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ROUGH BEST-WORST METHOD FOR SUPPLIER SELECTION IN BIOFUEL COMPANIES BASED ON GREEN CRITERIA

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Research paper

Abstract. *This paper concerns with the integration of rough set theory with the Best Worst method to evaluate information system performance within supplier selection problem of biofuel companies. First, a set of main criteria and sub-criteria are collected and then to include uncertainty in decision making, rough set theory is employed. The rough best worst method is applied for weighing and supplier evaluation with respect to information system performance and environmental impacts. Further, a case study is conducted for biofuel company supplier selection and the results imply the effectiveness of the approach in tactical performance evaluation. The best criteria effective on the green supplier selection of ISs performance is determined to be Quality.*

Key words: *Biofuel company; Information systems; supplier selection; Rough Best Worst Method*

1. Introduction

Each organization performs specific and different activities and the cornerstone of each organization's activities is information. Therefore, a proper information system (IS) is essential to better manage the flow of information in the organization. (Sweis, 2015). An organization must be able to make the right decisions to survive and improve, these decisions must be based on the proper processing of information within the organization and this information must be stored, processed and analyzed in a database, (IS) is the database. (Salmeron et al., 2001). Information systems are

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made up of different parts, the most important of which are people and information. Secondly, software and hardware for storing information and communication networks for transfer and sending information within the organization (Kim & Lee, 2004).

Information Systems (IS) have become essential for all organizations to survive in today's technology-oriented environment. The number of companies and organizations are increasing which have invested widely in their IS infrastructures to present better services and to produce more valuable products. Anyway, it has been reasoned that not the (IS) solution but their utilization provides the competitive advantages (Zaied, 2012). Thus, because of the aforementioned functions and importance of IS, there are too many studies to emphasize the impact of ISs on other contexts like health and medicine (Sirintrapun & Artz, 2016; Sahay et al., 2018), transportation (Chen et al., 2017), energy (Sicilia et al., 2017), biology (Miller, 2017), education (Duman et al., 2015), environment (Anjana et al., 2018), geography (Wagner, 2017) and so many other disciplines. But one of the most important fields that the trace of ISs has been seen is the selection of green suppliers.

Supplier selection is a significant task for modern companies considering the evolution and development of information systems. With respect to environmental factors, green supplier selection is now a substantial challenge for policy and decision makers requiring collecting and processing mass information (Stevic et al., 2018; Matic et al., 2019; Stevic et al., 2020). It is necessary to make the supplier green. Accordingly, many researchers have addressed the various aspects of the green suppliers selecting and specifically worked on the evaluation and ranking of the effective criteria which are important in choosing green suppliers (Sureeyatanapas et al., 2018; Trautrims et al., 2017; Govindan et al., 2015). A comprehensive review on defining the relevant criteria effective of sustainable supplier selection problem was investigated in (Durmić, 2019).

Banaeian et al. (2018) have selected the green supplier using the fuzzy group decision making methods. Actually, they compared the result of three different techniques- TOPSIS, VIKOR and GRA methods in a fuzzy environment. Sureeyatanapas et al (2018) used the TOPSIS technique to simplify, choosing the suppliers based on the uncertain and unavailable information. Further, they used to the rank order centroid (ROC) method, to gather the weights of criteria to decrease the degree of subjectivity required from the decision makers. Yazdani et al. (2017) represented an integrated approach through considering different environmental performance factors to select the green supplier. Therefore, they used DEMATEL technique to determine the internal-relationships between the customer requirements and used Quality Function Deployment to make a central relationship matrix in order to identify degree of relationship between each pair of supplier selection criteria through the fuzzy extended AHP method. Gupta & Barua (2017) worked on the evaluation of supplier selection based on the green innovation abilities among the small and medium companies. Jauhar & Pant (2017) tended to develop an efficient system for sustainable supplier system through the combination of the Data envelop analysis (DEA) (Despić et al. 2019) with Differential evolution (DE) algorithm and further with Multi-Objective Differential Evolution (MODE) to overcome the inherent drawbacks of DEA. And finally, Hsu and Hu (2009) applied hazardous substance management (HSM) to select the supplier through the analytic network process (ANP). In their model, there were five criteria including

Procurement management, R&D management, Process management, Incoming quality control and Management system and 19 sub-criteria.

To obtain sustainable development, the integration of environmental, economic and social performance turned into the complex challenge for them. Because of above reasons, companies which buy their required materials and services from specific suppliers prefer to fulfill their expectations like low-cost, high-quality, short lead-time, and environmental criteria simultaneously (Đalić et al., 2020; Durmić et al., 2020; Lee et al., 2009 Fazlollahtabar & Kazemitash, 2021).

There are too many researches about green supplier selection (GSS) and ISs separately as two crucial parts of contemporary organizations, while except some limited studies in which (IS) is considered as the effective factor for GSS, there is not any research that investigate their relation. On the other hand, the second issue that is observed in the majority of the previous studies is using the complicated and time-consuming techniques like DEMATEL, AHP, ANP, DANP, TOPSIS and VIKOR to compute the needed requirements (Stevic et al., 2017).

Through the integrated Rough Best-Worst method (RBWM) the local and global weights of criteria and sub-criteria will be obtained by the experts' opinions. Next step is measuring the ISs' performance in association with green supplier selection which are gained by the experts' opinions. Ultimately, as a conclusion, companies could be able to focus on the specific IS or ISs which play the more important role in the green supplier selection processes and reinforce them if necessary. Because of the complex condition of today's business, all companies need to have a long-term relationship with their partners, and it's the reason why all corporations should be aware and alert to identify and select the supply resources. Hence, it can show the extreme importance of supplier selection (Gurel et al., 2015).

The aim of this paper is evaluating of each single IS on the green suppliers' selection and actually finding the level of effectiveness of each IS on the green supplier selection process. At the first step, it represents a localized GSS model including eight criteria and 31 sub-criteria of green supplier selection, based on the GSS experts' opinions (first problem). Then it illustrates the performance of every IS in relation with green supplier selection process using the RBWM (which computes the importance (weights) of every measure of GSS model) and performance item-scores (which represents the effectiveness and performance of ISs to select the green suppliers) of all existing ISs in a company (second and third problem).

2. Methods and materials

The purpose of this study is evaluating the performance of various ISs of a company, in green supplier selection process (GSS). This aim is met by MCDM methods to gain the global weights of green supplier selection' sub-criteria, and another technique to rank the ISs based on their performances in connection with the GSS. It looks necessary to show the steps of RBWM as the MCDM method and item-scoring to rank the ISs. Best-Worst method was proposed by Rezaei (2015) that in comparison with other decision-making methods, BWM needs less data, since full pairwise comparison is not required providing a more consistent result. That is the main reason why it's applied in this study. Also, rough set theory presented by

Pawlak (1982) is a mathematical tool to deal with uncertainty. Further, the rough set theory is appropriate in practice characterized by a small amount of data. After the presentation of the model, the procedures of problems solving are demonstrated as techniques, step by step. The conceptual model is depicted in Figure 1.

Figure 1. The conceptual model of green supplier selection's criteria and sub-criteria

As it's been pictured, there are three primitive operations in which 8 criteria and 31 sub-criteria have been selected by a number of organization's experts that have been extracted from the literature. Then, the integrated Rough BWM as the MCDM technique is started including three sub-sections in which the local weights of criteria, the local weights of sub-criteria and finally the global weights of sub-criteria are computed, respectively. As the last step, by determining the ISs' performances regarding the meeting the green supplier selection criterion, the scores of the ISs are calculated. Ultimately, based on the computed final scores of ISs, they are ranked. Through this way, the determined goals of study are achieved, or indeed, the mentioned problems of the study are solved.

2.1. Rough Best-Worst Method

Given that Best-Worst is a new but well-known method. The steps of the (RBWM) are briefly mentioned as follow:

Step 1. Determining the set of evaluation criteria.

Step 2. Determining the most and the least significant criteria.

Step 3. Determining the preferences of the most significant criterion (B) from set C;

$$A_B^e = (a_{B1}^e, a_{B2}^e, ..., a_{Bn}^e); 1 \le e \le m \tag{1}$$

Step 4. Repeat Step 3 for the worst criterion (W) and the set C ;

$$A_W^e = (a_{1W}^e, a_{2W}^e, ..., a_{nW}^e); 1 \le e \le m \tag{2}$$

Step 5. Determining the rough BO matrix for the average answers of the experts.

$$A_B^{*e} = [a_{B1}^m, a_{B2}^m, ..., a_{B1}^k; a_{B2}^1, a_{B2}^2, ..., a_{B2}^m; ...; a_{Bn}^1, a_{Bn}^2, ..., a_{Bn}^m]_{1\times n} \tag{3}$$

BO matrix $A_B^{*1}, A_B^{*2}, ..., A_B^{*m}$ is obtained from the sequence $RN(a_{Bj}^e)$. Then, the average rough sequence is computed using Equation (4).

$$RN(\overline{a}_{Bj}) = RN(a_{Bj}^1, a_{Bj}^2, ..., a_{Bj}^e) = \begin{cases} \overline{a}_{Bj}^L = \dfrac{1}{m}\sum_{e=1}^{m} a_{Bj}^{eL} \\ \overline{a}_{Bj}^U = \dfrac{1}{m}\sum_{e=1}^{m} a_{Bj}^{eU} \end{cases} \tag{4}$$

where, e represents the $e-th$ expert $(e = 1, 2, ..., m)$, $RN(a_{Bj}^e)$ represents the rough sequences. We thus obtain the averaged rough BO matrix of average responses:

$$\overline{A}_B = [\overline{a}_{B1}, \overline{a}_{B2}, ..., \overline{a}_{Bn}]_{1\times n} \tag{5}$$

Step 6. Determining the rough OW matrix of average expert responses.

$$A_W^{e*} = [a_{1W}^1, a_{1W}^2, ..., a_{1W}^m; a_{2W}^1, a_{2W}^2, ..., a_{2W}^m; ...; a_{nW}^1, a_{nW}^2, ..., a_{nW}^m]_{1\times n} \tag{6}$$

The sequence for the worst criterion is also computed.

$$RN(\overline{a}_{jW}) = RN(a_{jW}^1, a_{jW}^2, ..., a_{jW}^e) = \begin{cases} \overline{a}_{jW}^L = \dfrac{1}{m}\sum_{e=1}^{m} a_{jW}^{eL} \\ \overline{a}_{jW}^U = \dfrac{1}{m}\sum_{e=1}^{m} a_{jW}^{eU} \end{cases} \tag{7}$$

The average rough sequence is in hand:

$$\overline{A}_W = [\overline{a}_{1W}, \overline{a}_{2W}, ..., \overline{a}_{nW}]_{1\times n} \tag{8}$$

Step 7. Calculation of the optimal rough weight coefficients of the criteria $[RN(W_1), RN(w_2), \ldots, RN(w_n)]$ from set *C*.

$$\left|\frac{RN(w_B)}{RN(w_j)} - RN(a_{Bj})\right| and \left|\frac{RN(w_j)}{RN(w_W)} - RN(a_{jW})\right| \tag{9}$$

The previously defined limits will be presented in the following min-max model:

$$\begin{aligned} &\min \max_j \left\{ \left|\frac{RN(w_B)}{RN(w_j)} - RN(a_{Bj})\right|, \left|\frac{RN(w_j)}{RN(w_W)} - RN(a_{jW})\right| \right\} \\ &s.t. \\ &\begin{cases} \sum_{j=1}^{n} w_j^L \le 1 \\ \sum_{j=1}^{n} w_j^U \ge 1 \\ w_j^L \le w_j^U, \forall j = 1,2,\ldots,n \\ w_j^L, w_j^U \ge 0, \forall j = 1,2,\ldots,n \end{cases} \end{aligned} \tag{10}$$

Model (10) is equivalent to the following model:

$$\begin{aligned} &\min \xi \\ &s.t. \\ &\begin{cases} \left|\frac{w_B^L}{w_j^U} - \overline{a}_{Bj}^U\right| \le \zeta ; \left|\frac{w_B^U}{w_j^L} - \overline{a}_{Bj}^L\right| \le \zeta \\ \left|\frac{w_j^L}{w_W^U} - \overline{a}_{jW}^U\right| \le \zeta ; \left|\frac{w_j^U}{w_W^L} - \overline{a}_{jW}^L\right| \le \zeta \\ \sum_{j=1}^{n} w_j^L \le 1 \\ \sum_{j=1}^{n} w_j^U \ge 1 \\ w_j^L \le w_j^U, \forall j = 1,2,\ldots,n \\ w_j^L, w_j^U \ge 0, \forall j = 1,2,\ldots,n \end{cases} \end{aligned} \tag{11}$$

where $RN(w_j) = [w_j^L, w_j^U]$ represents the optimum values of the weight coefficients, $RN(w_B) = [w_B^L, w_B^U]$ and $RN(w_W) = [w_W^L, w_W^U]$ represents the weight coefficients of the best and worst criterion respectively. By solving model (11) we obtain the optimal values of the weight coefficients for the evaluation criteria $[RN(w_1), RN(w_2), \ldots, RN(w_n)]$ and ξ^*.

For MCDM problems with more than one level of criteria such as this study, first of all, the weights for different levels should be obtained through the BWM steps. Then, the weights of different levels have to be multiplied to determine the global weights (Salimi & Rezaei, 2018). To show this process clearly, in Figure 2 the sub-steps of every single technique, the order of them and major techniques and finally the output of them are observed. In Figure 2, there are three main steps and their corresponding sub-steps from collecting the criteria and sub-criteria, purification, weighing, ranking and performance evaluation.

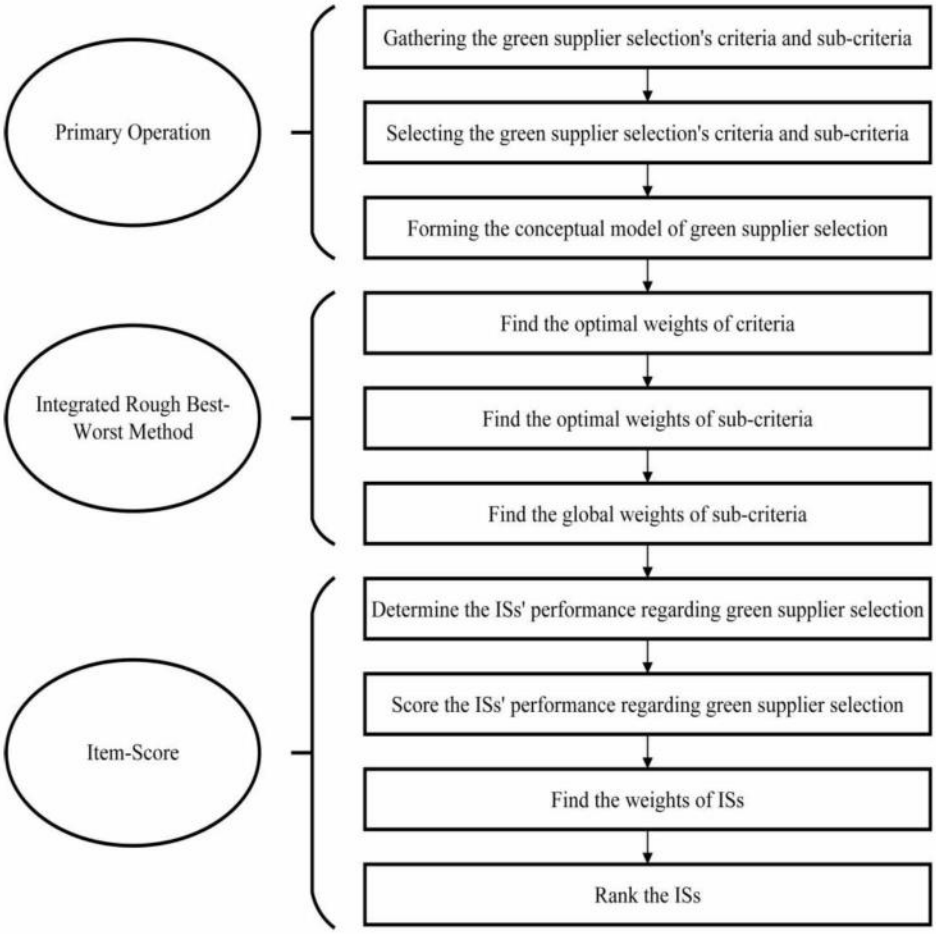

Figure 1. The proposed hybrid MCDM model

3. Case study

The proposed information system effectiveness model is tested to evaluate and rank the using ISs in Biofuel Company. To ensure sustainability, new energies have recently attracted a lot of attention. So far, the supply chain and the select of supplier of these energies have been presented from different perspective. Biofuel, as one of the types of renewable energy, has a significant amount of use in this type of fuel because this type of fuel can be obtained from the recycling of other materials. The optimal weights are obtained through the expert opinions, while the scores, are computed based on the data from a survey among the 100 experts of ISs.

3.1. Weights of green supplier selection measures:

To obtain the weights of the criteria and sub-criteria, the comparison data needed for BWM is gained by interviewing with 20 experts in the field of green supplier selection, individually. Next, the weights of criteria and their sub-criteria are determined using BWM. Finally, the overall weights for the criteria and sub-criteria are computed by using the aggregation (based on a simple average). Table 1 shows the aggregated weights of the eight main criteria and the sub-criteria based on the inputs which are provided by the experts. Based on these results, design for reduction or elimination of hazardous materials as the third sub-criteria of the Green Design (weight = 0.1176) has the most weight which illustrates the most effectiveness role which sub-criteria could play with respect to the green supplier selection, though the Green Product has the most amount of weight among the criteria.

3.2. Green supplier selection item-scores of ISs:

As the first step, in a survey among the 50 ISs' experts of the mentioned firm, their opinions about the ISs performance and effectiveness with respect to the selection of green suppliers are provided, in which the respondents rated the 10 most common ISs level based on items from different GSS determined sub-criteria on a nine-point Likert type scale. And finally, the last operation of this step is that the experts' opinions for every single sub-criterion are averaged.

Table 1. Global rough weights for criteria and sub-criteria.

Criteria	Local weights	Sub-criteria	Local weights	Global weights of sub-criteria
Green design	[0.1729,0.1786]	Design for resource efficiency	[0.0878,0.0890]	[0.0149,0.0162]
		Design of products for reuse, recycle, and recovery of material	[0.2336,0.2388]	[0.0405,0.0417]
		Design for reduction or elimination of hazardous materials	[0.6731,0.6774]	[0.1169,0.1181]
Service	[0.0978,0.1107]	Rate of processing order	[0.2323,0.2342]	[0.0230,0.0238]
		Service quality	[0.7655,0.7679]	[0.0757,0.0793]
Green Image	[0.0155,0.0451]	Ratio of green customers to total customers	[0.8406,0.8429]	[0.0285,0.0307]
		Green purchase trend of customers	[0.1573,0.1596]	[0.0047,0.0063]
Quality	[0.1233,0.1339]	Quality-related certificates	[0.6303,0.6324]	[0.0828,0.0854]
		Capability of quality management	[0.2520,0.2550]	0.0327,0.0345
		Reject Rate	[0.1141,0.1157]	[0.0149,0.0156]
Environmental Management	[0.0884,0.1057]	Environmental Protection policies/plans	[0.1463,0.1481]	[0.0136,0.0155]
		Environment Protection System	[0.1091,0.1123]	[0.0101,0.0122]

		Certification		
		EUP	[0.4438,0.4460]	[0.0429,0.0457]
		ODC	[0.0525,0.0566]	[0.0048,0.0070]
		RoHS	[0.1133,0.1162]	[0.0110,0.0119]
		WEE	[0.1275,0.1293]	[0.0120,0.0340]
Green Product	[0.2409,0.2519]	Cost of Component Disposal	[0.1367,0.1381]	[0.0326,0.0353]
		Green Production	[0.2909,0.2944]	[0.0716,0.0728]
		Green Certifications	[0.1176,0.1201]	[0.0287,0.0303]
		Green Packaging	[0.1328,0.1375]	[0.0321,0.0349]
		Recycle	[0.1266,0.1285]	[0.0301,0.0327]
		Remanufacturing	[0.0414,0.0439]	[0.0100,0.0120]
		Reuse	[0.1451,0.1487]	[0.0359,0.0365]
Delivery	[0.1198,0.1271]	Order Frequency	[0.0857,0.0872]	[0.0103,0.0206]
		Order Fulfillment Rate	[0.2518,0.2524]	[0.0296,0.0318]
		Lead time	[0.1802,0.1819]	[0.0215,0.0232]
		Delivery efficiency	[0.4783,0.4826]	[0.0575,0.0590]
Cost	[0.0891,0.0903]	Buying Friendly Materials	[0.0825,0.0848]	[0.0052,0.0096]
		Compliance with Sectorial Pricing	[0.1407,0.1440]	[0.0112,0.0145]
		Performance Value/Price	[0.5254,0.5291]	[0.0466,0.0479]
		Transportation Cost	[0.2460,0.2467]	[0.0214,0.0223]

There are two different ways that it's possible to evaluate and investigate the performance of ISs to support the GSS process based on. In one hand, it's available to assess the performance of ISs through their overall aggregations and rankings, so that the more overall aggregation, the better ranking. For instance, MIS possesses the most overall aggregation (6.8800), so it's the first information system as the best one. It means that it has the most effectiveness and best performance in related with GSS. And after that, ERP (6.7986), CRM (6.6319), SCM (6.5756), DSS (6.3210), EC (6.1931), BI (6.0805), KM (5.8977), OAS (5.0642) and TPS (4.7460) are placed in the following ranking respectively. On the other hand, it's possible to investigate the ISs based on their scores and rankings in every single part (the aggregation of every criterion). For example, MIS performance as the best one among the 10 mentioned ISs, is placed as the first one in the Quality criteria, the second one in three criteria, including Environmental Management, Green Product and Cost criteria, the third one in the Green Design criteria, the fourth one in the Green Image criteria and the sixth one in the Service criteria. As this way evaluates the performance of ISs in every GSS criteria, it's the best one to compare two different ISs which have close overall aggregations (not exact the same). For example, there is a slight difference between the overall aggregation of MIS and ERP which are 6.8800 and 6.7986 respectively, thus in the eyes of someone, it couldn't explain the superiority of MIS rather than ERP clearly. Therefore, they rely on the second way to describe the differences and performance of every one in comparison with others. In this case, ERP's performance (rank or actually aggregated score) is better than MIS in three criteria in consist of Service, Delivery and Green Product in which the ERP has the best performance, while in other criteria MIS has better scores and rankings.

The developed method in this paper can be employed to compare the GSS with respect to ISs performance; this way the position of ISs in the final ranking can be considered.

4. Conclusions

This research tried to take into account the green supplier selection indices to allow each IS to determine its overall weight. Moreover, ISs can improve their green supplier selection performance based on the importance of each perspective. More precisely, if an IS wants be prominent in Green Product as the most important criteria in GSS process, it should focus on and invest in Green Production, since the given information in Table 1 display that the Green Production level is the most important item from a Green Product perspective. Therefore, the criteria and sub-criteria effective on the GSS with respect to the corresponding weights leading to improve the IS performance of green supplier selection. As such, these results can help ISs enhance their overall performances.

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ASSESSING THE PERFORMANCE OF SUB-SAHARAN AFRICAN (SSA) RAILWAYS BASED ON AN INTEGRATED ENTROPY-MARCOS APPROACH

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Abstract: *In this study, the performance of Sub-Saharan African railways systems (SSA) is assessed by using an integrated Entropy-MARCOS (Measurement Alternatives and Ranking according to COmpromise Solution) - based methodology. In the first phase, the Entropy method is employed to determine the weights of each sub-criterion of the decision model. This process identifies six main criteria, i.e., safety, security, internal business aspect, intermodal aspect, innovation, and learning aspect, and customer satisfaction which are further supplemented by 13 sub-criteria. In the second phase, the MARCOS method is used to rank the countries based on their railway performance assessment. Based on the results from the proposed method, a sensitivity analysis was carried out through a comparative analysis with seven other multi-criteria decision-making (MCDM) methods. The results of the study indicate that the most weighted sub-criterion is the labor productivity (internal business perspective criteria) followed by the terrorist incidence (security criteria) and the number of employees going through training/exposure sessions (innovation and learning perspective criteria). Moreover, it was revealed that Kenya is the best alternative in terms of its railway performance followed by Ethiopia, Cameroon, Nigeria, and Ghana. Based on the findings from this study, decision-makers can be assisted during the operative, designing, and planning investigations of the railway system through the consideration of these parameters as insert indicators. Also, the findings can help as a benchmark for the performance analysis of other railway systems in other African countries.*

Keywords: *Railways, Sub Saharan Africa, Performance, Entropy, MARCOS, Multi-criteria decision making*

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1. Introduction

In the present's severe rivalries between railway and road transportation modes in the major corridors of the African sub-region, a distinguished service distribution change into a regional trade demand. One of the pivotal constituents for modern railway corporations is performance appraisal and efficacy. This can reinforce reaching the organization's goals and analyze their achievement with identical leading policies marketing. To meet these excellent positions, a method should be elaborated by the railway corporation to create this evaluation in a beneficial approach.

Railway has lately undergone a universal renaissance via its network expansion and yearly traffic values. According to Bayane and Yanjun (2017) and Bouraima, Yang, and Qiu (2017), this improvement of railways is related to socio-economic and environmental advantages produced by the transport sector. Railway plays a considerable role through the assistance of economy and commerce of any country due to heavy traffic transportation of people and goods over long distances. A relative evaluation of air, road, and railway mode showed its potentiality in terms of cost, greenhouse gas, and carbon emission (Bouraima et al., 2020). In 2010, a coherent performance and demand development was universally reported in the railway system through a 40% rise in cargo and passenger traffic in comparison to an antecedent year. However, an opposite trend in the performance was noticed in Africa. While dynamic growth has been recorded in Asia, Europe, and America, Africa has seen a drop in passengers' services and freight transport.

Due to the recent powerful rise of the transport market worldwide, the contradictory trend in Sub Saharan Africa (SSA) revealed the crucial deficient railway system (Olievschi, 2013). In 2010, the Africa Union Commission has expressed the will to ameliorate the infrastructure condition through the infrastructure development program in the continent (Union, 2009). During this period, political leaders have expressed the connectivity ambition at both regional and continental levels (Commission, 2012). Nonetheless, this ambition has been rapidly impeded by several factors that affect railway development.

Several endogenous and exogenous factors restrict the competitiveness of African railway systems. While poor connectivity and interoperation of railways have seen to be the endogenous factors (Bouraima & Qiu, 2018; Bouraima & Yanjun, 2020), exogenous parameters are related to rivalry with road transport and the lack of policy related to transport (Bayane, Yanjun, & Bekhzad, 2020; Bouraima & Dominique, 2018; Bouraima, et al., 2020).

Literature available so far indicates the dramatic status of the railway sector in Sub-Saharan Africa (Bullock, 2009). A study by Mbangala Mapapa (2004) on the measurement of African railways productivity over 21 years indicated that the average efficiency is relatively low. As consequence, a need of improving the sector performance is imperative. Sabri, Colson, and Mbangala (2008) used data enveloped analysis (DEA) and Preference Ranking Organization METHod for Enrichment of Evaluations (PROMETHEE) II methods for the financial and technical performance analyses of five firms in North Africa. Sabri (2016) provided complimentary detailed information on the productivities of North African railways using a Malmquist quantity index. De Bod and Havenga (2010) highlighted the considerable cost depletion benefits feasible via the condensation of railway goods through prolonged distances, with related indications for profitability rise for rail operators. Olievschi (2013) suggested an extensive improvement method for the performance of the railway sector together with its governance modes. Wangai, Rohacs, and Boros (2020) introduced a harmonized interaction methodology including socio-economic needs, technical expansion, and rule for the development process of railway systems in low-income countries. Kutlar, Kabasakal, and Sarikaya (2013) measured the technical and allocative efficiencies scores of 31 railways companies using DEA and TOBIT analyses, respectively. Blumenfeld et al., (2019) proposed a technical strategy that captured the crucial capacity to be recommended to reach upcoming achievement in railway infrastructure in low-income countries while highlighting the necessity for arising technologies to be employed for appropriate solution.

Among these studies (Blumenfeld et al., 2019; Bullock, 2009; Mbangala Mapapa, 2004; Sabri, 2016; Sabri et al., 2008; Wangai et al., 2020), none of them have examined the key performance indicators (KPI's) of SSA's railways. Moreover, none of them have applied the MCDM method for the performance assessment of Sub-Saharan African railways. This paper proposed an integrated Entropy-MARCOS approach for the assessment of SSA's railways. The criteria and alternatives associated with the KPI's of railways are defined. A questionnaire survey was prepared for data collection and assigned to the railway experts from different countries. All experts hold senior positions with associated working experience and most of them had practiced in the field for 15 years at least. They all belong to the railway corporation in their respective countries: Cameroon Railway Corporation (CAMRAIL), Ethiopian Railway Corporation (ERC), Ghana Railway Corporation (GRC), Nigeria Railway Corporation (NRC), and Kenya Railway Corporation (KRC). The survey of experts is carried out in the study so that necessary data will be collected to determine relative criteria weight using the entropy method. The measurement and ranking of alternatives are assessed through the MARCOS method.

Through the proposed model in this study, various objectives are elucidated: 1) Review of the existing methodologies for the evaluation of different areas of the railway transport; 2) Enhancing the methodology for railway performance assessment and determining criteria weights and alternatives ranks through the development of the original multi-criteria entropy-MARCOS model; 3) Proposal of new methodology for the railway performance assessment; and (4) Cross over the existing gap for the railway performance evaluation approach in Sub-Saharan Africa.

The remaining sections of the paper are as follows. Section 2 includes the review of similar research topics in which are applied the models for the analysis of railway transport. Section 3 deals with the materials and methods. In section 4, the results and the discussion of the entropy-MARCOS methods are provided. Section 5 presented and discussed a comparative analysis of the proposed method with others MCDM methods. Section 6 ends with the conclusion along with the benefit of the research and the guidance for upcoming research.

2. Literature review

The analytical hierarchy process (AHP) introduced by Saaty (1990), is the most frequently applied MCDM approach in transport sector problems (Yannis et al., 2020). Vesković et al., (2016) used the fuzzy AHP approach to examine the operation of railways. Vesković et al., (2018) evaluate the management of railway through the combination of the Delphi- SWARA - MABAC approaches. The performance of goods transport in the railway sector is measured by Blagojević et al., (2020) through the usage of fuzzy-AHP-DEA approaches. Simić, Soušek, and Jovčić (2020) assessed the risk related to the railway infrastructure through the application fuzzy MCDM picture. Blagojević et al., (2021) examined the safety degree of the railway crossings with a new hybrid fuzzy MCDM approach so that durable traffic management can be reached. A new hybrid SAW (Simple Additive Weighting) - RN (rough numbers) method introduced by Stević et al., (2017) was used to choose wagons for the internal logistic transport enterprise. A choice of suitable alternative for the passenger rail operators business was done by Vesković et al. (2020) through a new hybrid fuzzy PIPRECIA (Pivot Pairwise Relative Criteria Importance Assessment)- fuzzy -EDAS approach. Blagojević et al., (2020) assessed the safety of railway traffic using a new integrated fuzzy PIPRECIA-entropy-DEA.

Not much structural performance has been achieved in most of SSA's countries' railways, especially in recent times. Nonetheless, new investments and developments have been noticed on the rail and some actions are taken in place to rejuvenate the railway system in most of SSA's countries. A renaissance has been felt in the railway system through the development of new lines and modernization and rehabilitation of old lines. As consequence, performance criteria are very important to measure and manage the railway sub-sector. The performance indicators for the railway system have been elucidated by Onatere, Nwagboso, and Georgakis (2014) in Nigeria. However, no research has been conducted regarding a comparative analysis of these performance indicators between countries from different regions of Sub-Saharan Africa. As consequence, this research is new and different from previous studies related to African railway performance since it takes into account countries from West Africa (Ghana and Nigeria), East Africa (Ethiopia and Kenya), and Central Africa (Cameroon).

3. Materials and methods

Section 3 is divided into two sub-sections. The first sub-section presents the materials which are the case study, where thirteen parameters are used to assess the railway performance of five selected SSA countries. The second sub-section deals with the presentation of the models used and the entropy-MARCOS algorithm is shown

3.1 Materials (case study)

Section 3.1 includes the background of the railway system in the selected countries (section 3.1.1), the definition of key performance indicators (section 3.1.2), and the formation of the multi-criteria model (section 3.1.3).

3.1.1. Overview of the railway in selected countries

In this study, five countries have been selected for the performance analysis based on the recent construction of new lines and maintenance and rehabilitation of existing networks. They comprise Ghana and Nigeria in West Africa, Ethiopia and Kenya in East Africa, and Cameroon in Central Africa, as can be seen in Figure 1.

The construction of the existing railway in Cameroon dates back to the 1900s. Being single track, it consists of the metric gauge with wood and iron sleepers. The Cameroonian railway network may be categorized into three routes: TRANSCAM I line (also referred to as the Central railway line), connecting Douala to Yaoundé, is CAMRAIL's central line; TRANSCAM II line (also referred to as the Northern line) connecting Yaoundé to Ngaoundere; and the Western line running between Douala and Kumba (Douala-Mbanga-Nkongsamba line, Mbanga~Kumba line). The total length of the railways is 1, 270km (Figure 2-a). Although the country has the most important and heaviest railway structures among countries of the sub-region, it is less extensive and operational in only part of the country. The only line that is functional provides a durable communication link between the north and south of the country, whereas it is still not operating at the international level. As consequence, the Cameroonian government commissioned the National Railway Master Plan in Cameroon Project in 2009 intending to construct 6000 km of lines categorized into short (S), mid (M), and long (L) term; with double track and standard gauge and in the same time develop urban railway for Yaoundé and Douala.

