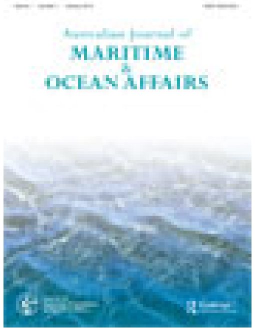

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An integrated MCDM approach for evaluating the Ro-Ro marine port selection process: a case study in black Sea region

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ABSTRACT

Selection of the appropriate Roll-on Roll-off (Ro-Ro) port is one of the crucial tasks for the maritime industry. Because there are many factors affecting the selection process, this selection process is essentially a multi-criteria decision-making problem. This paper proposes a integrated approach consisting of the CRITIC (Criteria Importance Through Intercriteria Correlation) technique and the EDAS (Evaluation based on Distance from Average Solution) method to evaluate the Ro-Ro marine ports selection. The obtained results by using the proposed model have been verified carrying out a comprehensive sensitivity analysis. In accordance with this purpose, 10 different scenarios were established and five MCDM methods were applied to make a comparison. Results obtained using the suggested model were verified in dynamic conditions. The main purpose of this implementation is to determine whether any change in the obtained results for each determined scenario. Carried out sensitivity analysis shows that the suggested hybrid MCDM model consisting of CRITIC and EDAS techniques has validity and the obtained results are accurate and realistic. When the results of the sensitivity analysis are reviewed, it can be seen that the P1 option is the best alternative for all scenarios.

Introduction

Roll-on Roll-off (Ro-Ro) transportation is a very important component of Short Sea Shipping (SSS). According to the European Community Shipowner Association (ECSA); Short sea shipping' is the movement of cargo and passengers by sea over short distances (ECSA 2020). The European Commission describes short sea shipping as follows: 'short sea shipping includes domestic and international maritime transport, including feeder services, along the coast and to and from the islands, rivers, and lakes' (EC 2020). In addition to the Baltic Sea and the Mediterranean, the Black Sea has been described as very important and appropriate waterways in aspects of Short Sea Shipping by the European Commission (EC 2020). Short distances between seaports is a crucial factor to conduct lower cost, speedy, effective, and productive short sea shipping operations such as Ro-Ro transportation.

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There are six countries in the Black Sea region such as Turkey, Russia, Georgia, Bulgaria, Romania, and Ukraine in this region. The most important trade routes among European, Central Asian, and far east countries pass through this region. In addition to that, there are many transport alternatives including both unimodal and multimodal transportation in this region. But some transportation alternatives are not appropriate in aspects of productivity and effectivity. The Black Sea region can be accepted as one of the most suitable waterways in the world in terms of Ro-Ro freight transport activities because distances among seaport in this region are relatively short. More importantly, Ro-Ro freight transport has vital importance for economies of the black sea countries economically growing ever at 8% annually (BTSB 2020) in the last decades as is seen Table 1.

Continuing to develop of these economies is possible depending on more speedy, lower costly, productive, and effective logistics operations, which can be provided by SSS type operations such as Ro-Ro transportation. The Black Sea can be accepted as an inland sea; and there is only one gate called Istanbul Straits to reach the international open seas. When alternative transportation options are evaluated railway transportation is important. However, there are difference among rail systems between European countries, central Asian countries and Russia (i.e. while the distance between two rails (gauge) is 1435 mm in European system, it is 1520 mm in the Russian and central Asian countries systems). As a result of factors such as these differing gauges, clearance limits of railway equipment, the number of wagons in a rolling stock, types of equipment, conditions of loading and cargo security and safety may mean that shifting between both rail systems requires changing of bogies and shifting of cargo positions and location in wagons may also be needed. As a result, transportation and logistics processes may be interrupted. Depending on these limitations, an integrated railway system within European countries effectively ends at the border of the European Union as seen in Figure 1. Consequently, unimodal railway transportation options, which are available in the Black sea region, cannot provide uninterrupted transportation opportunity among European countries, Russia, Central Asian, and far east countries.

When the unimodal road transportation options available in the region are evaluated, this kind of transportation alternative may not be productive. Institution of Transportation of European Union accept that road transportation is virtually unbeatable over distances of up to 300 km when considering Its flexibility, speed and ability to deliver door-to-door (EU 2012). Over 300 km, reducing may be seen in productivity and effectivity of unimodal road freight transportation.

Table 1. GDP per capita (current US$) of the black sea countries.

Year	Bulgaria	Ukraine	Turkey	Russian Fed.	Romania	Georgia
2010	50363.28	136013.16	771901.77	1524917.5	166225.18	12243.51
2011	57363.61	163159.67	832523.68	2045925.6	183443.15	15107.44
2012	54013.81	175781.38	873982.25	2208295.8	171196.27	16488.41
2013	55591.34	183310.15	950579.41	2292473.3	190949.07	17189.55
2014	56883.17	133503.41	934185.92	2059242.3	199626.81	17627.12
2015	50630.71	91030.96	859796.87	1363481.1	177893.45	14953.95
2016	53785.05	93355.99	863721.65	1276787.2	188494.14	15141.76
2017	58950.13	112190.36	852676.78	1574199.4	211695.42	16242.92
2018	66200.85	130901.86	771350.33	1669583.1	241626.95	17599.72
2019	67927.18	153781.07	754411.71	1699876.6	250077.44	17743.21

Source: https://www.bstdb.org.

Figure 1. Europa EU trans-European transport network (TEN-T).

In addition, EU is also concerned about environmental impacts of road transportation as negative environmental impacts of unimodal road transportation may increase in long distances. When it is evaluated in this respect, in addition to unimodal road transportation cannot provide an interrupted logistics flows between EU and other regions, its negative environmental impacts may also be high. More importantly, high-way and road conditions are not meet to requirements on logistics and international transportation in the most of Black sea countries. For example, Moldova's public roads are still not in good condition compared to EU road standards (TRACECA 2020).

Other option is the maritime container transportation in the region. But, because marine ports are close of the each other and handling operations are needed, consider-able reducing on logistics flows and speed may come into question. Even if these marine container ports have shown high performance in open seas container transportation, container transportation among seaports in the region may not be productive and effectively.

When all transportation options, which are available in the Black sea region are evaluated with together, Ro-Ro transportation is seen the best option to strength connection between European and Asian countries, develop the trade among countries in the region. In addition, it can help to increase the logistics flow reduce the transportation and logistics costs. In addition to its other advantages, Ro-Ro transportation has lower environmental impacts compared to the other maritime transport alternatives. Table 2 shows environmental impacts of the vessel types (Oztürk and Turan 2020).

In addition to transportation options, which available in the region, one of the most important factors is sea ports located in the region. Sea ports in the Black sea region have three main functions related to transportation. First, trade and material flow among the black sea countries realise through these seaports. Therefore, these seaports

Table 2. Total annual emission values (tons/year).

