalised dimensionless criteria values, using particular optimal solution methods, is one of the basic stages in evaluation process. Therefore, normalisation method must be chosen according to the objectives so as to meet special requirements, with regard to possible inaccuracy or uncertainty threats and influence on the final ranking of the alternatives or even the final decision.

Keywords: normalisation methods; uncertainty influence; multi criteria Decision Support Systems; DSSs; game theory.

Reference to this paper should be made as follows: Migilinskas, D. and Ustinovichius, L. (2007) 'Normalisation in the selection of construction alternatives', *Int. J. Management and Decision Making*, Vol. 8, Nos. 2/3, pp.297–313.

Biographical notes: Darius Migilinskas received a Master of Civil Engineering and is a PhD student in the Department of Construction Technology and Management, Vilnius Gediminas Technical University (VGTU), Lithuania. He obtained his Honour's Bachelor (2001) and Honour's Master (2003) degrees from VGTU. He has also participated in Leonardo da Vinci programmes. He is the author of more than ten publications. His research interests and activities include building technology and management, decision making and normalisation methods, game theory adaptation in construction, computer-aided systems in design and construction evaluation.

Prof. Leonas Ustinovichius held various positions at Vilnius Gediminas Technical University, Lithuania, such as Dr. (1989), Lecturer (1988–1990), Senior Lecturer (1990–1993), Associate Professor (1993–2002), Senior Researcher (2000–2003), Dr. Habil. (2003), Professor (since 2002), Chairman Laboratory of Construction Technology and Management since 2000 and Chief Researcher since 2003. He is also an Associate Academician of International Information Academy. He is the Deputy Editor-in-Chief of the Journal *Technological and Economic Development of Economy*. He has participated in Leonardo da Vinci programmes. He is the author of more than 115 publications and 3 monographs. His research interests and activities include multiple attribute valuation and automated programming of technological solutions in construction and investment project efficiency, decision support systems building technology and management, decision-making theory and expert systems.

1 Introduction

The main objective in executing construction project at all stages is to choose the best alternative. This choice cannot be made based on preferences or supposed interests and must be supported by precise calculations of: economic benefit, workability of alternatives, investments and other significant criteria. The great variety of alternatives and criteria complicate the systemising of data and decision making. This process is facilitated by using multiple criteria Decision Support System (DSS) methods (Zavadskas and Ustinovichius, 2001). These methods based on the utility theory, game theory, statistical distribution and probability, were improved and adjusted by Zavadskas et al. (2002) due to decision-making needs in construction.

In the case of certainty, uncertainty and risk, the appropriate methods and rules are used to find optimal strategies. Zavadskas et al. (2004), in their works describe these main decision support stages: the formation of a matrix of alternatives, the selection of criteria, the selection of optimum criteria, the validation of criteria compatibility estimated by experts, decision matrix normalisation, the evaluation of alternatives rationality, the multi criteria evaluation and the final decision. Thus, the evaluation process is the comparison of dimensionless criteria values, using particular methods (Peldschus, 2001). It follows from the description, that one of the basic stages for further evaluation of dimensionless values is the normalisation of criteria values.

Hovanov (1996) and Cloquell et al. (2001) analysed the usage of value normalisation methods and determined what precise and appropriate data transformation is important, because the inaccuracy of value normalisation methods used in decision making or the application of the wrong methods affects final decision.

Zavadskas and Ustinovichius (2001) stated what is the serious problem to decision support approaches, because it is not clear which method fits a particular construction problem better. Cloquell et al. (2001) in their research noticed why it is important to choose right normalisation method and to follow up with this point it must be done according to the problem objectives (Körth, 1969 and Weitendorf, 1976), special requirements and with regard to possible inaccuracy or uncertainty threats.

Therefore, the main aim of this paper is to make the analysis of inaccuracy with respect to construction technology and economy problems under uncertainty, and to compare value normalisation methods. As a result it will be offered particular normalisation methods usage based on the analysis of value normalisation diagrams, possible data uncertainty and inaccuracy.

2 The object of research

Zavadskas et al. (2001–2004) study various problems encountered in construction and describe the evaluation needed for making final decision. For the analysis, the modular data of building reconstruction investment alternatives analysed by Zavadskas and Ustinovichius (2001) was used. The data is about the purchase, reconstruction, partial finish and reselling of ten buildings investment alternatives evaluated by 12 criteria.

The values of criteria weights are based on the validation of criteria compatibility estimated by construction experts as described by Zavadskas and Ustinovichius (2001). To reduce the amount of analysed data, the values (quantity of the criteria, the values of criteria weight and the values of alternative's criteria) in author's original table were mathematically condensed. All alternatives are evaluated using four main criteria (see Table 1). These complex criteria are combined from 12 basic criteria analysed by Zavadskas and Ustinovichius (2001), the criteria weights are given in brackets:

1 *Economic criteria ($q_1 = 0.35$) include*: profit, the building sell price, the price of building purchase and reconstruction.

2 *Criteria of maintenance ($q_2 = 0.26$) include*: durability of building, the cost of maintenance and the properties of thermal insulation.

3 *Criteria of business ($q_3 = 0.19$) include*: business prospects, the times of project realisation, availability of parking and the exterior view.

4 *Criteria of convenience ($q_4 = 0.20$) include*: building convenience and building place.