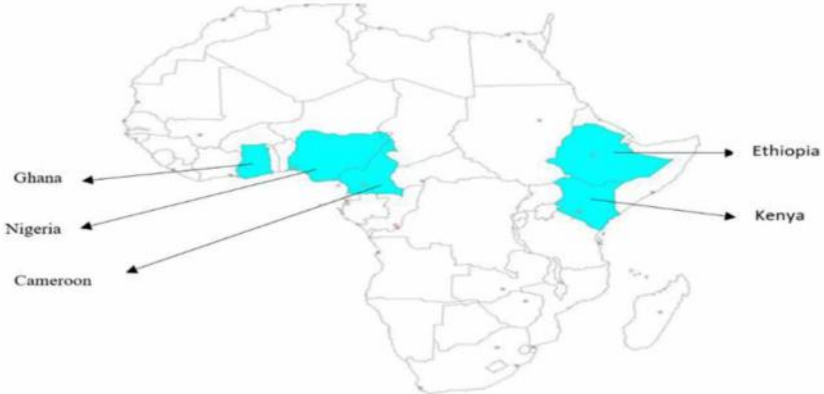
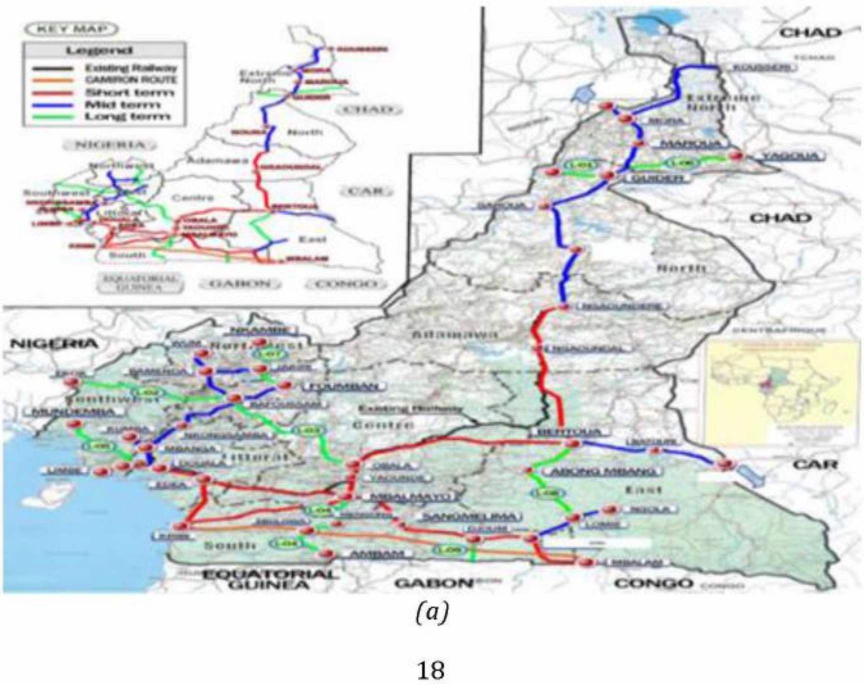


Figure 1. Countries of Sub-Saharan African contemplated in the study

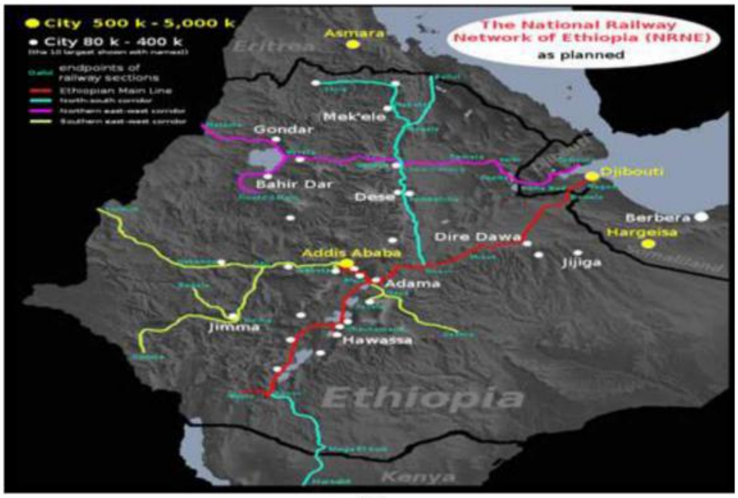
The first railway line built in Ethiopia dates back to 1917 and links Ethiopia to Djibouti (Figure 2-b). It is a 784km metric gauge railway of which 475 km are destroyed and abandoned due to poor maintenance. The national railway network of Ethiopia (NRNE) is in charge of the management and operation of the railway. In recent years, the national railway has been modernized through the completion of the Addis Ababa–Djibouti electrified standard gauge railway and the ongoing construction of the Awash–Weldiya and Weldiya–Mekelle lines. Additionally, there is an urban light rail system in the capital which started operation in 2015 and represents the first light rail and rapid transit in the eastern and sub-Saharan Africa region. The existing 947 km Ghanaian railway network (Figure 2 c) comprises three lines: the eastern line (Kumasi –Accra: 303.9 km), the western line (Kumasi to Sekondi-Takoradi: 266.8 km), and the Central line (eastern-western). Most of the existing lines are single track, except a 32 km double-track line from Takoradi to Manso.

The Kenyan narrow-gauge railway (NGR) still plays a crucial role in the country's transport and logistics. Its construction began in the year 1896 under British rule. The mainline is composed of the 530.3km Mombasa-Nairobi section and the 551.88km Nairobi- Nakuru-Malaba, at Kenya's border with Uganda (Figure 2-d). This line is operational mostly for freight with a speed range of 20km/h to 30km/h from the Mombasa to Malaba border. The Kenya Vision 2030 which is the country's future development blueprint puts forward expansion and development of the railway system as one of the key flagship projects. The Kenya Government identified the Northern corridor and the LAPSSET corridor for the development of the modern Standard Gauge Railway (SGR). The Northern corridor is made up of; Mombasa-Nairobi, Nairobi-Naivasha, Naivasha–Narok–Bomet–Nyamira–Kisumu, and Kisumu–Yala–Mumias–Malaba. The Lamu Port South Sudan Ethiopia Transport (LAPSSET) corridor is a regional project intended to create seamless connectivity between Kenya and her neighbors Ethiopia and South Sudan.

The construction of Nigeria's existing railway network began in 1898 under British colonial power. This includes a 3,505 km old narrow-gauge single track running through three main north-south branch lines that run diagonally through the country (Figure 2-e). These lines initially played a significant economic role. To develop and refurbish the railway network, as mentioned in the 25-year strategic plan, all the existing 3505-km network of the narrow-gauge track will be converted for commercial freight and new standard-gauge lines will be built for passenger traffic that will link the economic centers and all the main states. This explains the construction of two main standard gauge railway (SGR) Greenfield projects that have been backed by Chinese funding: the new 2,733 km Lagos-Kano SGR line project is the first one substituting the colonial track, and split into four portions: Lagos-Ibadan, Ibadan-Kaduna, Kaduna-Kano, and Abuja-Kaduna and the new coastal railway line linking Lagos to Calabar through Port Harcourt and Warri.



(a)


City 500 k - 5,000 k
City 80 k - 400 k
endpoints of railway sections
Ethiopian Main Line
The National Railway Network of Ethiopia (NRNE) as planned
Asmara
Eritrea
Mek'ele
Gondar
Bahir Dar
Dese
Djibouti
Berbera
Hargeisa
Dire Dawa
Jijiga
Addis Ababa
Adama
Jimma
Hawassa
Ethiopia
Kenya

(b)


BURKINA FASO
BENIN
TOGO
COTE D'IVOIRE
ACCRA
GULF OF GUINEA
LEGEND

(c)


Ethiopia
Uganda
Kenya
Somalia
Eldoret
Nairobi
Garissa
Arusha
Moshi
Mombasa
United Republic of Tanzania
INDIAN OCEAN

(d)

(e)

Figure 2. Railway networks of different countries (a) Cameroon, (b) Ethiopia, (c) Ghana, (d) Kenya, (e) Nigeria.

3.1.2. Defining key performance indicators

Different actions were employed to examine and trace an organization's development upon its objective. According to Henning, Essakali, and Oh (2011), the quality of an organization's performance is quantified through KPIs. The choice and operation of adequate KPIs might be completely difficult, particularly when handling an organization like the railway sector in Sub-Saharan Africa. For this purpose of evaluating Sub-Saharan African railway performance, thirteen indexes were applied, as shown in Figure 3. In this study, we follow the indexes based on the literature reviews related to KPIs (Onatere et al., 2014) as follows: safety, security, internal business aspect, intermodal aspect, innovation, and learning aspect, and customer satisfaction.

Safety is related to the preservation of property and life through the advanced technology, rule, and management of all kinds of the railway sector. Some railway accidents have been noticed in some of the sub-Saharan African countries because of the poor safety measures. There is the occurrence of the death of some individuals because of the disposition of wares by traders along rail lines and carelessness of people when traversing lines. Also, the congested state of trains with people on the rooftop causes deaths of people who fall from trains. The KPIs for the safety criteria are shown in Figure 3.

Security is a component of safety, from the substantial preservation of infrastructure to techniques that protect the information network. Appropriate security actions are very important in the country where there is the occurrence of terrorist attacks and the presence of hard drugs and hemp used by people during the train journey. The KPIs for the security criteria are shown in Figure 3.

Internal business viewpoint is an ameliorated inner performance of the railway transport which is important for the customer satisfaction requirements. As consequence, the evaluation of whether the inner performance directed the necessity or prediction of the client is pivotal. The KPIs for the internal business viewpoint are shown in Figure 3.

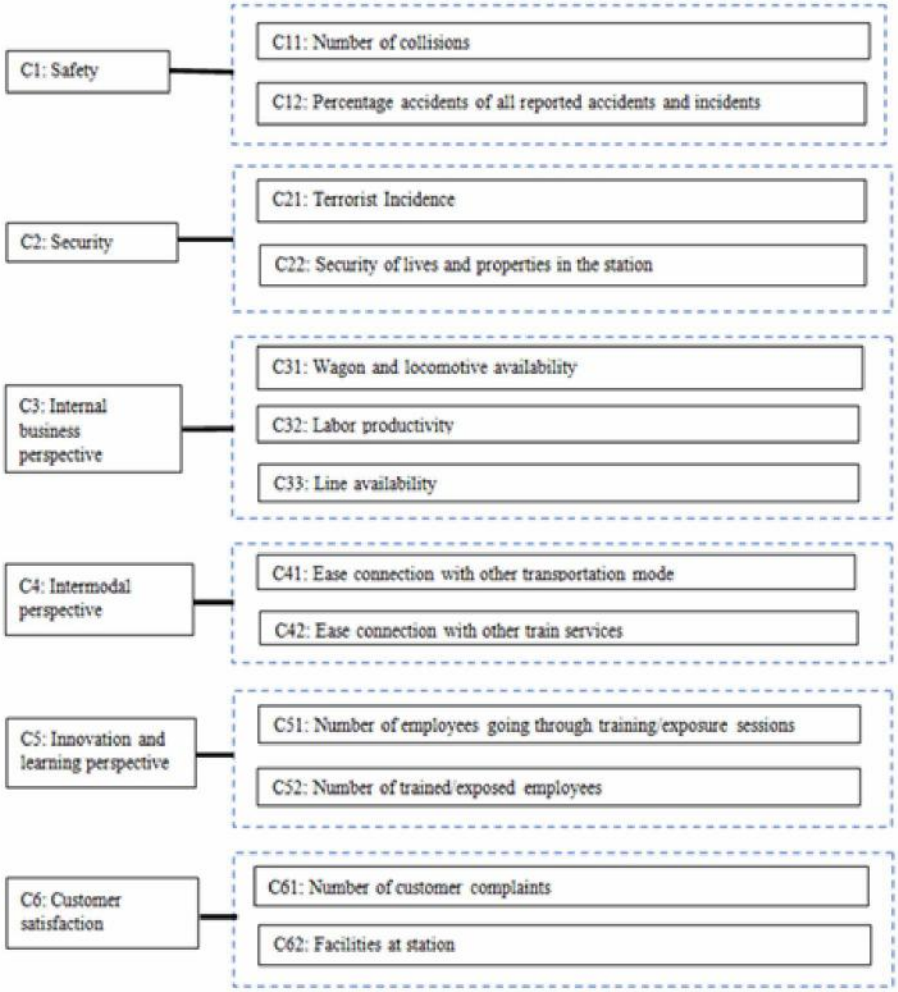


Figure 3. Performance indicators for railway system measurement

Intermodality is the involvement of diverse transportation modes for travel. As consequence, the construction of stations of different types of public transport modes such as rail, airport, and bus should be close to each other. By preference, they should just step away, which makes it convenient for the traveler to link with other transport means. The KPIs for intermodal perspective are shown in Figure 3.

Innovation and learning perspective is considered as the design and application of the business management initiatives emphasized by the company that foster increased innovation and learning among the workforce. The sector in most Africans has endured deterioration with regards to high profile personnel. The KPIs for innovation and learning criteria are shown in Figure 3.

Customers' satisfaction has mostly been ignored in the existing African rail transport system due to poor facilities. The satisfaction of commuters should become a preference and vital for sustainable railway development since under normal cases, transport services are required by commuters. As consequence, in the case of dissatisfaction, they will refer to other modes of transport. The KPIs for customer satisfaction are shown in Figure 3.

Among these criteria, the number of collisions, the recorded accidents and incidents, the terrorist incidence, and the number of customer complaints are criteria of underestimate type and are included in the cost group. Meanwhile, others are criteria of interest type, i.e. they need to be enhanced.

3.1.3. Forming a multi-criteria model

Based on criteria associated with the KPIs, experts from different countries have evaluated each criterion based on the linguistic scale (Table 1) to make a decision matrix (Table 2).

Table 1. Linguistic scale for the evaluation of alternatives depending on the type of criteria

Criteria	scale
1	Very poor-VP
2	Poor -P
3	Medium poor-MF
4	Fair -F
5	Medium good -MG
6	Good-G
7	Very good-VG

Table 2. Decision matrix

	A1	A2	A3	A4	A5
	CAM	NIG	GHA	ETH	KEN
C11	3	3	3	2	2
C12	3	3	2	2	2
C21	3	3	2	2	1
C22	4	4	5	6	6
C31	4	4	2	5	5
C32	4	4	2	6	5
C33	2	2	3	4	5
C41	2	2	2	2	4
C42	2	2	4	3	4
C51	4	4	2	6	5
C52	4	4	3	5	5
C61	4	4	4	4	4
C62	4	4	3	5	4

Note: CAM (Cameroon), NIG (Nigeria), GHA (Ghana), ETH (Ethiopia), KEN (Kenya)

3.2. Methods

The entropy- MARCOS model is implemented in two steps. In the first step, the determination of criteria weights is done using the entropy model (Shannon, 1948) right after their evaluation by experts. In the second step, these weight coefficients are employed to rank alternatives through the MARCOS model. In the following sections (sections 3.2.1 and 3.2.2), the steps of the entropy and MARCOS model are presented.

3.2.1. Entropy method

The entropy method, originally obtained from thermodynamics (Clausius, 1865), and employed to examine the irremediable situation of a procedure (Mon, Cheng, & Lin, 1994), is a means of ambiguity in information produced regarding the hypothesis of the probability. The entropy theory is firstly initiated by Shannon (1948) as a concept to determine weights in an objective manner(Zou, Yi, & Sun, 2006). It includes successive steps:

At first, the initial matrix is normalized through Equation (1).

$$r_{ij} = x_{ij} / \sum_{i=1}^{m} x_{ij} \tag{1}$$

Where r_{ij} stands for normalized values and x_{ij} represents primary decision-making matrix values.

Secondly, equation (2) is employed to compute the entropy measure e_j

$$e_j = -\frac{1}{\ln(m)} \sum_{i=1}^{m} r_{ij} \ln(n_{ij}) \tag{2}$$

Where *m* stands for the number of alternatives.

Thirdly, equation (3) is used to compute the criterion weight w_j

$$w_j = (1 - e_j) / \sum_{j=1}^{n} (1 - e_j) \tag{3}$$

where n stands for criteria quantity

3.2.2. MARCOS method

The MARCOS method depends on the interaction between ideal and anti-ideal options and alternatives. Regarding the established correlations, the beneficial functions of options are settled and the compromise classification is produced according to both options. The beneficial function is the location of an alternative concerning both options. The best option is the one that is the nearest to ideal and concomitantly the anti-ideal mentioning point. The MARCOS method is performed through the following steps (Đalić et al., 2020; Mitrović Simić et al., 2020; Puška, Stević, & Stojanović, 2021; Stanković et al., 2020; Stević & Brković, 2020; Puška, & Chatterjee, 2020; Stević, Tanackov, & Subotić, 2020):

Step 1: Initial decision-making matrix creation through the evaluation by experts.

Step 2: Extended initial matrix modeling through the setting of the ideal (AI) and anti-ideal (AAI) solution.

$$X = \begin{matrix} & C_1 & C_2 & \dots & C_n \\ AAI & x_{aa1} & x_{aa2} & \dots & x_{aan} \\ A_1 & x_{11} & x_{12} & \dots & x_{1n} \\ A_2 & x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots & \dots \\ A_m & x_{m1} & x_{22} & \dots & x_{mn} \\ AI & x_{ai1} & x_{ai2} & \dots & x_{ain} \end{matrix} \quad (4)$$

The anti-ideal solution (AAI) is the least effective option while the ideal solution (AI) represents the best option. Regarding the criteria aspect, equations (2) and (3) are respectively applied to determine the AAI and AI:

$$AAI = \min_i x_{ij} \quad if \;\; j \in B \quad and \quad \max_i x_{ij} \quad if \;\; j \in C \quad (5)$$

$$AI = \max_i x_{ij} \quad if \;\; j \in B \quad and \quad \min_i x_{ij} \quad if \; j \in C \quad (6)$$

where there is benefit group criteria (B) and cost group criteria (C)

Step 3: Extended initial matrix normalization (X). In this step, equations (7) and (8) are used to get the components of the normalized matrix: N= $[n_{ij}]_{m\times n}$

$$n_{ij} = \frac{x_{ai}}{x_{ij}} \text{ if j} \in \text{C} \quad (7)$$

$$n_{ij} = \frac{x_{ij}}{x_{ai}} \text{ if j} \in \text{B} \quad (8)$$

where x_{ij} and x_{ai} are the components of the matrix X

Step 4: Weighted matrix V= $[v_{ij}]_{m\times n}$calculation through equation (9) multiplying the normalized matrix *N* with the weight coefficients of the criterion w_j

$$v_{ij} = n_{ij} \times w_j \quad (9)$$

Step 5: Computation of utility degree Ki, using equations (10) and (11) concerning the anti-ideal and ideal options.

$$K_i^- = \frac{S_i}{S_{aai}} \quad (10)$$

$$K_i^+ = \frac{S_i}{S_{ai}} \quad (11)$$

where S_i (i=1, 2,..., *m*) stands for the aggregates of the components of the weighted matrix *V*, and calculation through equation (12)

$$S_i = \sum_{i=1}^{n} v_{ij} \quad (12)$$

Step 6: Use equation (13) to compute the utility function of alternatives f (Ki). The utility function is the arrangement of the detected option concerning both solutions.

$$f\,(K_i) = \frac{K_i^+ + K_i^-}{1+\frac{1-f(K_i^+)}{f(K_i^+)}+\frac{1-f(K_i^-)}{f(K_i^-)}}; \quad (13)$$

where $f(K_i^-)$, the utility function (anti-ideal solution, see equation 14) and $f(K_i^+)$, the utility function (ideal solution, see equation 15)

$$f(K_i^-) = \frac{K_i^+}{K_i^+ + K_i^-} \tag{14}$$

$$f(K_i^+) = \frac{K_i^-}{K_i^+ + K_i^-} \tag{15}$$

Step 7: Classification of the alternatives according to the utility function results. Alternative with greater utility function value is advisable.

4. Results and discussion

4.1 Entropy method

The entropy method is used for the determination of weights for each criterion. At first, equation (1) is employed to normalize the decision matrix (Table 3) for profitable and non-profitable criteria, respectively. Then, the determination of entropy measures of each criterion is made. Next, equations (2) and (3) are used for the weight calculation (Table 4). The results from Table 4 showed that labor productivity (internal business perspective) is the most significant criterion with a higher value (0.138). This is understandable because most considerable growth in resources is predicted from it. This is succeeded by the terrorist incidence (security) which is a non-profitable criterion at a value of 0.133. The quantity of employees that are exposed to the training (innovative and learning viewpoint) which is of beneficial type comes in the third position with a value of 0.114. The other criteria are classified as follows: C31 (benefit type) > C41 (benefit type) > C42 (benefit type) > C33 (benefit type) > C52 (benefit type) > C12 (cost type) > C11 (cost type) > C62 (benefit type) > C22 (benefit type) > C61 (cost type).

Table 3. Normalized matrix

	A1	A2	A3	A4	A5
C11	0.231	0.231	0.231	0.154	0.154
C12	0.250	0.250	0.167	0.167	0.167
C21	0.273	0.273	0.182	0.182	0.091
C22	0.160	0.160	0.200	0.240	0.240
C31	0.158	0.211	0.105	0.263	0.263
C32	0.150	0.200	0.100	0.300	0.250
C33	0.176	0.118	0.176	0.235	0.294
C41	0.167	0.167	0.167	0.167	0.333
C42	0.133	0.133	0.267	0.200	0.267
C51	0.227	0.182	0.091	0.273	0.227
C52	0.261	0.174	0.130	0.217	0.217
C61	0.238	0.190	0.190	0.190	0.190
C62	0.238	0.190	0.143	0.238	0.190

Table 4 Entropy values and entropy weights

	Entropy value	Entropy weight
C11	0.989	0.039
C12	0.987	0.043
C21	0.961	0.133
C22	0.990	0.034
C31	0.969	0.107
C32	0.960	0.138
C33	0.972	0.095
C41	0.970	0.103
C42	0.972	0.096
C51	0.967	0.114
C52	0.984	0.054
C61	0.997	0.009
C62	0.990	0.035

4.2. MARCOS method

Table 5 shows the extended initial matrix based on step 2 of the MARCOS approach through equations (4)– (6). The rate of collisions (C11), the terrorist incidence (C21), and the number of customer complaints (C61) are of a non-profitable type and using equation (5), the anti-ideal solution (AAI) has been calculated and represents the maximum attribute, with a value of 3 for C11, C12, and C21, and a value of 5 for C61.

Table 5. Extended initial decision matrix

Criteria	AAI	A1	A2	A3	A4	A5	AI
C11	3	3	3	3	2	2	2
C12	3	3	3	2	2	2	2
C21	3	3	3	2	2	1	2
C22	4	4	4	5	6	6	6
C31	2	3	4	2	5	5	5
C32	2	3	4	2	6	6	6
C33	2	3	2	3	4	5	4
C41	2	2	2	2	2	4	2
C42	2	2	2	4	3	4	3
C51	2	5	4	2	6	6	6
C52	3	6	4	3	5	6	5
C61	5	5	4	4	4	4	4
C62	3	5	4	3	5	5	5

For the security of human being and belongings in the station (C22), the wagon and locomotive availability (C31), the labor productivity (C32), the line availability (C33), the ease of connection with another transportation mode (C41), the ease connection with other train services (C42), the number of employees for training/exposure sessions (C51), quantity of trained/exposed employees (C52), and the facilities at station (C62), 4, 2, and 3 are the lowest values for (C22); (C31, C32, C33, C41, C42, C51); and (C52, C62) respectively and are involved in the AAI solution. The determination of values comprised of the ideal solution (AI) is made using equation (6). The values of 2, 1, and 4 are the smallest ones for (C11, C12), (C21), and (C61), whereas 6, 5, and 4 are the highest ones for (C22, C32, C51, C52), (C31, C33, C62), and (C41, C42), respectively for non-beneficial type (cost). Following the extension of the initial matrix, equation (7) is used for the normalization of non-profitable type while equation (8) is applied in the case of the profitable type. Table 6 illustrated the normalization of the decision matrix.

$n_{ij} = \frac{x_{ai}}{x_{ij}}$ if $j \in C$ $\leftrightarrow$ n_{111}=2/3=0.667, for non-beneficial type

$n_{ij} = \frac{x_{ij}}{x_{ai}}$ if $j \in B$ $\leftrightarrow$ n_{442} =3/4=0.750, for benefit type

Table 6. Normalized decision matrix

	AAI	A1	A2	A3	A4	A5	AI
C11	0.667	0.667	0.667	0.667	1.000	1.000	1.000
C12	0.667	0.667	0.667	1.000	1.000	1.000	1.000
C21	0.333	0.333	0.333	0.500	0.500	1.000	1.000
C22	0.667	0.667	0.667	0.833	1.000	1.000	1.000
C31	0.400	0.600	0.800	0.400	1.000	1.000	1.000
C32	0.333	0.500	0.667	0.333	1.000	0.833	1.000
C33	0.400	0.600	0.400	0.600	0.800	1.000	1.000
C41	0.500	0.500	0.500	0.500	0.500	1.000	1.000
C42	0.500	0.500	0.500	1.000	0.750	1.000	1.000
C51	0.333	0.833	0.667	0.333	1.000	0.833	1.000
C52	0.500	1.000	0.667	0.500	0.833	0.833	1.000
C61	0.800	0.800	1.000	1.000	1.000	1.000	1.000
C62	0.600	1.000	0.800	0.600	1.000	0.800	1.000

The weight normalized matrix is then computed through the multiplication of the precedent normalized matrix by the alternatives/ criteria values acquired in the entropy approach. Table 7 indicates the normalized weighted matrix.

Table 7. Weight normalized decision matrix

	AAI	A1	A2	A3	A4	A5	AI
C11	0.026	0.026	0.026	0.026	0.039	0.039	0.039
C12	0.029	0.029	0.029	0.043	0.043	0.043	0.043
C21	0.044	0.044	0.044	0.067	0.067	0.133	0.133
C22	0.023	0.023	0.023	0.028	0.034	0.034	0.034
C31	0.043	0.064	0.085	0.043	0.107	0.107	0.107
C32	0.046	0.069	0.092	0.046	0.138	0.115	0.138
C33	0.038	0.057	0.038	0.057	0.076	0.095	0.045
C41	0.052	0.052	0.052	0.052	0.052	0.103	0.103
C42	0.048	0.048	0.048	0.096	0.072	0.096	0.096
C51	0.038	0.095	0.076	0.038	0.114	0.095	0.114
C52	0.027	0.054	0.036	0.027	0.045	0.045	0.054
C61	0.007	0.007	0.009	0.009	0.009	0.009	0.009
C62	0.021	0.035	0.028	0.021	0.035	0.028	0.035

Through the MARCOS approach, the final results have been obtained in Table 8 with the application of equations from (10) to (15). The summarization of all values for the alternatives (by rows) is shown below through equation (12).

S_{AAI}=0.026+0.029+0.044+0.023+0.043+0.046+0.038+0.052+0.048+0.038+0.026+0.007+0.021=0.441

At the same time, the values for the remained alternatives are procured. The calculation of the utility of degree concerning the anti-ideal solution is done through equation (10). An illustration calculation is shown bellows.

$$K_1^- = \frac{0.602}{0.441} = 1.365$$

Meanwhile, the utility degrees concerning the ideal solution are acquired by applying equation (11), e.g.:

$$K_1^+ = \frac{0.601}{1} = 0.602$$

Equation (14) is used to set the utility function regarding the anti-ideal solution as follows:

$$f(K_i^-) = \frac{K_i^+}{K_i^+ + K_i^-} = \frac{0.602}{0.602 + 1.365} = 0.306$$

At the same time, equation (15) is used for the utility function regarding the ideal solution as follows:

$$f(K_i^+) = \frac{K_i^-}{K_i^+ + K_i^-} = \frac{1.365}{0.602 + 1.365} = 0.694$$

At last, equation (13) is used to get the utility function of Alternative A1:

$$f\,(K_i) = \frac{K_i^+ + K_i^-}{1 + \frac{1 - f(K_i^+)}{f(K_i^+)} + \frac{1 - f(K_i^-)}{f(K_i^-)}} = \frac{0.602 + 1.365}{1 + \frac{1 - 0.694}{0.694} + \frac{1 - 0.306}{0.306}}$$
$$= \frac{1.967}{1 + 0.442 + 2.268} = \frac{1.967}{3.709} = 0.531$$

The remained values that appeared in the final results are got identically as elucidated in Table 8.

Based on the results of the new integrated method, the performance evaluation showed that the alternative with code 5 (Kenya) has the best performance followed by alternatives under codes 4 and 1 (Ethiopia and Cameroon) in the classification, respectively. A look in the classification showed that no much difference exists between the third and fourth positions and a variation in the classification can be predicted for future evaluation based on expert judgment. Although the railway system in Nigeria is being rejuvenated through the construction of new standard gauge railway lines, its railway performance is lower in comparison to Cameroon.

This can be explained by the fact that there are security challenges, poor facilities at a station in the old railway networks, and a higher rate of commuter complaints.

Table 8 Finding of the MARCOS approach.

	S_i	K_{i-}	K_{i+}	f_{K-}	f_{K+}	f_{Ki}	Rank
AAI	0.441	1.000					
A1	0.602	1.365	0.602	0.306	0.694	0.531	3
A2	0.586	1.327	0.586	0.306	0.694	0.516	4
A3	0.553	1.252	0.553	0.306	0.694	0.487	5
A4	0.830	1.880	0.830	0.306	0.694	0.731	2
A5	0.942	2.135	0.942	0.306	0.694	0.830	1
AI	1.000		1.000				

5. Sensitivity analysis

A comparative evaluation is carried with other seven methods: EDAS – evaluation based on distance from average solution (Keshavarz Ghorabaee et al., 2015), SAW – Simple Additive Weighting method (Kishore et al., 2020, Durmić et al. 2020), ARAS – additive ratio assessment (Zavadskas & Turskis, 2010), CoCoSo - Combined Compromise Solution (Yazdani et al., 2019), MABAC – Multi-Attributive Border Approximation area Comparison (Pamučar & Ćirović, 2015, Pamučar et al. 2021), TOPSIS – Technique for Order of Preference by Similarity to Ideal Solution (Anthony et al., 2019), and WASPAS – weighted aggregated sum product assessment (Zavadskas et al., 2012).

The results of this comparative analysis are shown in Figure 4. As can be seen from it, there were certain changes in the ranks, which is a consequence of a diverse normalization approach in applying other approaches. As consequence, one of the sources of variations in the rankings is emulated in a very small variation in the values of some alternative solutions obtained in the initial model. A look at Figure 5 indicates that the greatest alternative does not vary from its initial position whichever method is applied. As consequence, the fifth alternative keeps its first place. The second place is assigned to the fourth alternative for all the methods, with exception of TOPSIS, where it takes the fourth place. There is no variation in position for all the alternatives when using the MARCOS, WASPAS, ARAS, EDAS, and SAW approaches. However, when using MABAC and the five antecedent methods, there is only one variation in the classification where A2 and A3 replace their positions occupying the fifth and the fourth place, respectively.

When applying the MARCOS and CoCoSo methods for a comparative analysis for the classification, some moderate variations are noticed whereas in the case of the TOPSIS method, the variation in the classification is a little bit more.

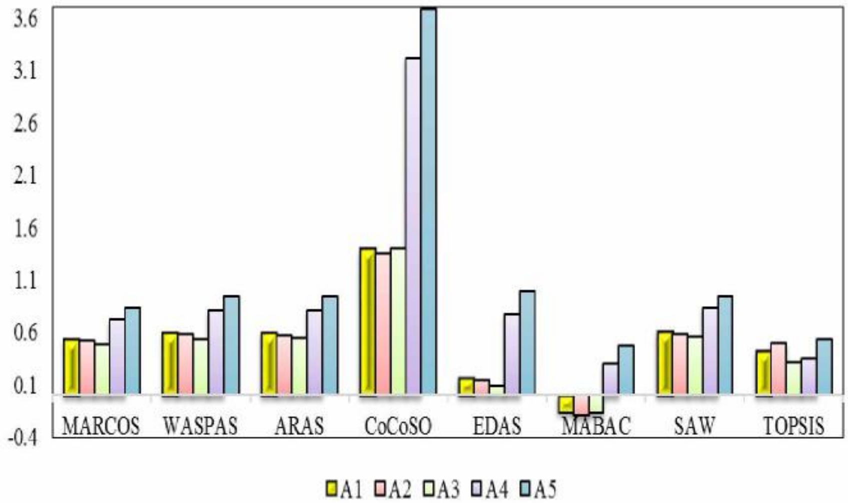


Figure 4. Values of alternatives through a comparative analysis

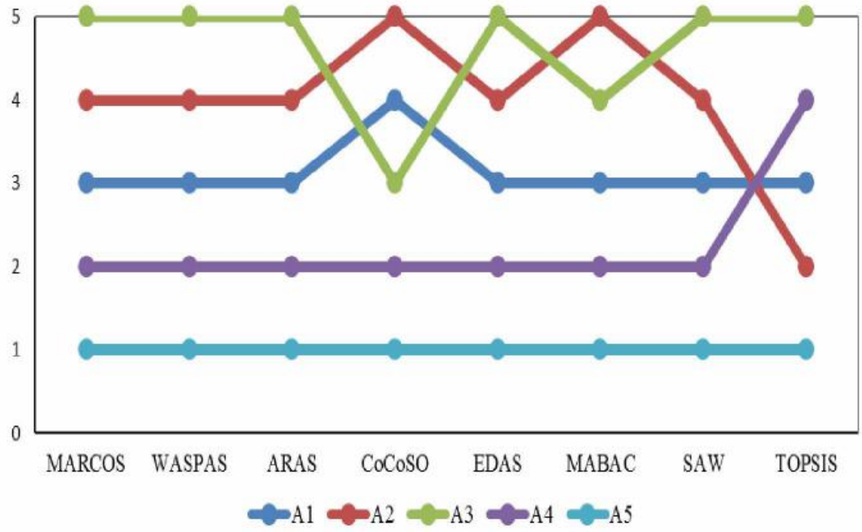


Figure 5. Ranking in a comparative analysis of different methods

The WS coefficient developed by Salabun and Urbaniak (2020) was computed to examine the rankings similarity as shown in Figure 6. The benefit of this coefficient relies on the fact that locations at the summit of the classification have a powerful influence on the similarity than those more distant, which is accurate in the process of decision making.

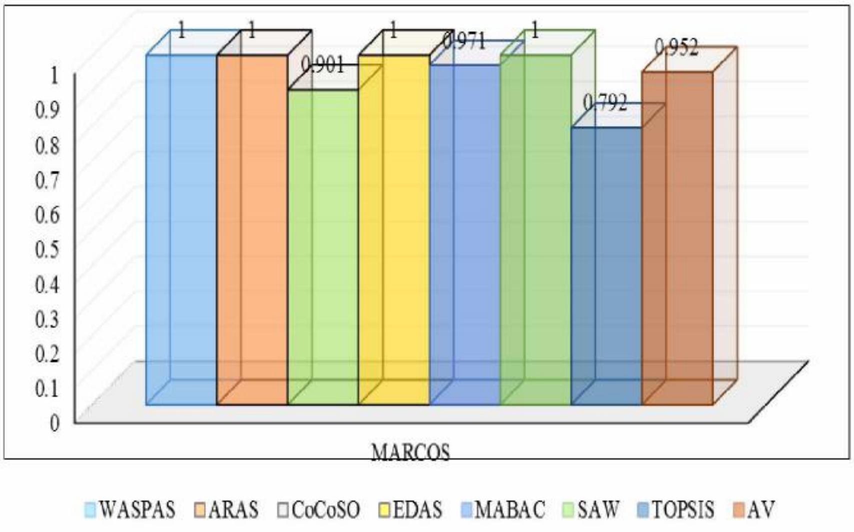


Figure 6. Determination of the WS coefficient

As can be seen in Figure 6, the previous discussion where the WS coefficient has values 1 (WASPAS, ARAS, EDAS, and SAW), and 0.971 (MABAC) show an extremely high correlation in ranking alternatives. A little bit of correlation of MARCOS method with CoCoSo exists and the value is 0.901, whereas the difference is large for MARCOS method in comparison to the TOPSIS method, i.e., the smallest correlation with a value of 0.792.

6. Conclusion

In this paper, an assessment of Sub-Saharan African railways performance was conducted. A multi-criteria model consisting of six main criteria and five alternatives was formed. For their evaluation, a new integrated Entropy-MARCOS model was proposed and applied. The results showed that labor productivity is the most weighted sub-criterion. Considering the ranking of the railway's performance, Kenya is the best alternative with a higher utility function value of 0.830 followed by Ethiopia with 0.731 as the utility function value. Cameroon and Nigeria came in the third and fourth positions with approximately the same utility function value of 0.531 and 0.516, respectively. Ghana represents the worst alternative with the lowest utility function value of 0.487. The results obtained in the paper were validated through an extensive sensitivity analysis. The findings of this paper can assist decision-makers to consider these parameters as insert indicators for all operative, designing, and planning investigations. In addition, the findings can also serve as a benchmark for the performance analysis of other railway systems in other African countries.

