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Multi-Criteria Selection of a Deep-Water Port in Klaipeda

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Abstract

The Klaipeda port is an arterial transport corridor between Eastern and Western Europe. There is need to develop a deep-water sea port in the Klaipeda region to satisfy economic needs. This problem involves a multitude of requirements and uncertain conditions that have to be taken into consideration simultaneously. This paper proposes an integrated multi-criteria decision-making model to solve the problem. The backbone of the proposed mode consists of a combination of entropy and WASPAS methods.

Keywords: Deep-water port, alternatives, entropy weights, WASPAS.

1. Introduction

International logistics is a problem of crucial importance for modern world development [1]. Critical infrastructures play a significant role in countries due to the essentiality of national security, public safety, socioeconomic security and a way of life [2]. Infrastructures are very important for integrating EU countries.

Klaipeda is the only ice-free port on the eastern coast of the Baltic Sea. Unfortunately its infrastructural capacity will not be sufficient for further effective activities, not even after fully mastering the exiting and reserved port areas. The Port of Klaipeda has problems in handling Baltmax type ships.

Problems in selecting seaports have been investigated by many researchers. Wiegmans [3] presented the problem regarding container terminal selection for deep-sea container carriers. This study reveals that port selection and terminal selection are not the same, when it comes to the criteria for terminal selection, which mainly depend on handling speed, handling costs, reliability and hinterland connections. This analysis concludes that decision-making differs per container carrier, per trade and per port type, thereby implying that a one size fits all approach is not relevant.

The major problem that port professionals (e.g., port risk managers and port auditors) are facing is the lack of an appropriate methodology and evaluation techniques to support their decisions [4].
Decision-making problems often involve a complex decision-making process by which multiple requirements and uncertain conditions have to be taken into consideration simultaneously. Effectiveness of multi-criteria decision-aiding system as well as accuracy of decisions is based on an application of a proper MCDM method [5].

WASPAS method was selected for problem for increase the ranking accuracy. Methodology for optimization of weighted aggregated function was proposed, that enables to reach the highest accuracy of estimation [6].

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2. Outer port development plan

The cargo turnover at Klaipeda Port throughout 1999–2011 has more than doubled, from 15 million tons to 36.6 million tons of cargo respectively. The annual capacity of Klaipeda Port amounts to over 52 million tons; therefore the presumption is that the port capacity will be entirely exhausted by 2017, due to the growth of cargo throughput.

A deep-water port should be developed within the present territory to deal with the lack of capacity and to satisfy the shipping needs of Baltmax type ships to remain competitive in the Baltic Sea.

The best construction site for a deep-water port can be selected after a detailed analysis and investigation of the targeted number of alternatives. A deep-water port would only involve development of strategically important terminals.

The Lithuanian government signed an agreement with the Japan International Cooperation Agency (JICA) for Klaipeda port development feasibility studies to come to some resolution regarding the development of Klaipeda Port. JICA experts conducted the study and presented options (Fig. 1) for construction of the outer port in Klaipeda (at Melnragė) [7, 8].

Fig. 1. The outer port of Klaipeda JICA experts vision

3. Weighted aggregated sum product assessment [6]

The Weighted Sum Model (WSM) is one of the best known and applied in solving of multi-criteria problems. A given MCDM problem is defined on *m* alternatives and *n* decision criteria. w_j d enotes the relative significance of the criterion and x_{ij} is the performance value of alternative *i* when it is evaluated in terms of criterion *j.* Then the total relative importance of alternative *i,* denoted as $Q_i^{(1)}$, is defined as follows [9, 10] ($\overline{x}_{ij}$ – normalised vlue of *j*-th criterion of *i*-th alternative):

$$Q_i^{(1)} = \sum_{j=1}^{n} \overline{x}_{ij} w_j . \tag{1}$$

According to the Weighted Product Model (WPM) the total relative importance of alternative *i,* denoted as $Q_i^{(2)}$, is defined as follows [11, 12] :

$$Q_i^{(2)} = \prod_{j=1}^{n} \left(\overline{x}_{ij}\right)^{w_j} . \tag{2}$$

There was an attempt to apply a joint criterion for determining a total importance of alternative, giving equal contribution of WSM and WPM for total evaluation [13]:

$$Q_i = 0.5 Q_i^{(1)} + 0.5 Q_i^{(2)}. \tag{3}$$

Based on previous research [6] and supposing the increase of ranking accuracy and, respectively, the effectiveness of decision-making, the Weighted Aggregated Sum Product Assessment (WASPAS) method for ranking of alternatives is proposed in the current research:

$$Q_i = \lambda \sum_{j=1}^{n} \bar{x}_{ij} w_j + (1-\lambda) \prod_{j=1}^{n} (\bar{x}_{ij})^{w_j}, \quad \lambda = 0,...1. \tag{4}$$