Table 1 Data table of combined complex criteria and weight for further normalisation

Criteria, X_i	*Economic, X_1*	*Maintenance, X_2*	*Business, X_3*	*Convenience, X_4*
Weight of criteria, q_i	$q_1 = 0.35$	$q_2 = 0.26$	$q_3 = 0.19$	$q_4 = 0.20$
Min or max / *Alternatives*	*Max* ↑	*Min* ↓	*Max* ↑	*Max* ↑
1st alternative, A_1	4.718	6.434	3.721	2.414
2nd alternative, A_2	4.334	5.239	3.381	2.268
3rd alternative, A_3	4.904	6.343	3.213	1.707
4th alternative, A_4	4.313	5.239	3.381	2.414
5th alternative, A_5	4.463	6.434	3.597	3.122
6th alternative, A_6	4.605	6.434	3.721	3.122
7th alternative, A_7	4.587	6.434	3.721	3.122
8th alternative, A_8	5.167	6.434	3.591	3.122
9th alternative, A_9	4.924	6.434	3.591	3.122
10th alternative, A_{10}	3.551	7.231	3.813	2.414

Mostly in evaluations, criteria of economic benefits (the expected profit, the largest revenue, etc.) have great importance and weight. Also in this paper economic criterion has high weight value (35%), so the analysis of the inaccuracy influence is made on the basis of this criterion value normalisation and usage in evaluation of alternatives. Zavadskas et al. (2002) have analysed the usage of several data transformation methods, but they compared methods analysing just three alternatives. This paper analyses how many alternatives have to be used in order to see how data influence the evaluation process.

3 Normalisation methods and analysis

The normalisation is considered to be the operation with which a group of values of a certain magnitude are transformed into other dimensionless values (Hwang and Yoon, 1981). Dimensionless values prepared for evaluation can be used in the free and the fixed predetermined scale. Commonly, in multi criteria decisions evaluation, the normalised non-dimensional values in the fixed scale [0; 1] are used (Cloquell et al., 2001).

By the opinion of VGTU professors (Zavadskas et al., 2003),

> "Solving the technological problems in construction applying the games theory methods, the dimensionless values must have proportion with ideal value, do not depend on matrix type and must be the same for the same proportional difference in the maximised and minimised problems".

The HKTW professor Peldschus (1986, 2001) also accentuates, that "the usage of certain matrix normalisation may affect the final decision, but the values of normalised decision support matrix must be in fixed scale [0; 1] or [0; ∞]".

To achieve the aim of this paper, it is analysed by linear and non-linear value normalisation methods and data analysis with multiple criteria evaluation programme for construction solutions LEVI 3.0 (Zavadskas et al., 2002). The analysis consists of the methods employed to solve one-sided and two-sided problems of the game theory. For the one-sided construction problem, only the method of 'proximity to the ideal point' is used. For the two-sided construction problem, a distinction is made between games with rational behaviour and games against nature.

Scientists describe normalisation methods are mostly used in multiple criteria DSSs (Cloquell et al., 2001; Hovanov, 1996). Eight value normalisation methods used in analysis are given in Table 2 (for maximised values) and Table 3 (for minimised values). Additionally, tables include the evaluation of the proportionality and the concentration tendency in normalised data for each of the normalisation methods.

Table 2 Description of the different normalisation methods, when normalised values maximised

No. Method	*Value normalisation method (when normalised values maximised)*	*Proportionality*	*Value concentration*
No. 1. (1) Proximity to ideal point	$b_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^{2}}}$	Is maintained	High
No. 2. (2) Weitendorf	$b_{ij} = \frac{a_{ij} - min\, a_{ij}}{max\, a_{ij} - min\, a_{ij}}$	Not maintained	Average
No. 3. (3) Hwang	$b_{ij} = \frac{a_{ij}}{\max_i a_{ij}}$	Is maintained	Low
No. 4. (4) Jüttler–Körth	$b_{ij} = 1 - \left\lvert \frac{a_j^* - a_{ij}}{a_j^*} \right\rvert$	Not maintained	Low

Table 2 Description of the different normalisation methods, when normalised values maximised (continued)

No. Method	*Value normalisation method (when normalised values maximised)*	*Proportionality*	*Value concentration*
No. 5. (5) Sum	$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{m} a_{ij}}$	Is maintained	High
No. 6. (6) Peldschus	$b_{ij} = \left(\frac{a_{ij}}{\max_i a_{ij}} \right)^2$	Not maintained	Low
No. 7. (7) Hovanov 0.5	$b_{ij} = \left(\frac{a_{ij} - \min a_{ij}}{\max a_{ij} - \min a_{ij}} \right)^{0,5}$	Not maintained	Average
No. 8. (8) Hovanov 2	$b_{ij} = \left(\frac{a_{ij} - \min a_{ij}}{\max a_{ij} - \min a_{ij}} \right)^2$	Not maintained	Average

Table 3 Description of the different normalisation methods, when normalised values minimised

No. Method	*Value normalisation method (when normalised values minimised)*	*Proportionality*	*Value concentration*
No. 1. (9) Proximity to ideal point	$b_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^2}}$	Is maintained	High
No. 2. (10) Weitendorf	$b_{ij} = \frac{\max a_{ij} - a_{ij}}{\max a_{ij} - \min a_{ij}}$	Not maintained	Average
No. 3. (11) Hwang	$b_{ij} = \frac{\min_i a_{ij}}{a_{ij}}$	Is maintained	Low
No. 4. (12) Jüttler–Körth	$b_{ij} = 1 - \left\| \frac{a_j^* - a_{ij}}{a_j^*} \right\|$	Not maintained	Low
No. 5. (13) Sum	$b_{ij} = 1 - \frac{a_{ij}}{\sum_{i=1}^{m} a_{ij}}$	Is maintained	High
No. 6. (14) Peldschus	$b_{ij} = \left(\frac{\min_i a_{ij}}{a_{ij}} \right)^3$	Not maintained	Average
No. 7. (15) Hovanov 0.5	$b_{ij} = \left(\frac{\max a_{ij} - a_{ij}}{\max a_{ij} - \min a_{ij}} \right)^{0,5}$	Not maintained	Average
No. 8. (16) Hovanov 2	$b_{ij} = \left(\frac{\max a_{ij} - a_{ij}}{\max a_{ij} - \min a_{ij}} \right)^2$	Not maintained	Average

The analysis data matrix consists of elements a_{ij} (quantity of rows $i = 1,\ldots,m$ and quantity of columns $j = 1,\ldots,n$) and additionally for normalisation the extreme values min a_{ij} and max a_{ij} are selected. The formulas of the normalisation methods are used to calculate the elements b_{ij} for matrix of the normalised values.