The continuity of this study pertains to the incessant surveying and repeated assessment of the railway transportation system in the sub-Saharan Africa region together with the newly built standard gauges' railways across the region, which can contribute to the socio-economic and regional inter-trade integration and wealth of the region. Although a new integrated entropy-MARCOS is proposed in this research, the future study may apply the use of integrated FUCOM- MARCOS, fuzzy PIPRECIA-DEA, Delphi-SWARA-MABAC, and fuzzy-AHP for the evaluation of railway transportation system or factors that impede its sustainability. Also, the analysis of the railway system should be at the continental level.

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VALUE STREAM MAPPING AND SIX SIGMA METHODS TO IMPROVE SERVICE QUALITY AT AUTOMOTIVE SERVICES IN INDONESIA

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Abstract: *Automotive service industry currently holds an important role in helping to increase customer satisfaction. Various strategies are carried out to win the competition for increasing customer satisfaction. Quality service combined with the right instruments can be used to increase customer satisfaction and loyalty. Customer satisfaction is the key to success in the manufacturing and service industries. Service quality is an important attribute and it is a key factor in service industries. Improving lead time service in automotive Toyota dealer service industries is the focus of this research. Value Stream Mapping succeeded in identifying problems that were happening as an impact of waiting for services, washing processes, and length of service processes. The DMAIC (Define, Measure, Analyze, Improve and Control) method assisted by tools of quality successfully analyzed and gave recommended corrective actions to reduce the lead time of Express Maintenance Service from 120.06 minutes to 64.00 minutes or improved 53% per service cycle, and succeeded in increasing the capability of the service process from 1.96 sigma to 3.80 sigma. Quality of service can be improved to get customer satisfaction, increase company profitability, and increase the competitiveness of companies in maintaining the sustainability of the industry in the future.*

Keywords: *Service Quality, Lead Time, Value Stream Mapping, DMAIC*

1. Introduction

Global competition in the increasingly stringent industry requires business people to get effective strategies to meet customer satisfaction. Customer satisfaction is a

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feeling of consumers for the product or service that has been used (Kuhlang et al. 2011). Customer satisfaction can be formed if the organization might be able to provide product characteristics or attributes following customer expectations (Pyzdek, 2003). Thus, it can be interpreted that customer satisfaction is one of the important attributes in the industrial world, especially the service industry. Based on this fact, the service industry must be able to identify important elements and be able to make improvements to receive intended customer satisfaction. The automobile services industry in Indonesia is a type of automotive industry or commonly referred to as a dealer that provides sales, repair, and sales for four-wheeled vehicle parts. The results of a survey conducted by JD Power 2018, Jandhagi et al. (2011) in Indonesia found an important finding namely low customer satisfaction caused by scheduling appointments via digital channels that are very low, with a percentage value of 7% of customers who schedule their service appointments via its website or through smartphone applications. An automobile service company is a service industry that serves sales, maintenance, repair, and supply of vehicle part services. The service operation branch also provides spare parts and workshops that provide special maintenance and repair services for vehicles. It consists of three main divisions, which are Sales Department, Service Department, and Spare Parts Department. The key element in determining the level of service quality is after-sales customer satisfaction. The quality of after-sales services provided by car dealers has a great influence on customer satisfaction to maintain long-term relationships with their customers and many businesses. Have changed their strategic focus to emphasize customer retention (Rego et al. 2013).

The high after-sales service lead time in automobile services in Toyota dealers in Indonesia is 120.06 minutes in one service cycle, higher than the lead time charged at 60 minutes. It is a problem that must be resolved so that customer satisfaction, which is an important attribute in the service industry can be met. By mapping the after-sales service process in automotive services Toyota dealer using Value Stream Mapping, it is expected that the actual conditions of current service processes can be identified and found, which processes are causing the high after-sales service lead time that occurs. By assisting various tools of quality in the Six Sigma method, it is also expected to be able to provide analysis and recommendations for corrective actions so that the quality of service is in line with expectations and can be improved. It is believed that good service quality will result in customer satisfaction and will have an impact on the reuse of products and services that have been used and help improve company's image through product information and services to other customers (Gijo et al. 2012, Thompson, 2005, Lam et al. 2004, Venkamteswaran and Padmanaban, 2018).

Six sigma is a systemic and structured method with DMAIC stages (Define, Measure, Analyze, Improve, and Control) that has been proven effective in identifying, measuring, analyzing, and providing recommendations for improvement of problems that occurred (Causevic & Golub, 2019). Researched at Portugal Automotive industry using DMAIC (Define, Measure, Analyze, Improve and Control) cycle for process improvement could decrease 0.98% on the indicator of work-off generated by the production system, the financial impact could save over 165,000 € per annum (Costa et al. 2017). Omar & Mustafa (2014) stated that the adoption of Six Sigma does not only mean a process improvement but it is a business strategy that uses a systematic approach to increase productivity, corporate financial benefits, and customer satisfaction (Pucheta et al. 2019). Other research in automotive that selected as observed machine DMAIC could reduce the machine breakdown time from 111 became 85 minutes/month and breakdown quantity from 4.7 became 3.5 times/month and increase the availability value from 90.8% became 96.0% and the impact was increasing OEE (Overall Equipment Effectiveness) value from 87% became 92% (Rozak et al. 2020).

In the United Kingdom 2012, the Six Sigma method had succeeded in reducing the waiting time from 24 minutes to 11 minutes or more than 50% of Pathology Department service processes in the healthcare industry (Hussain et al. 2014). Other studies had also successfully revealed that the implementation of Six Sigma can improve the attitude of health workers better (53%), compared to government employees (18%) (Sethi et al. 2018). Based on the facts from previous studies, it is proven that the implementation of Value Stream Mapping and Six Sigma combined with other tools of quality successfully resolve various problems and succeeded in enhancing customer satisfaction and company profits.

2. Literature Review

Customer satisfaction is the lifeblood of every company, so customer satisfaction is one important element in improving the performance of a company or organization (Nagi & Altarazi, 2017). Customer satisfaction can be formed if the customers get what is expected from a product or service they use (Croft & Kovach, 2012, Pyzdek, 2003). Customer satisfaction is a comparison between the actual performance in products and the expected performance (Caesaron & Simatupang, 2015). Customer satisfaction is a response from the comparison of product performance with several standards before, during, and after consumption (Minh & Huu, 2016, Srivasnavar & Bhatnagar, 2013, Barrios & Jimenez, 2016). Especially in the service industry, customer satisfaction is closely related to the level of service quality in which there is a direct interaction between the system, the operator, and the customer, where process the customer can feel directly the quality of services which at the same time can provide an assessment of the quality of the service without passing through other stages of the process.

Service quality is the main process in the service organization/industry that prioritizes the achievement of service quality that meets or even exceeds customer expectations (Barrios & Jimenez, 2016). Other research stated that the success of industry without exception a service industry is very dependent on human resources and processes owned so that in the service industry the improvement of human resource competencies and continuous process improvement are important factors as well as determinants of the industry to gain its success (Vijay, 2014). Identification of ongoing process conditions including in the service industry which aims to find opportunities for continuous process improvement is an important activity so that quality of service that can meet customer expectations can be realized. Some various methods and tools can help identify the ongoing process to get the opportunity for improvement as intended. This research seeks to combine Value Stream Mapping and Six Sigma methods with the help of other tools of quality in identifying, measuring, and analyzing the processes that occur in automotive after-sales services in Indonesia, it is hoped that the processes currently running can be identified and opportunities for improvement can be found in efforts to improve quality services that can meet or exceed expectations and certainly increase customer satisfaction.

The identification of ongoing process conditions is very important in the strategy of quality improvement in the industrial world both in the manufacturing and service industries. Especially in the service industry, the quality of service that can be felt simultaneously in the process becomes very important to always be identified and evaluated quickly and effectively so that the quality of service and the image of the organization in customer perspectives can be maintained. Value Stream Mapping is a device that has been widely used by various industries including the service industry in identifying and analyzing the conditions of ongoing processes to find opportunities for further improvement. Value Stream Mapping can optimize the power sources by eliminating non-value of added activities to improve productivity and sense of competitiveness (George, 2003).

Value Stream Mapping is a successful method that is used internationally, usually applied in a single project that has a high innovative impact and is developed towards continuous improvement with a systematic process management approach (Kuhlang et al. 2011). The Value Stream Mapping method has successfully identified the operational conditions through the study of takt time and succeeded in reducing the process lead time from 7.6 to 3.2 days or a 73% reduction in the automotive industry cycle time in India (Chang & Wang, 2007). Value Stream Mapping has also succeeded in identifying bottleneck processes and reducing waiting time by up to 27% (Otim & Grover, 2006). Referring to the various studies, it can be understood that the Value Stream Mapping method is very effective in identifying ongoing processes to obtain opportunities for improvement and can improve the productivity and quality of processes and products in both manufacturing and service industries.

Six Sigma is a comprehensive, flexible and measurable system for achieving, maintaining, and maximizing increasingly competitive business success. Six Sigma is a quality improvement approach that is systematically effective for improving organizational performance based on the use of various statistical analysis techniques (Pande & Holpp, 2002). In general, Six Sigma has two meanings, namely Six Sigma as a philosophy for continuous improvement in reducing defective products and Six Sigma as a technical tool in measuring the number of defects per 1 million products produced. Six Sigma in technical methods has a statistical. Approach orientation to the calculation of product defects. The goal is to reduce the variance process by eliminating the entire defects interfering with customer satisfaction (Peng & Wang, 2006). For the service industry, Six Sigma is a business improvement methodology that maximizes shareholder value by achieving the fastest rate of increase in customer satisfaction, cost, quality, processing speed, and investment capital (Haviana & Hernadewita, 2019).

Six Sigma is a version, philosophy, strategy, and a set of tools to improve process and service quality, for services-based industries, where customer needs are the main focus, and their needs often seem unpredictable (Ebrahimi & Keykavossi, 2018). Six Sigma is a systemic and structured method with DMAIC (Define, Measure, Analyze, Improve, and Control) steps. It has been proven effective in identifying, measuring, analyzing, and providing recommendations for improvement that have a focus on reducing the variety of processes and products that can increase customer satisfaction, profitability, and competitiveness of the company (Elbireer et al. 2011, Jona than, 2013, Trimarjoko et al. 2019). The researches showed that most service organizations in the UK have been implementing Six Sigma for more than three years. The company's average sigma quality level is around 2.8 around 98,000 Defects Per Million Opportunities (DPMO). Management commitment and involvement, customer focus and Six Sigma integration with business strategy are important factors in implementing Six Sigma (Syafwiratama et. al. 2016). The implementation of the Six Sigma method can reduce shipping delays and lead time in the small and medium scale industries in the United Kingdom and increase the sigma level from 1.44 to 2.09 Sigma (Otim & Grover, 2006). The application of the Six Sigma method proves that the average waiting time for maternal and child hospital services decline from 6.89 days to 4.08 days and the standard deviation dropped from 1.57 days to 1.24 days. In this way, the hospital will serve pregnant women faster, reducing the risk of perinatal and maternal death (Omar & Mustofa, 2014).

The combination of Value Stream Mapping and Six Sigma methods can reduce the lead time of a delivery process at the automotive dealers in Mexico from 50,499.5 minutes (35.06 days) to close to 30,240 minutes or even 20,160 minutes or down 60.17% (Parasuraman & Grewal, 2000). Other research in India using Value stream mapping and Six Sigma methods showed that lead time has been reduced by 14.88%, processing time 14.71%, and waste of material movement 37.97%. As proposed in the model, WIP (Work In Process) inventories have decreased by 17.76% and labor 17.64%. Furthermore, it will generate 161,800 Rupees profit per year. And get a net savings of 145,560 Rupees per year (Shahin, 2006). Referring to these studies, it shows that Six Sigma methods in the service industry combined with other methods are very effective in identifying, analyzing, and improving processes and products to get better service quality and also able to increase the profit and competitiveness of the industry by 37.97%. Referring to these studies, the Six Sigma method in the service industry combined with other methods is very effective in identifying, analyze and improve processes and products to get better service quality and can increase the profitability and competitiveness of the industry.

3. Case Study

Automotive Toyota dealers service in Indonesia have a problem with high after-sales service lead time is 120.06 minutes in one service cycle, which is higher than the lead time charged by 60 minutes for a type of Expres Maintenance service. By combining Value Stream Mapping and Six Sigma based on other tools of quality, it is expected that the problem of high after-sales lead time in the automotive Toyota dealer services industry can be identified and get improvement recommendations so that the problem can be solved effectively and efficiently. The proposed implementation framework is an integrated approach of Lean and Six Sigma and is shown in Figure 1. It is based on the traditional five phases of the DMAIC Six Sigma improvement model: (Define, Measure, Analyze, Improve, and Control). Each phase of the DMAIC: Define, Measure, Analyze, Improve and Control methodology utilizes several Six Sigma tools to improve the mobile order fulfillment process. In this study, both qualitative and quantitative data were collected from multiple sources. Qualitative data were obtained from direct observations in the field and unstructured interviews with team leaders, experienced team members, and systems experts, while quantitative data were obtained from the company's historical records. Several tools and techniques, such as a Pareto chart, Value Stream Mapping (VSM), cause-and-effect analysis, process capability analysis, a control chart, and 5W + 1H analysis, were used through the DMAIC (Define, Measure, Analyze, Improve and Control) methodology. All statistical analysis of data (at a 5% level of significance) and graphical presentations were performed using Minitab statistical software.

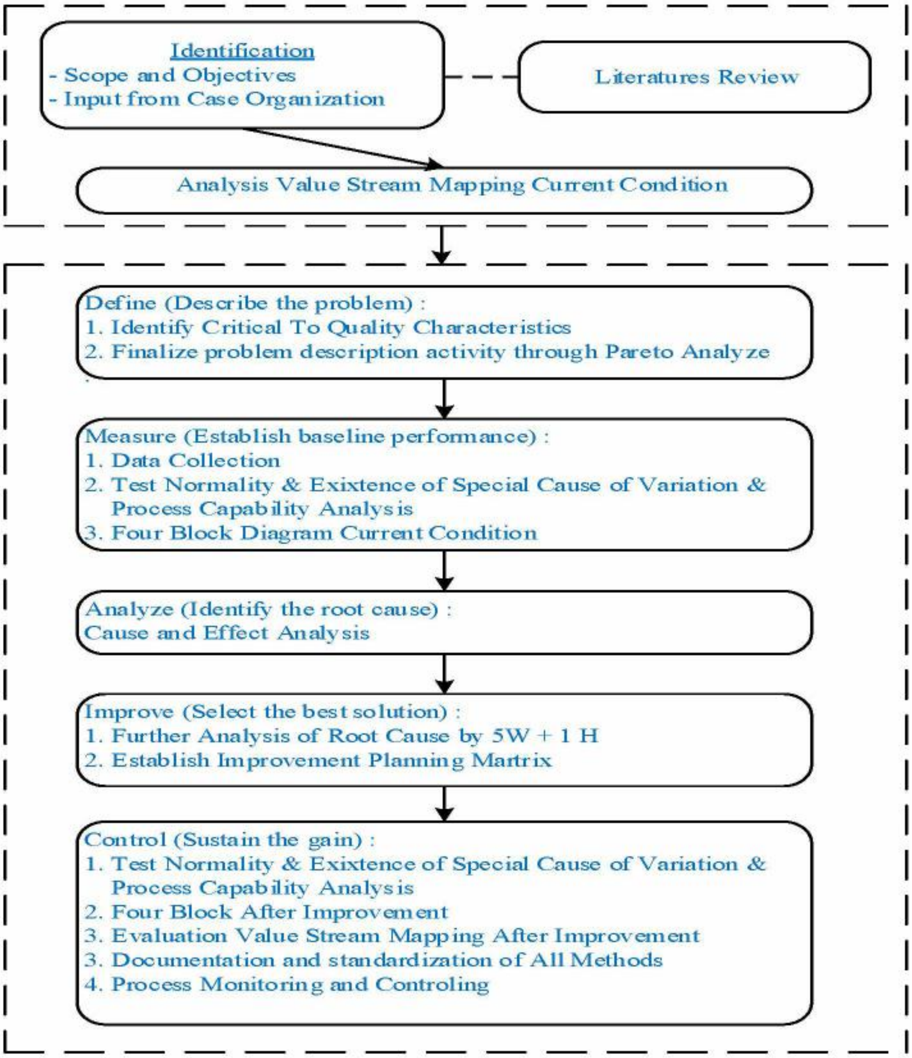

Figure 1. Implementation Framework

Value Stream Mapping has been widely used in various companies both manufacturing and services that are useful for knowing the condition of the ongoing process and very effective in knowing which of all sub-processes (workstations) are bottlenecks and have an impact on current problems. These conditions are termed as current stage conditions, while Value Stream Mapping can also be reused in mapping a series of processes after repairs called Future Stage conditions so that with the improved results Value Stream Mapping can also be identified.

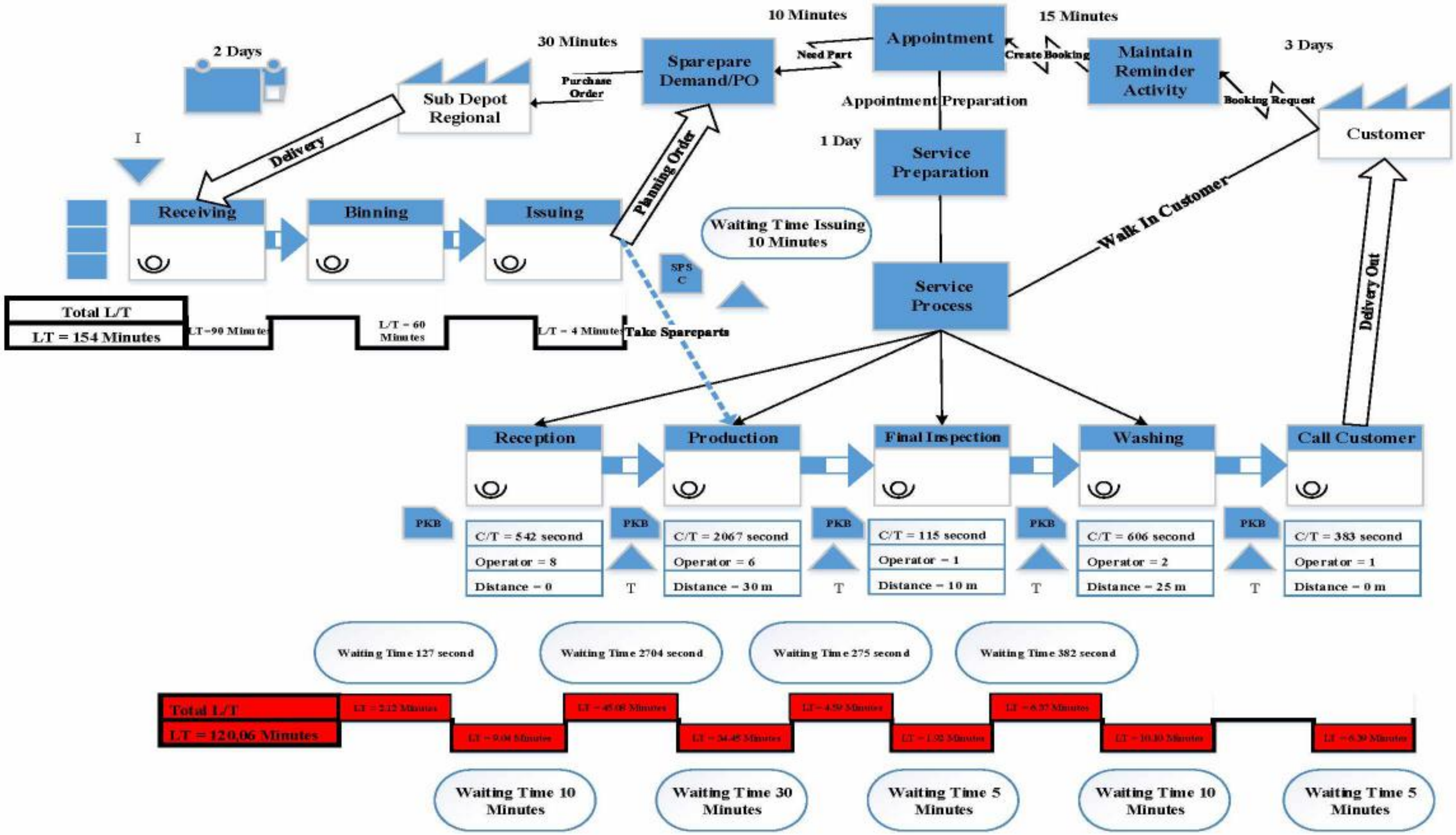

Figure 2. Value Stream Mapping Current Condition

Figure 2 explains Value Stream Mapping (VSM) that illustrates the current condition of the process that is ongoing (before improvement). The condition was analyzed to find out which workstations were causing the high lead time. Based on Value Stream Mapping current condition as obtained in Figure 2, the average lead time process in the automotive Totota dealer services industry was a minimum of 46 ~ 65 minutes, a maximum of 263 ~ 389 minutes with an average of 120.06 minutes for a type of Express Maintenance service. Its condition exceeded the company's target of 60 minutes, using Value Stream Mapping The Value Stream Mapping for general description can be explained in Table 1.

Table 1. Evaluation of the actual time of overall workstations current condition

Order Type Service	Count (Valid)	Work Process (minute)										Total Lead Time
EM (Express Maintenance)		Waiting Receptionist	Process Receptionist	Waiting Service	Process Service	Another Job Order	Waiting Final Inspection	Process Final Inspection	Waiting Washing	Washing Process	Call Customer	
	TimeActual	2.12	9.04	45.08	34.45	0.00	4.59	1.92	6.37	10.10	6.39	120.06
	Target	0.00	10.00	0.00	30.00	0.00	0.00	5.00	0.00	10.00	5.00	60.00
	Evaluation	X	V	X	X	V	X	V	X	X	X	X

Note : *X: unable to meet the target.*
V: able to meet the target.

Referring to the evaluation of each workstation contained in the Express Maintenance (EM) process, in this case, the process of handling after-sales customer complaints in the automotive Toyota dealer services, the results showed that up to 80% were not able to meet the target of the company so that the overall total lead time was not be fulfilled. Therefore, further analysis is needed to get the total lead time following the company's target. The application of the Six Sigma method is based on theoretical studies that had been found and had been proven effective in solving problems in various industries both manufacturing and service industries. Six Sigma with its structured stages will be used in solving the problem of high after-sales/express maintenance lead time in the automotive. Services industry in this study. The Six Sigma analysis used in this study was:

3.1. Define phase

The define stage was the first stage. In this stage, the problem description activity was carried out, determining Critical to Quality (CTQ) and the target to be achieved. From the data collection and mapping process with Value Stream Mapping, it is known that the problem that occurred was the high after-sales lead time on average of 120.06 minutes of the specified target was 60.0 minutes. As for the data obtained, we floated in the Pareto diagram to find out the Critical to Quality that occurred, while the Pareto diagram is shown in Figure 3. Based on the Pareto diagram in Figure 3 it explained that 80% of the longest Express Maintenance lead time was on the waiting service 49.15 minutes or 56%, washing process 12.27 minutes difference to the target or 14% and process (service) 10.45 minutes, so based on the Pareto diagram Critical To Quality of this research was as many as 3 types, i.e. waiting for service, service process, and washing process. The target to be achieved in this research was lead maintenance Express Maintenance service time of 60.0 minutes.

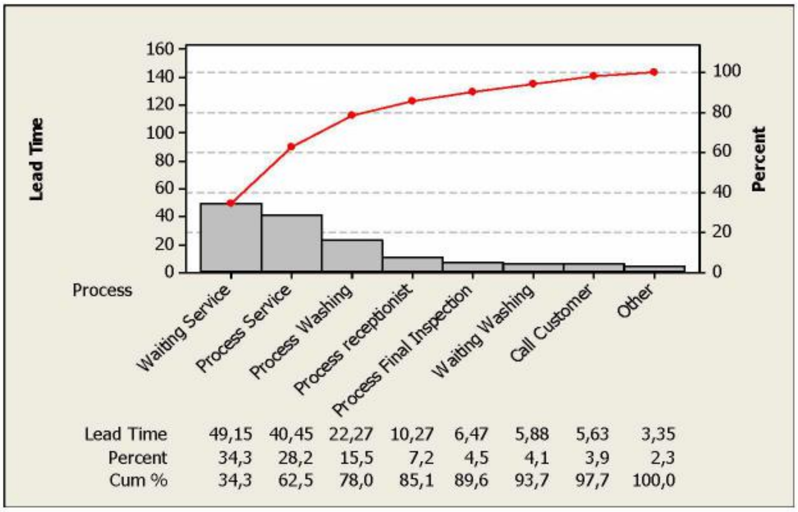

Figure 3. Pareto Diagram analysis of the Express Maintenance process

3.2. Measure phase

Measure phase was the second stage. In this step, the capability of the express maintenance process was calculated, aimed to find out the current condition of the process under this study. From data collection which had been obtained, to be then calculated the capability of the process as follows:

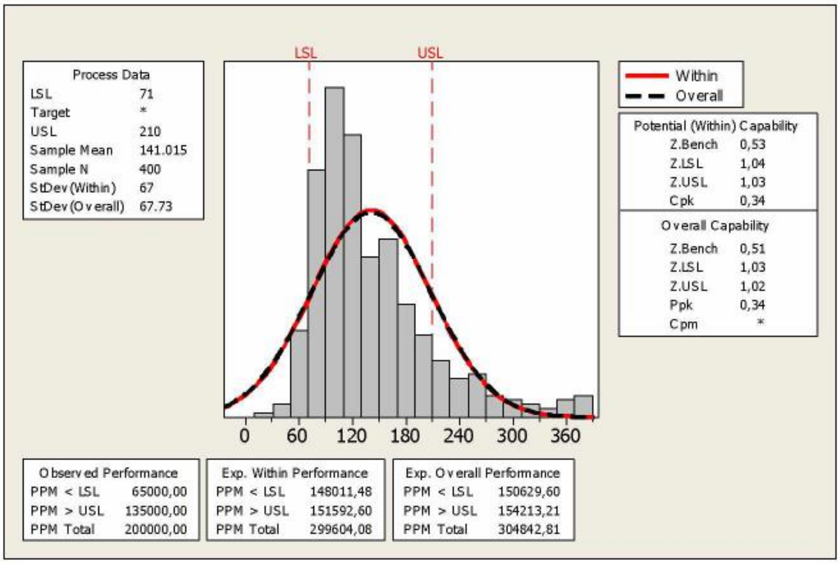

Figure 4. The Capability Process of Z bench St Express Maintenance

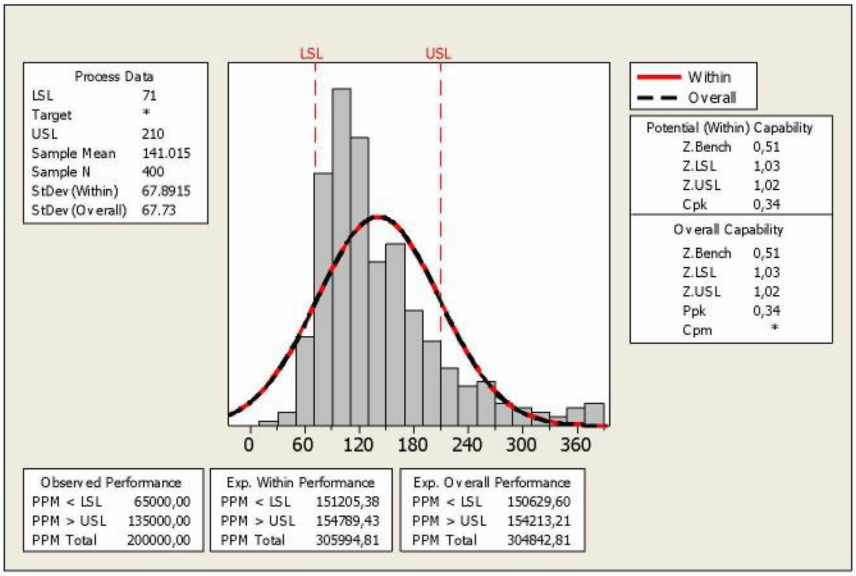

Figure 5. The Capability Process of Z bench Lt Express Maintenance

From the calculation of Z bench St (sigma level) and the value of Z bench Lt, it can be plotted into four block diagrams as an illustration of improvement direction from the control and technology side, by calculating Z shift with the following result from calculating and converting Defect Per Million Opportunity (DPMO) to sigma level 1.96 Sigma. So that the capabilities of the running process can be plotted in the four-block diagrams in Figure 6, as follows.

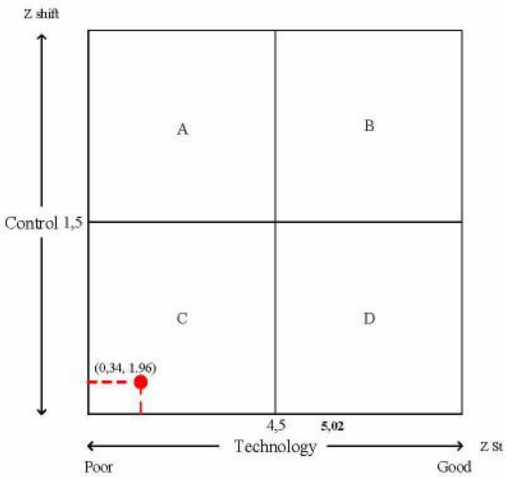

Figure 6. Four block diagram current condition

Figure 6 explains that the condition of the sigma level of the ongoing process in terms of control is good but in terms of technology is still very bad. So that effective improvement is needed to get a better sigma level.

3.3. Analyze phase

Referring to Value Stram Mapping Define and Measure phases It is known that the high lead time Express maintenance (EM) was caused by 3 processes, namely: waiting for service, service process, and washing service. By using the Cause-effect diagram, the problems of processes were analyzed to get what was the dominant cause of the 3 processes. The Cause-effect diagram of the problem is shown in Figure 7 below:

The maintenance process was caused by:

1. Equipment Factor

The condition of the equipment used by Express Maintenance mechanics was only 40% in good condition and suitable for use, 24% was damaged, 7% was lacking and 29% was missing or not yet used. Utilizing the tools which were broken and lacking was temporarily displaced by stalls Express Maintenance 1 and 2 tools whereas, for devices that did not exist, EM had not used them. They still used standard tools that were periodically serviced.

2. Material Factors

The rapidity of providing spare parts for regular service. For the procurement stock of spare parts, consumers still often waited due to the availability of spare following periodic service manuals.

3. Management Factors

The length of time Express Maintenance service takes place was because mechanical mechanics received work orders that had complaints either Express Maintenance booking or Express Maintenance Walk-in (direct coming). Express Maintenance work should have as few complaints as possible due to the distribution of improper mechanical task dividers for cars coming in for service and the lack of digging information from the booking service staff.

4. Environmental Factors

EM mechanics should look for cars that needed to be serviced in the service parking area because cars were mixed with other cars which were not included as the Express Maintenance (EM) service customers. Moreover, when the car park was full, it was placed in another parking area, making it more difficult for mechanics to find the cars. The fact that an indicator to search the cars was only a periodic service indicator without a sign or special identity of Express Maintenance also made it hard to identify the cars.

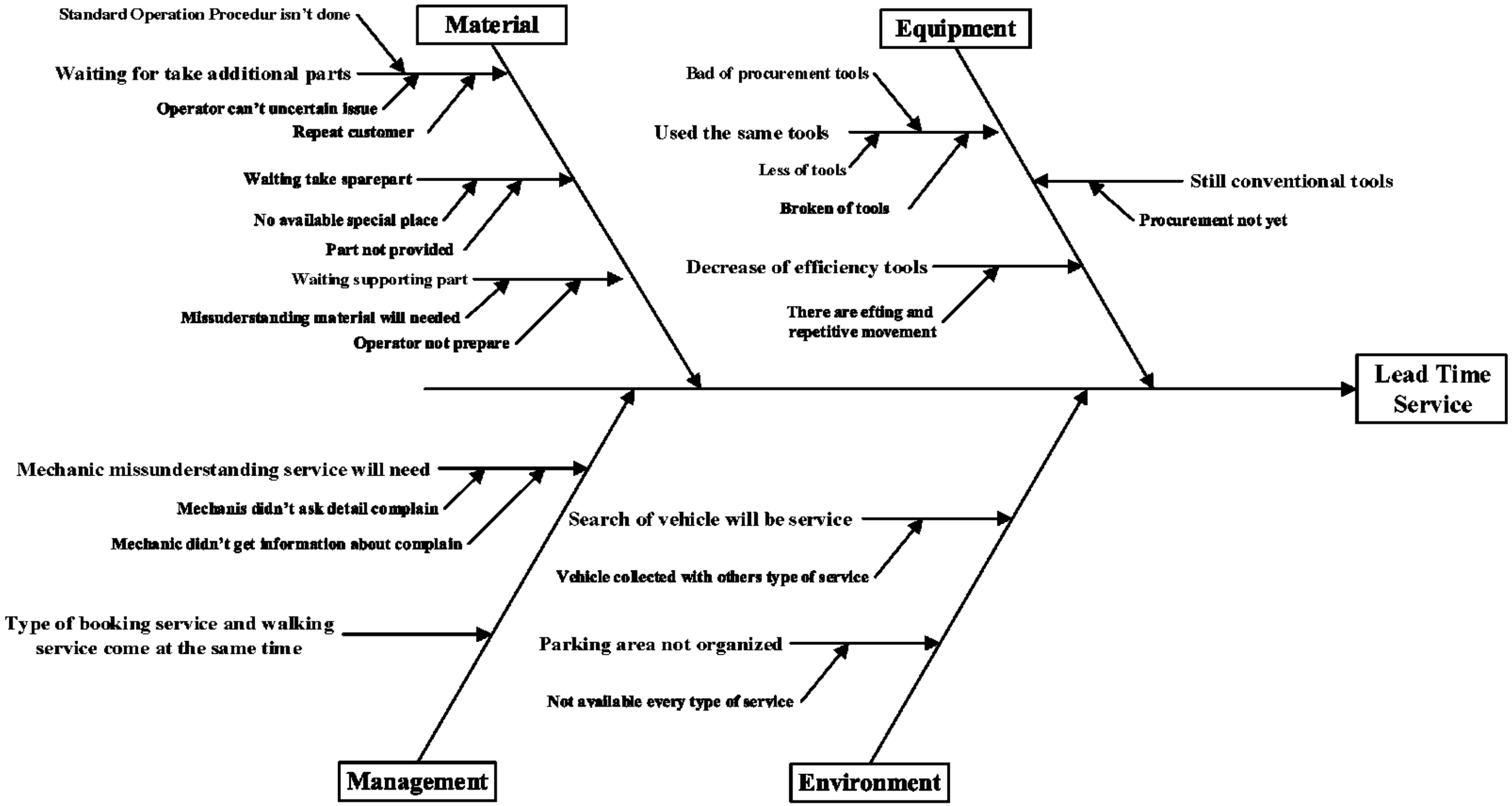

Figure 7. Cause and Effect Diagram Analysis

3.4. Improve phase

Activities in this stage were to determine the proposed improvement of the root of the causes that have been carried out at the Analyze stage by conducting a brainstorming using 5W + 1H and the Improvement Matrix Plan of the service process and washing process that becomes the problem in this study. A large amount of lead time in services at the dealer had been found. It might likely occur due to the long duration of handling throughout the service process, and many miscommunication errors. Thus, it will be one of the main points for improvement in the next step of the DMAIC improvement cycle. With the following improvements: The improvement in the production area or service process aimed to reduce the service process time from the actual time before repairing 34.45 minutes while the expected target is 30 minutes. The improvement steps taken by the Small Group Activity Express Maintenance team (SGA EM) were as follows: *Failure1:* Provide Special Parking Wait Express Maintenance Service. *Failure 2:* Provide Parts with Standard Operation Procedure (SOP) Pre-Picking Rack. *Failure 3:* Provide Material with Standard Operation Procedure Pre-Picking. *Failure 4:* Loss of manpower with the addition of Man Power. By carrying out the corrective footsteps as mentioned above, it is expected that the high maintenance lead time of 120.06 minutes can be reduced to the target of 60.00 minutes per service cycle.