Ship type	NOx	SO2	CO2	HC	PM
Bulk carrier	166.904	129.546	7684.081	6.625	13.348
General Cargo	141.844	108.544	6440.612	5.612	11.430
Container	160.901	113.427	6663.062	6.926	15.044
Tanker	96.973	85.108	5015.332	5.359	7.315
Ro-Ro	73.253	58.635	3455.104	3.117	6.125
Total	639.875	495.259	29258.180	27.638	53.261

can be accepted as the most important factors in aspects of trading performed among these countries. Secondly, these seaports are connected with open seas ports and the Black sea countries can enter intense commercial relations with far countries thanks to these seaports. Thirdly, these seaports can be accepted as very important junction points of transportation routes used among European, Central Asian, and far east countries and logistics activities and material flows performed through these routes and seaports are at very high level.

As is known, connections among European countries are provided with the help of ten transportation corridors (TEN-T Corridors) as seen Figure 1. Two of them, which called Orient East Mediterranean and Rhine -Danube, are connected to the west black seaports such as Varna, Burgos, and Constanza. These seaports are connected with east black seaports such as Novorossiysk, Poti, Sochi ports and these connections provide an opportunity to carry out uninterrupted transportation operations between both continents.

Using and developing transportation options such as Ro-Ro transportation mode providing integration among seaports and increasing the material flow rate can con-tribute to regional economic development and enhancing the trade among countries. In addition, the European Union give importance to develop Ro-Ro transportation that is a crucial part of Short Sea Shipping (SSS) and it attributes importance to the Black sea region, Mediterranean, and Baltic Sea in this perspective (OECD 2001). In the same text, OECD has indicated that it is expected that support this kind of transportation mode can remarkable contribute to development of the global trade (OECD 2001).

When all transport options are evaluated in the light of arguments that mentioned above; open sea maritime transportation, unimodal road and rail freight transportation are not suitable to provide uninterrupted logistics flows in the Black sea region. It is clear that Ro-Ro transportation mode is a useful and suitable transport system for carrying out uninterrupted logistics operations between two continents compared to other transport alternatives. The most important issue is whether the Ro-Ro terminals in the region are sufficient for realising the effective and productive logistics and transportation operations. In fact, performance analysis for the Ro-Ro terminals is a very complicated decision-making problem because there many variables and factors that can affect the seaport performance.

All Ro-Ro terminals located in the Black Sea region were included in the scope of this study (Figure 1); and factors were also determined as selection criteria following information gained from key experts.

Initially, a main research question was directed to the members of the expert panel: What are the main selection criteria for determining the proper Ro-Ro seaport? Each expert prepared a list about the selection criteria and final selection criteria have been determined by combining these lists after the repeated criteria were removed. Determined decision alternatives and selection criteria can be seen in Tables 3 and 4.

Considering the selected criteria and decision alternatives, data were collected from databases of international and national statistical institutes. Also, the statistics published by the ministry of transport of the Black Sea countries and various official institutes, which are given in Table 5, have been taken into consideration. Collected data about Ro-Ro seaports in the Black Sea region can be seen in Table 5.

This paper is organised into six sections. In the section 1, that is, the introduction, the main aim of this paper is discussed and summarised. A literature review is offered, and previous studies are reviewed in the section 2. This section summarises the studies, which focus on the performance analysis of Ro-Ro seaports and the evaluation of the marine seaport selection process. In addition to that, literature related to the proposed MCDM model and methods is also reviewed. The integrated MCDM approach applied in this paper is described in the section 3. A numerical analysis was performed to show how it applies to make Ro-Ro seaport and terminal performance analysis by using the proposed MCDM model in the section 4. In the section 5, the obtained results and findings are evaluated with the help of a sensitivity analysis. In the final section 6, this study is concluded; and a range of suggestions are made for future research.

Literature review

The number of scientific works related to this kind of transport mode is very scarce in the literature, even though Ro-Ro transport plays a crucial role in international transportation and trade and it has lower environmental impacts because it can lead to reducing external costs (Perakis and Denisis 2008). When the literature is reviewed completely it is seen that only seventeen studies are available. Moreover, studies related to Ro-Ro ports are seen as extremely rare. Existing studies in the literature focused on some issues related to Ro-Ro shipping such as the competitiveness of this transport mode (Hjelle and Fridell 2010), integration among transport modes (Medda and Trujillo 2010), development of a simulation for Ro-Ro transportation (Balaban and Mastaglio 2013), performance requirements of the Ro-Ro ports for making competition to other transport modes (Sauri, Morales, and Martin 2012) in general.

In addition to those, Forte and Siviero (2014) examined the competitive powers of both sea and rail intermodal transport modes in the Italian Ro-Ro ports. Ozdemir and Deniz (2014) evaluated the Ro-Ro transportation within the perspective of geographical advantages of the Zonguldak city and its hinterland. Similarly, Torbianelli (2012) examined Ro-

Table 3. The selection criteria for Ro-Ro seaport.

Code	Criterion	Definition
CI	Draught	Meter
C2	Total vehicle capacity	The number of vehicle
CS	Total quay length	Meter
C4	Maximum ship size	Meter
C5	The number of regular liner services	Number
C6	Stock area capacity	Square meter m^2
C7	Port service costs	Euro/ton
CS	Port safety level	ISPS Level
C9	Location of the port	Average distance to organised industrial zones in region-wide

Table 4. Decision options for evaluation of Ro-Ro seaports.

Code	Country	Port	Ro-Ro Terminal
PI	Bulgaria	Varna	Varna Ferry Terminal
P2	Georgia	Batumi	Batumi Ferry Terminal
PS		Poti	Poti Ferry Terminal
P4	Romania	Constanza	Constanza Ferry Terminal
P5	Russia	Kavkaz	Kavkaz Ferry Terminal (Berth 6 & 7)
P6		Novorossiysk	Novorossiysk Ferry Terminal
P7		Sochi	Sochi Ferry Terminal
P8	Turkey	Derince	Derince Ferry Terminal
P9		Haydarpasa	Haydarpasa Ferry Terminal
PI0		Samsun	Samsun Ferry Terminal
P11		Trabzon	Trabzon Ferry Terminal
PI2	Ukraine	Ilyichivsk	Ilyichivsk Ferry Terminal
PI3		Krym	Krym Ferry Terminal
PI4		Odessa	Odessa Terminal
PI5		Sevastopol	Sevastopol South Bay Ferry Terminal
PI6		Yalta	Yalta Ferry Terminal

Ro transport operations between Turkish and Italian Ro-Ro seaports. Marzano et al. (2020) analysed Ro-Ro and Ro-Pax transportation market in Italy. Mabrouki and Bellabdaoui, Mousrij (2013) evaluated risks in Ro-Ro ports and terminals. Dias, Calado, and Mendonca (2010) examined the impacts of European Ro-Ro ports on the European automobile supply chains.