4 Analysis methodology and process

It is suggestible to use the algorithm of the construction alternative selection and analysis of solving construction problems in the uncertainty as shown in Figure 1. An analysis is made according to algorithm steps and consists of several main stages:

1. The initial evaluation values from data table (see Table 1) are normalised according to the maximisation or minimisation demand (Peldschus, 1986), using eight appropriate value normalisation methods (see Tables 2 and 3).
2. Using the ranked normalised values of each alternative criterion and all eight normalisation methods, the four basic and one additional diagram for complex analysis are made (see Figures 2–6).
3. The obtained results of each criterion value normalisation – four 8 × 10 size matrices (see Tables 4–7) – are used for the further multi criteria evaluation and the final decision making as the basic multi criteria evaluation data matrices for decision support program LEVI 3.0 (Zavadskas et al., 2002). Program uses optimal solution methods to find the priorities of alternatives. The applied optimal solution methods are as follows (Zavadskas et al., 2003): simple min–max principle, extended min–max principle, Wald's rule (Wald, 1945), Savage and Niehaus criterion (Savage, 1951), Hurwicz's rule (Hurwicz, 1951), Laplace–Bernouli's rule (Bernouli, 1738), Bayes–Laplace's rule (Arrow et al., 1949) and Hodges–Lehmann rule (Hodges and Lehmann, 1952).
4. From the results of eight value normalisation and six optimal solution finding methods (forty-eight 6 × 10 size matrices) the final alternative priority table (Migilinskas and Ustinovichius, 2004) is aggregated (see Table 8).
5. The final alternatives evaluation made by using the penalty scores method developed by Zavadskas et al. (2003). The evaluation using this method consists of summing up the penalty scores of alternatives separately for each optimal solution finding methods in current table cell (see Table 8). The certain alternative gains penalty point for each rank position below the best alternative cell (e.g. alternative in first place gains 1 penalty point, alternative ranked fourth – gains four penalty points, and so on till alternative in the tenth place gain 10 penalty points).
6. The results of the each alternative penalty score are collected into final diagram (see Figure 7) and the final decision is made.
7. To achieve a comprehensive evaluation of normalisation methods, the penalty scores (Zavadskas et al., 2003) of alternatives are calculated separately for each normalisation method (see Figure 8).
8. To complete the analysis of normalisation methods, conclusions are presented, based on the described intermediate notices and the final result tendencies.

Figure 1 The algorithm of the construction alternative selection and analysis of solving construction problems in the uncertainty

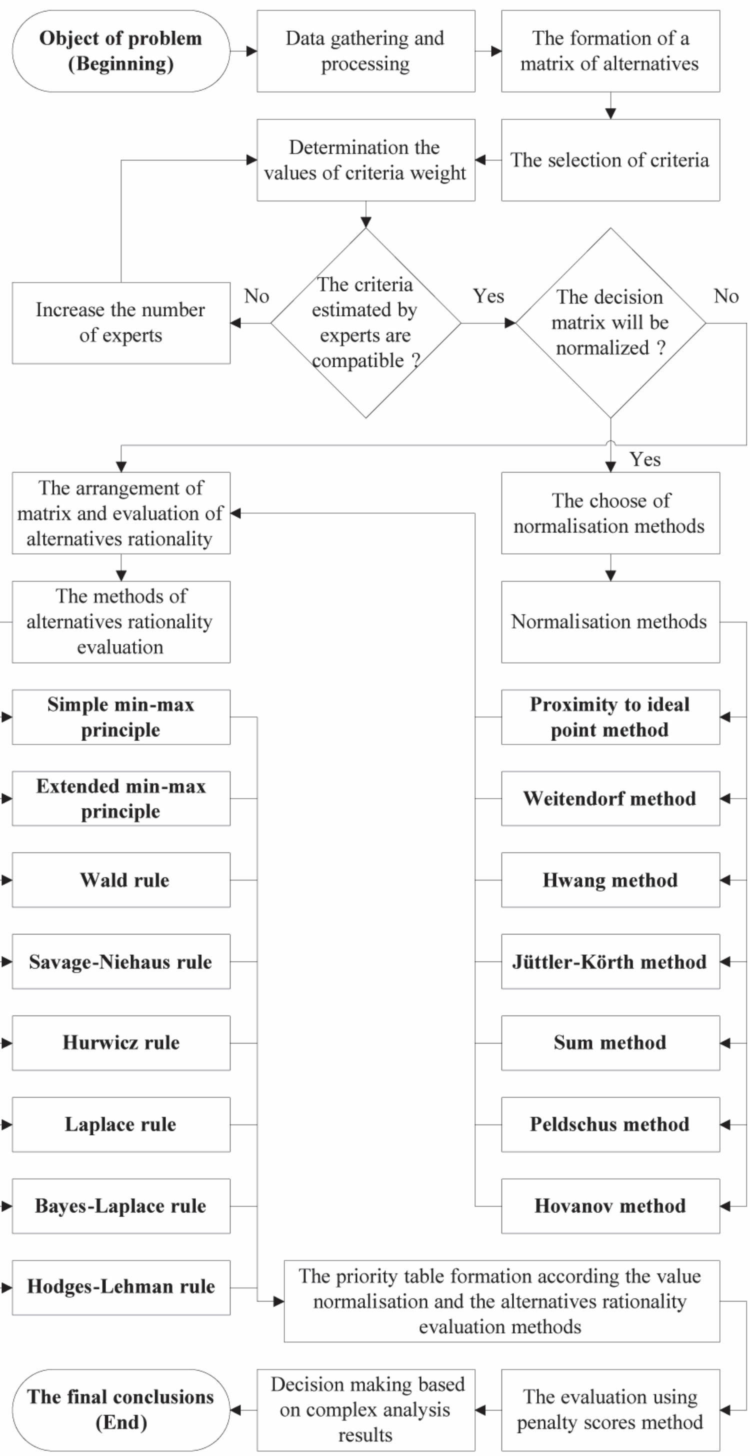


Figure 2 The diagram of the economic criteria ranked normalised results (when values are maximised)