3.5. Control phase

The control stage was the last in the Six Sigma method, where this stage the process capability (sigma level) calculation was conducted again after the improvement. Observation activities as in the measuring stage were still applied. Sigma level could be calculated by using Minitab software that could also by calculating Z shift with the following result from calculating and converting Defect Per Million Opportunity (DPMO) to sigma level 3.80 Sigma.

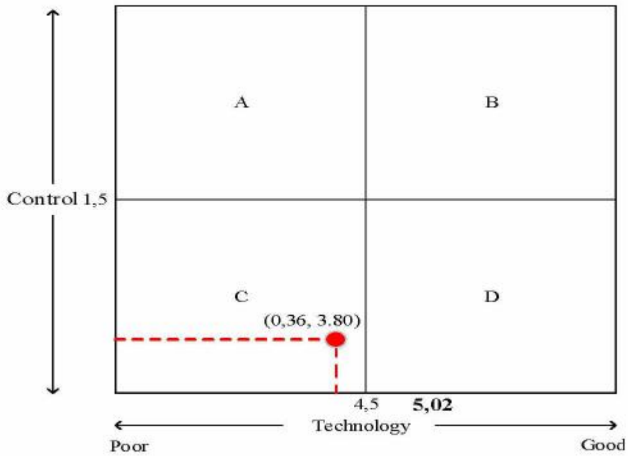

Figure 8. Four block diagram after improvement

Figure 8 shows the results of improvement in this study. It has better results than the conditions before the improvement. Then, to get the stability of the Express Maintenance process, the documentation of improvement was made into a work standard in the form of 1. Making a Work Squance Sheet (WSS), was a written work procedure that was a detailed job in detail. 2. Stick Work Squance Sheet (WSS) in areas related to WSS attached to areas that had been improvised, placing Work Squance Sheet (WSS) in a location that was visible and readable by officers in their respective areas. 3. Socializing Work Squance Sheet (WSS) socialization and improvement programs were conducted when the regular All Small Group Activity (SGA) meetings are held every month. Also, it was socialized at the machine shop roll call, which was routinely held on Tuesday and Thursday. Every morning roll call, each Smal Group Activity can report the progress of the repairs that have been made. Furthermore, to find out the lead time analysis of the Express Maintenance process after improvement, this mapping was carried out again after the improvement using Value Stream Mapping in Figure 9.

Figure 9 explains Value Stream Mapping (VSM) that illustrates condition after improvement process. Figures 2 and 9 Value Stream Mapping are the same, both the flow process and the location map, only the difference is that the results of the lead time have been made improvements to the work process. Value Stream Mapping (VSM) shows the condition of the process that is being Express Maintenance after a repair, as for the general description can be explained in Table 3:

Table 3. Evaluation of the overall actual time of work stations at After Improvement

Order Type Service	Count (Valid)	Work Process (minute)										Total Lead Time
EM (Express Maintenance)		Waiting Receptionist	Process Receptionist	Waiting Service	Process Service	Another Job Order	Waiting Final Inspection	Process Final Inspection	Waiting Washing	Washing Process	Call Customer	
	TimeActual	1.57	7.53	13.00	23.70	0.00	3.63	1.25	5.46	3.45	4.45	64.00
	Target	0.0	10.00	0.00	30.00	0.00	0.00	5.00	0.00	10.00	5.00	60.00
	Evaluation	X	V	X	V	X	X	V	X	V	V	

Note : *X: unable to meet the target.*
V: able to meet the target.

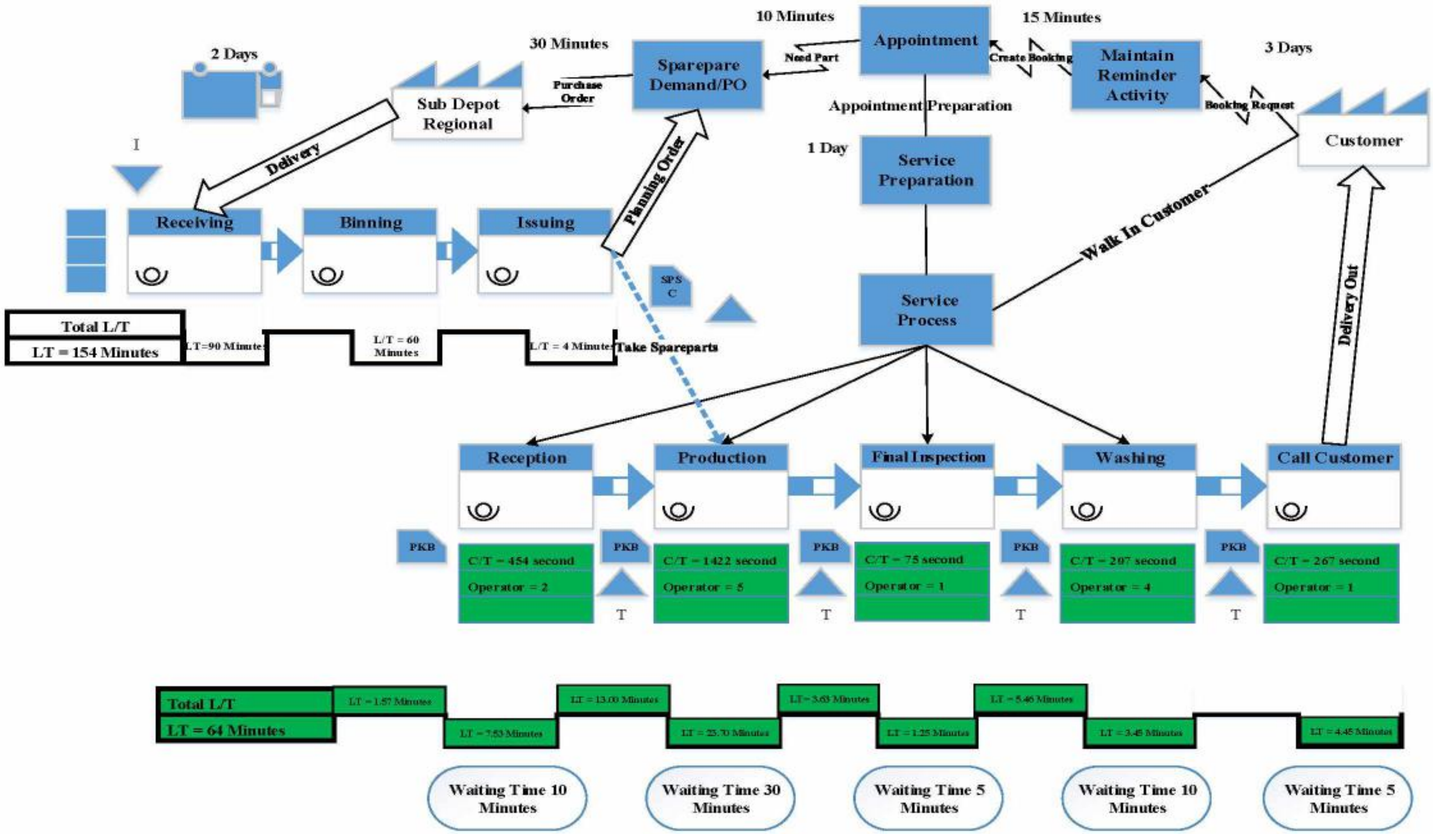

Figure 9. Value Stream Mapping After Improvement

Table 3. Evaluation of the overall actual time of work stations at future conditions. Based on the results of the Current Stream Mapping mapping, three dominant factors are causing the Express Maintenance service duration of the vehicle flow, namely: waiting service 13.00 minutes, washing process 3.45 minutes, and service process 23.70 minutes with an average completion process reaching 64 minutes. The state map after improvement was created to show the condition after repair. Improvements in processing time and waiting time resulted from the dominant length of work for the Express Maintenance service, namely the washing process, service process, and cycle time service. The improvement state map that has been created will be a reference for the current state map which requires corrective action to achieve the next future. All of this is done continuously to achieve the ideal conditions of Express Maintenance services.

4. Result

The combination of Value Stream Mapping and Six Sigma used in this study proved effective and succeeded in reducing the lead time of Express Entertainment services in the automotive services in Toyota dealer. That would be seen by reviewing the results of the comparison of the Four Block Diagrams, before and after improvements to the car service that can experience an increase in terms of technology. Thus, it means resolving the problem using the Define, Measure, Analyze, Improve and Control (DMAIC) method in the automobile Totota dealer service succeeded in increasing the process capability from 1.96 to 3.80 sigma, mapping process using Value Stream Mapping analysis was seen to be able to reduce the length of service time and waiting time of each process in the car service with a total lead time to 64.0 minutes from 120.06 minutes or can reduce the Express Maintenance service lead time by 53%.

5. Conclusion

This study aims to improve car dealer services by reducing the Express Maintenance lead time in the automobile Toyta dealer services. For this reason, it is necessary to know the stages of the process that results in dealer service issues ranging from acceptance to submission back to the customer and can be analyzed and prevented from occurring problems. Value Stream Mapping helps to define key process stages to make improvements to the problems that occur in each stage of the process. This research uses an integrated Value Stream Mapping (VSM) and Six Sigma mechanism that tries to unravel the problem that is happening the Express Maintenance service in the automotive Toyota dealer services industry in Indonesia, namely a high lead time of 120.06 minutes from the management target of 60.00 minutes. By assisting the Value Stream Mapping method, it was able to identify which part of the series of processes caused the problem and managed to find out the total lead time that was running at 120.06 minutes and after repairing the value stream it was also found that the total lead time Express Maintenance decreased to 64.00. Six Sigma method with DMAIC (Define, Measure, Analyze, Improve and Control) steps were also carried out in this study with the help of other tools of quality such as Pareto diagrams, process capability with four block diagrams, Cause-Effect diagram analysis of 5W + 1H also and succeeded in measuring, analyzing, repairing and controlling the process of Express Maintenance so that total lead time of the process can be derived as above and can raise the sigma level of the Express Maintenance process from 1.96 sigma to 3.80 sigma. In general, Value Stream Mapping and Six Sigma methods in this study reinforce previous studies, namely increasing sigma level, which is marked by decreasing total lead time Express Maintenance so that the quality of service can be improved to get customer satisfaction, increase company profitability, increase the competitiveness of companies in maintaining the sustainability of the industry in the future.

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EVALUATION OF OECD COUNTRIES WITH MULTI-CRITERIA DECISION-MAKING METHODS IN TERMS OF ECONOMIC, SOCIAL AND ENVIRONMENTAL ASPECTS

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Abstract: *Exhausted natural resources and deteriorating ecological balance, together with the social privileges that people expect to have, are proof that the development of countries cannot be reduced to economic development alone. In this respect, this study aimed to evaluate the economic, social and environmental aspects of Organization for Economic Co-operation and Development (OECD) countries. Within this scope, the countries were firstly divided into two groups by performing cluster analysis in order to create more homogeneous country groups. Then, 12 criteria, consisting of four economic, four social and four environmental criteria, were determined by considering the literature and expert opinions. The criteria importance through intercriteria correlation (CRITIC) method was used to weight the determined criteria and using the calculated criterion weights, the countries in each cluster were then evaluated with the measurement of alternatives and ranking according to compromise solution (MARCOS) method. As a result, the most successful countries in the first cluster were determined as Switzerland, Denmark and Ireland with 68.8%, 62.7% and 62.5% performance scores, respectively. Whereas, the most unsuccessful countries were USA, Canada and Australia with 49.8%, 50.0% and 50.1% performance scores, respectively. The most successful countries in the second cluster were found as Slovenia, Spain and Portugal with 65.9%, 65.5% and 64.5% performance scores, while the most unsuccessful countries were Turkey, Chile and Colombia with 45.9%, 55.4% and 55.9% performance scores, respectively. Finally, in order to test the sensitivity of the MARCOS method, the solution was repeated with the MAIRCA, WASPAS, MABAC and CoCoSo methods using the weights obtained by the CRITIC method. A high correlation (greater than 80%) was found between the rankings acquired using the other methods and the rankings obtained by the MARCOS method.*

Key words: *OECD countries, economic- social- environmental development, CRITIC, MARCOS*

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1. Introduction

The continuous increase of the world population and the inequality in resource sharing drive countries into a constant growth war. This is because countries that strive to get the highest share of limited natural resources, especially oil, are aware that the primary way to achieve this is economic growth. However, the socio-environmental effects created by the economic growth of countries have brought forth increasing concerns in society. As developing countries begin to consume resources at the same level as developed countries, the planet is constantly being dragged into a disastrous situation. Economic growth is often accompanied by adverse environmental and social impacts such as excessive use of natural resources, income inequality, exploitation of manual labor and toxic gas emissions. Therefore, in order to evaluate the socio-economic performance of nations, economists have gradually started to address issues related to social welfare and environment as well as economic growth (Santana et al., 2014). However, it is still widely accepted to rank countries or regions by evaluating their performance and growth levels in terms of their gross domestic product (GDP).

GDP is useful for measuring and comparing market activity, as its intended purpose is to measure crude economic activity. However, in the last few decades GDP has been given a role that goes beyond its intended purpose. It has started to be used as a proxy indicator of economic competence as well as human progress and general social and economic well-being. Today, GDP is characterized as the most widely used indicator of a country's overall performance, even though it was never designed for such a purpose (Charles & D'Alessio, 2020). This is because societies with strong economic backgrounds are considered to be highly developed. However, obtaining and comparing the development level of societies only according to economic indicators can yield unrealistic and unreliable results. In fact, economic indicators cannot fully reflect the performance of countries in areas such as environment, public health, public education, etc. (Omrani et al., 2020). In any case, evaluating a country's performance should not be limited to only economic data or only non-economic data. Countries should be considered from both aspects simultaneously and in a coherent framework. More specifically, a country’s GDP level of is seen as its ability to provide its citizens with the appropriate opportunities to take advantage of their economic, social and environmental conditions. Increase in per capita GDP can only be considered as a basic precondition for improving the living standards of a population (Cracolici et al., 2010). Therefore, in recent years, many indexes including the Social Progress Index (SPI), Human Development Index (HDI), Environmental Performance Index (EPI), Life Satisfaction Index (LSI), have been created in order to evaluate countries especially in terms of environmental and social aspects. However, although such indexes have been put forward by many different organizations, none of the indexes alone are sufficient for the social and environmental evaluation of countries.

Although economic growth, social development and environmental quality seem to be completely independent from each other, there are meaningful relationships between them. For instance, environmental constraints can lead to a decrease in regional growth, which is necessary for demographic development, and subsequently increased levels of unemployment (Fakher & Abedi, 2017), while population explosion and the struggle to improve economic growth can lead to more pollution and waste from industrial, agricultural and construction activities (Iram et al., 2020). In addition, healthy economic growth can be used as a social welfare tool for the citizens of that country. As can be understood from the examples, there are tight ties between the economic, social and environmental development of countries. Therefore, this study aimed to evaluate the Organization for Economic Co-operation and Development (OECD) countries in terms of economic, social and environmental aspects. It does not seem possible for a country to develop only economically or socially or environmentally. Economic development in a country means that a person living in that country earns more income. People who earn more income will want to have various social rights and privileges after their basic physiological needs are met. In addition, only people who can meet their basic physiological needs will be able to concern themselves with environmental issues. Therefore, all economic, social and environmental data should be taken into account when evaluating a country properly. From this point of view, as this study used economic, social and environmental data it yielded important results.

In recent years, there have been studies conducted with a tendency to evaluate the sustainability performance of countries. Using multiple-criteria decision-making methods, Tajbakhsh & Shamsi (2019) evaluated the sustainability performance of 133 countries while Antanasijevic et al. (2017) evaluated that of European countries, Ecer et al. (2019) evaluated that of 41 OPEC countries and Costa et al. (2019) evaluated that of 34 OECD countries. In this direction, the aim of contributing to the studies in the literature and evaluating the sustainability performances of OECD countries with regard to economic, environmental and social criteria constituted the main motivation of the present study. Differently from other studies in the literature, a cluster analysis was first performed in order to evaluate countries in more homogeneous groups. Following the cluster analysis, the sustainability performances of the countries were evaluated with a hybrid model using the CRITIC-MARCOS methods.

The particular goals of the present study specified to fill the gaps in the literature are listed below.

- Carrying out a performance evaluation for OECD countries with regard to the three main criteria of the concept of sustainability,
- Performing a cluster analysis in order to obtain homogeneous groups of countries prior to the performance evaluation,
- Comparatively presenting the outcomes of potential multiple-criteria decision-making methods that can be used for sustainable performance evaluation,
- Proposing an applicable methodology for the determination of the OECD country with the highest sustainability performance.

The criteria importance through intercriteria correlation (CRITIC) method was used to determine the importance weights of the criteria used to evaluate the countries in the study. Since the CRITIC method reaches outcomes by performing processes that are based on real data, it eliminates the impact of decision-makers on the decision. Due to the inclusion of real data related to three main criteria and sub-criteria for the OECD countries in the present study and the importance of the correlations between these criteria, the CRITIC method was used for weighting criteria. Then, the criterion weights calculated with the CRITIC method were used in the measurement of alternatives and ranking according to compromise solution (MARCOS) method and the countries were ranked according to their performances. In the MARCOS method, the utility functions of decision alternatives are obtained and the performances of alternatives are revealed with compromise rankings based on reference values (ideal and anti-ideal solution values). It is a flexible method and the fact that it allows for the evaluation of a large number of criteria with compromise solution, that it can be used in the solution of complex problems despite being a simple solution algorithm and that it is a strong and reliable decision-making tool for the optimization of multiple purposes can be listed as its advantages in comparison with other similar methods. Finally, in order to test the sensitivity of the solution obtained by the CRITIC-MARCOS methods, solution values were obtained by using different MCDM methods and the obtained results were compared.

2. Literature Review

Studies in the literature have examined countries economically, socially and environmentally many times using different methods. Although methods such as structural equation modelling (Cracolici et al., 2010), fuzzy logic (Phillis et al., 2011) and multiple regression (Kaklauskas et al., 2020) have been used for the economic, social and environmental evaluation of countries, multi criteria decision making (MCDM) methods are often preferred for this assessment.

Table 1. MCDM studies in which economic, social and environmental criteria was used

Writer	Criteria			Methods*	Countries/Areas
	Eco.	Soc.	Env.		
Charles & D'Alessio (2020)	√	√	√	DEA	28 areas of Peru
Giannakitsidou et al. (2020)	√		√	DEA	26 European countries
Iram et al. (2020)	√		√	DEA	26 OECD countries
Iqbal et al. (2019)	√		√	DEA	20 industrial countries
Ecer et al. (2019)	√	√	√	CoCoSo	41 OPEC countries
Costa et al. (2019)	√	√		ELECTRE TRI-C	34 OECD countries
Tajbakhsh & Shamsi (2019)	√	√	√	DEA	133 countries
Kılıç Depren & Bağdatlı Kalkan (2018)	√	√	√	Entropy ve MULTIMOORA	37 OECD countries
Moutinho et al. (2018)	√		√	DEA	16 Latin American countries
Antanasijevic et al. (2017)	√	√	√	PROMETHEE	30 European countries
Skare & Rabar (2017)	√	√	√	DEA	30 OECD countries
Şahin & Öztel (2017)	√	√		COPRAS	BRICS countries and Turkey
Santana et al. (2014)	√	√	√	DEA	BRICS countries
Shmelev & Rodríguez-Labajos (2009)	√	√	√	NAIADE	Austria
Malul et al. (2008)	√	√	√	DEA	38 developed, 53 developing countries

*MCDM Methods name, *MULTIMOORA:* Full Multiplicative Form of Multi-Objective Optimization by Ratio Analysis, *ELECTRE:* ELimination Et Choix Traduisant la Realité, *DEA:* Data Envelopment Analysis *NAIADE:* Novel Approach to Imprecise Assessment and Decision Environments, *COPRAS:* Complex Proportional Assessment, *PROMETHEE:* Preference Ranking Organization Method For Enrichment Evaluations), *CoCoSo:* Combined Compromise Solution

Among these studies, there are studies that have examined countries using economic, social and environmental criteria as well as studies that have examined only economic and social or only economic and environmental criteria. Table 1 shows the criteria and methods used in the literature to examine countries.

Most decisions made in the real world have many criteria that often conflict. Therefore, MCDM methods have become an extremely necessary tool for decision makers (Benítez & Liern, 2020). In recent years, MCDM methods have been used in many decision problems. Panchal et al. (2017) used Fuzzy AHP, Fuzzy CODAS methods to evaluate maintenance decisions in the urea fertilizer industry; Panchal et al. (2019) used Fuzzy FMEA, Fuzzy TOPSIS, Fuzzy EDAS, Fuzzy VIKOR methods to analyze the performance problems of the chemical process plant; Chatterjee et al. (2020) used EDAS in biomaterial selection; Gopal & Panchal (2020) used Fuzzy COPRAS, Fuzzy TOPSIS methods for risk analysis and reliability assessment of the milk processing industry; Das et al. (2021) used PFMEA, TOPSIS, VIKOR methods for risk analysis in the milk industry. In this study, MCDM methods were preferred as there were many criteria, most of which were conflicting. First of all, the CRITIC method recommended by Diakoulaki et al. (1995) and used in many decision problems such as air conditioning selection (Vujicic et al., 2017), risk assessment (Ayrım & Can, 2017), third party logistics service provider selection (Keshavarz Ghorabaee et al., 2017), construction equipment evaluation (Keshavarz Ghorabaee et al., 2018), financial performance evaluation (Şenol & Ulutaş, 2018), bank performance evaluation (Akbulut, 2019), cargo company assessment (Ulutaş & Karaköy, 2019), corporate sustainability performance analysis (Yalçın & Karakaş, 2019), venture capital investment trusts assessment (Apan & Öztel, 2020), personnel selection process (Ayçin, 2020), R&D performance assessment of countries (Orhan & Aytekin, 2020) and 5G industry assessment (Peng et al., 2020) was preferred to weigh the selected criteria. Then, using these weights, the countries were evaluated with the MARCOS method developed by Stević et al. (2020) and used in decision problems such as project management software evaluation (Puška et al., 2020), human resources assessment in the transportation sector (Stević & Brković, 2020), supplier selection (Stević et al., 2020; Badi & Pamucar, 2020; Chattopadhyay et al., 2020; Madenoğlu, 2020), risk assessment of railway infrastructure (Simić et al., 2020), distribution channel selection (Dalić et al., 2020), stacker selection for logistics systems (Ulutaş et al., 2020), traffic risk analysis (Stanković et al., 2020), sanitary landfill selection for medical waste (Torkayesh et al., 2021), healthcare performance assessment of insurance companies (Ecer & Pamucar, 2021) and e-service quality assessment in the airline industry (Bakır & Atalık, 2021). As seen in the detailed literature review, the CRITIC and MARCOS methods were not used in studies conducted to evaluate countries. In this respect, the present study is the first of its kind in the literature.

3. Method

3.1. CRITIC

Diakoulaki et al. (1995) proposed the CRITIC method to overcome the problems of subjective weighting methods such as reliability and consistency (Diakoulaki et al., 1995). The procedure of the CRITIC method consists in the following steps:

Step 1: Forming the decision matrix

In the first step, the decision matrix includes a set of n criteria and m alternatives are constructed by using Equation (1).

$$X = A_1\ A_2\ \vdots\ A_m\ [x_{11}\ x_{12}\ \dots\ x_{1n}\ x_{21}\ x_{22}\ \dots\ x_{2n}\ \vdots\ \vdots\ \dots\ \vdots\ x_{m1}\ x_{m2}\ \dots\ x_{mn}\ ] \qquad (1)$$

Step 2: Normalization

The values of the criteria with different units in decision problems should be standardized to take a value in the range of [0,1] by the normalization process. The normalized decision-making matrix is calculated using Equations (2) and (3):

$$r_{ij} = \frac{x_{ij}-x_j^{min}}{x_j^{max}-x_j^{min}} \qquad j = 1,2,\dots,n \qquad if\ j \in B \qquad (2)$$

$$r_{ij} = \frac{x_j^{max} - x_{ij}}{x_j^{max} - x_j^{min}} \qquad j = 1,2,\dots,n \qquad if\ j \in C \qquad (3)$$

where B is a group of benefit criteria and C is a group of cost criteria.

Step 3: Constructing the correlation coefficient matrix

The correlation coefficient matrix consisting of linear relationship coefficients is created to measure the degree of the relationships between the criteria. The correlation coefficient is calculated by using Equation (4).

$$\rho_{jk} = \sum_{i=1}^{m} (r_{ij} - \overline{r_j}).(r_{ik} - \overline{r_k}) \Big/ \sqrt{\sum_{i=1}^{m} (r_{ij} - \overline{r_j})^2 . \sum_{i=1}^{m} (r_{ik} - \overline{r_k})^2} \qquad j,k = 1,2,\dots,n \qquad (4)$$

Step 4: Calculating the C_j Values

Information contained in MCDM problems is related to both the contrast intensity and conflict of the decision criteria. Hence, the amount of information C_j, emitted by the jth criterion can be determined by composing the measures that quantify the two notions using Equations (5) and (6).

$$C_j = \sigma_j \sum_{k=1}^{n} (1 - \rho_{jk}) \qquad j = 1,2,\dots,n \qquad (5)$$

$$\sigma_j = \sqrt{\sum_{i=1}^{m} (r_{ij} - \overline{r_j})^2 / (m-1)} \qquad (6)$$

Step 5: Calculating the final criteria weights

In the last step of the CRITIC method, the objective weights are calculated by using Equation (7).

$$w_j = c_j / \sum_{k=1}^{n} c_k \tag{7}$$

3.2. MARCOS

Stevic et.al presented the main ideas of the MARCOS method, which is based on defining the relationship between alternatives and reference values (ideal and anti-ideal alternatives). On the basis of the defined relationships, the utility functions of the alternatives are determined and compromise ranking is made in relation to ideal and anti-ideal solutions. Decision preferences are defined on the basis of utility functions. Utility functions represent the position of an alternative with regards to an ideal and anti-ideal solution. The best alternative is the one that is closest to the ideal and furthest from the anti-ideal reference point (Stevic et al., 2020). The procedure of the MARCOS method consists of the following steps (Stevic et al., 2020, Ecer, 2020; Đalić et al. 2021):

Step 1: Forming the initial decision matrix.

The initial decision matrix includes a set of n criteria and m alternatives. In the case of group decision-making, expert evaluation matrices are aggregated into an initial group decision-making matrix.

Step 2: Forming the extended initial decision matrix.

The extended initial decision matrix is created by defining ideal (AI) and anti-ideal (AAI) solutions as shown in Equation (8).

$$\begin{matrix} C_1 & C_2 & \dots & C_n \end{matrix}$$
$$X = A_1 \; A_2 \; \vdots \; A_m \; A_{AAI} \; A_{AI} \; [x_{11} \; x_{12} \; \dots \; x_{1n} \; x_{21} \; x_{22} \; \dots \; x_{2n} \; \vdots \vdots \vdots \; \vdots \; x_{m1} \; x_{m2} \; \dots \; x_{mn} \; x_{aa1} \; x_{aa2} \; \cdots \; x_{aan} \; x_{ai1} \; x_{ai2} \; \cdots \; x_{ain} \,] \tag{8}$$

AI and AAI are calculated by using Equations (9) and (10) depending on the nature of the criteria.

$$AI = x_{ij} \;\; if \; j \; \in B \; and \; x_{ij} \;\; if \; j \; \in C \tag{9}$$

$$AAI = x_{ij} \;\; if \; j \; \in B \; and \; x_{ij} \;\; if \; j \; \in C \tag{10}$$

where B is the benefit-based criteria and C is the cost-based criteria.

Step 3: Normalizing the extended initial decision matrix.

The normalized matrix N is calculated by using Equations (11) and (12).

$$n_{ij} = \frac{x_{ij}}{x_{ai}} \quad if \; j \; \in B \tag{11}$$

$$n_{ij} = \frac{x_{ai}}{x_{ij}} \quad if \; j \; \in C \tag{12}$$

where x_{ij} and x_{ai} are the elements of the extended initial decision matrix (X).

Step 4: Determining the weighted decision matrix (V).

The weighted matrix, V, is obtained by multiplying the normalized matrix elements with the weight coefficients of the criterion w_j as shown in Equation (13).

$$v_{ij} = n_{ij} \times w_j \tag{13}$$

Step 5: Forming the utility degrees of the alternatives (K_i).

The utility degrees of alternatives are calculated by using Equations (14) and (15).

$$K_i^{+} = \frac{S_i}{S_{ai}} \tag{14}$$

$$K_i^{-} = \frac{S_i}{S_{aai}} \tag{15}$$

S_i represents the sum of the elements of the weighted decision matrix (V) as shown in Equation (16).

$$S_i = \sum_{i=1}^{n} v_{ij} \tag{16}$$

Step 6: Forming the utility function of the alternatives f(K_i).

The utility function is the compromise of the observed alternative in relation to the ideal and anti-ideal solution. This function is calculated by using Equation (17).

$$f(K_i) = \frac{K_i^{+} + K_i^{-}}{1 + \frac{1 - f(K_i^{+})}{f(K_i^{+})} + \frac{1 - f(K_i^{-})}{f(K_i^{-})}} \tag{17}$$

Utility functions in relation to the ideal and anti-ideal solution are calculated by using Equations (18) and (19).

$$f(K_i^{+}) = \frac{K_i^{-}}{K_i^{+} + K_i^{-}} \tag{18}$$

$$f(K_i^{-}) = \frac{K_i^{+}}{K_i^{+} + K_i^{-}} \tag{19}$$

Step 7: Ranking the alternatives.

The final values of the utility function allow for a comparison between the alternatives. The best alternative has the highest rank in terms of the value of the utility function.

4. Data

When determining the criteria used in this study, the criteria used in previous studies that evaluated countries in terms of economic, social and environmental aspects were taken into consideration. Among these, the most used 12 criteria based on a comprehensive literature review, namely four economic, four social and four environmental criteria, were selected to evaluate the OECD countries. Information regarding the direction and unit of the selected criteria, in which study they are used and where they were obtained from are presented in Table 2.

Table 2. Criteria used in the study

	Criteria (abbreviation)	Aspect	Unit	Source	Data
Economical	GDP per capita (GDP)	Max	$	Antanasijevic et al., 2017; Ecer et al., 2019; Malul et al., 2008; Moutinho et al., 2018 ; Santana et al., 2014; Shmelev & Labajos, 2009; Chattopadhyay & Bose, 2015; Fare et al., 1994; Skare & Rabar, 2017; Karakış & Göktolga, 2016; Özbek & Demirkol, 2019	Worldbank, 2019
	Unemployment rate (UR)	Min	%	Antanasijevic et al., 2017; Cracolici et al., 2010; Phillis et al., 2011; Shmelev & Labajos, 2009; Chattopadhyay & Bose, 2015; Ela & Kurt, 2019; Eyüboğlu, 2016; Skare & Rabar, 2017; Podvezko, 2011; Karakış & Göktolga, 2016; Özbek & Demirkol, 2019	International Labor Organization (ILO), 2019
	Inflation rate (IR)	Min	%	Ecer et al., 2019; Chattopadhyay & Bose, 2015; Ela & Kurt, 2019; Eyüboğlu, 2016 ; Skare & Rabar, 2017; Karakış & Göktolga, 2016; Özbek & Demirkol, 2019	Worldbank, 2019
	Growth rate (GR)	Max	%	Ela & Kurt, 2019; Eyüboğlu, 2016; Podvezko, 2011; Karakış & Göktolga, 2016; Özbek & Demirkol, 2019	Worldbank, 2019
Social	Social progress index (SPI)	Max	0-100	Kaklauskas et al., 2020; Benitez & Liern, 2020; Giannakitsidou et al., 2020; Charles & D'Alessio, 2020	Social Progress Imperative, 2020
	Gini coefficient (GINI)	Min	0-1	Ecer et al., 2019; Malul et al., 2008; Shmelev & Labajos, 2009; Costa et al., 2019; Eren et al., 2017; Cravioto et al., 2011	Worldbank, OECD, 2015-2018
	Human development index (HDI)	Max	0-1	Malul et al., 2008; Krylovas et al., 2019; Şahin & Öztel, 2017; Eren & Kaynak, 2017; Eren et al., 2017; Bilbao-Terol et al., 2014; Cravioto et al., 2011	United Nations Development Programme (UNDP), 2020
	Life satisfaction index (LSI)	Max	0-10	Shmelev & Labajos, 2009; Kılıç Depren & Bağdatlı Kalkan, 2018; Cravioto et al., 2011	OECD Better Life Index , 2019
Environmental	Share of Renewable Energy in Gross Final Energy Consumption (SRE)	Max	%	Antanasijevic et al., 2017; Moutinho et al., 2018; Phillis et al., 2011	Worldbank, 2015

CO_2 emissions per capita (CO_2)	Min	Tones	Cracolici et al., 2010; Ecer et al., 2019; Moutinho et al., 2018; Phillis et al., 2011; Santana et al., 2014; Shmelev & Labajos, 2009	Our World in Data, 2019
Environmental performance index (EPI)	Max	0-100	Malul et al., 2008; Olafsson et al., 2014; Bilbao-Terol et al., 2014; Fakher & Abedi, 2017	EPI, 2020
Ecological footprint per capita (EA)	Min	Hectar	Olafsson et al., 2014; Bilbao-Terol et al., 2014; Blancard & Hoarau, 2013	Global Footprint Network 2019

The criteria used in the study consist of various economic, social and environmental indicators and indices. Definitions regarding these indicators and indices are given below.

Gross Domestic Product per capita (GDP): GDP per capita, which is used as a criterion in many economic performance studies, is obtained by dividing the GDP by the mid-year population. The data published annually by the World Bank are given in current US dollars.

Unemployment Rate (UR): The indicator obtained by proportioning the non-working people in the working population over the age of 15 to the total workforce is used in many studies to measure economic performance. The labor force rate is calculated annually by the International Labor Organization (ILO) using national estimates.

Inflation Rate (IR): Inflation, which is measured by the consumer price index, reflects the annual percentage change in the average cost of purchasing a basket of goods and services that can be fixed or changed at certain intervals such as every year. The inflation rate, which is frequently used in economic performance reviews and calculated annually by the International Monetary Fund (IMF), is published by the World Bank.

Growth Rate (GR): This is the annual GDP growth rate at constant local currency-based market prices. The indicator, calculated on the basis of constant 2010 USD, is shared annually by the World Bank.

Social Progress Index (SPI): It is an index calculated using basic indicators (access to food, personal security, etc.), welfare indicators (access to information, health rights, etc.) and opportunity indicators (personal freedoms, human rights, etc.). It is calculated by "The Social Progress Imperative" using 12 different indicators in three main headings.