Although there many studies on the evaluation of the container and dry bulk seaport selection in the literature, literature pertinent to the evaluation of Ro-Ro port selection is extremely limited. Similarly, there are also scarce studies on Ro-Ro transportation when it is compared to the other maritime transportation types such as container, tanker, and dry

Table 5. Official sources statistical data in the black sea region.

Institutions	Webpages	Classifications
Executive Agency "Maritime Administration"	https://www.marad.bg/en	Ministry
Ministry of Infrastructure of Ukraine	https://mtu.gov.ua/en/	Ministry
The Ministry of Transport of the Russian Fed.	https://mintrans.gov.ru/	Ministry
Ministry of Economy and Sust. Dev. of Georgia	http://www.economy.ge	Ministry
Republic of Turkey Ministry of Transport	www.ubak.gov.tr	Ministry
Ministry for Transport, Inf. and Com. of Romania	http://www.mt.ro/web14/	Ministry
Republic of Bulgaria National statistical institute	https://www.nsi.bg	Statistical Institute
Statistical Institute of Turkey	https://data.tuik.gov.tr	Statistical Institute
State Statistics Service of Ukraine	https://ukrstat.org/en	Statistical Institute
Federal State Statistic Service	https://eng.gks.ru/	Statistical Institute
National Statistical Office of Georgia	https://www.geostat.ge	Statistical Institute
National Institute of Statistics of Romania	https://insse.ro/cms	Statistical Institute
Port of Burgas	https://port-burgas.bg	Port Authority
Port of Varna	https://port-varna.bg	Port Authority
Port of Sochi	http://www.morport-sochi.ru	Port Authority
Port of Novorossiysk	http://www.nmtp.info	Port Authority
Port of Kyrm	http://gos-parom.ru/	Port Authority
Port of Derince	http://www.safiport.com.tr	Port Authority
Port of Odessa	http://www.port.odessa.ua	Port Authority
Port of Sevastopol	http://www.morport.sebastopol.ua	Port Authority
Port of Yalta	http://www.sifservice.com	Port Authority
Port of Constanza	https://www.portofconstantza.com	Port Authority
Port of Haydarpa¸sa	https://www.tcdd.gov.tr	Port Authority
Port of Samsun	http://www.samsunport.com.tr	Port Authority
Port of Trabzon	http://trabzonport.com.tr	Port Authority
Port of Batumi	https://www.batumiport.com/	Port Authority

bulk transport. Even though multi-criteria decision-making techniques are frequently used as computational tools for solving decision-making problems faced in the field of transportation, when the literature related to the maritime industry and transportation is evaluated, there is no study using MCDM techniques for solving the Ro-Ro seaport selection problems directly.

This paper examines how a Ro-Ro port can select by decision-makers and it proposes an applicable methodological frame to decision-makers to evaluate the appropriate Ro-Ro seaports. The proposed model can be applied for selecting a suitable Ro-Ro port by public authorities, operators, and other stakeholders who plan the construction of new Ro-Ro lines. The current paper considers some criteria, costs, logistics requirements, operational abilities, and so on to make a rational and realistic evaluation of the Ro-Ro port selections.

The proposed methodology

The selection of suitable Ro-Ro seaport and terminal is a very complicated and time-consuming process for decision-makers as there are many conflicted selection criteria affecting the selection process. Therefore, the selection of the proper Ro-Ro seaport can be accepted as a decision-making problem. In order to solve these kinds of the decision-making problems, decision-makers need an algorithm that can be followed as a methodological frame. For this purpose, this paper suggests a hybrid MCDM model combined the CRITIC and the EDAS techniques.

The proposed integrated approach consists of two multi-criteria decision-making methods. The CRITIC (CRiteria Importance Through Intercriteria Correlation) method is used to calculate the weight value of each selection criteria. The second part of the proposed model is the EDAS (The Evaluation Based on Distance from Average Solution) method; and it was applied to determine the proper and best decision alternative.

Since all selection criteria and decision options determined in the paper have numerical values, implementing the CRITIC technique that is an objective weighting method is reasonable. As is seen in Table 2, all criteria determined by researchers with together the members of the board of experts have numerical values. Therefore, the CRITIC method is a weighting technique giving very successful and accurate results free from individual evaluations and verbal judgments of the decision-makers (Gao et al. 2017). Also, the EDAS technique has been chosen as a ranking method to determine the relative importance of the options.

The main reason of that is the EDAS technique has many advantages as well as it is a multi-criteria decision-making technique. The main advantage of the EDAS method has high efficiency and needs less computation in comparison with other decision-making and classification methods (He et al. 2020). Secondly, calculation of the distances from ideal and negative ideal solutions is required by decision-makers in order to determine the best option in many assessment techniques.

As an advantage of the EDAS method, calculation of the distances from the ideal and negative ideal solutions is not required for the EDAS technique as it can determine the best alternative based on the distance from Average Values (Kundakci 2019). The proposed hybrid multi-criteria decision-making model can be seen in Figure 2.

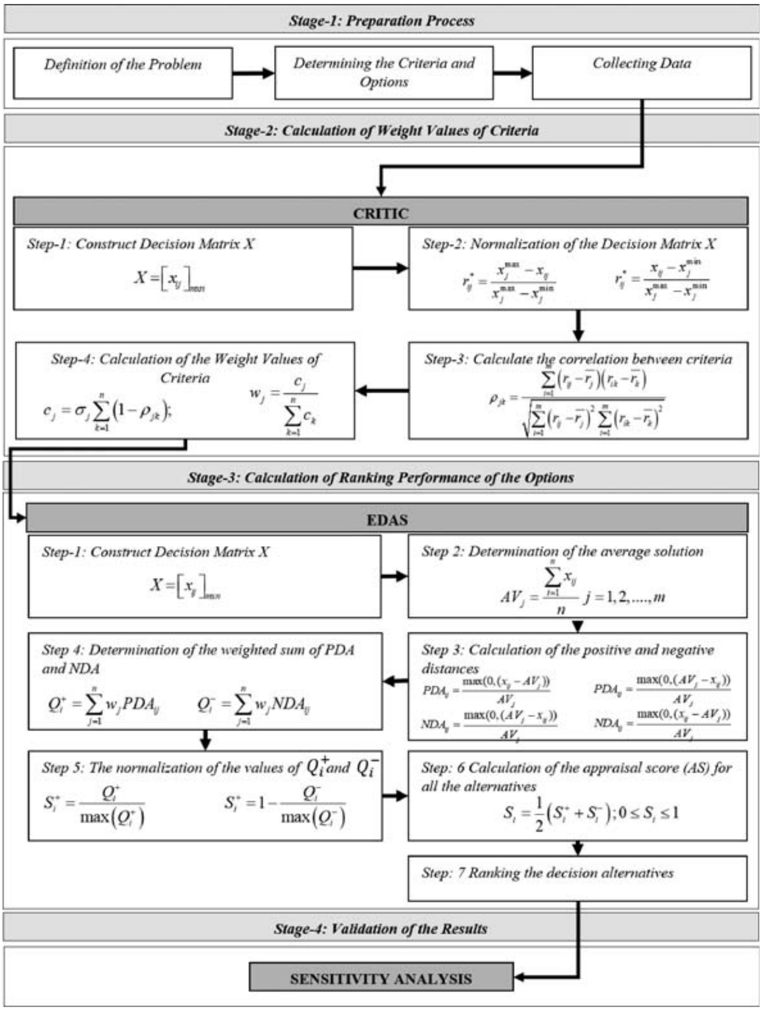

Figure 2. The proposed model and implementation steps.