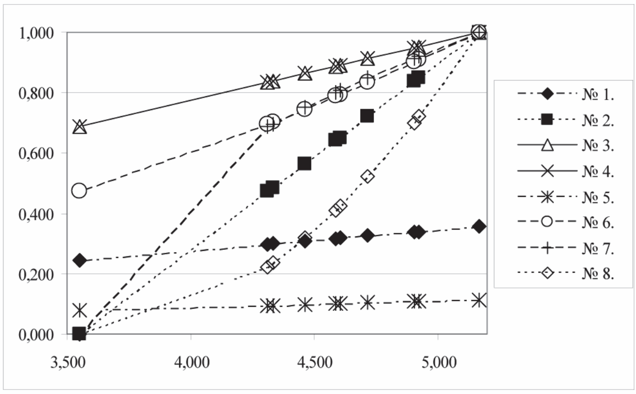


Figure 3 The diagram of the maintenance criteria ranked normalised results (when values are minimised)

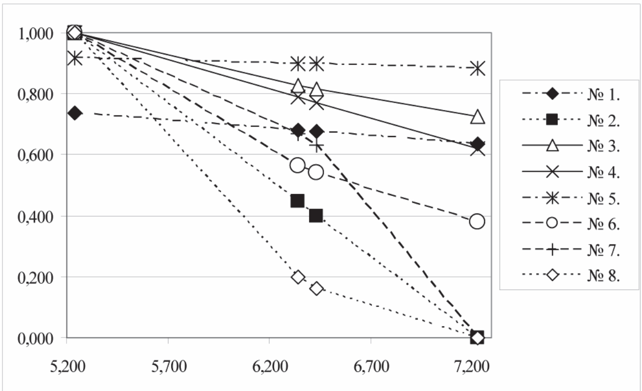


Figure 4 The diagram of the business criteria ranked normalised results (when values are maximised)

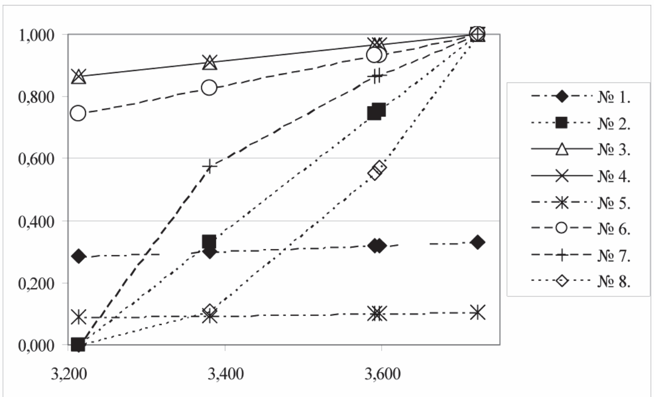


Figure 5 The diagram of the convenience criteria ranked normalised results (when values are maximised)

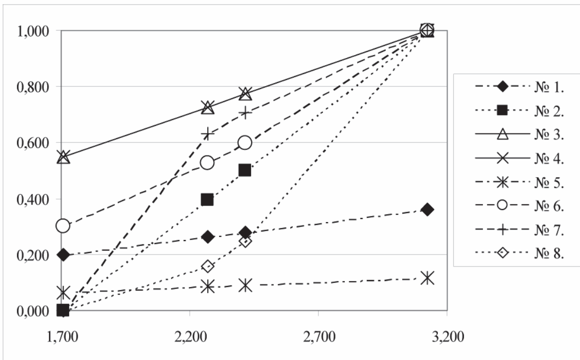


Figure 6 The additional diagram of the economic criteria ranked normalised results (when values are minimised)

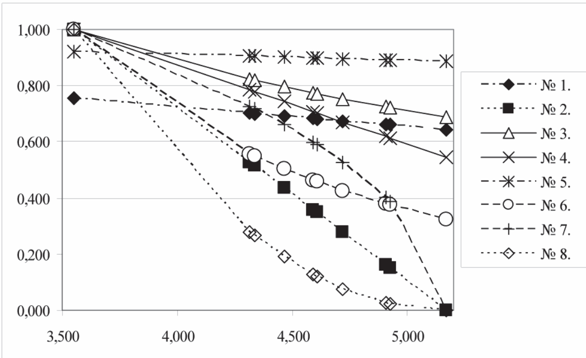


Table 4 The results obtained with the different value normalisation methods used on data of economic criteria

Max	*Economic, X_1*	*No. 1*	*No. 2*	*No. 3*	*No. 4*	*No. 5*	*No. 6*	*No. 7*	*No. 8*
A_1	4.718	0.326	0.722	0.913	0.913	0.104	0.834	0.850	0.521
A_2	4.334	0.300	0.485	0.839	0.839	0.095	0.704	0.696	0.235
A_3	4.904	0.339	0.837	0.949	0.949	0.108	0.901	0.915	0.700
A_4	4.313	0.298	0.472	0.835	0.835	0.095	0.697	0.687	0.222
A_5	4.463	0.308	0.565	0.864	0.864	0.098	0.746	0.751	0.319
A_6	4.605	0.318	0.652	0.891	0.891	0.101	0.794	0.808	0.426
A_7	4.587	0.317	0.641	0.888	0.888	0.101	0.788	0.801	0.411
A_8	5.167	0.357	1.000	1.000	1.000	0.113	1.000	1.000	1.000
A_9	4.924	0.340	0.849	0.953	0.953	0.108	0.908	0.922	0.721
A_{10}	3.551	0.245	0.000	0.687	0.687	0.078	0.472	0.000	0.000

Table 5 The results obtained with the different value normalisation methods used on data of maintenance criteria