Gini Coefficient (GINI): It measures the extent to which the distribution of income (or, in some cases, consumption expenditures) deviates from an exactly even distribution among individuals or households in an economy. A GINI coefficient of 0 represents perfect equality while a coefficient of 1 indicates perfect inequality. The most up-to-date data on the GINI coefficient, which is not calculated for each year, varies between 2015 and 2018 according to country.

Human Development Index (HDI): This index is published annually by the United Nations Development Program and includes indicators related to income, life expectancy and educational opportunities. The HDI consists of three dimensions: the long and healthy life dimension, which is measured by life expectancy at birth; the knowledge dimension, which is measured by schooling times for adults aged 25 and over, and the expected education period for children at school starting age, and the decent standard of living dimension, which is measured by gross national income per capita.

Lıfe Satisfaction Index (LSI): This index is based on the results of a survey that measures how people evaluate their lives as a whole rather than their current emotions. It is based on the average of the answers given to the question "how happy are you?", which is asked to the participants to determine the Better Life Index. It is calculated annually for all OECD member countries.

Share of Renewable Energy in Gross Final Energy Consumption (SRE): This is the share of renewable energy in the total energy consumption in the country where the data is provided. This indicator is frequently used to measure environmental performance, as it is thought that the increase in renewable energy consumption will have positive environmental consequences.

CO_2 Emission per capita (CO_2): The contribution of the citizens of each country to the CO_2 emission can be obtained by dividing the total emissions of that country by the total population. The achieved value is called CO_2 emissions per capita. CO_2 emission per capita is one of the most frequently used indicators in environmental performance measurements.

Environmental Performance Index (EPI): This index is calculated using 32 performance indicators under 11 dimensions and ranks countries in terms of environmental health and ecosystem vitality. The EPI provides a national scale indicator of how close countries are to setting environmental policy goals. Due to the large number of performance indicators it contains, it can be used on its own in many environmental performance evaluation studies.

Ecological Footprint (EF): Ecological Footprint per person is obtained by dividing a nation's total ecological footprint by the nation's total population. To live within the resources of our planet, the Earth's ecological footprint must equal the available biocapacity per person on our planet, currently 1.7 global hectares. Thus, if a country's EF is 6.8 global hectares per person, it means that the citizens of that country demand four times the resources and waste that our planet can regenerate and absorb in the atmosphere.

OECD members consist of countries that are economically, socially and environmentally different from each other. These differences can reduce the quality of the evaluations made. In the present study, the countries were grouped in order to prevent this and to reveal more homogeneous country groups. Accordingly, cluster analysis was performed using the two-step cluster method. The silhouette, which was examined in order to test the consistency and accuracy within the data sets in the clustering analysis, revealed that the grouping was at a "fair" level. The country groups formed as a result of the cluster analysis are shown in Table 3.

Table 3. OECD country clusters

First cluster countries		Second cluster countries
USA	Sweden	Estonia
Germany	Switzerland	Spain
Australia	Japan	Italy
Austria	Canada	Colombia
Belgium	Luxemburg	Latvia
Czech Republic	Norway	Lithuania
Denmark		Hungary
Finland		Poland
France		Portugal
South Korea		Slovakia
Holland		Slovenia
England		Chile
Ireland		Turkey
Israel		Greece

When conducting the cluster analysis, 12 criteria were taken into account to evaluate OECD countries economically, socially and environmentally. As Mexico's growth rate was negative, it was excluded from the analysis and only 34 countries were included in the cluster. Of these 34 countries, 20 were in the first cluster and 14 were in the second cluster.

5. Results

When evaluating the countries, the criteria were weighted with the CRITIC method. Then, using the obtained weights, the countries were evaluated using the MARCOS method. In this section, the solution values calculated with the CRITIC and MARCOS methods are shown respectively.

5.1. CRITIC Results

The decision matrix used in both the CRITIC method and the MARCOS method was created as shown in Equation (1). As a result of the clustering analysis, the decision matrices created with the values taken by the OECD countries, which were divided into two clusters, according to the criteria shown in Table 2 are presented in Table 4.

The normalization process was implemented primarily to the maximization and minimization criteria by using the values in the decision matrix given in Table 4. Then, the correlation coefficient matrix was created by using the criterion values in the normalized decision matrix. Finally, the criterion weights were calculated using the C_j values representing the amount of information of the criteria. The criteria weights for each cluster of countries obtained after the operations seen in Equations (2)-(7) were carried out are shown in Table 5.

Table 4. Decision matrix of the clusters

	Countries	Economic Criteria				Social Criteria				Environmental Criteria			
		GDP	UR	IR	GR	SPI	GINI	HDI	LSI	SRE	CO_2	EPI	EF
		max	min	min	max	max	min	max	max	max	min	max	min
First Cluster	USA	65118	3.7	1.8	2.3	85.7	0.39	0.92	6.9	8.72	16.2	69.3	8
	Germany	46258	3.1	1.4	0.6	90.5	0.28	0.93	7	14.21	9.6	77.2	4.7
	Australia	54907	5.2	1.6	1.9	91.2	0.32	0.93	7.3	9.18	16.9	74.9	7.3
	Austria	50277	4.5	1.5	1.6	89.5	0.27	0.91	7.1	34.39	7.9	79.6	6
	Belgium	46116	5.4	1.4	1.4	89.4	0.26	0.91	6.9	9.2	8.5	73.3	6.6
	Czech Republic	23101	2	2.8	2.6	86.6	0.24	0.89	6.7	14.83	9.9	71	5.5
	Denmark	59822	5	0.8	2.4	92.1	0.26	0.93	7.6	33.17	6.0	82.5	6.9
	Finland	48685	6.7	1	1	91.8	0.26	0.92	7.6	43.24	8.1	78.9	5.8
	France	40493	8.4	1.1	1.5	88.7	0.29	0.89	6.5	13.5	5.3	80	4.6
	South Korea	31762	3.7	0.4	2	89.0	0.35	0.90	5.9	2.71	12.5	66.5	6.2
	Holland	52447	3.4	2.6	1.8	91.0	0.28	0.93	7.4	5.89	9.6	75.3	5
	England	42300	3.7	1.7	1.4	88.5	0.36	0.92	6.8	8.71	5.8	81.3	4.2
	Ireland	78661	4.9	0.9	5.5	90.3	0.29	0.94	7	9.08	8.1	72.8	5
	Israel	43641	3.8	0.8	3.5	83.6	0.34	0.90	7.2	3.71	7.8	65.8	5.5
	Sweden	51610	6.8	1.8	1.2	91.6	0.27	0.93	7.3	53.25	4.2	78.7	6.1
	Switzerland	81993	4.4	0.4	0.9	91.4	0.29	0.94	7.5	25.29	4.5	81.5	4.5
	Japan	40246	2.4	0.5	0.7	90.1	0.33	0.91	5.9	6.3	9.3	75.1	4.7
	Canada	46194	5.7	1.9	1.7	91.4	0.31	0.92	7.4	22.03	15.5	71	8.1
	Luxemburg	114704	5.6	1.7	2.3	89.5	0.32	0.90	6.9	9.03	15.6	82.3	12.8
	Norway	75419	3.7	2.2	1.2	92.7	0.26	0.95	7.6	57.77	8.2	77.7	5.8
Second Cluster	Estonia	23659	4.4	2.3	4.3	87.2	0.30	0.88	5.7	27.48	14.1	65.3	7.2
	Spain	29613	14.1	0.7	2	88.7	0.33	0.89	6.3	16.25	5.8	74.3	4
	Italy	33189	10	0.6	0.3	87.3	0.33	0.88	6	16.52	5.7	71	4.4
	Colombia	6432	10	3.5	3.3	74	0.50	0.76	6.3	23.56	1.9	52.9	1.9
	Latvia	17836	6.3	2.8	2.2	83.1	0.35	0.85	5.9	38.1	3.7	61.6	6.1
	Lithuania	19455	6.3	2.3	3.9	83.9	0.37	0.86	5.9	28.96	4.7	62.9	5.9
	Hungary	16475	3.4	3.3	4.9	81.0	0.28	0.84	5.6	15.56	5.1	63.7	3.7
	Poland	15595	3.3	2.2	4.1	84.3	0.27	0.87	6.1	11.91	8.8	60.9	4.7
	Portugal	23145	6.5	0.3	2.2	87.7	0.32	0.85	5.4	27.16	5.3	67	4.4
	Slovakia	19329	5.8	2.7	2.4	83.1	0.22	0.85	6.2	13.41	6.6	68.3	4.4
	Slovenia	25739	4.4	1.6	2.4	87.7	0.24	0.90	5.9	20.88	6.8	72	4.9
	Chile	14896	7.3	2.6	1.1	83.3	0.46	0.84	6.5	24.88	4.5	55.3	4.3
	Turkey	9042	13.7	15.2	0.9	68.2	0.40	0.80	5.5	13.37	5.2	42.6	3.5
	Greece	19582	17.3	0.3	1.9	85.7	0.31	0.87	5.4	17.17	7.0	69.1	4.1

Table 5. Criteria weights of the clusters determined using the CRITIC method

First Cluster w_j	Economic Criteria			
	GDP	UR	IR	GR
	0.072	0.099	0.103	0.089
	Social Criteria			
	SPI	GINI	HDI	LSI
	0.069	0.081	0.072	0.082
	Environmental Criteria			
	SRE	CO_2	EPI	EF
	0.083	0.087	0.088	0.075
Second Cluster w_j	Economic Criteria			
	GDP	UR	IR	GR
	0.071	0.094	0.058	0.099
	Social Criteria			
	SPI	GINI	HDI	LSI
	0.065	0.079	0.068	0.107
	Environmental Criteria			
	SRE	CO_2	EPI	EF
	0.100	0.093	0.063	0.104

When the criteria weights in Table 5 are examined, it can be seen that the most important criteria for the first cluster were inflation rate (IR), unemployment rate (UR) and growth rate (GR), while the most important criteria for the second cluster were the life satisfaction index (LSI), ecological footprint (EF) and the share of renewable energy in gross final energy consumption (SRE).

5.2. MARCOS Results

In the next step, the MARCOS method was used to evaluate the economic, social and environmental performance of the OECD countries. The mathematical steps of the MARCOS method as shown in Equations (8)-(19) were followed respectively and the results are shown in Table 6.

Table 6. Results of the MARCOS method for the clusters

	Country	S_i	K_i-	K_i+	$f(K_i\text{-})$	$f(K_i\text{+})$	$f(K_i)$	Rank
First Cluster	USA	0.5620	1.3157	0.5620	0.2993	0.7007	0.4983	20
	Germany	0.6230	1.4585	0.6230	0.2993	0.7007	0.5524	13
	Australia	0.5659	1.3249	0.5659	0.2993	0.7007	0.5018	18
	Austria	0.6472	1.5152	0.6472	0.2993	0.7007	0.5738	8
	Belgium	0.5862	1.3724	0.5862	0.2993	0.7007	0.5198	17
	Czech Republic	0.6462	1.5129	0.6462	0.2993	0.7007	0.5730	9
	Denmark	0.7072	1.6557	0.7072	0.2993	0.7007	0.6270	2
	Finland	0.6581	1.5407	0.6581	0.2993	0.7007	0.5835	6
	France	0.6250	1.4633	0.6250	0.2993	0.7007	0.5542	12
	South Korea	0.6187	1.4483	0.6187	0.2993	0.7007	0.5485	14
	Holland	0.6143	1.4381	0.6143	0.2993	0.7007	0.5446	15
	England	0.6280	1.4703	0.6280	0.2993	0.7007	0.5568	11
	Ireland	0.7054	1.6514	0.7054	0.2993	0.7007	0.6254	3
	Israel	0.6334	1.4828	0.6334	0.2993	0.7007	0.5616	10
	Sweden	0.6933	1.6232	0.6933	0.2993	0.7007	0.6148	5

	Switzerland	0.7769	1.8188	0.7769	0.2993	0.7007	0.6888	1
	Japan	0.6562	1.5362	0.6562	0.2993	0.7007	0.5818	7
	Canada	0.5647	1.3221	0.5647	0.2993	0.7007	0.5007	19
	Luxemburg	0.5888	1.3785	0.5888	0.2993	0.7007	0.5221	16
	Norway	0.7033	1.6465	0.7033	0.2993	0.7007	0.6236	4
Second Cluster	Estonia	0.6807	1.7267	0.6807	0.2828	0.7172	0.6125	8
	Spain	0.7289	1.8489	0.7289	0.2828	0.7172	0.6558	2
	Italy	0.6358	1.6126	0.6358	0.2828	0.7172	0.5720	11
	Colombia	0.6220	1.5776	0.6220	0.2828	0.7172	0.5596	12
	Latvia	0.6932	1.7582	0.6932	0.2828	0.7172	0.6236	5
	Lithuania	0.6904	1.7512	0.6904	0.2828	0.7172	0.6211	6
	Hungary	0.7170	1.8187	0.7170	0.2828	0.7172	0.6451	4
	Poland	0.6815	1.7287	0.6815	0.2828	0.7172	0.6132	7
	Portugal	0.7179	1.8208	0.7179	0.2828	0.7172	0.6459	3
	Slovakia	0.6555	1.6628	0.6555	0.2828	0.7172	0.5898	9
	Slovenia	0.7329	1.8591	0.7329	0.2828	0.7172	0.6594	1
	Chile	0.6164	1.5636	0.6164	0.2828	0.7172	0.5546	13
	Turkey	0.5106	1.2950	0.5106	0.2828	0.7172	0.4593	14
	Greece	0.6381	1.6185	0.6381	0.2828	0.7172	0.5741	10

Results were obtained for each cluster with the MARCOS model. When Table 6 is examined it can be observed that for the first cluster Switzerland, Denmark and Ireland had the highest performance score, while USA, Canada and Australia had the lowest performance score and for the second cluster Slovenia, Spain and Portugal had the highest performance score, while Turkey, Chile and Colombia had the lowest performance score.

6. Examination of Results

In this section, the sensitivity analysis of the CRITIC-MARCOS methodology is presented. For this purpose, the reliability and validity of the proposed model were analyzed by using the multi-attribute ideal-real comparative analysis (MAIRCA), attributive border approximation area comparison (MABAC), weighted aggregated sum product assessment (WASPAS) and combined compromised solution (CoCoSo) methods. The comparative results of these MCDM methodologies for the first and second cluster are shown in Figures 1 and 2, respectively.

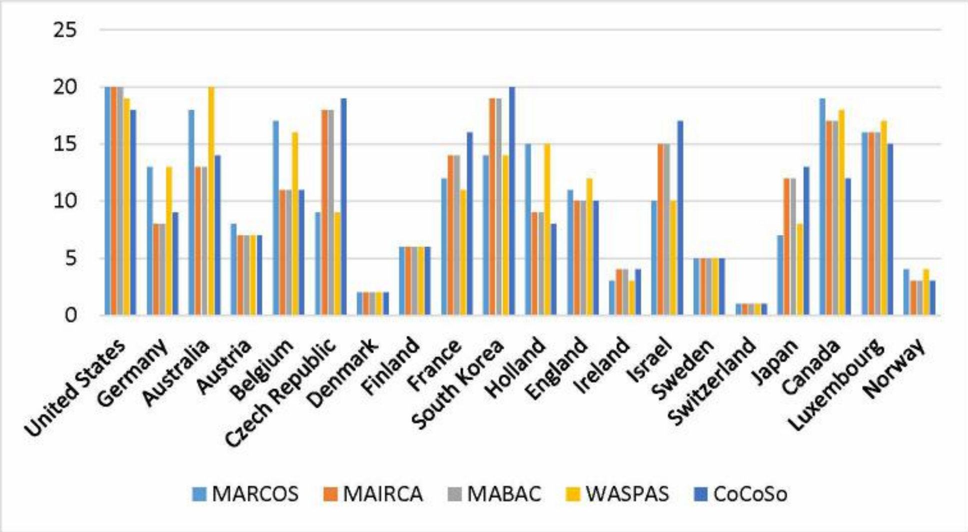

Figure 1. Sensitivity results of the first cluster

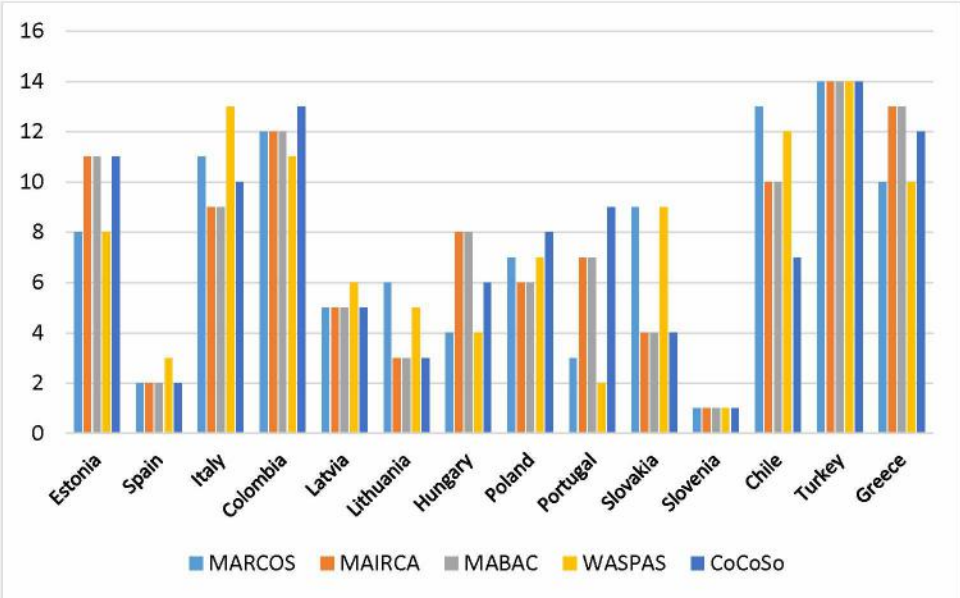

Figure 2. Sensitivity results of the second cluster

Spearman's correlation coefficient was used to determine the ranking position of the difference between the results of the CRITIC-MARCOS methodology and the all other mentioned MCDM methods. The Spearman correlation coefficients for both clusters are shown in Table 7.

Table 7. Spearman correlation results

Cluster/Method	MAIRCA	MABAC	WASPAS	CoCoSo	Average Value
Cluster-1 (CRITIC-MARCOS)	0.782*	0.782*	0.991*	0.690*	0.811
Cluster-2 (CRITIC-MARCOS)	0.785*	0.785*	0.978*	0.723*	0.818

According to Table 10, the correlation coefficients of each cluster was above 80.0%. These results show a significant correlation between the ranks of the proposed CRITIC-MARCOS methodology and all other mentioned MCDM methods in both clusters. This confirms that the ranking results suggested by the CRITIC-MARCOS methodology were valid and credible.

7. Discussion

Firstly, the countries were divided into two clusters using cluster analysis in order to make the heterogeneous structure of the countries homogeneous and evaluate the countries with similar characteristics together. There were 20 developed countries including USA, Germany, Denmark and Switzerland in the first cluster, while there were 14 relatively less developed countries including Estonia, Lithuania, Slovenia and Colombia included in the second cluster.

After the countries were clustered, 12 criteria used for the economic, social and environmental evaluation of each cluster were weighted using the CRITIC method. The most important criteria for the first cluster were determined as inflation rate (IR: 0.103), unemployment rate (UR: 0.099) and growth rate (GR: 0.089), while the most important criteria for the second cluster were found as the life satisfaction index (LSI: 0.107), ecological footprint (EF: 0.104) and the share of renewable energy in gross final energy consumption (SRE: 0.100), respectively. Kılıç Depren & Bağdatlı Kalkan (2018) used both unemployment rate and the life satisfaction index criteria to evaluate OECD countries. In the study where 24 criteria were weighted using the entropy method, the life satisfaction index was determined as the ninth most important criterion while unemployment rate was determined as the twentieth most important criterion. In the present study, unemployment rate was determined as the second most important criterion for the countries in the first cluster while the life satisfaction index was determined as the most important criterion for the second cluster. This result is proof that different combinations of criteria produce different results in the evaluation of countries.

The countries were evaluated using the criterion weights obtained by the CRITIC method in the MARCOS method. Among the countries in the first cluster, Switzerland, Denmark and Ireland had the best performances, respectively, while Australia, Canada and USA had the worst performances. It is noteworthy that the economic data of countries with good performance in particular were higher than the other countries in the first cluster. Even though the economic data of the poor performing countries were similar to the other countries in the first cluster, the GINI coefficient representing the income equity and the CO_2 emissions representing the air quality were worse than the other countries in the cluster. Therefore, these countries should focus on policies that will ensure income justice and take steps to improve air quality.

Among the countries in the second cluster, Slovenia, Spain and Portugal performed the best, while Colombia, Chile and Turkey performed the worst. The GDP values of the most successful countries in the second cluster were relatively better than the other countries in the cluster. Likewise, the social progress and human development index values of these countries were higher than the other countries in the cluster. The economic data of the most unsuccessful countries were noticeably worse than the other countries in the cluster.

In previous studies in the literature, similar results emerged although countries were not evaluated in two different clusters. In many recent studies, Switzerland and Denmark, which are at the top of the first cluster, demonstrated the highest performance while Chile and Turkey, which are at the bottom of the second cluster, were among the countries with the lowest performance (Skare & Rabar, 2017; Kılıç Depren & Bağdatlı Kalkan, 2018; Costa et al., 2019; Iram et al., 2020). Australia, Canada and USA, which are among the countries in the first cluster with the lowest performance, demonstrated high performance in some studies (Kılıç Depren & Bağdatlı Kalkan, 2018; Costa et al., 2019; Iram et al., 2020) and lower performance in others (Skare & Rabar, 2017). Therefore, the findings obtained in the present study support the current literature.

The country rankings obtained using the CRITIC and MARCOS methods were rankings belonging to this combination of criteria. It is possible to reach different rankings under different criteria. In order to test the accuracy and consistency of the criteria used in this study and the rankings acquired, a sensitivity analysis was performed. By using the criterion weights obtained by the CRITIC method, the model was re-solved using MAIRCA, MABAC, WASPAS and CoCoSo methods and country rankings were achieved. The Spearman rank correlations between the country rankings obtained with the MARCOS method and those acquired with the other methods were calculated. The calculated correlation values revealed that there were significant relationships between the rankings. An average of over 80% similarity was found between the rankings obtained with MARCOS and the rankings acquired by the other methods. This shows that the analysis made was a consistent and accurate analysis.

8. Conclusion

In general, when trying to determine the development levels of countries economic data are taken into consideration. However, economic development alone is not often sufficient for the people of a country to live in tranquility and prosperity. Income increase resulting from economic development can be considered as a tool to support the social development of people. Moreover, socially developed individuals are also more likely to be more interested in the environment. These meaningful connections between economic, social and environmental development were the main motivation for the present study. Therefore, OECD member countries with heterogeneous characteristics in terms of economic, social and environmental aspects were evaluated in this study.

The findings obtained include those that policymakers of countries will refer to when developing economic, social and environmental policies. Based on these findings, certain managerial implications were proposed for policymakers to utilize.

For many years, decision-makers tend to rank countries based on their GDP. However, the results of the present study serve as proof that countries should not be ranked based on GDP only. For example, although the GDP of the USA, which ranks last in the first cluster, is approximately three times that of the Czech Republic, Czech Republic ranked ninth. Therefore, GDP alone is not enough to reflect national welfare. Furthermore, in the findings of the present study, economic criteria were determined as the most important criteria for the first cluster, which consists of countries that completed their social and environmental development, while social and environmental criteria stood out for countries in the second cluster. Based on this, it is necessary for particularly the countries in the second cluster to develop economic policies towards increasing their GDP while focusing on developing policies to improve their social and environmental performance by increasing medical and educational expenditures. Both the data on the countries and the results of the present study indicate that countries that were regarded as the greatest global forces in the past are beginning to lose importance against countries that were previously ineffective. The great powers of the past such as the USA, England, France and Germany are unable to provide their citizens with the opportunities that countries such as Switzerland, Sweden, Denmark and Ireland offer to their citizens. This situation cannot be explained by the difference in population between the countries or the richness of national resources alone. In addition to economic data, national welfare depends on a number of non-economic factors such as income equality, freedom of speech, gender equality and CO_2 emissions, as well. Therefore, countries that are unable to demonstrate high performance in economic, social and environmental terms should use benchmarking processes based on successful countries while developing policies.

Although the present study produced original results in terms of the criteria, methodology and methods used, it has certain limitations in terms of scope and content. The most apparent limitation of the present study is the number of countries. The present study, in which only OECD countries were evaluated due to time and resource constraints, can be used to evaluate all countries in the future. Another limitation in the present study is regarding the criteria used. 12 criteria were used to evaluate OECD countries in the present study. In future studies, different countries can be evaluated under the same criteria. In addition, different results can be obtained by using different combinations of criteria or MCDM methods based on expert opinions.

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MODELING A MULTI-CRITERIA DECISION SUPPORT SYSTEM FOR PREQUALIFICATION ASSESSMENT OF CONSTRUCTION CONTRACTORS USING CRITIC AND EDAS MODELS

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Abstract: *Contractor prequalification assessment in the construction industry is an essential part of the project development process because contractors play a pivotal role in the extension of projects and resources. The main objective of the present study is comprised prequalification assessment for classifying contractors by applied the EDAS method for recognizing the contractors' potential before competitive tendering and obtaining bids. First, an inclusive, detailed list of 56 sub-factors under 5 main factors for project prequalification was compiled following a thorough literature review, and review of contractors by experts of Bandar Imam Khomeini municipality who already have done projects with contractors. Second, used the CRITIC method for obtained the weighing and importance of each factor. Third, classified the contractors by applied the EDAS system for recognizing the contractors' potential before competitive tendering and obtaining bids. Finally, the prequalification assessment process was developed to obtaining the rank of each contractor and help the stakeholders to select the right contractors. The effectiveness of the present approach was tested by applying it to a case study of the prequalification assessment of four construction companies' in Bandar Imam Khomeini municipality, Khuzestan, Iran. It is worth mentioning that the prequalification assessment by the proposed approach is approved by the project stakeholders and is consistent with their expectations. It can be concluded that based on relevant ranking and weighing of companies that procedure can be extended to the same studies in this regard, and the contribution of the present study is to propose a support system for prequalification and identification of contractors' ability, before assigning projects to companies for success in projects.*

Keywords: *Support system, Contractor Prequalification, MCDM, CRITIC, EDAS*

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1. Introduction

Construction plays a key role in any economy; henceforth, it is important to push forward and support the construction industry for developing the countries suffering from under development. The gross output of the construction industry is the value of all the buildings and works produced by the industry in a given period of time, normally a year. In the world as a whole, it is probably about 10 percent of Gross National Product (Xu et al., 2020). In most developing economies around the world, the construction industry plays a significant role in the economy and can be hailed by the government as a platform to stimulate national economic transformation towards the status of a developed country (Mat Isa et al., 2015). In the concern of developing the countries, the construction industry is typically the alarm for financial growth and the main producer of skilled occupations. Important challenges in presentation, productivity, labor, and sustainability contains undermined industry reliability and growth. Despite extensive studies, the development of the industry has shown slow progress. It is almost certain that the existing construction studies have contributed a lot to sympathetic the major causes and consequences of construction issues. Therefore, poor presentation in construction developments remains a worldwide marvel (Yap et al., 2019).

The construction industry in Iran is challenged with other glitches such as unpredictability in the cost of material, wobbliness in production and investment laws and guidelines, the frailty of transportation infrastructure, international sanctions etc. Furthermore, the selection of suitable contractors also is a major crisis for the entire world and majorly for Iran construction industries (Poloie et al., 2012). Construction Contractors play an important part in any construction projects, for the successful or unsuccessful release of projects, that's why contractor selection is the most critical decision for project. The selection process should embrace the investigation of contractors' potential to deliver a service of an acceptable standard, on time, and budget (Topcu, 2004).

Khuzestan province is the major oil-producing region of Iran, and is also one of the wealthiest provinces in Iran. Khuzestan ranks third among Iran's provinces in GDP. The highest construction budget in the whole country was allocated to Khuzestan, Iran in 2019. The government construction budget was $ 226,732,000 for the Khuzestan province in 2019. The municipality's construction budget of Khuzestan province allocated around $ 125,224,000 in 2019 in Khuzestan province, Iran. According to the interview of the mayor of Bandar Imam Khomeini, 350 active construction projects were running there in 2017. One of the main functions of the Plan and Budget Organization (PBO) is to take the assessment of Iranian Contractors, Considering criteria and capacity qualifying in five grade terms of throughput and from large to small ranked as follows, contractors ranking from level one to level five. Numerous factors are influential in determining the rank and grade of a contracting company. Educational and work records of the board members and staff of the company, work records of the company, the status of financial accounts, etc.

Therefore, this paper tries to make a support system for the prequalification of contractors within the enterprise, that an organization or client can recognize the potential of the contractor before competitive tendering and obtaining bids. Prequalification is an important part of the process of finding the right contractor for the project. Therefore, this research attempts to make certain distinctions and classification between contractors, which are at the same level. Based on the author's point of view, there is a difference between the contractor who has five years'

experience with that who has only one-year experience where both of them are in the same rank; thus offering a particular classification between contractors who are at the same rank is requirement. The necessity in the system for the prequalification assessment of construction contractors (Iran) gets back to the lack of relevant study comprising of the need to put the required qualifications in a frame for the identification of contractors' ability, before assigning projects to companies. Therefore, our efforts were focused to propose a support system for the assessment of construction contractors. Success in any construction project majorly depends on choosing the right contractors, contractor prequalification is a process that is widely used to select responsible and competent contractors to perform the construction contract and provide the desired results with minimal damage, because potential contractors are measured and judged according to a set of common criteria, the contractor's prequalification can be considered as a multi-criteria decision issue (Nieto-Morote & Ruz-Vila, 2012). The present study focuses on exploring support system for the prequalification assessment of contractors by offering a review of literature to identifying the various assessment criteria of construction contractor.
First, various assessment criteria of construction contractor are identified from available literature and categorized to secure the five prominently used performance measures of a firm, namely: general information, financial aspect, technical and equipment information, management information, professional Experience information of companies in the framework of a questionnaire. Developing a frame for contractors' prequalification assessment through MCDM practices is an essential step for project owner's for recognizing the potential of construction contractors to address their variable future needs. Few studies discuss how prequalification assessments are essential for sustaining the competitive advantage of a construction project as a whole, and no proper classifications and guidelines exist to classify contractors holding the same rank. Hence, this study focuses on:

i. Identifying various construction contractor assessment criteria from the existing literature.
ii. Recognizing the contractors' potential before the tender process.
iii. Classifying contractors, which are holding the same rank.

The most important message from this research is prequalification of contractors within the enterprise, that an organization or client can recognize the potential of the contractor before the tender process. Contractor selection is a critical activity that plays a major role in the success of the projects؛ and prequalification is an important part of the contractor selection process of finding the right contractor for the project.

2. Literature review

Awad & Fayek (2012) recognized and categorized the most significant assessment factors that guarantee applicants and brokers considerations when assessing a particular construction project for runway purposes. They used many data collection methods such as interviews, questionnaires, and interacting meetings, with highly experienced experts, which were conducted to compile a comprehensive and detailed list of the evaluation criteria. For solution methodology, they used fuzzy logic and expert systems mutual to grow a decision support system for applying in contractor and project assessment. They asserted that the strategic system could assist contractors to self-assess and to recognize areas for promotion to better get an attachment for construction projects.

Ng (2001) demonstrated the performance and presentation of the method by analyzing with the theoretical system, which is called case-based reasoning System that can help expert and decision-makers to additional reliable, prompt decisions for the contractor's prequalification dimension and offer as a new case for formulating factors for the contractor's prequalification for expert judgment. Experimental results show that the satisfied and the case-based reasoning System is appropriate for modeling the scope of the contractor's prequalification. El-Sawalhi et al., (2007) established a state-of-the-art system for prequalification based on combining the merits of the AHP, Neural Network, and Genetic Algorithm in one consolidated model, which is able to overcome the limitations of the published system. They used this method in the Gaza Strip and West Bank and all sub-criteria will be tested via an email questionnaire to reach a consensus for achieving that prequalification that is suitable to be adopted. The proposed Genetic-Neural Network model will overcome most of the disadvantages of published models, particularly the accuracy of the model outputs and the prediction of the contractor's performance. Nieto-Morote and Ruz-Vila, (2012) researched a case study for the rehabilitation project of a building at the University Polytechnic of Cartagena is presented to illustrate the use of the proposed model and linguistic assessment or exact assessment of the performance of the contractors on qualitative or quantitative criterion, respectively, they suggested system provides a systematic scaffold for contractor assessment in a Fuzzy environment that can be easily extended to the analysis of other classification problems in project management. Kishore et al., (2020) developed a framework for construction subcontractor's selection, they used AHP and SAW method for Analyzing data, in a real case study in Iran Khuzestan's presence, for collecting quantitative data from main contractors and Subcontractors applied a prequalification assessment, finally, the result showed the priority in subcontractors' selection as Hejrat Manesh Izeh (i), Khesht Sazan Karoun (ii), Yeganeh saze omid (iii), Sakht karan Moongasht (iv), Darya Sanat Khavarmianeh (v), Omran mehragane Yosef (vi) respectively. Jafari (2013) investigated the central aims of prequalification to recognize an array of appropriate contractors that are required for post-qualification steps and further considerations, proposed a novel contractor prequalification model with the goal of deciding this issue, he used quality function deployment to involve the 'voice of the project owners' through the prequalification of contractors in the construction projects, this model employs the quality function placement system and reflects the project owner's needs and the contractor's abilities, used a numerical example and found that the thought of the project goals or the project owner's needs and prospects can influence contractor prequalification.

Khosrowshahi (1999) suggested the artificial neural network as the most suitable technique to grade contractors, because of its competence to process the noisy data, and thus reliable for building a non-linear association among the score of the individual criterion and its impact on the decision to be made. Ka Chi Lam and Yu, (2011) developed a novel technique for contractor prequalification, which is called the multiple kernel learning method, Hence, the capability of the multiple kernel learning method was compared with support vector machine models through a case study, From the outcome, it has been shown that both method perform well in classification, and multiple kernel-learning model is better than support vector machine models.

Sönmez et al., (2002) investigated a contractor prequalification problem to show how the evidential reasoning approach can overcome this issue; used the Dumpster-Shafer theory to obtain partial evidence for an acceptable conclusion, finally the proposed method, the evidential reasoning approach, makes the concept of degree of belief. Sacks and Harel (2006) proposed an economical game theory approach for understanding the behavior of subcontractors in assigning resources to projects and the influences on workflow constancy applied in gaming theory. The study asserted that impractical scheduling and over-commitments of subcontractors in manifold projects jeopardize the relations between the supervisors or managers and the subcontractors and thus, achieving success in projects. Finally suggested into thought subcontractors' behaviors across organizational, social, and technical aspects as pre-qualification criteria in instruction to control possible achievement goals in projects. Banaitiene and Banaitis, (2006) studied on the criteria employed for contractor selection and assessment of bid Tender offer in Lithuania and abroad, which analyzes issues related to the evaluation of contractors' qualifications, the data was collected from the questionnaire survey, the outcomes presented that the proposals are based on experts' estimates of the weight of contractors' evaluation criteria. Finally, the finding indicated three main weights of contractor evaluation criteria such as (i) Bid price (ii) Legal activity (iii) Contractor adequacy.