Optimal values of λ can be find when searching extreme function:

$$\lambda = \frac{\sigma^2\left(Q_i^{(2)}\right)}{\sigma^2\left(Q_i^{(1)}\right) + \sigma^2\left(Q_i^{(2)}\right)}. \tag{5}$$

The variances $\sigma^2\left(Q_i^{(1)}\right)$ and $\sigma^2\left(Q_i^{(2)}\right)$ should be calculated:

$$\sigma^2\left(Q_i^{(1)}\right) = \sum_{j=1}^{n} w_j^2 \sigma^2(\bar{x}_{ij}), \tag{6}$$

$$\sigma^2\left(Q_i^{(2)}\right) = \sum_{j=1}^{n} \left(\frac{\prod_{j=1}^{n} (\bar{x}_{ij})^{w_j} w_j}{(\bar{x}_{ij})^{w_j} (\bar{x}_{ij})^{(1-w_j)}} \right)^2 \sigma^2(\bar{x}_{ij}). \tag{7}$$

Estimates of variances of normalized initial criteria values are calculated as follows:

$$\sigma^2(\bar{x}_{ij}) = (0.05\bar{x}_{ij})^2. \tag{8}$$

4. Case study

Study experts conclude that port expansion within the existing territory of Klaipeda Port is limited. Considering the city and port development trends at that time, JICA experts recommend constructing an artificial island (1.5 km long and 700 m wide) next to the northern breakwater of the port's entrance (near Melnragė settlement), 350 m from the coast, with the natural depth of 17.5 m [7, 8].

There must be five terminals for the Outer Port to work effectively. Namely it is to include a Petroleum Jetty, Grain Terminal, Fertilizer Terminal, General Cargo Terminal and Container Terminal [7, 8].

A multi-criteria decision-making problem aimed at determining the most accurate relative importance of alternatives as well as ranking alternative decisions is analyzed in the chapter. The given MCDM problem is defined on 4 alternatives (Table 2) and 12 decision criteria (Table 1). Relative significances of criteria were determined by means of entropy (Table 2) [14, 15, 16, 17]. Values of variances are presented in Table 3. The performance levels of alternatives are presented in Table 4 and Fig. 2.

Table 1. A set of criteria for alternatives assessment

Criteria	Comparison Item	Units	Optimum
X_1	Accessibility to the marine terminals for railcars from the railway yard within the outer port area	points	max
X_2	Accessibility to terminals by vehicles from outside the port	points	max
X_3	Attractiveness to port-related industries	points	max
X_4	Efficiency of land use	10^4 m^2	max
X_5	Conservation of the natural sand beach	points	max
X_6	Impact of a railway access line on the existing residential areas behind the Outer Port area	points	max
X_7	Construction cost	10^6€	min
X_8	Ease of further expansion	points	max
X_9	Accessibility to the marine terminals for calling vessels	points	max
X_{10}	Competitiveness with other Baltic seaports	points	max
X_{11}	Storage capacity	10^4 t	max
X_{12}	Efficiency of dockside operations	points	max

Table 2. Relative significances of criteria determined by means of entropy

		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
Alternatives	A_1	0.977	0.977	0.970	0.876	0.803	0.985	0.954	0.985	0.947	0.863	1.000	0.863
	A_2	0.953	0.621	1.000	0.926	0.772	0.627	1.000	0.642	0.960	1.000	1.000	0.863
	A_3	0.621	1.000	0.611	0.810	0.504	1.000	0.976	0.975	0.983	0.845	1.000	0.860
	A_4	1.000	0.977	0.951	1.000	1.000	1.000	0.936	1.000	1.000	0.870	1.000	1.000
Level of entropy		E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	E_{11}	E_{12}
E_j		0.262	0.246	0.273	0.258	0.520	0.222	0.094	0.234	0.078	0.281	0.000	0.277
Variability level		d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8	d_9	d_{10}	d_{11}	d_{12}
d_j		0.738	0.754	0.727	0.742	0.480	0.778	0.906	0.766	0.922	0.719	1.000	0.723
Criteria weights		w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9	w_{10}	w_{11}	w_{12}
w_j		0.080	0.082	0.079	0.080	0.052	0.084	0.098	0.083	0.100	0.078	0.108	0.078