Min	*Maintenance, X_2*	*No. 1*	*No. 2*	*No. 3*	*No. 4*	*No. 5*	*No. 6*	*No. 7*	*No. 8*
A_1	6.434	0.677	0.400	0.814	0.772	0.897	0.540	0.633	0.160
A_2	5.239	0.737	1.000	1.000	1.000	0.916	1.000	1.000	1.000
A_3	6.343	0.681	0.446	0.826	0.789	0.899	0.563	0.668	0.199
A_4	5.239	0.737	1.000	1.000	1.000	0.916	1.000	1.000	1.000
A_5	6.434	0.677	0.400	0.814	0.772	0.897	0.540	0.633	0.160
A_6	6.434	0.677	0.400	0.814	0.772	0.897	0.540	0.633	0.160
A_7	6.434	0.677	0.400	0.814	0.772	0.897	0.540	0.633	0.160
A_8	6.434	0.677	0.400	0.814	0.772	0.897	0.540	0.633	0.160
A_9	6.434	0.677	0.400	0.814	0.772	0.897	0.540	0.633	0.160
A_{10}	7.231	0.637	0.000	0.725	0.620	0.885	0.380	0.000	0.000

Table 6 The results obtained with the different value normalisation methods used on data of business criteria

Max	*Business, X_3*	*No. 1*	*No. 2*	*No. 3*	*No. 4*	*No. 5*	*No. 6*	*No. 7*	*No. 8*
A_1	3.721	0.331	1.000	1.000	1.000	0.105	1.000	1.000	1.000
A_2	3.381	0.301	0.331	0.909	0.909	0.095	0.826	0.575	0.109
A_3	3.213	0.286	0.000	0.863	0.863	0.090	0.746	0.000	0.000
A_4	3.381	0.301	0.331	0.909	0.909	0.095	0.826	0.575	0.109
A_5	3.597	0.320	0.756	0.967	0.967	0.101	0.934	0.869	0.571
A_6	3.721	0.331	1.000	1.000	1.000	0.105	1.000	1.000	1.000
A_7	3.721	0.331	1.000	1.000	1.000	0.105	1.000	1.000	1.000
A_8	3.591	0.319	0.744	0.965	0.965	0.101	0.931	0.863	0.554
A_9	3.591	0.319	0.744	0.965	0.965	0.101	0.931	0.863	0.554
A_{10}	3.591	0.319	0.744	0.965	0.965	0.101	0.931	0.863	0.554

Table 7 The results obtained with the different value normalisation methods used on data of convenience criteria

Max	*Convenience, X_4*	*No. 1*	*No. 2*	*No. 3*	*No. 4*	*No. 5*	*No. 6*	*No. 7*	*No. 8*
A_1	2.414	0.280	0.500	0.773	0.773	0.090	0.598	0.707	0.250
A_2	2.268	0.263	0.396	0.726	0.726	0.085	0.528	0.630	0.157
A_3	1.707	0.198	0.000	0.547	0.547	0.064	0.299	0.000	0.000
A_4	2.414	0.280	0.500	0.773	0.773	0.090	0.598	0.707	0.250
A_5	3.122	0.362	1.000	1.000	1.000	0.116	1.000	1.000	1.000
A_6	3.122	0.362	1.000	1.000	1.000	0.116	1.000	1.000	1.000
A_7	3.122	0.362	1.000	1.000	1.000	0.116	1.000	1.000	1.000
A_8	3.122	0.362	1.000	1.000	1.000	0.116	1.000	1.000	1.000
A_9	3.122	0.362	1.000	1.000	1.000	0.116	1.000	1.000	1.000
A_{10}	2.414	0.280	0.500	0.773	0.773	0.090	0.598	0.707	0.250

Table 8 The final ranking of the alternatives for each of the normalisation and decision methods (evaluated with LEVI 3.0)

Methods of value normalisation/ group	*Optimal solution finding methods (principles and rules)*					
	Wald	*Savage–Niehaus*	*Hurwicz λ = 0.5*	*Laplace–Bernouli*	*Bayes–Laplace*	*Hodges–Lehman*
No. 1/1st group	**6>7>5>8> >9>4>1> >10>2>3**	6>7>8>9> >1>5>2> >4>3>10	4>2>6>7> >5>8>9> >1>10>3	**8>9>6>7> >5>4>1> >2>3>10**	8>9>6>7> >5>1>4> >2>3>10	**6**
No. 2/4th group	***5>6>7>8> >9>1>4> >2>3>10***	**1>5>6>7> >8>9>2> >3>4>10**	8>9>1>6> >7>2>4> >5>3>10	***8>9>6>7> >1>5>4> >2>3>10***	8>9>6>7> >1>5>2> >4>3>10	**8**
No. 3/2nd group	**6>7>5>8> >9>4>1> >10>2>3**	**1>5>6>7> >8>9>2> >4>3>10**	8>9>6>7> >5>1>4> >3>2>10	**8>9>6>7> >5>4>1> >2>3>10**	8>9>6>7> >5>1>4> >2>3>10	**6**
No. 4/2nd group	**6>7>5>8> >9>4>1> >10>2>3**	***2>4>1>5> >6>7>8> >9>3>10***	8>9>6>7> >5>1>4> >3>2>10	8>9>6>7> >5>4>2> >1>3>10	8>9>6>7> >4>5>2> >1>3>10	**6**
No. 5/1st group	**6>7>5>8> >9>4>1> >10>2>3**	6>7>8>9> >1>5>4> >2>3>10	4>2>6>7> >5>8>9> >1>10>3	8>9>6>7> >5>1>4> >2>3>10	8>9>6>7> >5>1>4> >2>3>10	**6**
No. 6/3rd group	5>6>7>8> >9>4>1> >2>10>3	***2>4>1>5> >6>7>8> >9>3>10***	8>9>6>7> >1>5>4> >3>2>10	8>9>6>7> >4>5>2> >1>3>10	8>9>6>7> >4>2>5> >1>3>10	**8**
No. 7/3rd group	***5>6>7>8> >9>1>4> >2>3>10***	1>5>6>7> >8>9>2> >4>3>10	8>9>6>7> >1>5>4> >2>3>10	***8>9>6>7> >1>5>4> >2>3>10***	**8>9>6>7> >1>5>4> >2>3>10**	**8**
No. 8/4th group	1>5>6>7> >8>9>4> >2>3>10	3>1>6>7> >8>9>5> >2>4>10	8>9>2>4> >3>7>5> >6>1>10	***8>9>6>7> >1>5>4> >2>3>10***	***8>9>6>7> >1>5>4> >2>3>10***	**8**