Implementation of the CRITIC method

The CRITIC (criteria importance through inter-criteria correlation) method was introduced by Diakoulaki, Mavrotas, and Papayannakis (1995). It is a very successful computational tool used in various fields for determining the weights of selection criteria. This method focuses on differences among values of all objects on the same indexes and examines the correlation between two indexes to detect the conflict between them. If there is a weak positive correlation between these indexes, the conflict between them can be accepted as high. Therefore, the main focal point of this technique is the correlation among the indexes. The CRITIC method has three implementation steps as follows: Diakoulaki, Mavrotas, and Papayannakis (1995), Rostamzadeh et al. (2018).

Step-1: Construct Decision Matrix X: In this step, a decision matrix is constructed and the initial decision matrix consists of n criteria and m options and x_{ij} represents the performance value of *i*th option with respect to *j*th criterion.

$$X = [x_{ij}]_{mxn} \tag{1}$$

Step-2: Normalisation of the Decision Matrix X: Using equations (2) and (3) the elements of the decision matrix are normalised and the normalised matrix is constructed. While equation (2) is used for benefit criteria, equation (3) is applied for cost criteria.

$$r_{ij} = \frac{x_{ij} - x_j^{\min}}{x_j^{\max} - x_j^{\min}} \tag{2}$$

$$r_{ij} = \frac{x_j^{\max} - x_{ij}}{x_j^{\max} - x_j^{\min}} \tag{3}$$

Step-3: Calculate the correlation between criteria: In this step, correlation values between criteria are calculated with the help of equation (4), i.e. each correlation value represents the correlation between criterion *j* and criterion *k*.

$$\rho_{jk} = \frac{\sum_{i=1}^{m} (r_{ij} - \bar{r}_j)(r_{ik} - \bar{r}_k)}{\sqrt{\sum_{i=1}^{m} (r_{ij} - \bar{r}_j)^2 (r_{ik} - \bar{r}_k)^2}} \tag{4}$$

Step-4: Calculation of the Weight Values of Criteria: The weights of criteria are computed by using equations (5) and (6).

$$c_j = \sigma_j \sum_{k=1}^{n} (1 - \rho_{jk}) \tag{5}$$

$$w_j = \frac{c_j}{\sum_{k=1}^{n} c_k} \tag{6}$$

where; $i = 1, 2,3, \ldots ,m$ and j, k = 1,2,3, … ,n.

Implementation of the EDAS method

The EDAS method, which is used as a multi-criteria decision-making technique, was introduced by Ghorabaee et al. (2017). The EDAS method, which is a MCDM technique, is a computational tool for solving many decision-making problems. Previous studies using this method show that it has the potential to solve very complicated decision-making problems. EDAS method argues that the best solution is based on the distance from the average solution. This approach has seven implementation steps as can be seen below (Ghorabaee et al. 2017).

The EDAS method has seven implementation steps; and relative importance values of decision alternatives are determined by applying the following procedure.

Step 1: Construction of the Decision Matrix: in the first step, a decision matrix generated in the first step of the CRITIC technique is used similarly.

Step 2: Determination of the average solution: for each selection criterion, the average value is calculated by using equation (7).

$$AV = [AV_j]_{mxn} \tag{7}$$

Here;

$$AV_j = \frac{\sum_{i=1}^{n} x_{ij}}{n}$$

$$j = 1, 2, 3, \ldots, m$$

Step 3: Calculation of the positive and negative distances: considering the directions of criteria, the positive (PDA) and negative distances (NDA) of each criterion from average are determined by using equations 8, 9, 10, and 11. If criterion j is benefit criterion;

$$PDA_{ij} = \frac{\max(0, (x_{ij} - AV_j))}{AV_j} \tag{8}$$

$$NDA_{ij} = \frac{\max(0, (AV_j - x_{ij}))}{AV_j} \tag{9}$$

If criterion j is cost criterion;

$$PDA_{ij} = \frac{\max(0, (AV_j - x_{ij}))}{AV_j} \tag{10}$$

$$NDA_{ij} = \frac{\max(0, (x_{ij} - AV_j))}{AV_j} \tag{11}$$

The PDA and the NDA matrices are generated as follows:

$$PDA = [PDA_j]_{mxn} \tag{12}$$

$$NDA = [NDA_j]_{mxn} \tag{13}$$

Step 4: Determination of the weighted sum of PDA and NDA: by using equations 14 and 15, values of weighted PDA and NDA are calculated. Where Q_i^+ represents the weighted sum of PDA and Q_i^- symbolised the weighted sum of NDA.

$$Q_i^+ = \sum_{k=1}^{n} w_j PDA_j \tag{14}$$

$$Q_i^- = \sum_{k=1}^{n} w_j NDA_j \tag{15}$$

w_j is the weight values of jth criterion it has been calculated with the help of the CRITIC technique.

Step 5: The normalisation of the values of Q_i^+ and Q_i^-: the weighted sums of PDA and NDA are determined using equations (16) and (17).

$$S_i^+ = \frac{Q_i^+}{\max(Q_i^+)} \tag{16}$$

$$S_i^- = \frac{Q_i^-}{\max(Q_i^-)} \tag{17}$$

Step: 6 Calculation of the appraisal score (AS) for all the alternatives: the appraisal scores are computed using equation (18) as follows:

$$S_i = \frac{1}{2}(S_i^+ + S_i^+);\ 0 \le S_i \le 1 \tag{18}$$

Step: 7 Ranking the decision alternatives: decision alternatives are ranked according to the descending appraisal values of options. The alternative that has the highest score is determined as the best and proper decision option.

A numerical illustration

By using the first-three implementation steps of the proposed model weights of factors were computed. Initially, the decision matrix X was constructed as is seen in Table 6.

In the second step of the CRITIC method, the elements of the decision matrix were normalised with the help of equations (2) and (3). The normalised matrix was generated as is seen Table 7.