Table 3. Estimates of variances of normalized initial criteria values are calculated

Criteria values $\sigma^2(\bar{x}_{ij})$													
		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
Alternatives	A_1	0.0024	0.0024	0.0024	0.0019	0.0016	0.0024	0.0023	0.0024	0.0022	0.0019	0.0025	0.0019
	A_2	0.0023	0.0010	0.0025	0.0021	0.0015	0.0010	0.0025	0.0010	0.0023	0.0025	0.0025	0.0019
	A_3	0.0010	0.0025	0.0009	0.0016	0.0006	0.0025	0.0024	0.0024	0.0024	0.0018	0.0025	0.0018
	A_4	0.0025	0.0024	0.0023	0.0025	0.0025	0.0025	0.0022	0.0025	0.0025	0.0019	0.0025	0.0025

Table 4. Determined optimality criteria by applying weight aggregation of WASPAS method

	$\sigma^2\left(Q_i^{(1)}\right)=\sum_{j=1}^{n}\bar{x}_{ij}w_j^2\sigma^2\left(\bar{x}_{ij}\right)$	$\sigma^2\left(Q_i^{(2)}\right)=\sum_{j=1}^{n}\left(\frac{\prod_{j=1}^{n}\left(\bar{x}_{ij}\right)^{w_j}w_j}{\left(\bar{x}_{ij}\right)^{w_j}\left(\bar{x}_{ij}\right)^{(1-w_j)}}\right)^2\sigma^2\left(\bar{x}_{ij}\right),$	$\lambda=\frac{\sigma^2\left(Q_i^{(2)}\right)}{\sigma^2\left(Q_i^{(1)}\right)+\sigma^2\left(Q_i^{(2)}\right)}$	Ranking of alternatives applying optimal λ
A1	0.000192	0.000212	0.524860	0.9393
A2	0.000171	0.000209	0.550624	0.8654
A3	0.000173	0.000209	0.548061	0.8612
A4	0.000205	0.000213	0.509588	0.9776

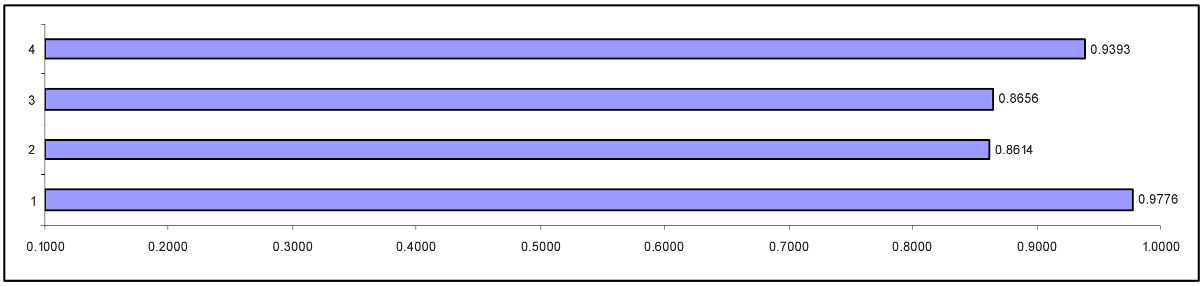

Fig. 2. Performance comparison of alternatives

According to the assessment results the alternatives ranks as follows: $A_4 \succ A_1 \succ A_2 \approx A_4$. It means that first of all should to be implementing the first alternative. In the worst case, the second or forth alternatives should to be realized.

5. Conclusions

Numerous individual and integrated approaches were found as proposals to solve the site selection problem. All of them are capable of handling multiple quantitative and qualitative criteria. Extensive multi-criteria decision-making approaches have been proposed for site selection, such as the analytic hierarchy process, analytic network process, case-based reasoning, data envelopment analysis, fuzzy set theory, genetic algorithm, mathematical programming and as well as their hybrids. The presented case study shows that the model developed by applying two different MCDM methods and integrated with the fuzzy sets theory is suitable to solve complicated location problems.

The presented case study shows that the model developed by applying two different MCDM methods and integrated with WASPAS is suitable to solve complicated location problems.

The best alternative according to the proposed model for resolving the problem is the fourth alternative. The proposed model shows the performance ratio of each alternative to the optimal alternative.

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