Kukoyi et al., (2021) determined the prequalification of selecting construction project contractors using Health and safety criteria Cronbach's alpha was used to test the reliability of the questionnaire used for data collection, the results show that health and safety is not a clients' goal or a project value hence, health and safety are not viewed as a vital pre-qualification criterion for contractor selection.

Acheamfour et al., (2019) declared that contractors' prequalification models that considered clients' objectives only focused on cost, time, and quality as criteria for selection. Furthermore, associating the lowest bidder with a satisfactory project outcome is not the best act. Duarte and Sousa, (2020) Developed a simple and fast supply chain partner prequalification process, which agrees to a questionnaire, an automatic assessment, and a classification method, used the prequalification questionnaire and the questionnaire consists of grouped questions, the main achievement was the managers' lack of familiarity with analysis and improvement techniques, the difficulty of defining quality. Landy et al., (2020) figuring out the service quality factors that are considered more important in the construction sector, the procedure was documental and based on a review of articles obtained from major scientific databases, the result shows that in all cases, the traditional models of service quality were used as guidelines to explain and adapt to specific contexts, overall, the results indicate a generalized conservative approach that characterizes this sector. Acheamfour et al., (2019) investigated the impact of contractors prequalification on construction project delivery with empirical arguments and has given some recommendations regarding success in construction project delivery performance in terms of time and quality in the adoption of due process, not minding the cost of the project, the contractual qualification building projects' time delays, finances the fund's credentials and project characteristics and cost increases are closely linked to contractors' qualifications criteria. Patil et al., (2020) evaluated five criteria along with their sub criteria for contractor prequalification, such as technical considerations, management considerations, financial considerations, reputation considerations and health, safety and environmental considerations, figuring out the top three causes of inadequate contractor prequalification, the outcome shows serves as the fundamental for further experiential studies on contractor prequalification criteria. (Adedokun, 2020) identified the significant factors for the selection of contractors in construction projects, for data collection used 120 questionnaire surveys adopted, observed that capital bid, financial status, experience, the experience of technical personnel, and client-contractor relationship are the most important sub-factors for contractors' prequalification. (Khoso et al., 2020) investigated the most suitable criteria for the pre-qualification process for Pakistan construction projects, data collection gathered through interviews and floating several questionnaires, for data analysis applied computer software, observed that the most important factors are experience and past performance, financial stability, personnel capabilities, equipment capabilities, and managerial capabilities.

Doloi (2009) studied prequalification criteria in contractor selection and impacts of contractor selection on project success, selected criteria (43 cases) for evaluating project performance through multiple linear regression models, applied a questionnaire survey and expert opinion to data collection. Jaskowski et al., (2010) based on the questionnaire survey tried to find the right contractor in the prequalification step, applied an example that illustrates this approach to determine criteria weights for bidder assessment, the findings passed through the pairwise comparison, AHP weighing system, and Fuzzy set theory with the emergency of pertinent outcomes in the assay. The outcomes demonstrated that the offered fuzzy AHP method is superior to the classic AHP in terms of developed excellence of criteria prioritization. Rashvand et al., (2015) developed a comprehensive contractor assessment system that directly addresses the contractor's abilities and practices as a critical element at the prequalification stage, analyzed data based on an analytic network project model, the results showed that this model evaluated scores that are the effectiveness of a contractor's management ability. K C Lam et al., (2000) introduced a model to support contractor prequalification selection using artificial neural networks.

The prequalification assessment of the contractor has been done via an extension of the multi-kernel learning model based on the questionnaire. The following step verified results via sensitivity analysis of a few decision support systems that were actually algorithms measurement (Ka Chi Lam & Yu, 2011).

Korytárová et al., (2015) completed the research based on 345 tenders for public works contracts in the Czech Republic and compared the results with the projects in Poland from 2013-2014, the data collected from official databases; the significant differences appeared in two areas of professional experiences and economic and financial qualifications. A study used the support vector regression model to select the contractor with relevant results for 250 virtual contractors. Awad and Fayek (2012) Used questionnaires, face-to-face and individual interviews, and interacting group meetings, with highly experienced experts for contractor selection. Therefore, 38 alternatives and 32 prequalification cases were chosen to configure the dimensions of the decision-making system with an accuracy of up to 84.0%, and developed a new pre-qualification method using a quality function deployment technique based on availability and requirements of the project and contractor. Attar et al., (2013) Proposed a method to support vector machine that has been based on the forecast of a contractor's deviation from a client's objectives, for analyzing the system, Contractor prequalification for two hundred and fifty contractors was solved, they believe that the suggested system had a great generalization in linear, nonlinear, noisy, and inductive environments. The results showed that support vector machines could reliably perform even with a small amount of training data. Contractors' pre-qualification models that considered clients' objectives only focused on cost, time, and quality as criteria for selection; Furthermore, associating the lowest bidder with a satisfactory project outcome is not the best practice, Insights on various prequalification criteria can have positive impacts on projects (Acheamfour et al., 2019). Chen et al., (2021) Proposed an integrated subjective-goal approach to calculate criterion weights and to put into effect an ELECTRE III-based method that incorporates that consists of HFLTS opportunity distributions, which permit treating the indetermination, imprecision, and uncertainty embedded in value determinations of alternative-criterion selections whilst comparing bids. Prasetia and Imaroh (2020) Developed an approach for carrying out an evaluation of the contractor's selection/providers in the upstream oil and gas industry with the goal of enforcing green supply chain management with the AHP method, the result shows that the two most important criteria are environmental criteria and health and safety criteria. Marović et al., (2021) Developed an analytic hierarchy process (AHP) together with PROMETHEE for Selecting the Optimal Contractor, the result of their synergy were proposed that: (i) allows the incorporation of opposing stakeholders' demands; (ii) increases the transparency of decision-making and the consistency of the decision-making process; (iii) enhances the legitimacy of the outcome. Kukoyi et al., (2021) Determining the reasons for clients contending with contractors that are not committed to health and safety, using a questionnaire for data collection, and Mean scores for data analysis, finally provided information on influence clients to have to respect health and safety as a prequalification criterion and towards construction workers' health and safety. Dehmourdi et al., (2021) Studied the impact of the crisis in construction projects, using the CRITIC method to the weighting of crisis factors and WASPAS method to find out the most influential crisis factors and made a case study of "Khuzestan province (Iran), finally, observed that most influential crisis factors in the Khuzestan construction industry are the economic crisis, followed by the market and real estate. Okifitriana Latief (2021) developed the Quality Management System (QMS) for the Construction Services Procurement Process to Improve the Quality of Contractor Performance in universities Indonesia, used the survey, and statistical analysis for data analysis, and finally developed a Quality Management System for the construction services procurement process in universities Indonesia. Afshar et al., (2017) proposed a practical prequalification technique for contractor assessment that uses interval type-2 fuzzy sets to report both linguistic imprecision and differences of opinions, they solve a numerical example has been presented to exemplify how the prequalification technique is carried out using type-1 and type-2 fuzzy sets. Associating the outcomes shows the effect of preserving the erraticism of the evidence in the chain of reasoning. The contractor prequalification assessment is a screening instrument by the in-charge staff, client, and project supervisor based on a certain and defined framework where lots of criteria and factors are allocated to be processed by a variety of MCDM models (Russell & Skibniewski, 1988). Topcu (2004) provided a new framework based on the MCDM models for the construction contractor and suggested to the Turkish public sector, the system suggested that three key goals have been produced for assortments as cost, time, and quality, they asserted this model can be used as a decision support system by the project owners in order to recognize the most appropriate contractor that will be given the contract. Nassar and Hosny (2013) 294 projects passed through the prequalification assessment for contractor selection in UAE, the MCDM models of the AHP and Fuzzy algorithm used to categorize the companies for the projects pertain to quantitative and qualitative measures.

Keshavarz Ghorabaee et al., (2015) proposed a new approach for the EDAS, in the suggested approach of the system; according to positive and negative distances from the mean solution to evaluate the options, to prove the performance of the proposed method in the Multi-Criteria Cataloguing issue, it is mentionable for better understanding they used a mutual example, asserted that the proposed method could be used for multi-criteria decision-making problems, associated the proposed method with VIKOR, TOPSIS, SAW, and COPRAS as a numerical example. They observed that the suggested method is steady at dissimilar weights and is consistent with other methods. Kazan and Ozdemir (2014) studied financial ratios of economical statements of the fourteen-large scale conglomerates, which traded on ISE, used the CRITIC Weights method to calculate nineteen criteria over three periods (2009-2011), and found their financial ratio weights. Then among multi-criteria decision-making methods, the TOPSIS method was employed to measure and evaluate the performances of 14 large-scale ISE-listed conglomerates.

Kahraman et al., (2017) suggested that the intuitive fuzzy EDAS method used to evaluate the options for selecting a solid waste disposal site; Comparative analysis and sensitivity are also included. Sensitivity analysis is also given to show how strong decisions are made intuitively through fuzzy EDAS. Liang et al., (2018) evaluated a case of the cleaner production performance for four gold mines is provided to explain the application of the proposed method, first determined the comprehensive criteria weights obtained from the combined criteria weights extended SWARA model, a systematic comparison analysis with other existent methods is conducted to reveal the advantages of our method, in the last phases obtaining the ranking orders results indicate that the integrated EDAS-ELECTRE method is suitable and effective for gold mines to evaluate their cleaner production performance, and has important reference values for the cleaner production management and operation. Adalı and Işık (2017) evaluated four contract builder options using the CRITIC method and MAUT methods. For achieving the importance of criteria used CRITIC method, while the complete ranking of the contract builder options obtained using MAUT, and then the output it is important to work with the right contract manufacturer to gain a competitive advantage, they believe CRITIC and MAUT solve the problems of selecting a contractor for a textile company.

Žižović et al., (2020) Proposed a new method in modifying the (CRITIC) method, which waterfalls underneath objective methods for decisive factors weight constants, by presenting a new procedure of combination of weight constant values in the CRITIC-M method, a more complete sympathetic of data in the initial decision matrix was made possible, foremost to additional objective values of weight constants, Therefore, the relations between information in the initial decision matrix are obtainable in a more objective solution. Maheshwari et al., (2021) developed a finite element model for a ventilated brake disc is developed to numerically simulate the fatigue life and axial deflection, for data analyses and compare the various design parameter combinations, multi-criteria decision-making such as ARAS, EDAS, COPRAS, FEA, MCDM and TOPSIS are used. Applied TOPSIS to optimize process parameters of the vibration-assisted turning process; also investigated EDAS method in a broad range of technological systems to engineering problems. (Ghorabaee et al., 2018).

Mousavi-Nasab and Sotoudeh-Anvari (2017) reviewed application of MCDM techniques including EDAS in the field of material selection. Similarly, COPRAS (Complex Proportional Assessment) is an advanced MCDM methodology, which is based on the evaluation of alternatives to the solution of the problem proportionately. Zavadskas et al., (2019) introduced a new technique based on EDAS in the Minkowski space (EDAS-M), which was the modified extension of conventional EDAS approach. To develop the proposed plan, they used CRITIC method for obtaining the objective criteria weights, applied seven unusual methods for comparing their plan to validate the efficiency and effectiveness of the proposed method. Developed the Fuzzy evaluation based on distance from average Solution (Fuzzy EDAS) method for resolving the air-handling unit and the heating, ventilating and air conditioning system and its supplier collection problem for a green multifunctional shopping center project located in Russia, sensitivity analysis was approved out to show the constancy of the consequences (Polat & Bayhan, 2020).

The foremost aim for the applied EDAS method is to allow both the calculating the criteria weights and ranking the alternatives in a simple and easy way. If other MCDM methods such as COPRAS, fuzzy ARAS, VIKOR, MOORA, were chosen, they should have been integrated with the criteria weighting methods such as AHP, which would complicate the problem (Stević et al., 2018).

3. Methodology

The solution methodology applied for the present study is the CRITIC method for obtaining the importance and influence of contractor assessment factors and the EDAS system for recognizing the contractors' potential before competitive tendering and obtaining bids. A questionnaire was designed to collect the initial matrix of data. To determine the weight of each criterion used as per the weighing system of CRITIC concerning the variables. The members who participated to complete the assessment program were those who were in close connection with the contractor and supervisors of the project, around 4 members. In the present case study, four construction companies including Daghigh Koshan Sepahan, Hejrat Manesh Eizeh, Hemat Talash, and Omran Mehran Mongasht were assessed to get the contractor prequalification ranking levels. In addition, the contractors participated in tendering the project and evaluated in the Bandar Imam Khomeini municipality, Khuzestan, Iran. For obtaining the importance of each sub-factor using the CRITIC method and for classifying and ranking of the contractors by applying the EDAS system for recognizing the contractors' potential before competitive tendering and obtaining bids. The studied contractors are from the same competence ranking (rank 5) obtained from in-charge the Plan and Budget Organization (PBO) of Iran. Previous performance evaluation completed by staff who have related information with these companies in ways such as the director of the technical department, Supervisor Engineer, Resident Engineer, and Consultant Engineer. The sub-factors and main factors of assessment comprising the general ability, financial ability, technical and equipment ability, management ability, and professional experience of companies consists of 56 cases in this regard.

Many studies have analyzed construction contractor assessment in terms of their advantages and have produced conceptual frameworks. However, in Iran scenario, additional research is needed to identify the potential of contractors who in the same rank, before competitive tendering and obtaining bids. This study proposes to:

i. Identify the essential contractors prequalification assessment factors from existing literature;
ii. Conduct a questionnaire-based survey from Bandar Imam Khomeini municipality, Khuzestan, Iran experts to identify the importance of each factor;
iii. Conduct a second questionnaire-based survey with the same experts as respondents to obtain the potential of the four contractor;
iv. Apply CRITIC system to find the total grade of the each factor;
v. Identify the rank and potential of each contractor through EDAS method.

3.1. CRITIC Method

The MCDM models have always been associated with two factors and issues, one is the weighting of criteria and the other is the ranking of options. These two categories are complementary to each other, sometimes by one method and sometimes by a combination of methods. In this method, the data are analyzed based on the degree of interference and conflict between the factors or criteria. CRITIC method of processing causes the role of each factor to be applied correctly in the results of the calculations. In the CRITIC method, for each evaluation criterion, there is a range of variations of the measured values between the pixels (options), which are expressed in the form of a membership function. Each of the components formed for the criteria used has statistical parameters such as standard deviation. These parameters represent the degree of difference in the relevant standard values. The CRITIC method steps 1 to 3 as follows:

Step 1: The decision matrix X is formed, it shows the performance of different alternatives with respect to various criteria.

$$X = \begin{bmatrix} x_{11} & x_{11} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix} \quad (1)$$

Step 2: Decision matrix is normalized data using the equation 1:

$$r_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})} \quad (2)$$

r_{ij} - Normalized performance value

X_{ij} - Each sub-factors number

Step 3: While determining the criteria weights, both standard deviation of the criterion and its correlation between other criteria are included.

$$C_j = \sigma_j \sum_{j=1}^{n} (1 - r_j) \quad (3)$$

C_j - Quantity of information contained

σ_j - Standard deviation

For determine the importance of each sub-factor used equation number 3.

$$W_j = \frac{c_j}{\sum_{j=1}^{n} c_j} \tag{4}$$

3.2. EDAS Method

The EDAS method is the best solution is the distance from the average solution. This method does not need to calculate the positive and negative ideals, but consider two criteria for evaluating the desirability of options; the first is a positive distance from the mean (PDA) and the second is a negative distance from the mean (NDA). These measures can show the difference between each option and the median solution. Options are evaluated according to higher PDA values and lower NDA values. Higher PDA values or lower NDA values indicate that the option is better (Keshavarz Ghorabaee et al., 2015).

Step 1: Select the most important criteria that describe alternatives.

Step 2: Construct the decision-making matrix (X), shown as follows

Where Xij denotes the performance value of ith alternative on jth criterion.

Step 3: Determine the average solution according to all criteria, shown as follows:

$$AV = [AVJ]1 \times M \tag{5}$$

Where,

$$AVj = \frac{\sum_{i=1}^{n} xij}{N} \tag{6}$$

Step 4: Calculate the positive distance from average (PDA) and the negative distance from average (NDA) matrixes according to the type of criteria (benefit and cost), shown as follows:

If jth criterion is beneficial

$$PDA = \left([PDA_{ij}\, n \times m]\right) \tag{7}$$

$$NDA = \left([NDA_{ij}\, n \times m]\right) \tag{8}$$

And if jth criterion is non-beneficial,

$$PDA_{ij} = \frac{\text{MAX}(0,(Xij - AV\ j\ ))}{AV\ j} \tag{9}$$

$$NDA_{ij} = \frac{\text{MAX}(0,(AV\ j - Xij))}{AV\ j} \tag{10}$$

Where PDA_{ij} and NDA_{ij} denote the positive and negative distances of ith alternative from an average solution in terms of jth criterion, respectively.

Step 5: Determine the weighted sum of PDA and the weighted sum of NDA for all alternatives, shown as follows:

$$SP_i = \sum_{j=1}^{m} Wj\ PDA_{ij} \tag{11}$$

$$SN_i = \sum_{j=1}^{m} Wj\ NDA_{ij} \tag{12}$$

Where Wj is the weight of jth criterion.

Step 6: Normalize the values of SP and SN for all alternatives, shown as follows:

$$NSP_i = \frac{SP_i}{MAX_i(SP_i)} \tag{13}$$

$$NSN_i = 1 - \frac{SN_i}{MAX_i(NS_i)} \tag{14}$$

Step 7: Calculate the appraisal score (AS) for all alternatives, shown as follows:

$$ASI = \frac{1}{2}(NSP_i + NSN_i) \tag{15}$$

4. Results and discussion

Contractor prequalification assessment in the construction industry is an essential part of the project development process because contractors play a pivotal role in the extension of projects and resources.

Table 1. Sub criteria of general information

	Sub criteria	CRITIC	Daghigh Koshan	Hejrat Manesh	Hemat Talash	Omran Mehran
	Sub criteria of general information	weight	Appraisal Score (AS)			
1	Follow The extent of rules and regulations	0.0163	0.719	0.507	0.878	0.719
2	Follow The extent of standard and specification	0.0163	0.629	0.507	0.548	0.2057
3	Completeness of documents of firm	0.0163	0.629	0.169	0.125	0.360
4	Quality of documents plans and drawings	0.0133	0.527	0.098	0.477	0.587
5	Use the value engineering	0.0163	0.822	0.615	0.175	0.240
6	Observance the health, safety, environment, and energy	0.0163	0.822	0.120	0.292	0.144

7	Observance of rules	0.0163	0.091	0.676	0.878	0.205
8	Environmental, labor and social security	0.0157	0.325	0.334	0.590	0.197
9	Stability of board members and specialist staff	0.0163	0.476	0.094	0.585	0.449

Prequalification is an important part of the process of selecting the right contractor for the project. Whereas multiple criteria may contribute to prequalification measures, it is important to identify the essential assessment criteria. Based on the on the present case study the following results are determined. Table 1 shows the criteria of general information, appraisal score of each contractor, and total CRITIC score of each criteria. According to result of CRITIC method, the importance of most criteria in general information section almost match with each other.

Table 2. Sub criteria of financial information

	Sub criteria	CRITIC	Daghigh Koshan	Hejrat Manesh	Hemat Talash	Omran Mehran
Sub criteria of financial information		weight	Appraisal Score (AS)			
1	Financial position of the contractor	0.0163	0.339	1.000	0.702	0.450
2	The liquidity of contractor	0.0232	0.130	0.172	0.624	0.292
3	Total assets of contractor	0.0163	0.091	0.604	0.798	0.206
4	Securities other than shares	0.0133	0.075	0.415	0.358	0.588
5	Timely payment of wages of employees, agents, and subcontractors	0.0199	0.580	0.206	0.000	0.175
6	Insurance to all facilities, equipment, and personnel against possible accidents	0.0163	0.476	0.348	0.439	0.540
7	Shares and equity contractors in the bourse	0.0157	0.604	0.162	0.211	0.628
8	Insurance technical provisions in the site of the contractor	0.0163	0.646	0.121	0.293	0.360
9	Macroeconomic and financial developments in of contractor experience account	0.0163	0.476	0.716	0.251	0.000
10	Balance sheet vulnerabilities of	0.0173	0.667	0.538	0.266	0.218

	contractor					
11	Capital ratios of contractor	0.0163	0.494	0.508	0.251	0.000
12	Standalone bank credit ratings which contractor has account	0.0227	0.127	0.484	0.610	0.333

From the Table 2 it is observed the criteria of financial information, appraisal score of each contractor, and total CRITIC score of each criteria. It is observed that the liquidity of contractor (sub criteria number 2) has most influential in this section.

Table 3. Sub criteria of technical and equipment information

	Sub criteria	CRITIC	Daghigh Koshan	Hejrat Manesh	Hemat Talash	Omran Mehran
	Sub criteria of technical and equipment information	weight		Appraisal Score (AS)		
1	Site preparation	0.0163	0.494	0.508	0.702	0.450
2	Site amenities	0.0186	0.386	0.000	0.625	0.234
3	Transportation facilities contractor	0.0232	0.130	0.687	0.416	0.205
4	Provide communication and access ways	0.0227	0.000	0.705	0.610	0.714
5	Status of site technical office	0.0227	0.229	0.588	0.174	1.000
6	Quality of specifications standards	0.0163	0.091	0.121	0.251	0.514
7	Using new technology	0.0227	1.000	0.588	0.348	0.000
8	Quality and quantity of construction machines	0.0163	0.339	0.423	0.000	0.240
9	Quality and quantity materials control	0.0163	0.629	0.423	0.251	0.450
10	Quality operation in mechanical	0.0163	0.091	0.716	0.549	0.144
11	Quality operation in electrical	0.0163	0.548	0.508	0.798	0.000
12	Contractor performance in laboratory	0.0157	0.457	0.116	0.422	0.432
13	Take timely action for shortage and problems	0.0163	0.494	0.325	0.439	0.540
14	Provide timely report	0.0327	0.987	0.484	0.878	0.960
15	Provisional hand-	0.0173	0.436	0.179	0.000	0.255

	over timely					
16	Having suitable and sufficient equipment and machinery to carry out construction	0.0173	0.097	0.370	0.532	0.477

From the Table 3 it is noted the criteria of technical and equipment information, appraisal score of each contractor, and total CRITIC score of each criteria. From the Table 4 it is observed the criteria of management information, appraisal score of each contractor, and total CRITIC score of each criteria.

Table 4. Sub criteria of management information

	Sub criteria	CRITIC	Daghigh Koshan	Hejrat Manesh	Hemat Talash	Omran Mehran
Sub criteria of management information		weight	Appraisal Score (AS)			
1	Efficiency, accuracy and effectiveness planning of contractor's methods	0.0227	0.000	0.168	0.222	0.800
2	Performance and effectiveness of the contractor's methods for organization and control the project	0.0173	0.436	0.138	0.266	0.153
3	Performance and effectiveness of the contractor methods for quality and quality assurance	0.0163	0.411	0.348	0.702	0.450
4	Status of human resource management	0.0163	0.476	0.484	0.251	0.360
5	Stability in the organization and the executive team the contractor	0.0173	0.524	0.449	0.310	0.545
6	Coordination of contractor with covenants and other relevant factors	0.0157	0.000	0.487	0.527	0.197
7	Coordination of contractor with subcontractor	0.0163	0.091	0.121	0.293	0.851
8	Performance and abilities contractor project management	0.0227	0.127	0.392	0.976	0.333
9	Performance and abilities contractor site	0.0227	0.762	0.995	0.610	0.714

	management					
10	Methods of contractor procurement	0.0163	0.629	0.716	0.439	0.000
11	Performance of contractor program	0.0163	0.629	0.604	0.549	0.240

From Table 5 it is seen the criteria of professional experience information, appraisal score of each contractor, and total CRITIC score of each criteria. It is worth mentioning that the criteria number 7, (Good experience in previous works) was most influential in this section.

Table 5. Sub criteria of professional experience information

	Sub criteria	CRITIC	Daghigh Koshan	Hejrat Manesh	Hemat Talash	Omran Mehran
	Sub criteria of professional experience information	weight		Appraisal Score (AS)		
1	Executive experience in the field and field the desired work	0.0163	0.000	0.508	0.293	0.450
2	Classified documents and documentation of the work done in the previous project	0.0163	0.091	0.651	0.659	0.450
3	Native contractor or the project experience	0.0163	0.339	0.484	0.878	0.514
4	Creativity and Innovation in previous projects	0.0163	0.548	0.538	0.549	0.514
5	On-going communication and coordination with the client and monitoring devices	0.0163	0.494	0.282	0.176	0.654
6	Awards and appreciation official letters	0.0163	0.091	0.716	0.176	0.180
7	Good experience in previous works	0.0227	0.471	0.168	0.813	0.333
8	Quality of provided previously project	0.0186	0.104	0.482	1.000	0.615

The t-test and paired test statistical analysis confirmed no significant differences between both values of W for the AHP and CRITIC models. Figure 1 displays the comparison of the values of W of AHP and CRITIC. Figure 2 shows the sequence number diagram for both w values of the AHP and the CRITIC model. The Friedman test calculated the ranks for both W values as AHP (1.45) and CRITIC weighing system as 1.55 with a chi-square value of around 0.643. The distribution of weights of AHP was normal with a mean 0.02 and standard deviation 0.01 via a one-sample Kolmogorov-Smirnov test in the Null hypothesis (null hypothesis retained).

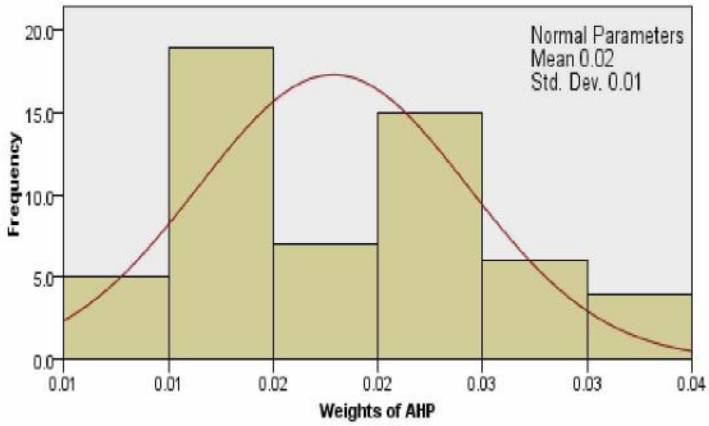

Figure 1. One-Sample Kolmogorov-Smirnov test.

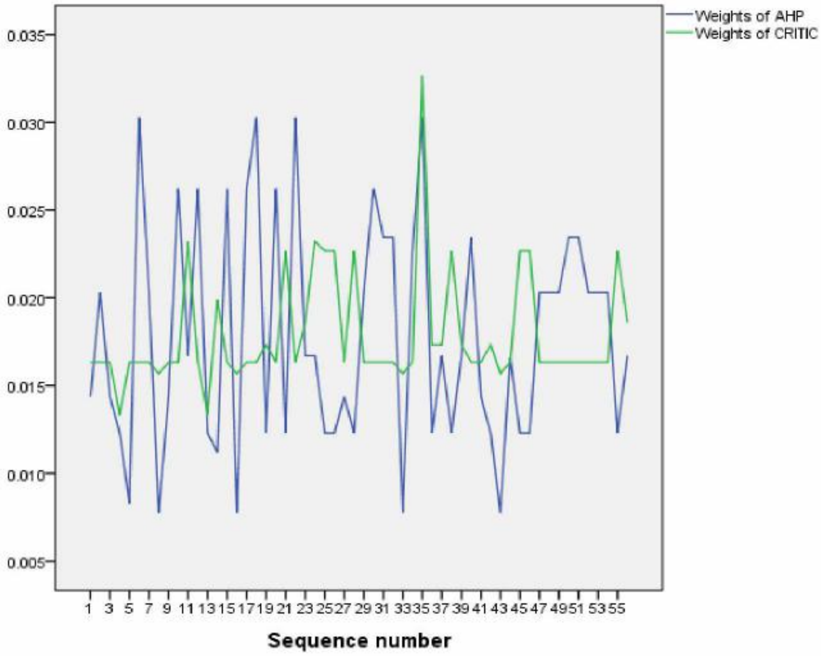

Figure 2. The sequence number diagram for both W values of AHP and CRITIC model

The sequence number diagram revealed that the expansion of W values does not follow a parallel trend but it is a linear development. The concept of a linear development refers to high overlapping between both w values when it goes to move with parallel lines. Figures 3 and 4 present the W values released in the ranking system of EDAS for both companies.

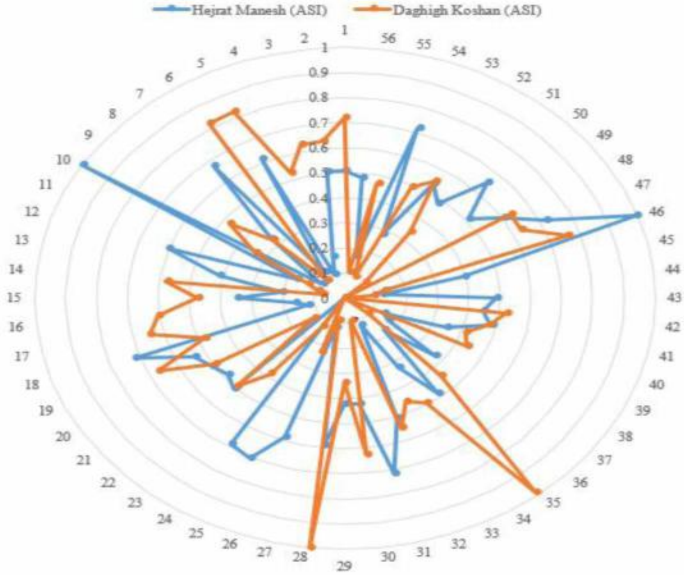

Figure 3. The W values released in the ranking system of EDAS for both companies

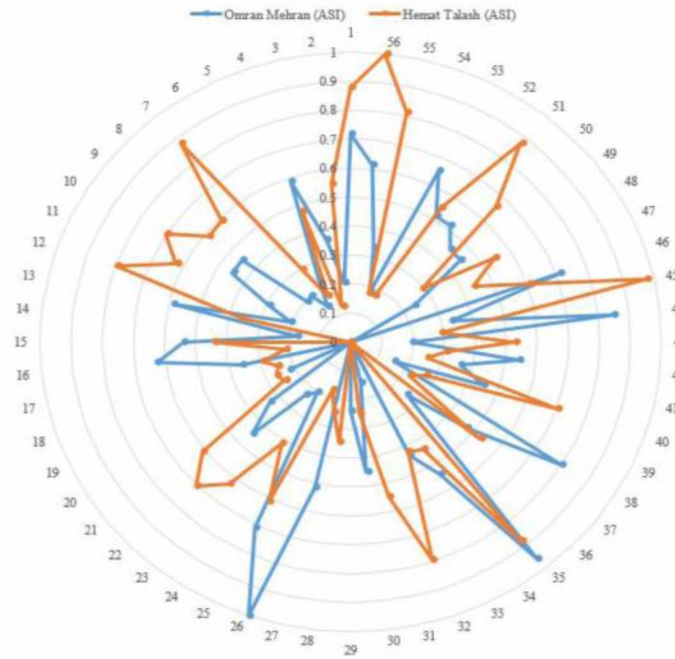

Figure 4. The W values released in the ranking system of EDAS for both companies

The findings of the EDAS model appeared in Table 6. The findings proved reasonable values in the ranking system with regard to this fact that the initial properties about companies were very close together. It needs to explain that the authors examined the various MCDM models to get the relevant response in this regard. However, the propinquity between findings caused us to fail and we could not realize the ranks for the companies.

Table 6.The Final ranking of companies in the EDAS model

Company	Score	Rank values
Daghigh Koshan Sepahan	22.38356729	3
Hejrat Manesh Eizeh	23.86945084	2
HematTalash	26.03712557	1
Omran Mehran Mongasht	21.8705158	4

5. Conclusion

The MCDM models facilitated the differentiation of the ranks between variables, criteria, and alternatives. The weighing systems also help to sort out the criteria based on values. A questionnaire was used to collect the initial data of research and was processed in the EDAS and CRITIC systems; it can be used to collect various kinds of data for the same objective. An inclusive, detailed list of 56 sub-factors under 5 main factors for project prequalification was compiled following a thorough literature review, and review of contractors by experts of Bandar Imam Khomeini municipality who already have done projects with contractors, and then used the CRITIC method for obtained the weighing and importance of each factor and classified the contractors by applied the EDAS system for recognizing the contractors' potential before competitive tendering and obtaining bids. By the present research, it was attempted to rank four companies in order to conduct a prequalification assessment. An inclusive, detailed list of 56 sub-factors under 5 main factors for project prequalification was compiled following a thorough literature review, and review of contractors by 4 experts who already have done projects with contractors, and then using the CRITIC method for obtained the weighing of each factor and classifying contractors by applied the EDAS system for recognizing the contractors' potential before competitive tendering and obtaining bids. The present research proposed herein a new approach to prequalification that accounts for multiple criteria when assessing the best contractor. The proposed support system was developed to help the tender holder, owner or client, and stakeholders to select the right contractors, and to afford a systematic and organized approach to the multifaceted issues. The effectiveness of the present approach was tested by applying it to a case study of the prequalification assessment of four construction companies' in Bandar Imam Khomeini municipality, Khuzestan, Iran. It is worth mentioning that the prequalification assessment by the proposed approach is approved by the project stakeholders and is consistent with their expectations. Note that, albeit the proposed method is a generalized approach and can be applied to a variety of projects, applying more pragmatic cases to approve the proposed approach is complicated because of the limited accessibility of project sources, the requirement to more adjust boundaries. The contribution of the present study proposed as a support system for prequalification and identification of contractors' ability, before assigning projects to companies for success in projects. The future research orientation can be oriented towards developing new MCDM models, weighing systems, and expansion in the content of questionnaires.

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ROBUST MAHALANOBIS DISTANCE BASED TOPSIS TO EVALUATE THE ECONOMIC DEVELOPMENT OF PROVINCES

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Abstract: *In this paper, 81 Turkish provinces with different development levels were ranked using the TOPSIS method. To evaluate the ranking with TOPSIS, we presented an improvement to Mahalanobis distances, by considering a robust MM estimator of the covariance matrix to deal with the presence of outliers in the dataset. Additionally, the homogenous subsets, which were obtained from the robust Mahalanobis distance-based TOPSIS were compared with robust cluster analysis. According to our findings, robust TOPSIS-M scores reflect the inter-class differences in economic developments of provinces spanning from the extremely low to the extremely high level of economic developments. Considering indicators of economic development, which are often used in the literature, İstanbul ranked first, Ankara second, and İzmir third according to the Robust TOPSIS-M method. Moreover, with the Robust Cluster analysis, these provinces were diagnosed as outliers and it was seen that obtained clusters were compatible with the ranking of Robust TOPSIS-M.*

Keywords: *Economic Development, Mahalanobis Distance, Robust Clustering, Robust TOPSIS-M, Outliers.*

1. Introduction

In today's world where globalization and competition are rapidly increasing, countries are trying to gain an advantage with both their economic activities and social policies. To increase the international competitiveness of the countries, it is aimed to keep the economic indicators in the national context. Because it has been observed that regional and local economies also affect the global economy and increase competition (Kılıç et al., 2011). Economic development has generally been

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conceptualized as a balance increase in per capita income (Ascani et al., 2012). However, studies draw attention to the importance of determining the factors affecting per capita income. For regional development, the necessity of both increasing exports and following import substitution strategies have been put forward (Shaffer, 1989; Blair and Carroll, 2008; Cooke and Watson, 2011). Exports are generally considered in two dimensions as the export of goods and services. Advanced technology and advanced industrial facilities used in developed countries increase the sales potential for the foreign market by enabling these countries to produce fast and high quality (Contractor and Mudambi, 2008). On the other hand, developing countries, follow a policy that will increase exports by utilizing their raw materials and underground resources. The service sector has been identified as a new growth engine for both developed and developing countries (Noland et al., 2012, Akın and Özsağır, 2012). Regions and provinces in the country carry out export activities according to the characteristics of their geographical location, production, and service types. According to these characteristics, there are important differences between the export capacities of the provinces and the development levels accordingly.