The weights of criteria were calculated by following the third step of the CRITIC technique; and the obtained results are shown in Table 8.

In the second phase of the proposed model, relative importance scores of the decision alternatives were computed by applying the steps of the EDAS method, and decision options were ranked. In the second step, positive and negative distances of each criterion from average were calculated and results can be seen in Tables 9 and 10.

Table 6. The decision matrix X.

		C1	C2	C3	C4	C5	C6	C7	C8	C9
P1	Varna Terminal	11.5	720	330	278	3	62630	3.88	3	1039.7
P2	Batumi Terminal	8	320	183	160	4	35000	2.27	2	1490.3
P3	Poti Terminal	6.5	180	97	85	1	69000	3.07	1	1516.7
P4	Constanza Terminal	13	860	364	320	1	17000	5.85	2	1064.3
P5	Kavkaz Terminal	5	120	130	110	1	12000	3.73	1	1246.8
P6	Novorossiysk Terminal	9.7	410	210	198	2	62200	2.65	2	1383.8
P7	Sochi Terminal	8.5	320	330	220	2	42000	2.17	1	1513.7
P8	Derince Terminal	10	480	160	140	2	11920	2.21	2	1056.8
P9	Haydarpasa Terminal	11.2	360	320	280	4	55000	2.32	1	1050.0
P10	Samsun Terminal	10.5	300	180	160	3	50000	3.65	2	1458.3
P11	Trabzon Terminal	12	360	290	260	2	23585	2.85	2	1485.2
P12	Ilyichivsk Terminal	10	420	310	270	5	27000	3.27	2	966.8
P13	Krym Terminal	7.2	120	110	90	1	8250	2.78	1	1290.2
P14	Odessa Terminal	13	280	220	180	1	65200	3.17	1	964.3
P15	Sevastopol Terminal	7	120	100	80	1	9500	2.35	1	1289.8
P16	Yalta Terminal	9	240	180	160	1	14000	3.12	1	1289.8

In the fourth step, the elements of positive distance and negative distance matrices were normalised with the help of equations (9) and (10). The obtained results are given in Tables 11 and 12.

The following Table 13 shows the weighted values Q_i^+ and Q_i^-, values of S_i^+ and S_i^-, S_i and appraisal score (AS). These values are obtained using the equations given in Step 5 and step 6 of the EDAS technique.

Sensitivity analysis

Considering the selected criteria and decision alternatives, data were collected from databases of international and national statistical institutes. Also, the statistics published by the ministry of transport of the Black Sea countries and various official institutes have been taken into consideration. Collected data about Ro-Ro seaports in the Black Sea region can be seen in Table 1. In the second phase of the proposed model, relative importance scores of the decision alternatives were computed by applying the implementation steps of the EDAS method; and decision options were ranked considering the relative importance scores.

In the second step of this technique, positive and negative distances of each criterion from average were calculated. A comprehensive sensitivity analysis has been carried out to evaluate the results obtained by using the proposed MCDM model. In order to evaluate the effects of changes in weight values of criteria on the ranking performance of the model different scenarios have been established. For this purpose, it was requested to evaluate nine selection criteria from ten decision-makers.

Afterward, ten different scenarios also including individual evaluations performed by these decision-makers were established. New weight values of criteria have been computed by using the SWARA technique for each scenario and the 11 scenarios was established by calculating the geometric mean of new weight values of criteria (Keršulienė, Kazimieras, and Turskis 2010). New weights of the criteria calculated for each scenario can be seen in Table 14.

The EDAS technique was implemented considering all different conditions obtained with new weight values of criteria for all 11 scenarios and decision options were

Table 7. The normalised matrix X.*

		C1	C2	C3	C4	C5	C6	C7	C8	C9
P1	Varna Terminal	0.435	0.167	0.294	0.288	0.333	0.132	0.663	0.333	0.685
P2	Batumi Terminal	0.625	0.375	0.530	0.500	0.250	0.236	0.388	0.500	0.983
P3	Poti Terminal	0.769	0.667	1.000	0.941	1.000	0.120	0.525	1.000	1.000
P4	Constanza Terminal	0.385	0.140	0.266	0.250	1.000	0.485	1.000	0.500	0.702
P5	Kavkaz Terminal	1.000	1.000	0.746	0.727	1.000	0.688	0.638	1.000	0.822
P6	Novorossiysk Terminal	0.515	0.293	0.462	0.404	0.500	0.133	0.453	0.500	0.912
P7	Sochi Terminal	0.588	0.375	0.294	0.364	0.500	0.196	0.371	1.000	0.998
P8	Derince Terminal	0.500	0.250	0.606	0.571	0.500	0.692	0.378	0.500	0.697
P9	Haydarpasa Terminal	0.446	0.333	0.303	0.286	0.250	0.150	0.397	1.000	0.692
P10	Samsun Terminal	0.476	0.400	0.539	0.500	0.333	0.165	0.625	0.500	0.962
P11	Trabzon Terminal	0.417	0.333	0.334	0.308	0.500	0.350	0.487	0.500	0.979
P12	Ilyichivsk Terminal	0.500	0.286	0.313	0.296	0.200	0.306	0.559	0.500	0.637
P13	Krym Terminal	0.694	1.000	0.882	0.889	1.000	1.000	0.475	1.000	0.851
P14	Odessa Terminal	0.385	0.429	0.441	0.444	1.000	0.127	0.542	1.000	0.636
P15	Sevastopol Terminal	0.714	1.000	0.970	1.000	1.000	0.868	0.402	1.000	0.850
P16	Yalta Terminal	0.556	0.500	0.539	0.500	1.000	0.589	0.533	1.000	0.850

*Normalised matrix to show difference between Table 6.

Table 8. Weight values of the selection criteria.

	Average	σ_j	$\sum_{k=1}^{n}(1-\rho_{jk})$	$\sigma_j\sum_{k=1}^{n}(1-\rho_{jk})$	w_j
C1	0.5628	0.1655	4.0997	0.6786	0.0665
C2	0.4717	0.2897	3.4596	1.0024	0.0982
C3	0.5325	0.2478	3.7256	0.9233	0.0905
C4	0.5168	0.2464	3.6138	0.8906	0.0873
C5	0.6479	0.3337	4.3307	1.4452	0.1416
C6	0.3897	0.2925	5.0667	1.4820	0.1452
C7	0.5272	0.1578	9.2717	1.4635	0.1434
C8	0.7396	0.2720	5.0397	1.3705	0.1343
C9	0.8286	0.1359	6.9796	0.9483	0.0929

ranked. Changes in ranking results in accordance with these scenarios can be seen in Figure 3.