Figure 7 Graphical form of the penalty scores distribution results for each optimal solution method

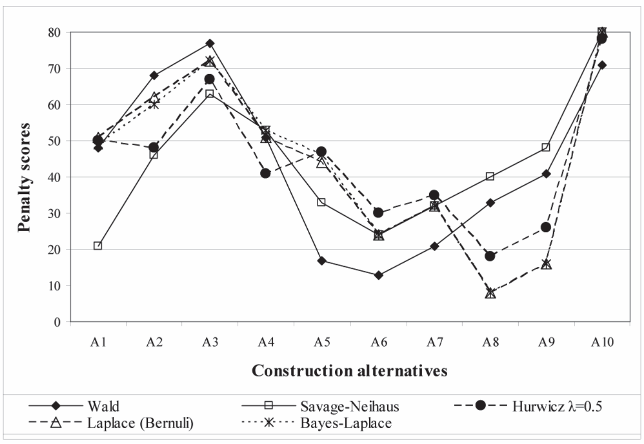
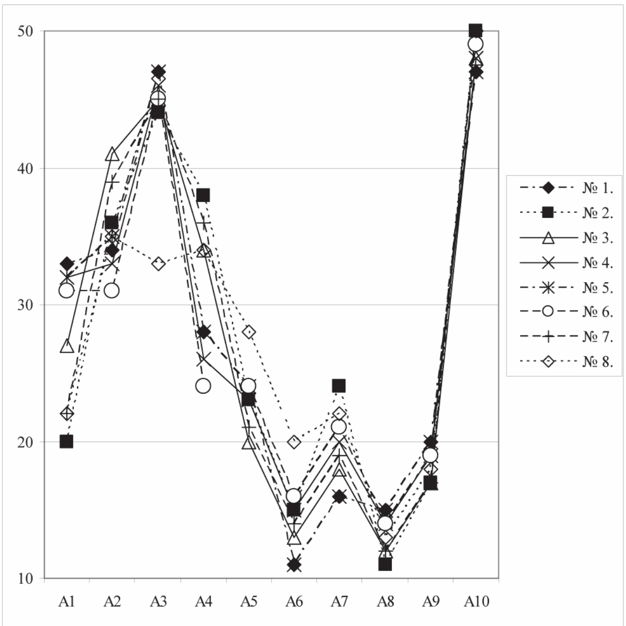


Figure 8 Graphical form of the analysis penalty scores distribution results for each normalisation method



5 Normalisation

After the finishing of the analysis data normalisation procedures (see Tables 4–7) according to analysis stage 2, the results are shown in Figures 2–6 and the following intermediate notices can be made:

1. From the problem data normalisation values (see Table 4) and their diagrams (see Figures 2–6), it is possible to classify the methods into four particular groups with similar attributes (analysing normalised value concentration and distribution): First group methods are 'Proximity to ideal point' and 'Sum' (No. 1 and No. 5 – with high value concentration and close distribution), second group methods are 'Hwang' and 'Jüttler–Körth' (No. 3 and No. 4 – with average value concentration and close distribution), third group methods are 'Peldschus' and 'Hovanov 0.5' (No. 6 and No. 7 – with low value concentration and average distribution) and fourth group methods are 'Weitendorf' and 'Hovanov 2' (No. 2 and No. 8 – with low value concentration and wide distribution).
2. Since the middle values (all except the highest and the lowest ones) are normalised by the 'Sum' method (No. 5) – are found highly concentrated in a small interval (0.108–0.095 = 0.013), making 37% of the whole interval of normalised values and as little as 1.3% of the whole interval of normalised values, and by insufficiency of the method, not all the criteria of the alternatives were adequately ranked (see Figure 2). However, this method will be used in the further complex objective analysis.

3 Methods of first group – ‘Proximity to ideal point’ (No. 1) and ‘Sum’ (No. 5) may be considered as normalisation methods with similar concentration and proportional association of the normalised values (other values can be found from one of values multiplied by a certain factor).

4 Methods of second group – ‘Hwang’ (No. 3) and ‘Jüttler–Körth’ (No. 4) yield the same rankings, which may be considered as normalisation methods with similar concentration of the normalised values. Also it is noticeable that the maximised normalised values match each other (see Figure 2), while the minimised normalised values of ‘Jüttler–Körth’ method (No. 4) in the additional diagram slightly differ (see Figure 6), being more closely associated with the values and the concentration characteristic of ‘Peldschus’ method (No. 6).

5 Methods of third group – ‘Peldschus’ (No. 6) and ‘Hovanov 0.5’ (No. 7) yield the same rankings, which may be considered as normalisation methods with similar concentration of the normalised values and their maximised normalised values are close to each other but, as mentioned above, minimised values of ‘Peldschus’ method (No. 6) are closely associated to values normalised with ‘Jüttler–Körth’ method (No. 4).

6 Methods of fourth group – ‘Weitendorf’ (No. 2) and ‘Hovanov 2’ (No. 8) yield the same rankings, which may be considered as normalisation methods with similar concentration and proportional association of the normalised values (other values can be found from one of the values multiplied by certain factor). These methods are close to the ideal straight average line or it multiplier, but their main disadvantage is that they exclude intermediate alternatives from a comparison list, and only the best and the worst values are considered for the further evaluation (wide value distribution).