Economic development, in another definition, focuses on increasing wealth (Mathur, 1999). According to this view, domestic savings are one of the most important sources of development. The positive relationship between saving and growth has been noted in studies of many countries (Room, 2002; Carroll and Weil, 1994). In recent years a decline was observed in domestic savings in Turkey. This decline causes a negative impact on the economy through a deficit and it has led to the emergence of domestic savings again. (Peace and Space, 2015).

Another factor that is thought to have an impact on economic development is population. However, the direction and strength of the relationship between economic development and population are still under debate. While some argue that rapid population growth has a negative effect on economic development (Srinivasan, 1988; Kentor, 2001), there are also studies showing that the relationship between them is not significant (Easterlin, 1967). The population-oriented economic growth hypothesis, which states that population growth supports economic development, also maintains its validity. It is seen that population growth has positive effects on economic development, especially in developing countries (Furuoka, 2009). Increasing population brings some needs with it. The most important of these is the need for housing. With the sale of housing, not only the construction sector but also many sub-sectors such as cement, ready-mixed concrete, iron, and steel are affected. Specifically, when the economic contraction begins in developing countries, a way out of this bottleneck is sought by increasing investment expenditures in the construction sector. Thus, economic recovery is provided.

TOPSIS (Technique for Order Preference by Similarity to Solution) method makes it possible to assess the objects concerning multidimensional economic phenomena based on the group of economic variables (Yoon and Hwang, 1995; Balcerzak and Pietrzak, 2016). Most economists think that international comparisons of the level of sustainable development must be done with an application of quantitative methods (Balcerzak and Pietrzak, 2016). TOPSIS is referred to be a very useful and informative technique for ranking and selecting variables (Shih et al., 2007; Bhutia and Phipon, 2012, Kizielewicz et al. 2021). For this reason, TOPSIS is widely used in studies that are based on the comparisons of economic and financial performances and real-world problems. Eyüboğlu (2016) compared the developing countries considering macro performances as economic growth, inflation rate, unemployment rate, and the current account balance/GDP using Analytic Hierarchy Process (AHP) and TOPSIS methods. Using similar variables, Dinçer (2011) ranked both European Union members and candidate countries using TOPSIS and similarly, Kuncova (2012) made the comparisons of European countries in terms of e-commerce. TOPSIS method was also preferred to evaluate economic performances of countries during the financial crisis period (Mangır and Erdoğan, 2011) and used to examine the development achievement by European countries in the field of implementing the concept of sustainable development (Balcerzak and Pietrzak, 2016). TOPSIS method was employed to evaluate the good governance development in the European Union countries for the years of 2007-2017 (Ardielli, 2019). To assess the e-Government in the countries TOPSIS was used (Ardielli and Halaskova, 2015). Besides the comparisons of countries, municipalities were evaluated considering environmental sustainability using DEMATEL based TOPSIS (Kiliç and Yalçın, 2020). Slovak municipalities were assessed according to management criteria using TOPSIS (Vavrek, et al, 2015). Different from the listed studies here, TOPSIS was also used to identify suitable health indicators to evaluate the efficiency of Slovak municipalities (Vavrek et al., 2021).

In this study, it was aimed to evaluate the level of economic competition of 81 Turkish provinces considering the economic indicators using TOPSIS-M (Mahalanobis distance-based TOPSIS) which is based on the robust covariance matrix. The TOPSIS method is used to construct the ranking of items considering many variables and it is based on Euclidean distance that assumes the criteria of monotonically increasing or decreasing and this approach disregards the dependence among variables. Conversely, TOPSIS-M uses dependencies between variables considering the correlation matrix. However, in the presence of outliers, the use of methods based on covariance matrix should be approached with attention. Because the covariance matrix can be manipulated by outliers and give misleading results.

TOPSIS method is based on the distances from the model values ("positive ideal solution" and "negative ideal solution") and in case of the existence of outliers in a dataset, the maximum and minimum values of the variables affect the model values inevitably and this leads to excessive remoteness from typical values of the considered variables that narrow the range of variability of the constructed synthetic measure (Luczak and Just, 2020). Several studies in the literature suggested limiting the effect of outliers on the TOPSIS method. Khalif, et al. (2017) proposed the Spearman correlation matrix to handle outlier effects in the TOPSIS method. Luczak and Just (2020) used robust standardization and spatial median to make the TOPSIS method resistant against outliers. De Andrede, et al. (2020) used Singular Value Decomposition (SVD) TOPSIS approach to decrease the impacts of outliers while evaluating the performance of TV programs.

In this study, different from the previous approaches we presented an improvement to TOPSIS-M by using robust Mahalanobis distances which are resistant to outliers. To make Mahalanobis distances resistant to outliers, a robust covariance matrix was used. The covariance matrix employed in this study is based on the MM estimator. However, MCD, OGK, and S estimators were also evaluated, but since the results were very similar, only the results based on the MM estimator are included here.

To evaluate the level of economic competition of provinces in this study, per capita GDP, the trade deficit (import-export), the population, the total housing sales numbers, and the total bank deposit accounts were determined as variables. Since this dataset includes socioeconomic variables belonging to the provinces, due to the provinces with different development levels, the existence of outliers and dependency between variables are expected. Therefore, in the first stage of the application, descriptive statistics and correlation matrices were used to evaluate the dataset and outliers were diagnosed. In the next stage, the findings obtained from TOPSIS, TOPSIS-M, and robust MM covariance matrix based TOPSIS-M were evaluated. In addition to rank the provinces by taking into account the economic indicators, it was also included to classify provinces with robust cluster analysis. At the final stage, findings of robust cluster analysis were compared homogenous subsets obtained from robust Mahalanobis distance-based TOPSIS.

2. Methodology

TOPSIS method, originally developed by Hwang and Yoon (1981), is a simple and efficient Multi-Criteria Decision-Making (MCDM) method to identify solutions from a finite set of alternatives. The main idea is based on determining the best alternative which should have the closest geometric distance from the ideal solution. However, there are some main disadvantages in the traditional TOPSIS model: (i) correlations between criteria, (ii) uncertainty in obtaining the weights only by objective and subjective methods, finally, (iii) possibility of alternative closed to positive and negative ideal points concurrently (Li et al., 2011). Additionally, when the data set does not only include regular observations, outliers may have effects on the definition of ideal solutions and the calculation of distances it is important to consider robust estimators to deal with outliers. Because of the listed disadvantages, traditional TOPSIS can lead to biased estimation of relative significances of alternatives and can cause inaccurate ranking results.

To overcome the deficiency of correlation between criteria in the TOPSIS model, Mahalanobis distance-based TOPSIS was preferred. Mahalanobis distance is a measure that takes into consideration the correlation in the data by using the covariance matrix. However, outliers have a major influence on the covariance matrix. Because covariance matrix is known as a low breakdown estimator. Outliers attract mean and inflate variance towards its direction (Becker and Gather, 1999). To make Mahalanobis distances resistant against outliers, robust estimates of the covariance matrix are preferred to use (Rocke and Woodruff, 1996). Robust estimators are used to reducing and limiting the effect of outliers and strong asymmetry when calculating Mahalanobis distance. The robustness of an estimator can be evaluated by considering breakdown points and influence function properties (Huber, 1981; Maronna et. al., 2006). Minimum Covariance Determinant (MCD) estimator, S-estimators, Orthogonalized Gnanadesikan-Kettenring (OGK) estimator, and MM-estimators are well-known high-breakdown robust estimator of mean and covariance matrix. The covariance matrix employed in this study is based on the MM estimator.

2.1. Mahalanobis Distance-Based TOPSIS (TOPSIS-M)

The Euclidean distance approach used by the TOPSIS method is insufficient in terms of investigating the relationship between the criteria in the MCDM problem and including it in the decision process. Therefore, it is more appropriate to use Mahalanobis distance in calculating the deviations from the ideal solutions. TOPSIS-M method is a type of analysis in which deviations are computed using Mahalanobis distance in traditional TOPSIS algorithm.

Mahalanobis distance measurement also takes into account the correlation between variables in measuring the distance between two points. This measurement was proposed by Mahalanobis in 1936 and is used under his name. Mahalanobis distance between x_1 and x_2 points is calculated with the help of the following equation:

$$d(x_1, x_2) = \sqrt{(x_1 - x_2)^T C^{-1} (x_1 - x_2)} \tag{1}$$

C in Eq. (1) shows the variance-covariance matrix of the *X* set consisting of *x* values. (Xiang et al., 2008).

Analysis of the decision problem with the TOPSIS-M method consists of the following steps.

Step 1. As in all MCDM problems, the analysis process in the TOPSIS method starts with generating a decision matrix in which is the performance score of the alternative according to the criterion is expressed together. The A matrix created by the decision-maker is shown as below:

$$A_{ij} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & \cdots & \cdots & a_{mn} \end{bmatrix} \tag{2}$$

Step 2. Since the performance values created in the decision matrix represent different units or sizes according to different criteria, the evaluation process is continued by standardizing the decision matrix. Standardized performance scores to standardize the decision matrix, represented by r_{ij}, are obtained as follows:

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^{m} a_{kj}^2}} \qquad i = 1, 2, \ldots, m \;\; j = 1, 2, \ldots, n \tag{3}$$

R standardized decision matrix is obtained by making use of Eq. (3).

Step 3. As mentioned in the definition of the TOPSIS-M method, it is based on the principle of proximity calculation to ideal solutions. In this step of the TOPSIS-M method, in which the ideal solution is handled in two directions, the ideal positive solution and the ideal negative solution sets are created, and the process continues. While creating the ideal solution clusters, the attributes of the criteria included in the decision problem are taken into account, considering the benefits and cost conditions.

In the TOPSIS-M method, the positive ideal solution set is calculated with Eq. (4), and the negative ideal solution set is calculated with the help of Eq. (5).

$$A^* = \left\{ (\max_i v_{ij} \left| j \in J), (\min_i v_{ij} \right| j \in J' \right\} \quad (4)$$

$$A^- = \left\{ (\min_i v_{ij} \left| j \in J), (\max_i v_{ij} \right| j \in J' \right\} \quad (5)$$

In the equations, J refers to Benefit Index and J' refers to Cost Index.

Step 4. In the TOPSIS-M method, the Mahalanobis distance approach is used to calculate deviations from ideal solution sets. As a result of the process, ideal separation values are calculated for each solution set.

The Positive ideal discrimination measure S_i^* is calculated using Eq. (6) and the negative ideal discrimination measure S_i^- is calculated using Eq. (7).

$$S_i^* = d\left(x_i, A^*\right) = \sqrt{\left(A^* - x_i\right)^T \Omega^T C^{-1} \Omega \left(A^* - x_i\right)} \quad (6)$$

$$S_i^- = d\left(x_i, A^-\right) = \sqrt{\left(x_i - A^-\right)^T \Omega^T C^{-1} \Omega \left(x_i - A^-\right)} \quad (7)$$

The *C* value in the equations represents the variance-covariance matrix of the *X* decision matrix of *mxn*, and Ω represents the square root of the elements of the weight vector on the diagonal matrix. The diagonal matrix Ω is obtained using Eq. (8).

$$\Omega = diag\left(\sqrt{w_1}, \sqrt{w_2}, \ldots, \sqrt{w_n}\right) \quad (8)$$

Step 5. In the calculation of the C_i^* value, which expresses the relative proximity of each alternative to the ideal solution, the ideal separation measures obtained in Step 5 are used.

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*}, \quad 0 \le C_i^* \le 1 \quad (9)$$

As the C_i^* values that take values between 0 and 1 grow, it expresses the absolute proximity to the positive ideal solution. The C_i^* value obtained as a result of the analysis steps is ranked in descending order and a ranking based on the closeness of the alternatives to the ideal is obtained (Wang and Elhag, 2006).

2.2. Robust MM Estimator

The MM-estimator is a high breakdown value estimator, and it is an extension of the S-estimator (Maronna et. al., 2006). S-estimator was proposed by Rousseeuw and Leroy (1987). S-estimators of location μ and covariance S are defined such that the determinant of the matrix S is minimized under the constraint (Maronna et. al., 2016):

$$\frac{1}{n}\sum_{i=1}^{n}\rho\sqrt{(X_i-\mu)^{'}S^{-1}(X_i-\mu)}=b \tag{10}$$

where b is a constant and $\rho(X)$ is the loss function. A popular choice loss is Tukey's bi-weight function (Hubert and Rousseeuw, 2013):

$$\rho(x)=\begin{cases}\frac{k^2}{6}\left(1-\left(1-\frac{x}{k}\right)^2\right)^3 & , \quad |x|\le k\\ \frac{k^2}{6} & , \quad |x|>k\end{cases} \tag{11}$$

For the estimation of the MM estimator the following steps should be considered (Maronna et. al., 2006.):

a) Define a loss function ρ to compute the S-estimators of location and covariance, ($\tilde{\mu}$ and $\tilde{\Sigma}$).

b) Calculate $\hat{\sigma}=|\tilde{\Sigma}|^{1/2p}$

c) Find the MM-estimator of the location and the shape parameter, $(\hat{\mu},\hat{\Gamma})$, that minimize:

$$\frac{1}{n}\sum_{i=1}^{n}\rho_1((X_i-\mu)^{'}\Gamma^{-1}(X_i-\mu))^{1/2}/\hat{\sigma}) \tag{12}$$

d) Compute the MM-estimator of the covariance matrix $\hat{\Sigma}=\hat{\sigma}\hat{\Gamma}$

2.3. Robust Cluster

Cluster analysis is based on identifying homogeneous clusters with large heterogeneity among them. Many studies emphasize outliers may impair clustering ability and clustering methods need to be robust if they are to be useful in applications (García-Escudero et al. 2010, Ruwet et al. 2012). For handling outliers, robustness in cluster analysis is needed because outliers appear many times joined together (Garcia-Escudero et.al. 2011). To refrain from the outlier effects García-Escudero et al. (2008) introduced the TCLUST approach. The TCLUST approach performs robust clustering to find clusters with different distribution structures and weights (Ruwet et al. 2012). The TCLUST algorithm allows for Eigenvalue Rate restriction and trimming of a specific observation rate determined by the researchers to eliminate the effect of outliers. The T-CLUST method is known as the trimmed k-means technique. In this study, TCLUST was used to identify clusters with trimming a rate of 5%.

The flowchart in Figure 1 summarizes the steps followed throughout the methodology. As can be seen from the flow chart in the first stage, Mahalanobis distances based on the solid MM covariance matrix were calculated using the first decision matrix and these distances were used for ranking in the TOPSIS process. Similarly, based on this decision matrix, TOPSIS scores, and TOPSIS-M scores based on the classical covariance matrix were obtained. In the last step, provinces were classified using robust cluster analysis and the findings were evaluated considering the MM covariance-based TOPSIS-M, TOPSIS-M, and TOPSIS rankings.

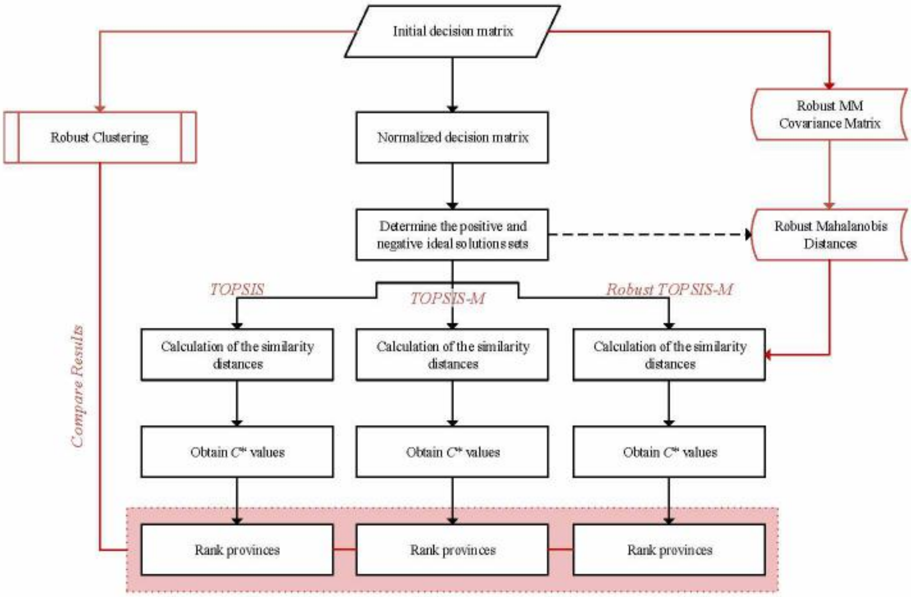

Figure 1. Flowchart of the evaluation methodology used.

3. Dataset and Results

In this study, the variables of GDP per capita, the trade deficit of the provinces (import-export), the population of the provinces, the total housing sales figures in the provinces, and the total bank deposit accounts of the provinces are used for the years 2019 and 2020. Datasets have been created through the official web page of the Turkish Statistical Institute and the Banking Supervision and Regulatory Agencies.

The reason why the TOPSIS method based on Mahalanobis distance was preferred in this study is the strong correlation coefficients between the variables. When the correlation values in Table 1 are examined, it is seen that there is a strong relationship. However, it was observed that the relationships were slightly weaker in the MM correlation matrix.

Table 1. Pearson Correlation Matrix

	Population	GDP per capita	Housing Sales	Trade deficit	Bank deposit
Population	1.00				
GDP per capita	0.52	1.00			
Housing Sales	0.97	0.61	1.00		
Trade deficit	0.85	0.39	0.77	1.00	
Bank deposit	0.96	0.52	0.93	0.94	1.00

Descriptive statistics were presented in Table 2. As can be seen from Table 2, the difference between mean and median values of variables (except GDP per capita) seem significantly different. This raises the suspicion of the existence of outliers. As a matter of fact, in a way to confirm this situation, outlying observations can be seen in Figure 2. Figure 2 corresponds to the distance-distance plot defined by Rousseeuw and van Zomeren (1991). This plot is based on classical Mahalanobis distances versus robust Mahalanobis distances (based on MM covariance estimator), it enables the classification of regular observations and outliers. The dashed line depicts the points where both distances are equal. The vertical and horizontal lines were drawn at the points ($\chi^2_{df=5,\ 0.975}$). Observations beyond these lines (Istanbul, Ankara, and Izmir) are defined as outliers.

Table 2. Descriptive statistics of development indicators

Variables	Mean	Std. Dev.	Median	MAD
Bank deposit	45353637,4	171658598	9715929	8497261
Housing Sales	18510,07	35694,54	7625	7168,37
Population	1032276,07	1872575,82	537762	419343
Trade deficit	-402315,83	4976466,74	35118	142794
GDP per capita	39506,76	13648,03	36820,7	10774,7

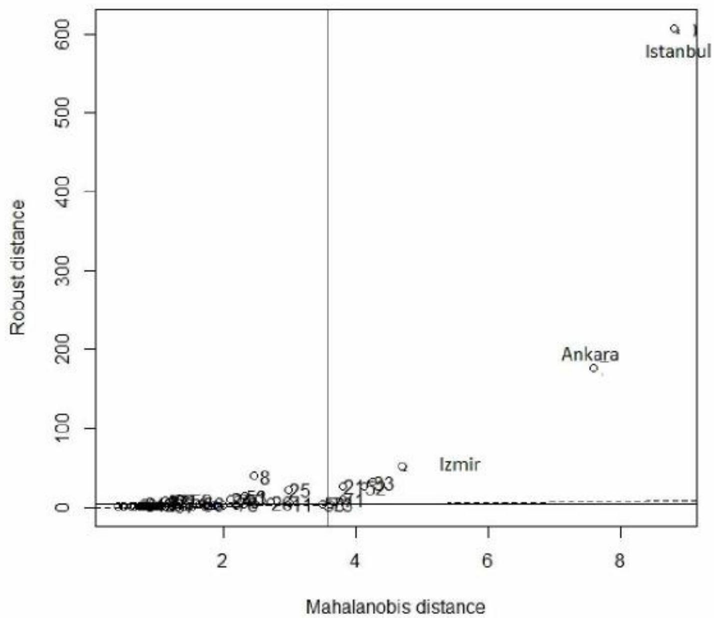

Figure 2. Distance-Distance plot (detection of outlying provinces).

Robust TOPSIS-M analysis steps and final scores of 81 provinces which obtained based on robust MM covariance matrix, are included in the Appendix. However, in Figure 3, provinces are divided into homogeneous groups based on these robust TOPSIS-M scores. As can be seen from this map, the provinces with the highest scores are respectively Istanbul, Ankara, Izmir, and Antalya. The scores with the lowest provinces are Ardahan, Bayburt, and Tunceli. These rankings are consistent with the actual values, considering the development levels of the provinces. Robust TOPSIS-M scores reflect the inter-class differences in the economic developments of provinces. Figure 3 presents ten classes of provinces, spanning from the extremely low to the extremely high levels of economic development.

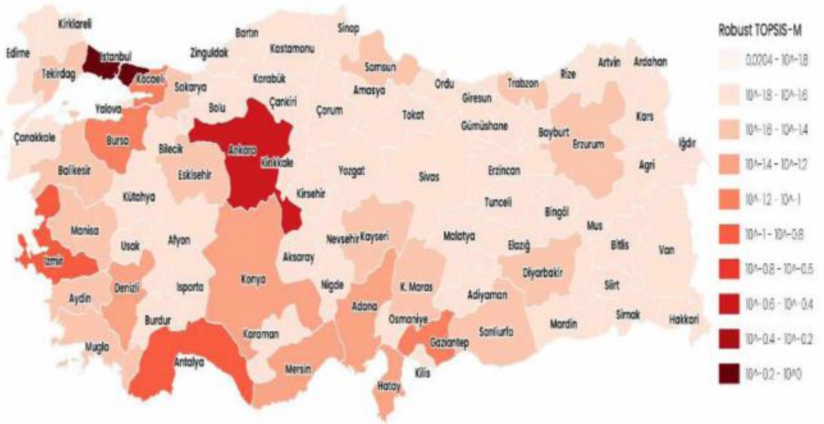

Figure 3. Classification of provinces according to Robust TOPSIS-M scores.

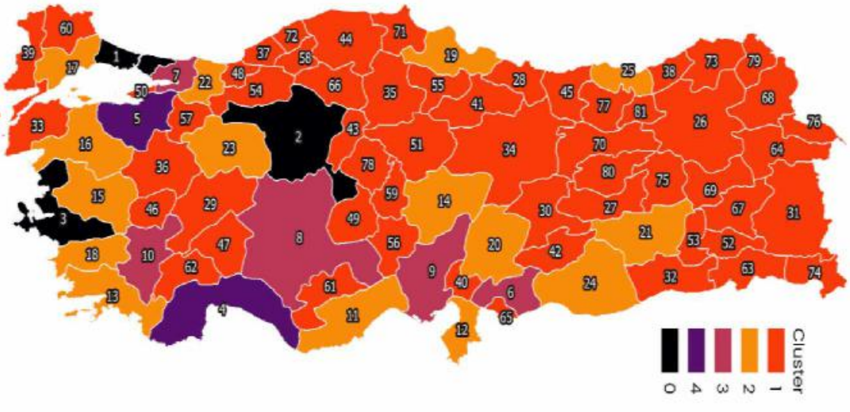

Figure 4. Classification of provinces according to robust clustering.

In Figure 4, robust clustering results were given. According to the TCLUST algorithm, four clusters and an outlier group were obtained. Cluster 0 consists of the outlying provinces. The map in Figure 4 also includes rank values of provinces according to robust TOPSIS-M scores. As can be seen, provinces were divided into four groups according to the robust clustering. Following the "distance-distance plot" in Figure1, Istanbul, Ankara, and Izmir have been determined as outliers here as well, and these provinces are in the top three with the robust TOPSIS-M ranking.

It is seen that the homogeneous groups defined based on robust TOPSIS-M scores in Figure 3 are compatible with the clusters in Figure 4. Although there are fewer clusters in Figure 4, only four clusters, these clusters can show the inter-class differences in terms of development indicators.

Table 3 presents the ranking of provinces according to TOPSIS, TOPSIS_M, and TOPSIS-MM approaches. This table also contains information about the cluster to which each province belongs. Rankings of provinces in the same cluster in Table 3 are expected to be close to each other. Although the order of provinces falling into clusters with 0 and 4 codes is close to each other in all three approaches, the order of provinces in clusters with codes 1-2 and 3 seems compatible only in TOPSIS-MM. Denizli, Kocaeli, Şırnak, Hatay, and Çorum are not compatible in the clusters in which they are ranked according to TOPSIS and TOPSIS-M approaches.

Table 3. Ranking of Provinces based on TOPSIS, TOPSIS-M, and TOPSIS-MM approaches

Province	TOPSIS	TOPSIS -M	Robust TOPSIS -M	Robust Cluster	Province	TOPSIS	TOPSIS -M	Robust TOPSIS -M	Robust Cluster
İstanbul	1	1	1	0	Adıyaman	47	50	42	1
Ankara	2	2	2	0	Kırklareli	35	39	43	1
İzmir	3	3	3	0	Kastamonu	42	38	44	1
Antalya	5	5	4	4	Giresun	40	42	45	1
Bursa	4	4	5	4	Uşak	45	36	46	1
Gaziantep	6	9	6	3	Isparta	37	35	47	1
Kocaeli	12	6	7	3	Düzce	41	52	48	1
Konya	7	8	8	3	Aksaray	44	37	49	1
Adana	10	7	9	3	Yalova	38	40	50	1
Denizli	14	15	10	3	Yozgat	57	46	51	1
Mersin	8	10	11	2	Siirt	64	75	52	1
Hatay	24	13	12	2	Batman	54	54	53	1
Muğla	17	11	13	2	Bolu	46	51	54	1
Kayseri	9	12	14	2	Amasya	55	60	55	1
Manisa	19	16	15	2	Niğde	53	59	56	1
Balıkesir	16	14	16	2	Bilecik	49	65	57	1
Tekirdağ	13	19	17	2	Karabük	68	49	58	1
Aydın	15	17	18	2	Nevşehir	59	44	59	1
Samsun	21	20	19	2	Kırşehir	63	57	60	1
Kahramanmaraş	25	25	20	2	Karaman	52	55	61	1
Diyarbakır	20	23	21	2	Burdur	51	56	62	1
Sakarya	11	22	22	2	Şırnak	39	73	63	1
Eskişehir	22	18	23	2	Ağrı	67	70	64	1
Şanlıurfa	18	27	24	2	Kırıkkale	56	64	65	1
Trabzon	23	21	25	2	Çankırı	62	67	66	1
Erzurum	36	43	26	1	Bitlis	74	76	67	1
Elazığ	32	34	27	1	Kars	72	69	68	1
Ordu	30	30	28	1	Muş	65	72	69	1
Afyonkarahisar	27	28	29	1	Erzincan	58	61	70	1
Malatya	28	29	30	1	Sinop	66	63	71	1
Van	31	45	31	1	Bartın	70	62	72	1
Mardin	26	58	32	1	Artvin	60	66	73	1
Çanakkale	29	26	33	1	Hakkari	77	78	74	1
Sivas	33	31	34	1	Bingöl	73	68	75	1
Çorum	81	32	35	1	Iğdır	71	74	76	1
Kütahya	34	41	36	1	Gümüşhane	78	77	77	1
Zonguldak	75	24	37	1	Kilis	76	79	78	1
Rize	50	47	38	1	Ardahan	79	80	79	1
Edirne	43	33	39	1	Tunceli	69	71	80	1
Osmaniye	61	53	40	1	Bayburt	80	81	81	1

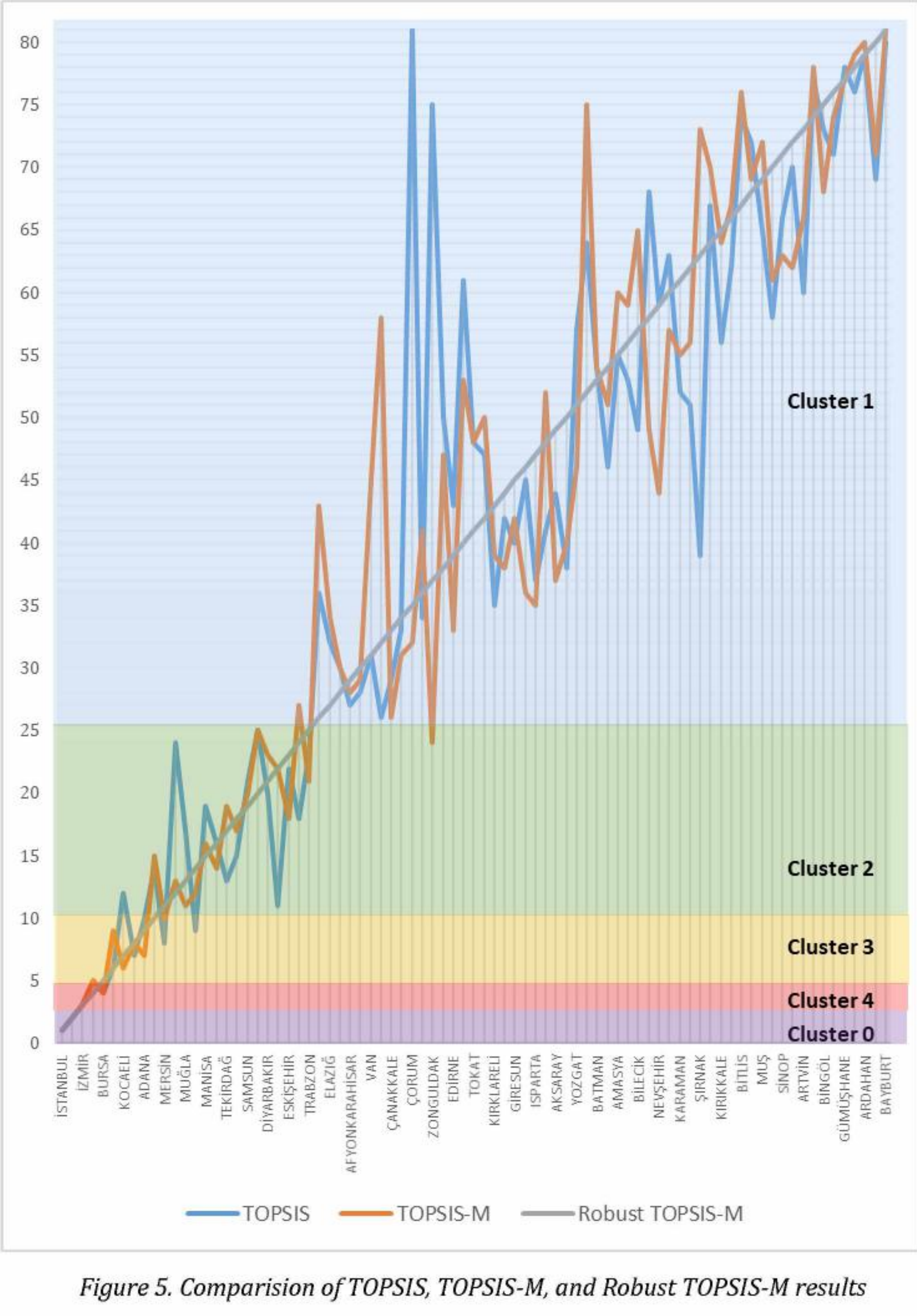

Figure 5. Comparision of TOPSIS, TOPSIS-M, and Robust TOPSIS-M results

The provinces that exists in cluster 0 and cluster 4 are also consistent in terms of rankings. While Denizli and Kocaeli should be in the third cluster, they are in the second cluster according to TOPSIS and TOPSIS-M rankings. The province of Zonguldak, which should be in the first cluster, falls in the second cluster according to the TOPSIS and TOPSIS-M rankings, and Şanlıurfa, which should be in the second cluster, falls into the first cluster. However, as can be seen in Figure 5, there is no inconsistency between Robust TOPSIS-M and clusters.

4. Conclusion

The TOPSIS method is an MCDM method that is frequently used to sort the observations and divide them into homogeneous groups, considering various variables. However, the TOPSIS method is calculated based on the Euclidean distance and ignores the relationship between variables. The TOPSIS-M method calculated based on the Mahalanobis distance takes into account the dependency structure between variables. However, since Mahalanobis distances are calculated based on the covariance matrix, these distances calculated when there are outliers in the data set give misleading results. In this study, it was proposed to make the TOPSIS-M method resistant with the use of the MM covariance matrix, which is resistant to outliers. Robust Mahalanobis distances are used frequently in the literature by using robust covariance matrix. However, to the best of our knowledge, this approach has not been applied to the TOPSIS-M method in studies conducted so far.

In this study, it was aimed to rank 81 Turkish provinces by taking into account the variables of per capita GDP, foreign trade deficit (import-export), population, total housing sales, and total bank deposit accounts. The limitation of this study is that the most up-to-date values of statistics collected by provinces are 2019.

The fact that the provinces have quite different levels of economic development inevitably made it necessary to consider the effect of outlying observations in the data. For this reason, since the TOPSIS-M method is based on the classical covariance estimator and this estimator is a low breakdown estimator, the covariance matrix was made resistant to outliers using the robust MM estimator. In addition, provinces were classified using the robust clustering method.

According to the Robust Cluster Analysis, Istanbul, Ankara, and Izmir, which are obtained as outliers were found to be the top 3 provinces with the Robust TOPSIS-M method. Antalya and Bursa, which are in the first cluster, are ranked as the fourth and fifth provinces in the ranking. Gaziantep, Kocaeli, Konya, Adana, and Denizli, which are in the second cluster, were ranked from 6 to 10 in the Robust TOPSIS-M ranking, again producing consistent results. The last 3 provinces in the ranking for economic development are Ardahan, Tunceli, and Bayburt.

The top provinces in the robust TOPSIS-M ranking and observations in clusters number three and four (including outliers) correspond to important industrial and trade centers. Likewise, it is seen that the population density is concentrated in these provinces. For this reason, housing sales are also high in these provinces. When the provinces that are the last in the ranking are examined, it is known that these provinces have some disadvantages such as natural disasters and terrorism due to their geographical location, and therefore economic development is lower. This situation both accelerates migration and prevents investment in these regions.

According to our findings, obtained robust clusters and homogenous groups that are based on MM estimator based TOPSIS-M and the actual situation seem compatible. This research presents that robust MM estimator based TOPSIS-M performs correct rankings and partitions homogeneous groups in case of variables with outliers. The ranking of the provinces taking into account the socio-economic indicators are included in various studies. However, while ranking in these studies, the dependency between indicators and the potential effects of outliers were not taken into account. The TOPSIS approach based on robust Mahalanobis distance, which is resistant to outliers, was used because the data used in this study consisted of provinces with different development levels and correlated variables. To make Mahalanobis distances resistant to outliers, a robust covariance matrix was used. The covariance matrix employed in this study is based on the MM estimator. The Findings obtained in this study are consistent with the real situation. For this reason, we recommend using robust MM estimator based TOPSIS-M for the evaluation of the economic development of provinces described by variables with outliers.