When the ranking results given in Figure 3 are evaluated, it is seen that P1 is the best option, P16 is the worst alternative for all scenarios. This situation has shown that it is fully appropriated with the ranking performance of the proposed model. In addition to that, there is no change in ranking performance of some options such as P3, P5, P8, P9, P12, P13, P14, and it is observed that their ranking positions exactly the same as ranking results that determined considering the experts' evaluations. There are minor changes in the ranking of the other decision alternatives such as P2, P4, P6, P7, P10, and P11.

Especially, the ranking performance of option P6 is the same as the ranking performance determined in the other eight scenarios except for scenarios 3, 9, and 10. Similarly, the ranking performance of option P7 is the same as the ranking performance of the proposed model for determined eight scenarios (except for scenarios of 6, 7, and 8). It is clearly seen that the ranking performance of both options is largely the same as the results obtained by applying an integrated approach.

When effects of changing the weight values of the criteria are taken into consideration considering the evaluations performed by decision-makers, while rankings of the options are the same at the rate of 63% with the ranking results of the proposed MCDM model, it is observed that there are minor differences for ranking results for the rate of 37%. In

Table 9. The positive distance matrix (PDA).

	C1	C2	C3	C4	C5	C6	C7	C8	C9
P1	0.2097	1.0535	0.5026	0.4871	0.4118	0.7758	0.0000	0.9200	0.1727
P2	0.0000	0.0000	0.0000	0.0000	0.8824	0.0000	0.2639	0.2800	0.0000
P3	0.0000	0.0000	0.0000	0.0000	0.0000	0.9565	0.0045	0.0000	0.0000
P4	0.3675	1.4528	0.6574	0.7118	0.0000	0.0000	0.0000	0.2800	0.1531
P5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0078
P6	0.0204	0.1693	0.0000	0.0592	0.0000	0.7636	0.1407	0.2800	0.0000
P7	0.0000	0.0000	0.5026	0.1769	0.0000	0.1909	0.2964	0.0000	0.0000
P8	0.0519	0.3690	0.0000	0.0000	0.0000	0.0000	0.2834	0.2800	0.1590
P9	0.1782	0.0267	0.4570	0.4978	0.8824	0.5595	0.2477	0.0000	0.1645
P10	0.1045	0.0000	0.0000	0.0000	0.4118	0.4177	0.0000	0.2800	0.0000
P11	0.2623	0.0267	0.3204	0.3908	0.0000	0.0000	0.0759	0.2800	0.0000
P12	0.0519	0.1979	0.4115	0.4443	1.3529	0.0000	0.0000	0.2800	0.2306
P13	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0986	0.0000	0.0000
P14	0.3675	0.0000	0.0017	0.0000	0.0000	0.8487	0.0000	0.0000	0.2326
P15	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2380	0.0000	0.0000
P16	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 10. The negative distance matrix (NDA).

	C1	C2	C3	C4	C5	C6	C7	C8	C9
P1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2581	0.0000	0.0000
P2	0.1584	0.0873	0.1668	0.1441	0.0000	0.0076	0.0000	0.0000	0.1859
P3	0.3162	0.4866	0.5583	0.5453	0.5294	0.0000	0.0000	0.3600	0.2069
P4	0.0000	0.0000	0.0000	0.0000	0.5294	0.5180	0.8969	0.0000	0.0000
P5	0.4740	0.6578	0.4081	0.4116	0.5294	0.6597	0.2095	0.3600	0.0000
P6	0.0000	0.0000	0.0438	0.0000	0.0588	0.0000	0.0000	0.0000	0.1012
P7	0.1059	0.0873	0.0000	0.0000	0.0588	0.0000	0.0000	0.3600	0.2045
P8	0.0000	0.0000	0.2715	0.2511	0.0588	0.6620	0.0000	0.0000	0.0000
P9	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3600	0.0000
P10	0.0000	0.1444	0.1804	0.1441	0.0000	0.0000	0.1848	0.0000	0.1605
P11	0.0000	0.0000	0.0000	0.0000	0.0588	0.3313	0.0000	0.0000	0.1818
P12	0.0000	0.0000	0.0000	0.0000	0.0000	0.2344	0.0603	0.0000	0.0000
P13	0.2426	0.6578	0.4991	0.5186	0.5294	0.7661	0.0000	0.3600	0.0267
P14	0.0000	0.2014	0.0000	0.0371	0.5294	0.0000	0.0279	0.3600	0.0000
P15	0.2636	0.6578	0.5447	0.5720	0.5294	0.7306	0.0000	0.3600	0.0264
P16	0.0533	0.3155	0.1804	0.1441	0.5294	0.6030	0.0117	0.3600	0.0264

Table 11. The weighted positive distance matrix (Q_i^+).

	C1	C2	C3	C4	C5	C6	C7	C8	C9
P1	0.0139	0.1035	0.0455	0.0425	0.0583	0.1127	0.0000	0.1236	0.0160
P2	0.0000	0.0000	0.0000	0.0000	0.1250	0.0000	0.0379	0.0376	0.0000
P3	0.0000	0.0000	0.0000	0.0000	0.0000	0.1389	0.0007	0.0000	0.0000
P4	0.0244	0.1427	0.0595	0.0621	0.0000	0.0000	0.0000	0.0376	0.0142
P5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0007
P6	0.0014	0.0166	0.0000	0.0052	0.0000	0.1109	0.0202	0.0376	0.0000
P7	0.0000	0.0000	0.0455	0.0154	0.0000	0.0277	0.0425	0.0000	0.0000
P8	0.0035	0.0362	0.0000	0.0000	0.0000	0.0000	0.0406	0.0376	0.0148
P9	0.0118	0.0026	0.0414	0.0434	0.1250	0.0813	0.0355	0.0000	0.0153
P10	0.0070	0.0000	0.0000	0.0000	0.0583	0.0607	0.0000	0.0376	0.0000
P11	0.0174	0.0026	0.0290	0.0341	0.0000	0.0000	0.0109	0.0376	0.0000
P12	0.0035	0.0194	0.0372	0.0388	0.1916	0.0000	0.0000	0.0376	0.0214
P13	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0141	0.0000	0.0000
P14	0.0244	0.0000	0.0002	0.0000	0.0000	0.1233	0.0000	0.0000	0.0216
P15	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0341	0.0000	0.0000
P16	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 12. The weighted negative distance matrix (Q_i^-).