6 Analysis results

Further evaluation with the program LEVI 3.0 (Larichev et al., 2004; and Zavadskas et al., 2004) shows interesting details on usage of the decision support optimal solution finding methods. The final rankings presented in Table 8, where the cells with the same grey shade means the ideal matching in the same group of normalisation methods and the bold or bold italic font means one or another ideal matching of the final alternative rankings between the different groups of normalisation methods. The following are intermediate notices after completing analysis stages 3 and 4:

1 The earlier dividing in four particular groups of value normalisation methods remains unchanged even after data evaluation, it means the dividing in the predetermined groups was correct.

2 After data evaluation using the program package LEVI 3.0, the final alternative rankings according to value normalisation and decision support methods, are matched: first group methods – ‘Proximity to ideal point’ (No. 1) and ‘Sum’ (No. 5) are matching >90%, second group methods – ‘Hwang’ (No. 3) and ‘Jüttler–Körth’ (No. 4) are matching >73%, third group methods – ‘Peldschus’ (No. 6) and ‘Hovanov 0.5’ (No. 7) are matching >61% and fourth group methods – ‘Weitendorf’ (No. 2) and ‘Hovanov 2’ (No. 8) are matching >62%.

3 These tendencies of an ideal matching (in exact preference order of several ranking places) between different groups of normalisation methods are determined: using Bayes–Laplace's and Laplace–Bernouli's rules – 100% for 4 ranking places, using Hurwicz's rule – 50% for 4 and 75% for 2 ranking places, using Wald's rule – 50% for 4 ranking places. These matching in usage of optimal solution finding methods means, what the analysis of the final ranking table is reasonable with enough tolerance for evaluation.

4 There is no ideal matching between the majority of the different normalisation methods' groups in the final ranking table where used the Savage and Niehaus criterion and Hodges–Lehmann rule for finding optimal solution.

The results of analysis stages 5–7 – analysis using the penalty scores method (Zavadskas et al., 2003), can be classified into three levels (see Table 9 and Figure 7): the alternatives with high penalty scores are A_3 and A_{10}; the alternatives with average penalty scores are A_1, A_2, A_4 and A_5; the alternatives with low penalty scores are A_6, A_7, A_8 and A_9. The alternatives with lowest penalty scores are A_6 and A_8, (the best alternative is A_6), but the final decision of evaluation must be done according to all analysis data. Additionally, from the results of alternatives penalty scores and the analysis penalty scores distribution (see Table 9 and Figure 8) it is seen, that the normalisation methods with high quantity of extreme penalty scores (see methods 'Proximity to ideal point' – No. 1, 'Weitendorf' – No. 2, 'Sum' – No. 5 and 'Hovanov 2' – No. 8) distort the graphical form of penalty scores values. In contrast, the normalisation methods with low quantity of extreme penalty scores (see methods 'Hwang' – No. 3, 'Jüttler–Körth' – No. 4, 'Peldschus' – No. 6 and 'Hovanov 0.5' – No. 7) show the average distribution in the penalty scores graphical form (see Figure 8).

Table 9 The results of penalty scores calculation for each of the normalisation methods after final ranking of the alternatives

Alternatives/Level of the penalty scores	*The penalty points for the normalisation methods*								ΣA_j
	No. 1	*No. 2*	*No. 3*	*No. 4*	*No. 5*	*No. 6*	*No. 7*	*No. 8*	
A_1/Average	**33**	*20*	27	32	32	31	22	22	219
A_2/Average	34	36	**41**	33	35	*31*	39	35	284
A_3/High	**47**	44	45	46	**47**	45	45	*33*	352
A_4/Average	28	**38**	34	26	28	*24*	36	34	248
A_5/Low	24	23	*20*	23	24	24	21	**28**	187
A_6/Low	*11*	15	13	15	*11*	16	14	**20**	115
A_7/Low	*16*	**24**	18	20	*16*	21	19	22	156
A_8/Low	**15**	*11*	12	14	**15**	14	12	13	106
A_9/Low	**20**	*17*	*17*	19	**20**	19	*17*	18	147
A_{10}/High	*47*	**50**	48	48	*47*	49	**50**	**50**	389
Min	3	3	2	0	3	2	1	1	15
Max	4	3	1	0	3	0	1	3	15
$\Sigma_{\text{min j \& max j}}$	**7**	**6**	**3**	**0**	**6**	**2**	**2**	**4**	**30**

A paradigmatic case of this situation would be the multiple criteria decision problems, where the aim is to select an option among a finite number of them mentioned by Larichev et al. (2003) and Zavadskas et al. (2004). In this type of problems, a high concentration level of the normalised values makes difficulty to clearly separate and distinguish the results of the different options, which means an additional difficulty when a justification for the selection of the best of alternatives is searched.

It is important to have the accurate data for evaluation in all construction stages (Sarkiene et al., 2004). Because the criteria values of alternatives are determined by the particular precision (Ustinovichius, 2004), in construction the range of calculated data bias can vary from 5% to 10% (Migilinskas and Ustinovichius, 2004). Considering this tendency, the difference between close normalised values of alternatives must exceed at least 5% of the whole range of normalisation. This statement must be obligatory in construction and can be solved using appropriate methods (it is suggested to use the third group of normalisation methods: 'Peldschus' – No. 6 and 'Hovanov 0.5' – No. 7) to avoid inaccuracy influence in evaluation process.