	C1	C2	C3	C4	C5	C6	C7	C8	C9
P1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0370	0.0000	0.0000
P2	0.0105	0.0086	0.0151	0.0126	0.0000	0.0011	0.0000	0.0000	0.0173
P3	0.0210	0.0478	0.0505	0.0476	0.0750	0.0000	0.0000	0.0484	0.0192
P4	0.0000	0.0000	0.0000	0.0000	0.0750	0.0752	0.1286	0.0000	0.0000
P5	0.0315	0.0646	0.0369	0.0359	0.0750	0.0958	0.0300	0.0484	0.0000
P6	0.0000	0.0000	0.0040	0.0000	0.0083	0.0000	0.0000	0.0000	0.0094

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P7	0.0070	0.0086	0.0000	0.0000	0.0083	0.0000	0.0000	0.0484	0.0190
P8	0.0000	0.0000	0.0246	0.0219	0.0083	0.0961	0.0000	0.0000	0.0000
P9	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0484	0.0000
P10	0.0000	0.0142	0.0163	0.0126	0.0000	0.0000	0.0265	0.0000	0.0149
P11	0.0000	0.0000	0.0000	0.0000	0.0083	0.0481	0.0000	0.0000	0.0169

(Continued)

Table 13. Ranking of the decision options.

	$\sum_{j=1}^{n} Q_i^+$	$\sum_{j=1}^{n} Q_i^-$	S_i^+	S_i^-	$S_i(AS)$	Rank
P1	0.5160	0.0370	1.0000	0.9115	0.9557	1
P2	0.2004	0.0652	0.3884	0.8442	0.6163	5
P3	0.1396	0.3095	0.2704	0.2599	0.2652	12
P4	0.3406	0.2788	0.6600	0.3332	0.4966	9
P5	0.0007	0.4182	0.0014	0.0000	0.0007	15
P6	0.1918	0.0217	0.3718	0.9475	0.6596	4
P7	0.1311	0.0843	0.2541	0.7961	0.5251	8
P8	0.1327	0.1510	0.2572	0.6347	0.4460	11
P9	0.3563	0.0484	0.6905	0.8830	0.7867	3
P10	0.1635	0.0845	0.3169	0.7955	0.5562	6
P11	0.1317	0.0733	0.2551	0.8225	0.5388	7
P12	0.3496	0.0427	0.6774	0.8967	0.7870	2
P13	0.0141	0.4082	0.0274	0.0121	0.0198	14
P14	0.1695	0.1504	0.3284	0.6362	0.4823	10
P15	0.0341	0.4132	0.0661	0.0000	0.0331	13
P16	0.0000	0.2785	0.0000	0.0000	0.0000	16

Table 14. New weights of the criteria with the help of the SWARA technique.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
C1	0.1051	0.1007	0.1130	0.0962	0.1029	0.1051	0.0822	0.0972	0.1007	0.0988	0.0999
C2	0.1061	0.1035	0.1130	0.1015	0.1039	0.1033	0.0897	0.1018	0.1081	0.1052	0.1034
C3	0.1042	0.1016	0.1120	0.0997	0.1039	0.1051	0.0858	0.0972	0.1051	0.1103	0.1022
C4	0.1179	0.1203	0.1067	0.1266	0.1136	0.1111	0.1490	0.1234	0.1275	0.1270	0.1218
C5	0.1091	0.1055	0.1081	0.1034	0.0969	0.1074	0.1014	0.1126	0.0991	0.1129	0.1055
C6	0.1071	0.1074	0.1061	0.1062	0.1060	0.1045	0.1032	0.1059	0.1057	0.1058	0.1058
C7	0.1179	0.1203	0.1168	0.1221	0.1240	0.1118	0.1156	0.1165	0.1183	0.1111	0.1174
C8	0.1158	0.1181	0.1147	0.1199	0.1298	0.1321	0.1366	0.1244	0.1240	0.1171	0.1230
C9	0.1168	0.1226	0.1097	0.1244	0.1190	0.1195	0.1366	0.1211	0.1116	0.1118	0.1191

Where C1, C2, … C*n* respresents Criteria, S1, S2, S3 … S*n* symbolises code of scenarios.

addition, correlations between the ranking results for each scenario, and the proposed MCDM model have been examined with the help of the Spearman correlation technique and evaluation results are given in Table 15. According to Table 12, the average correlation coefficient value is equal to 0.953, and correlation coefficient values for all scenarios are over the value of 0.941 that can be accepted as very high.

When the results of sensitivity analysis performed by considering 11 different scenarios are evaluated in general, ranking results are not sensitive to the decision-makers' evaluations and ranking results are largely the same as the ranking results obtained by using the suggested MCDM model for all scenarios. In this perspective, it can be accepted that the proposed MCDM model consisting of CRITIC and EDAS techniques is a model that can provide very successful, realistic, and accurate results and it can be applied as a methodological frame to solve these kinds of very complicated decision-making problems.

In the second phase of the sensitivity analysis, in order to make test the ranking performance of this suggested method, the EDAS technique applied to determine the ranking performance of the options has been compared to other commonly used

MCDM techniques. For this purpose, TOPSIS (Rostamzadeh et al. 2018), MAUT (Ömürbek et al. 2020), SAW (Altın et al. 2020), WASPAS (Ghorabae et al, 2017), and

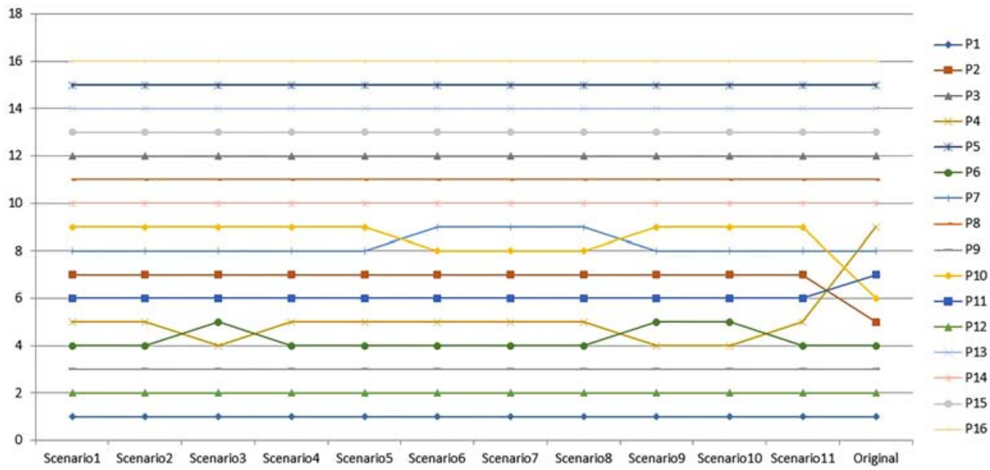

Figure 3. Obtained ranking results for each scenario.

ARAS (Altın et al. 2020) techniques were used. Changes in the ranking performance of the options are given in Figure 4.

As is seen in Figure 4, there is no change in the ranking position of option P1 for applied all techniques including the EDAS technique. In addition, the ranking position of the option P3 has not changed for all implemented techniques. EDAS, SAW, ARAS, and WASPAS techniques have given exactly the same ranking results for option P2. Except for the TOPSIS technique for option P6 and the MAUT method for option P8, the ranking results obtained by using other techniques are the same as the ranking results determined with the help of the suggested model. It is observed that there are minor differences in ranking results for options P13, P15, and P16. Correlation coefficient values showing the relationships among the ranking results of the proposed MCDM technique and implemented other MCDM techniques are given in Table 16.

It is understood from Table 13 and Figure 4 that while the highest correlation exists between the proposed model and WASPAS technique and the lowest correlation exists between the EDAS technique and MAUT method. As a result, except for the MAUT technique, correlation coefficient values of the ranking performances between applied techniques and the proposed MCDM method are over the value of 0.938 and these values can be accepted as very high. In this perspective, the suggested MCDM model can be evaluated as a computational tool that can be applied as a methodological frame to solve these kinds of decision-making problems.

Results and discussions

Considering the selected criteria and decision alternatives, data were collected from databases of international and national statistical institutes. Also, the statistics published by the ministry of transport of the Black Sea countries and various official institutes have been taken into consideration. Collected data about Ro-Ro seaports in the Black Sea region can be seen in Table 1. In the second phase of the proposed model, relative importance scores of the decision alternatives were computed by applying the implementation steps of the EDAS method; and decision options were ranked considering the relative

Table 15. Correlation coefficient values between the proposed fuzzy model and implemented other fuzzy techniques.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	Original
S1	1.000	1.000	0.997	1.000	1.000	0.997	0.997	0.997	0.997	0.997	1.000	0.956
S2	1.000	1.000	0.997	1.000	1.000	0.997	0.997	0.997	0.997	0.997	1.000	0.956
S3	0.997	0.997	1.000	0.997	0.997	0.994	0.994	0.994	1.000	1.000	0.997	0.941
S4	1.000	1.000	0.997	1.000	1.000	0.997	0.997	0.997	0.997	0.997	1.000	0.956
S5	1.000	1.000	0.997	1.000	1.000	0.997	0.997	0.997	0.997	0.997	1.000	0.956
S6	0.997	0.997	0.994	0.997	0.997	1.000	1.000	1.000	0.994	0.994	0.997	0.962
S7	0.997	0.997	0.994	0.997	0.997	1.000	1.000	1.000	0.994	0.994	0.997	0.962
S8	0.997	0.997	0.994	0.997	0.997	1.000	1.000	1.000	0.994	0.994	0.997	0.962
S9	0.997	0.997	1.000	0.997	0.997	0.994	0.994	0.994	1.000	1.000	0.997	0.941
S10	0.997	0.997	1.000	0.997	0.997	0.994	0.994	0.994	1.000	1.000	0.997	0.941
S11	1.000	1.000	0.997	1.000	1.000	0.997	0.997	0.997	0.997	0.997	1.000	0.956
Original	0.956	0.956	0.941	0.956	0.956	0.962	0.962	0.962	0.941	0.941	0.956	1.000

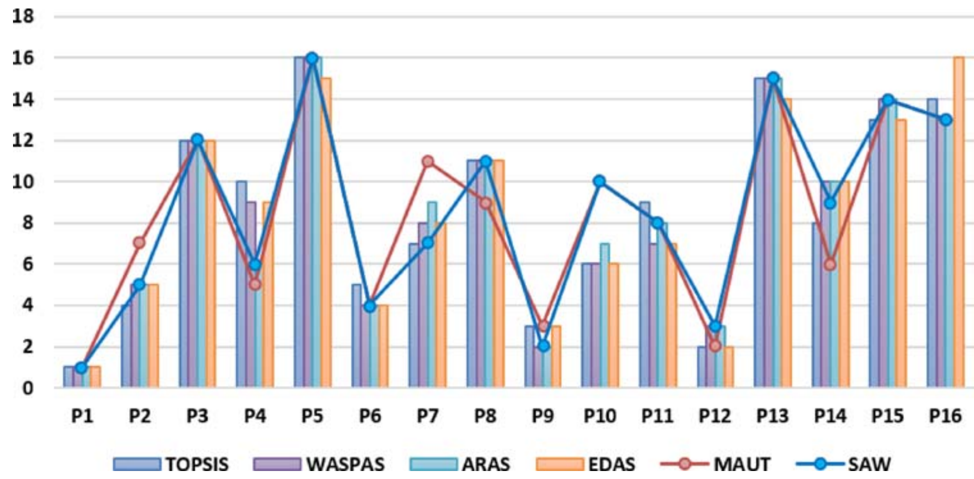

Figure 4. Comparison among ranking performances of the MCDM techniques.

importance scores. In the second step of this technique, positive and negative distances of each criterion from average were calculated.

This paper has made some significant contributions to the literature. Firstly, it is a novel integrated multi-criteria decision-making approach; and it provides a methodological framework to solve decision-making problems in the field of maritime transportation. Although there are numerous studies using the MCDM methods to evaluate the decision-making problems on container transportation, there is no study about performance analysis for Ro-Ro transport operations; and this paper has also the potential to contribute to the literature on Ro-Ro transportation.

In addition to those, this paper has employed a novel hybrid model, which had never been employed before until the current paper was prepared. It consists of the CRITIC and the EDAS methods; and applying this proposed model is very easy for decision-makers. More importantly, it can also be applied for solving decision-making problems faced in various fields.

The research focused on the analysis of the Ro-Ro seaports and terminals' performance and solution of the terminal selection problem. The findings of the research have provided valuable information for the stakeholders in the field of maritime transportation. In addition, it has provided a methodological framework. Especially, port authorities in the Black Sea region can comparatively evaluate their own performance with the help of information and the proposed integrated approach provided by this paper.

Table 16. Spearman's rho correlations.

	TOPSIS	MAUT	SAW	WASPAS	ARAS	EDAS
TOPSIS	1	0.885	0.941	0.976	0.953	0.974
MAUT	0.885	1	0.947	0.9	0.941	0.885
SAW	0.941	0.947	1	0.959	0.979	0.938
WASPAS	0.976	0.9	0.959	1	0.982	0.979
ARAS	0.953	0.941	0.979	0.982	1	0.962
EDAS	0.974	0.885	0.938	0.979	0.962	1

When the results and findings of this paper are evaluated, the Varna Ro-Ro terminal has been determined as the best terminal, which had the highest performance. According to the results of this paper, the second-best Ro-Ro terminal is Ilyichivsk terminal. When the results about the relative importance of the selection criteria are examined, the most important criterion is the storage area in m2 with a score of 14.5%. This criterion has been followed by criteria such as total costs of port services (C7), and the number of regular lines (C5).

In addition to sensitivity analysis performed by researchers, all obtained results were overviewed together with the board of experts in order to verify the results of the research; and all the members of this board approved that the results are significantly accurate. As a result, the general evaluation of this board and results of the sensitivity analysis prove that the proposed MCDM model can be applied to decision-making problems; and it has the potential to solve these kinds of problems.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Notes on contributors

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