7 Conclusions

Solving technological and economic problems in construction to find a optimal solution, it is advisable to use the DSSs, applying the games theory and using described value normalisation methods. An analysis of inaccuracy effect in solving construction technology and economy problems is completed. After analysing the choice of the value normalisation methods, the following conclusions and the advices of methods usage are made:

1. From the analysis, it is obviously seen what in the case of plenty (more than four) alternatives and their rankings, makes the choice of the value normalisation methods very important and this act may significantly influence problem results.
2. Because of value concentration (the whole interval of normalised values is <1.3% of the whole range of normalisation), the normalised values of the first group methods ('Proximity to ideal point' – No. 1 and 'Sum' – No. 5) can be used when five or less alternatives are evaluated. In other evaluation, to prevent the value concentration and to avoid wrong final decision, it is better not to use first group methods.
3. Second group methods ('Hwang' – No. 3 and 'Jüttler–Körth' – No. 4) are close to ideal, but their main disadvantage is that the best three alternatives are averagely concentrated (the interval of this alternatives normalised values is ~5% of the whole range of normalisation) and they are in the range of data precision.
4. Fourth group methods ('Weitendorf' – No. 2 and 'Hovanov 2' – No. 8) have very wide normalisation value distribution, they exclude intermediate alternatives from a comparison list and only the best and the worst values are considered.

Then, at least three or more alternatives must be evaluated and the value normalisation methods used in multi criteria decision making and DSS, the choice of the value normalisation methods significantly affects the final ranking of alternatives and final decision. Because normalised values of third group methods (‘Peldschus’ – No. 6 and ‘Hovanov 0.5’ – No. 7) are low concentrated, averagely distributed and express the average values of penalty scores, they are more appropriate.

References

Arrow, K.J., Blackwell, D. and Girshick, M.A. (1949) ‘Bayes and minimax solutions of sequential decision problems’, *Econometrica*, Vol. 17, pp.213–244.

Bernouli, D. (1738) ‘Specimen theoriae novas de mesura sortis’, *Comentarii Academiae Scientarium Imperialis Petropolitanae*, Vol. 5, pp.175–192 (Translated by Sommer, L. (1954) ‘Exposition of a new theory on the measurement of risk’, *Econometrica*, Vol. 22, pp.23–36).

Cloquell, V.A., Santamarina, C. and Hospitaler, A. (2001) ‘Nuevo procedimiento para la normalización de valores numéricos en la toma de decisions’, *Papers of XVII Congreso Nacional de Ingeniería de Proyectos – Organizacion y dirección de Proyectos*, 19–21 September, Universidad de Murcia, Murcia, pp.11–18 (in Spanish).

Hodges, J.L. and Lehmann, E.L. (1952) ‘The use of previous experience in reaching statistical decision’, *Annals of Mathematics Statistics*, Vol. 23, pp.396–407.

Hovanov, N. (1996) *Analysis and Synthesis of Parameters Under Information Deficiency*, St.Petersburg: St.Petersburg University Press, pp.11–22.

Hurwicz, L. (1951) ‘Optimality criteria for decision making under ignorance – Cowles commission discussion paper’, *Statistics*, No. 370.

Hwang, C.L. and Yoon, K.P. (1981) *Multiple Attribute Decision Making – Methods and Applications*, New York: Springer-Verlag, pp.81–149.

Körth, H. (1969) ‘Zur berücksichtigung mehrer zielfunktionen bei der optimierung von produktionsplanen’, mathematik und wirtschaft’, Band 6, Verlag die Wirtschaft, Berlin, pp.184–201.

Larichev, O., Kochin, D. and Ustinovichius, L. (2003) ‘Multicriteria method of choosing the best alternative for investments’, *DSS in the Uncertainty of the Internet Age*, Karol Adamiecki University of Economics in Katowice, Katowice, pp.255–270.

Migilinskas, D. and Ustinovichius, L. (2004) ‘An analysis of inaccuracy effect in solving construction technology and economy problems, applying games theory’, *The Eighth International Conference Modern Building Materials, Structures and Techniques*, Selected papers (19–21 May), Vilnius: Technika, pp.229–235.

Peldschus, F. (1986) ‘Zur anwendung der theorie der spiele für aufgaben der bautechnologie’, Dissertation B, TH Leipzig, p.119.

Peldschus, F. (2001) ‘Sensitivity investigations to methods of the multiple criteria decisions’, *Statyba (Civil Engineering)*, Vol. 7, No. 4, pp.276–280 (in German).

Sarkiene, E., Ustinovichius, L. and Sarka, V. (2004) ‘Model of selection architectural solutions in housing construction based on multiple criteria decision synthesis methods’, *Foundation of Civil and Environmental Engineering*, Poznan, Vol. 6, pp.25–37.

Savage, L.J. (1951) ‘The theory of statistical decision’, *Journal of the American Statistical Association*, Vol. 46, pp.55–67.

Ustinovichius, L. (2004) ‘Determination of efficiency of investments in construction’, *International Journal of Strategic Property Management*, Vol. 8, No. 1, pp.25–44.

Wald, A. (1945) ‘Statistical decisions functions which minimise the maximum risk’, *Annals of Mathematics*, Vol. 46, No. 2, pp.265–280.

Weitendorf, D. (1976) ‘Beitrag zur optimierung der räumlichen struktur eines gebäudes’, Dissertation A, Hochschule für Architektur und Bauwesen, Weimar.

Zavadskas, E.K., Peldschus, F. and Ustinovichius, L. (2003) 'Development of software for multiple criteria evaluation', *Informatica*, Vol. 14, No. 2, pp.259–272.

Zavadskas, E.K., Peldschus, F., Ustinovichius, L., Turskis, Z. and Messing, D. (2002) 'LEVI 3.0 – Multiple criteria evaluation program for construction solutions', *Journal of Civil Engineering and Management*, Vol. 8, No. 3, pp.184–191.

Zavadskas, E.K. and Ustinovichius, L. (2001) 'Appliance of multicriteria decision methods in the analysis of investment projects of building reconstruction', *Technological and economic development of economy*, Vol. 7, No. 1 (in Russian).

Zavadskas, E.K., Ustinovichius, L. and Stasiulionis, A. (2004) 'Multicriteria valuation of commercial construction projects for investment purposes', *Journal of Civil Engineering and Management*, Vol. 9, No. 2, pp.151–166.