In this study, the importance of the criteria was accepted as equal and the ranking was made accordingly. The importance of criteria can also be determined by subjective methods such as AHP, ANP, DEMATEL or objective weighting methods such as CRITIC and Entropy-based on expert opinion. In addition, the results can be compared by considering the VIKOR, ARAS, COPRAS methods. Another suggestion is that Robust estimators can be used when analyzing data sets containing outliers.

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Appendix

Appendix 1. Initial Decision Matrix

opt. direction	*max*	*max*	*max*	*min*	*max*
Provinces	C1	C2	C3	C4	C5
Adana	55967796.32	28014.82016	1877332.698	-311514.1	2250.26969
Adıyaman	1863197.32	2070.82016	251073.698	-31357.12	-12116.15031
Afyonkarahisar	6888921.32	4691.82016	355526.698	234945.9	1539.61969
Ağrı	-2645137.68	-2840.17984	154049.698	-87890.12	-17843.02031
Aksaray	713663.32	1693.82016	41625.698	19646.88	2482.87969
Amasya	-295349.68	150.82016	-45891.302	427.8769	1172.38969
Ankara	492294499.3	151783.8202	5281936.698	-3483295	36456.87969
Antalya	132877245.3	58586.82016	2166922.698	780921.9	26061.19969
Ardahan	-5284044.68	-5119.17984	-285224.302	-49309.12	74.52969
Artvin	-3411236.68	-3236.17984	-211884.302	-15058.12	16262.21969
Aydın	23029583.32	28466.82016	737698.698	511716.9	3318.19969
Balıkesir	25442739.32	26952.82016	858899.698	149926.9	9731.58969
Bartın	-3302268.68	-2577.17984	-182406.302	-31205.12	-2380.33031
Batman	-675291.68	-32.17984	238892.698	-58419.12	-11171.71031
Bayburt	-5952091.68	-4568.17984	-299475.302	-52799.12	-588.14031
Bilecik	24778.32	-1558.17984	-162668.302	2948.877	22498.06969
Bingöl	-4503701.68	-2761.17984	-99617.302	-50850.12	-7248.06031
Bitlis	-3181196.68	-3062.17984	-30391.302	-49285.12	-12390.60031
Bolu	203256.32	1250.82016	-66583.302	-106321.1	19585.19969
Burdur	-950198.68	-1557.17984	-114293.302	144657.9	7718.20969
Bursa	103889557.3	49910.82016	2720447.698	1892625	24386.28969
Çanakkale	5925653.32	7541.82016	160162.698	7834.877	19109.07969
Çankırı	-2747841.68	-2633.17984	-188957.302	46700.88	3018.99969
Çorum	6674460.32	3493.82016	148740.698	-1790497	-2984.09031

opt. direction	*max*	*max*	*max*	*min*	*max*
Provinces	C1	C2	C3	C4	C5
Denizli	53935630.32	12770.82016	659529.698	1355305	11958.85969
Diyarbakır	15438764.32	14021.82016	1402045.698	97005.88	-10925.07031
Düzce	1390404.32	2540.82016	14293.698	37837.88	9178.98969
Edirne	3728462.32	2354.82016	26377.698	-93268.12	9517.71969
Elazığ	7909597.32	5613.82016	206574.698	69351.88	-2341.99031
Erzincan	-3181739.68	-2104.17984	-146954.302	-33907.12	12717.06969
Erzurum	8618759.32	4625.82016	376893.698	-73632.12	-4335.33031
Eskişehir	18079022.32	16869.82016	507442.698	96372.88	21037.71969
Gaziantep	85062990.32	30046.82016	1719771.698	2837014	3062.58969
Giresun	1361999.32	2313.82016	67335.698	183646.9	-3347.60031
Gümüşhane	-4913512.68	-3789.17984	-239683.302	-17616.12	-5486.51031
Hakkari	-4193366.68	-5115.17984	-100871.302	-51723.12	-4378.33031
Hatay	35258735.32	19863.82016	1277934.698	-1128064	-3548.01031
Iğdır	-4458034.68	-3356.17984	-180071.302	20415.88	-3832.76031
Isparta	1270343.32	1548.82016	58918.698	115079.9	6658.64969
İstanbul	1461674123	259786.8202	15081066.7	-44100660	52227.99969
İzmir	184423821.3	88145.82016	4013308.698	3085818	25983.10969
Kahramanmaraş	22580684.32	10205.82016	786777.698	-173798.1	-464.72031
Karabük	206223.32	-727.17984	-137771.302	-253143.1	4144.99969
Karaman	-772106.68	-2061.17984	-126466.302	102636.9	12431.04969
Kars	-3063130.68	-2282.17984	-96462.302	-52533.12	-8298.62031
Kastamonu	1818376.32	1564.82016	-5008.302	98800.88	4187.53969
Kayseri	30238897.32	24721.82016	1040069.698	1343356	9640.35969
Kırıkkale	-1904612.68	1071.82016	-102682.302	-52676.12	4675.43969
Kırklareli	2668193.32	3197.82016	-19648.302	-25132.12	22464.03969
Kırşehir	-311130.68	-763.17984	-138343.302	-100793.1	-798.78031
Kilis	-5406827.68	-2276.17984	-238593.302	-35270.12	-5464.94031
Kocaeli	86408382.32	31458.82016	1615872.698	-1863656	46657.65969
Konya	60562975.32	31884.82016	1868634.698	1237525	6322.18969
Kütahya	3786265.32	2929.82016	195302.698	50603.88	7249.71969
Malatya	6182146.32	7375.82016	424770.698	120705.9	-4147.51031
Manisa	31011819.32	20323.82016	1069230.698	-208845.1	14896.21969
Mardin	4259936.32	3300.82016	473330.698	582686.9	-5707.20031
Mersin	37674319.32	38184.82016	1487371.698	317713.9	2502.11969
Muğla	33571393.32	16931.82016	619387.698	276033.9	21892.43969
Muş	-3682386.68	-2947.17984	29731.698	-29532.12	-11243.22031
Nevşehir	-435112.68	-1773.17984	-76423.302	-24949.12	2160.34969
Niğde	-370740.68	1959.82016	-19314.302	-50039.12	1344.10969
Ordu	6967854.32	6100.82016	380014.698	159544.9	-4303.13031
Osmaniye	3450177.32	1594.82016	167170.698	-342117.1	-4603.69031
Rize	4066309.32	-1308.17984	-37026.302	78696.88	6147.14969
Sakarya	16619602.32	17106.82016	661263.698	1655493	15186.54969
Samsun	22123112.32	20644.82016	974693.698	-115775.1	229.80969
Siirt	531142.32	-2521.17984	-50315.302	8529.877	-7978.65031
Sinop	-3238326.68	-1697.17984	-164925.302	-30873.12	-3016.23031
Sivas	4712271.32	4699.82016	254503.698	2109.877	418.87969
Şanlıurfa	13184870.32	20959.82016	1733870.698	-130692.1	-17105.90031
Şırnak	-2774068.68	-4059.17984	156376.698	528624.9	-7290.49031
Tekirdağ	23358321.32	29306.82016	699679.698	256729.9	36217.16969
Tokat	2076276.32	1249.82016	216475.698	-31300.12	-7668.86031
Trabzon	15582031.32	6753.82016	430515.698	909257.9	2743.69969
Tunceli	-5448571.68	-4318.17984	-297942.302	-52940.12	13259.17969
Uşak	1847229.32	680.82016	-11952.302	8509.877	9212.63969

opt. direction	*max*	*max*	*max*	*min*	*max*
Provinces	C1	C2	C3	C4	C5
Van	4106565.32	2366.82016	767956.698	-45450.12	-15861.99031
Yalova	1351893.32	6788.82016	-105335.302	-173924.1	20458.87969
Yozgat	409397.32	136.82016	37709.698	-58432.12	-5858.70031
Zonguldak	4575397.32	1537.82016	209818.698	-818261.1	2122.10969

Appendix 2. Normalize Decision Matrix

Provinces	C1	C2	C3	C4	C5
Adana	0.036	0.082	0.106	-0.007	0.017
Adıyaman	0.001	0.006	0.014	-0.001	-0.093
Afyonkarahisar	0.004	0.014	0.020	0.005	0.012
Ağrı	-0.002	-0.008	0.009	-0.002	-0.137
Aksaray	0.000	0.005	0.002	0.000	0.019
Amasya	0.000	0.000	-0.003	0.000	0.009
Ankara	0.313	0.446	0.298	-0.078	0.281
Antalya	0.084	0.172	0.122	0.017	0.201
Ardahan	-0.003	-0.015	-0.016	-0.001	0.001
Artvin	-0.002	-0.010	-0.012	0.000	0.125
Aydın	0.015	0.084	0.042	0.011	0.026
Balıkesir	0.016	0.079	0.048	0.003	0.075
Bartın	-0.002	-0.008	-0.010	-0.001	-0.018
Batman	0.000	0.000	0.013	-0.001	-0.086
Bayburt	-0.004	-0.013	-0.017	-0.001	-0.005
Bilecik	0.000	-0.005	-0.009	0.000	0.173
Bingöl	-0.003	-0.008	-0.006	-0.001	-0.056
Bitlis	-0.002	-0.009	-0.002	-0.001	-0.095
Bolu	0.000	0.004	-0.004	-0.002	0.151
Burdur	-0.001	-0.005	-0.006	0.003	0.059
Bursa	0.066	0.147	0.153	0.042	0.188
Çanakkale	0.004	0.022	0.009	0.000	0.147
Çankırı	-0.002	-0.008	-0.011	0.001	0.023
Çorum	0.004	0.010	0.008	-0.040	-0.023
Denizli	0.034	0.037	0.037	0.030	0.092
Diyarbakır	0.010	0.041	0.079	0.002	-0.084
Düzce	0.001	0.007	0.001	0.001	0.071
Edirne	0.002	0.007	0.001	-0.002	0.073
Elazığ	0.005	0.016	0.012	0.002	-0.018
Erzincan	-0.002	-0.006	-0.008	-0.001	0.098
Erzurum	0.005	0.014	0.021	-0.002	-0.033
Eskişehir	0.011	0.050	0.029	0.002	0.162
Gaziantep	0.054	0.088	0.097	0.063	0.024
Giresun	0.001	0.007	0.004	0.004	-0.026
Gümüşhane	-0.003	-0.011	-0.014	0.000	-0.042
Hakkari	-0.003	-0.015	-0.006	-0.001	-0.034
Hatay	0.022	0.058	0.072	-0.025	-0.027
Iğdır	-0.003	-0.010	-0.010	0.000	-0.030
Isparta	0.001	0.005	0.003	0.003	0.051
İstanbul	0.929	0.763	0.850	-0.987	0.402
İzmir	0.117	0.259	0.226	0.069	0.200
Kahramanmaraş	0.014	0.030	0.044	-0.004	-0.004
Karabük	0.000	-0.002	-0.008	-0.006	0.032
Karaman	0.000	-0.006	-0.007	0.002	0.096

Provinces	C1	C2	C3	C4	C5
Kars	-0.002	-0.007	-0.005	-0.001	-0.064
Kastamonu	0.001	0.005	0.000	0.002	0.032
Kayseri	0.019	0.073	0.059	0.030	0.074
Kırıkkale	-0.001	0.003	-0.006	-0.001	0.036
Kırklareli	0.002	0.009	-0.001	-0.001	0.173
Kırşehir	0.000	-0.002	-0.008	-0.002	-0.006
Kilis	-0.003	-0.007	-0.013	-0.001	-0.042
Kocaeli	0.055	0.092	0.091	-0.042	0.359
Konya	0.038	0.094	0.105	0.028	0.049
Kütahya	0.002	0.009	0.011	0.001	0.056
Malatya	0.004	0.022	0.024	0.003	-0.032
Manisa	0.020	0.060	0.060	-0.005	0.115
Mardin	0.003	0.010	0.027	0.013	-0.044
Mersin	0.024	0.112	0.084	0.007	0.019
Muğla	0.021	0.050	0.035	0.006	0.169
Muş	-0.002	-0.009	0.002	-0.001	-0.087
Nevşehir	0.000	-0.005	-0.004	-0.001	0.017
Niğde	0.000	0.006	-0.001	-0.001	0.010
Ordu	0.004	0.018	0.021	0.004	-0.033
Osmaniye	0.002	0.005	0.009	-0.008	-0.035
Rize	0.003	-0.004	-0.002	0.002	0.047
Sakarya	0.011	0.050	0.037	0.037	0.117
Samsun	0.014	0.061	0.055	-0.003	0.002
Siirt	0.000	-0.007	-0.003	0.000	-0.061
Sinop	-0.002	-0.005	-0.009	-0.001	-0.023
Sivas	0.003	0.014	0.014	0.000	0.003
Şanlıurfa	0.008	0.062	0.098	-0.003	-0.132
Şırnak	-0.002	-0.012	0.009	0.012	-0.056
Tekirdağ	0.015	0.086	0.039	0.006	0.279
Tokat	0.001	0.004	0.012	-0.001	-0.059
Trabzon	0.010	0.020	0.024	0.020	0.021
Tunceli	-0.003	-0.013	-0.017	-0.001	0.102
Uşak	0.001	0.002	-0.001	0.000	0.071
Van	0.003	0.007	0.043	-0.001	-0.122
Yalova	0.001	0.020	-0.006	-0.004	0.157
Yozgat	0.000	0.000	0.002	-0.001	-0.045
Zonguldak	0.003	0.005	0.012	-0.018	0.016

Appendix 3. Covariance Matrix

	C1	C2	C3	C4	C5
C1	7.76E+13	71414896520	2.90942E+12	3.62346E+11	30383494618
C2	7.14E+10	71756333	2661769030	374774730	34537249
C3	2.91E+12	2661769030	1.33093E+11	18567394308	-212823424
C4	3.62E+11	374774730	18567394308	32006766617	107912881
C5	3.04E+10	34537249	-212823424	107912881	165872410

Appendix 4. Robust TOPSIS-M results and Robust Clusters

Provinces	S-	S*	C*	Rank	Robust Cluster
İstanbul	3806970.55	0.00	1.0000	1	0
Ankara	1315344.95	2494550.68	0.3452	2	0
İzmir	540509.74	3274118.34	0.1417	3	0
Antalya	396058.35	3419752.48	0.1038	4	4
Bursa	330753.25	3487381.04	0.0866	5	4
Gaziantep	277507.93	3542972.56	0.0726	6	3
Kocaeli	276162.66	3541735.68	0.0723	7	3
Konya	219392.06	3603602.94	0.0574	8	3
Adana	207115.82	3615707.45	0.0542	9	3
Denizli	194374.17	3630396.97	0.0508	10	3
Mersin	163408.66	3664411.81	0.0427	11	2
Hatay	154532.08	3673023.35	0.0404	12	2
Muğla	147826.70	3681960.66	0.0386	13	2
Kayseri	145282.08	3686437.22	0.0379	14	2
Manisa	145128.76	3684833.95	0.0379	15	2
Balıkesir	132516.62	3700386.28	0.0346	16	2
Tekirdağ	127596.18	3706567.06	0.0333	17	2
Aydın	127282.54	3707360.65	0.0332	18	2
Samsun	126212.93	3708004.87	0.0329	19	2
Kahramanmaraş	125600.94	3708571.90	0.0328	20	2
Diyarbakır	116569.03	3721282.25	0.0304	21	2
Sakarya	116280.49	3723596.74	0.0303	22	2
Eskişehir	115656.03	3721757.37	0.0301	23	2
Şanlıurfa	114373.51	3724234.47	0.0298	24	2
Trabzon	111612.58	3728659.48	0.0291	25	2
Erzurum	98085.95	3747016.37	0.0255	26	1
Elazığ	96291.94	3750128.47	0.0250	27	1
Ordu	96003.68	3751018.17	0.0250	28	1
Afyonkarahisar	95901.64	3751339.97	0.0249	29	1
Malatya	95048.94	3752610.14	0.0247	30	1
Van	93597.31	3755186.68	0.0243	31	1
Mardin	93352.18	3756901.33	0.0242	32	1
Çanakkale	93207.95	3755240.61	0.0242	33	1
Sivas	91889.38	3757735.11	0.0239	34	1
Çorum	91063.00	3754443.44	0.0237	35	1
Kütahya	90466.14	3760470.56	0.0235	36	1
Zonguldak	90079.02	3758778.28	0.0234	37	1
Rize	89697.81	3761760.02	0.0233	38	1
Edirne	89321.95	3762063.33	0.0232	39	1
Osmaniye	89151.99	3761846.64	0.0232	40	1
Tokat	88192.13	3764793.87	0.0229	41	1
Adıyaman	88081.94	3765080.11	0.0229	42	1
Kırklareli	87977.97	3764919.61	0.0228	43	1
Kastamonu	87144.59	3767103.59	0.0226	44	1
Giresun	87058.94	3767686.80	0.0226	45	1
Uşak	87010.94	3767075.77	0.0226	46	1
Isparta	86840.86	3767906.40	0.0225	47	1
Düzce	86662.16	3767969.21	0.0225	48	1
Aksaray	85953.20	3769527.17	0.0223	49	1
Yalova	85801.86	3768973.01	0.0223	50	1

Provinces	S-	S*	C*	Rank	Robust Cluster
Yozgat	85421.17	3770463.34	0.0222	51	1
Siirt	85271.04	3770921.94	0.0221	52	1
Batman	85096.64	3771558.44	0.0221	53	1
Bolu	84797.12	3771567.26	0.0220	54	1
Amasya	84458.37	3772823.86	0.0219	55	1
Niğde	84410.23	3772788.28	0.0219	56	1
Bilecik	84407.81	3772772.88	0.0219	57	1
Karabük	84164.54	3772408.90	0.0218	58	1
Nevşehir	84142.10	3773447.97	0.0218	59	1
Kırşehir	83876.31	3773707.63	0.0217	60	1
Karaman	83874.45	3774547.24	0.0217	61	1
Burdur	83803.32	3774923.73	0.0217	62	1
Şırnak	83736.19	3777277.36	0.0217	63	1
Ağrı	82723.75	3777316.70	0.0214	64	1
Kırıkkale	82594.90	3777297.79	0.0214	65	1
Çankırı	81699.87	3780150.88	0.0212	66	1
Bitlis	81664.43	3780126.62	0.0211	67	1
Kars	81542.53	3780329.88	0.0211	68	1
Muş	81497.20	3780856.44	0.0211	69	1
Erzincan	81377.80	3780799.86	0.0211	70	1
Sinop	81221.97	3781266.28	0.0210	71	1
Bartın	81109.97	3781574.80	0.0210	72	1
Artvin	81017.96	3781881.92	0.0210	73	1
Hakkari	80631.68	3783181.03	0.0209	74	1
Bingöl	80405.97	3783954.88	0.0208	75	1
Iğdır	80323.38	3784453.71	0.0208	76	1
Gümüşhane	79753.45	3786130.63	0.0206	77	1
Kilis	79407.02	3787346.82	0.0205	78	1
Ardahan	79335.75	3787401.81	0.0205	79	1
Tunceli	79231.01	3787762.23	0.0205	80	1
Bayburt	78884.23	3789196.40	0.0204	81	1

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RELIABILITY CHARACTERISTICS OF RAILWAY COMMUNICATION SYSTEM SUBJECT TO SWITCH FAILURE

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Abstract. *In the present study, a railway communication system (RCS) reliability model is developed based on system failure. The proposed RCS has control centre and stations which are arranged in such a manner that failure of control centre or a single station stops the working of overall system i.e., all switches must be working for communication to be available. To improve the reliability of the proposed communication system, a ring architecture is employed. In this architecture one additional communication path is connected in parallel configuration. Provision of two path of communication ensures that failure of one path will not cause a communication failure and communication will be available through additional path. All failures of RCS are exponentially distributed. Mathematical modelling of the system is carried out using Markov process by which the differential equations are generated. These differential equations are further used to evaluate the reliability measures like availability, reliability, mean time to failure of the proposed RCS. Likewise, sensitivity analysis is done to determine the impact of failures on RCS's performance measures. The proposed Markov process-based model gives the information about the failure and working of the multi- state railway communication system. Finally, numerical results are provided with graphs to demonstrates the usefulness of the findings.*

Key words: *Railway communication system; Reliability; Mean time to failure; Markov process; Sensitivity*

1. Introduction

In the present day's society demands inexpensive, more secure, and timesaving public transport. Railway transportation systems attracts a lot of passengers because

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of their capacity of transporting the people with high luxury, great comfort and large get-up-and-go efficacy (Ai et al., 2014). A lot of people choose trains for travelling because of the easy understanding, experience and comfort that the rail transport gives. Railway communications systems are needed to develop the communication between train and path equipment for traffic management and dealing with continuous high-data-rate traveler services, hypermedia dispatching video transmissions, railway mobile ticketing, and the internet of things (IOT) for railways (Ai et al., 2015; Guan et al., 2017). The security of railway's employees, passengers and of the general public are the first requirements and is of specific significance in the railway industry. Railway industry looking for many aspects to improve the security / safety and the reliability of the railway systems.

A railway system is a very large and complex stochastic dynamic system. This system is already interesting by itself. Large, stochastic complex systems are generally examined with deterministic methods. Many authors have written about deterministic optimization of railway systems over the last twenty years. A lot of research has been done in the context of the different techniques to increase the reliability of a railway communication system. Aggarwal (1975) obtained reliability expression for communication system. Marquez et al. (2003) discussed about the improvement of a way to deal the use of remote monitoring to the reliability centred maintenance of railway attendances. Tao et al. (2007) used fault tree analysis method for RCS, in which main factors affecting the failure of RCS are determined by minimum cut set analysis.

De Felice and Petrillo (2011) proposed a methodological approach based on human reliability analysis (HRA) and failures modes, effects criticality analysis (FMECA) to calculate the reliability of railway transportation system. HRA gives a logical analysis of factors affecting human performance, prompts suggestions for improvement. Lin (2015) proposed an advanced finite state Markov chain channel model for high-speed railway fading channels and derived the expression of state transition probabilities under different speed modes. Unterhuber et al. (2016) provided a summary of communication systems in trains and discussed about possible direction for future wireless network. Also, authors identified the gaps for station classification in railway environment, total velocity, and relative velocity for radio broadcast measurement. He et al. (2017) studied the propagation characteristics for rapid railway communication system including metropolitan, rural and tunnel with straight and curved route. Zhang et al. (2018) proposed a Markov model for railway communication system and used multi-link transmission communication technique to improve the capacity of RCS. Kumar and Kumar (2019) evaluated the reliability, and mean time to failure of the wireless communication system regarding its component failure. Authors also identified the critical component by sensitivity analysis. Song (2019) described a communication-based train control system and discussed the different constraints that affects the working of communication system. Authors also evaluated system availability and performance by applied stochastic petri nets.

In this research article, a railway communication system with control centre and stations is considered. The considered multi-state repairable system having control centre and stations in such a manner that for communication, all switches must be in working condition. Failure in control centre and any of one station arises a communication failure. To improve the reliability of the proposed communication system, an additional path is connected in parallel configuration. In the proposed model of RCS, probability of each transition states is obtained and reliability measures such as system availability, system reliability, mean time to failure (MTTF), and sensitivity of reliability have been computed.

The rest of the paper is categorised as follows. The description of the proposed RCS with requisite assumptions and notations are presented in section 2. In section 3, the set of differential equations is constructed based on Markov process and also probability of each state is calculated using Laplace transformation. In section 4, the numerical calculations to compute the reliability measures of RCS such as availability, reliability, mean time to failure, and sensitivity analysis is given. In section 5, the behaviour of the reliability measures is discussed with the help of tables and graphs. Finally, section 6 gives the concluding remark to highlight the significant and some future prospects of the present work.

2. System modelling

In this study, a railway communication system with control centre and stations is considered. In this system a communication which is provided in the control centre as well as in each of the stations which are connected in a series configuration. It can be seen in the diagram that all switches must be working for the communication system to be function. If there is a failure in switch at any station, there will be a communication failure at those stations as well as at all stations beyond that point i.e., all switches must be working to continue communication. Further one additional communication path is connected in parallel configuration to improve the reliability of proposed system. Adding an additional path means that the communication will be available after failure of any one of the paths. On failure of both path's switches, the communication system will be failed.

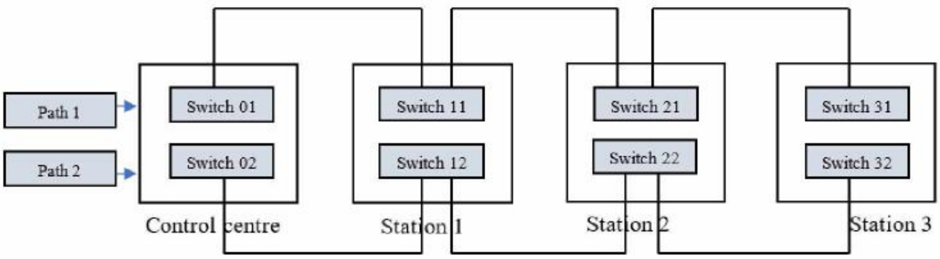

Figure 1. Reliability block diagram of railway communication system

To study and formulation of the system, following assumptions and notations are made (Table 1):

- The communication system consists of two paths namely path 1 and path 2, in which each path has a control centre and 3 stations.
- The proposed communication system has main three states full operation, degradation states and failure state.
- At time t = 0, control centre and stations are in fully operation state and communication system is available.

- This study assumes that the failure rates of path 1 units and path 2 units are statistically independent, constant and are exponentially distributed with failure rates λc_1, λ_1, and λc_2, λ_2.
- Failure of one path will not cause a communication failure.
- Repair service is always available to repair the failed unit, i.e., as soon as an operating unit fail, it is instantaneously detected and sent for repair.
- When a failed unit is repaired it considered to be a new one.

Table 1. Notations

t	Time variable
λc_1	Failure rate of path 1 control centre
λc_2	Failure rate of path 2 control centre
λ_1	Failure rate of all stations of path 1
λ_2	Failure rate of all stations of path 2
$P_i(t)$	The state probability of the system at instant 't' for i = 0 to 7
$P_i(x, t)$	The failed state probability of the system at instant 't' and an elapsed repair time x for i = 8 to 21
x	Elapsed repair time
$\mu(x)$	Repair rate for repaired state

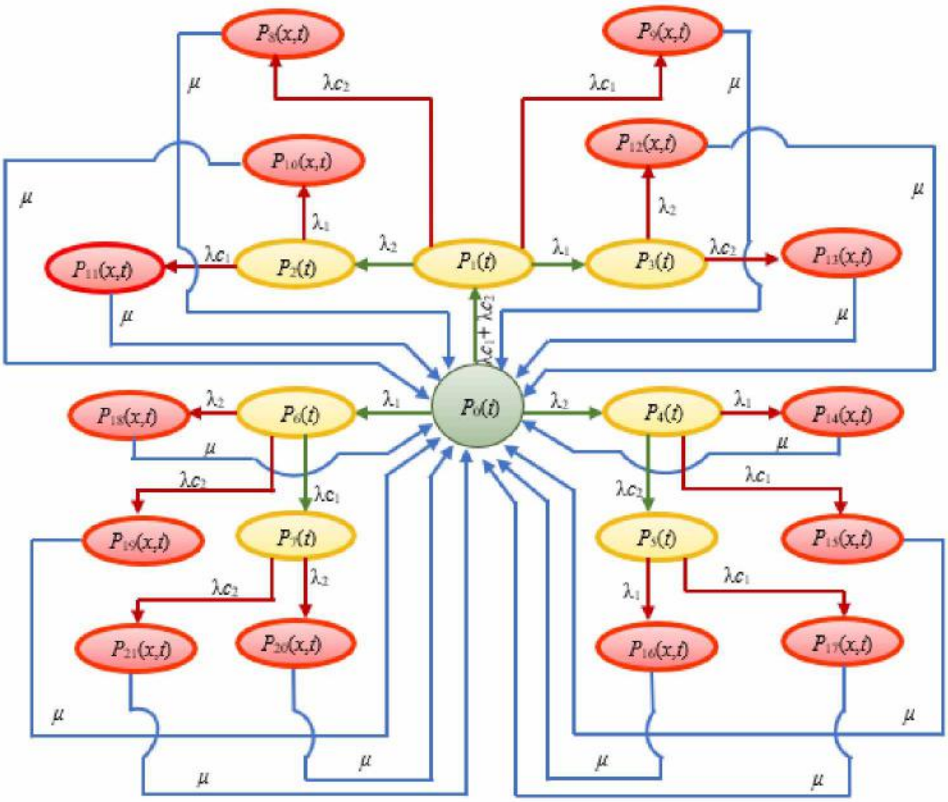

Figure 2. Transition diagram

3. Governing Equations

The following set of equations have been derived for the proposed communication system by using Markov process.

Original State

$$\left[\frac{\partial}{\partial t}+\lambda c_1+\lambda c_2+\lambda_1+\lambda_2\right]P_0(t)=\int_0^{\infty}\sum_{i=8}^{21}\mu P_i(x,t)dx \tag{1}$$

Degraded States

$$\left[\frac{\partial}{\partial t}+\lambda c_1+\lambda c_2+\lambda_1+\lambda_2\right]P_1(t)=\left(\lambda c_1+\lambda c_2\right)P_0(t) \tag{2}$$

$$\left[\frac{\partial}{\partial t}+\lambda c_1+\lambda_1\right]P_2(t)=\lambda_2 P_1(t) \tag{3}$$

$$\left[\frac{\partial}{\partial t}+\lambda c_2+\lambda_2\right]P_3(t)=\lambda_1 P_1(t) \tag{4}$$

$$\left[\frac{\partial}{\partial t}+\lambda c_1+\lambda c_2+\lambda_1\right]P_4(t)=\lambda_2 P_0(t) \tag{5}$$

$$\left[\frac{\partial}{\partial t}+\lambda c_1+\lambda_1\right]P_5(t)=\lambda c_2 P_4(t) \tag{6}$$

$$\left[\frac{\partial}{\partial t}+\lambda c_1+\lambda c_2+\lambda_2\right]P_6(t)=\lambda_1 P_0(t) \tag{7}$$

$$\left[\frac{\partial}{\partial t}+\lambda c_2+\lambda_2\right]P_7(t)=\lambda c_1 P_6(t) \tag{8}$$

Failed States

$$\left[\frac{\partial}{\partial t}+\frac{\partial}{\partial x}+\mu\right]P_i(x,t)=0,\quad i=8,9,...20,21 \tag{9}$$

Boundary Conditions

$$P_8(0,t)=\lambda c_2 P_1(t) \tag{10}$$

$$P_9(0,t)=\lambda c_1 P_1(t) \tag{11}$$

$$P_{10}(0,t)=\lambda_1 P_2(t) \tag{12}$$

$$P_{11}(0,t)=\lambda c_1 P_2(t) \tag{13}$$

$$P_{12}(0,t)=\lambda_2 P_3(t) \tag{14}$$

$$P_{13}(0,t)=\lambda c_2 P_3(t) \tag{15}$$

$$P_{14}(0,t)=\lambda_1 P_4(t) \tag{16}$$

$$P_{15}(0,t) = \lambda c_1 P_4(t) \tag{17}$$

$$P_{16}(0,t) = \lambda_1 P_5(t) \tag{18}$$

$$P_{17}(0,t) = \lambda c_1 P_5(t) \tag{19}$$

$$P_{18}(0,t) = \lambda_2 P_6(t) \tag{20}$$

$$P_{19}(0,t) = \lambda c_2 P_6(t) \tag{21}$$

$$P_{20}(0,t) = \lambda_2 P_7(t) \tag{22}$$

$$P_{21}(0,t) = \lambda c_2 P_7(t) \tag{23}$$

Initial Condition

$$\begin{aligned} &P_0(0) = 1 \\ &P_i(0) = 0, \qquad i = 1,2,\ldots,21 \end{aligned} \tag{24}$$

After taking the Laplace transform from Equations (1) to (23), one can get the following set of equations:

$$\left[s + \lambda c_1 + \lambda c_2 + \lambda_1 + \lambda_2\right]\overline{P}_0(s) = \int_0^{\infty}\sum_{i=8}^{21} \mu \overline{P}_i(x,s)dx \tag{25}$$

$$\left[s + \lambda c_1 + \lambda c_2 + \lambda_1 + \lambda_2\right]\overline{P}_1(s) = \left(\lambda c_1 + \lambda c_2\right)\overline{P}_0(s) \tag{26}$$

$$\left[s + \lambda c_1 + \lambda_1\right]\overline{P}_2(s) = \lambda_2 \overline{P}_1(s) \tag{27}$$

$$\left[s + \lambda c_2 + \lambda_2\right]\overline{P}_3(s) = \lambda_1 \overline{P}_1(s) \tag{28}$$

$$\left[s + \lambda c_1 + \lambda c_2 + \lambda_1\right]\overline{P}_4(s) = \lambda_2 \overline{P}_0(s) \tag{29}$$

$$\left[s + \lambda c_1 + \lambda_1\right]\overline{P}_5(s) = \lambda c_2 \overline{P}_4(s) \tag{30}$$

$$\left[s + \lambda c_1 + \lambda c_2 + \lambda_2\right]\overline{P}_6(s) = \lambda_1 \overline{P}_0(s) \tag{31}$$

$$\left[s + \lambda c_2 + \lambda_2\right]\overline{P}_7(s) = \lambda c_1 \overline{P}_0(s) \tag{32}$$

$$\left[s + \frac{\partial}{\partial x} + \mu\right]\overline{P}_i(x,s) = 0, \quad i = 8,9,\ldots 20,21 \tag{33}$$

$$\overline{P}_8(0,s) = \lambda c_2 \overline{P}_1(s) \tag{34}$$

$$\overline{P}_9(0,s) = \lambda c_1 \overline{P}_1(s) \tag{35}$$

$$\overline{P}_{10}(0,s) = \lambda_1 \overline{P}_2(s) \tag{36}$$

$$\overline{P}_{11}(0,s) = \lambda c_1 \overline{P}_2(s) \tag{37}$$

$$\overline{P}_{12}(0,s) = \lambda_2 \overline{P}_3(s) \tag{38}$$

$$\bar{P}_{13}(0,s) = \lambda c_2 \bar{P}_3(s) \tag{39}$$

$$\bar{P}_{14}(0,s) = \lambda_1 \bar{P}_4(s) \tag{40}$$

$$\bar{P}_{15}(0,s) = \lambda c_1 \bar{P}_4(s) \tag{41}$$

$$\bar{P}_{16}(0,s) = \lambda_1 \bar{P}_5(s) \tag{42}$$

$$\bar{P}_{17}(0,s) = \lambda c_1 \bar{P}_5(s) \tag{43}$$

$$\bar{P}_{18}(0,s) = \lambda_2 \bar{P}_6(s) \tag{44}$$

$$\bar{P}_{19}(0,s) = \lambda c_2 \bar{P}_6(s) \tag{45}$$

$$\bar{P}_{20}(0,s) = \lambda_2 \bar{P}_7(s) \tag{46}$$

$$\bar{P}_{21}(0,s) = \lambda c_2 \bar{P}_7(s) \tag{47}$$

Now, solving Equation (25) - (33) with the help of (34) - (47), the following state transition probabilities are obtained:

$$\bar{P}_0(s) = \frac{1}{(s+\lambda c_1+\lambda c_2+\lambda_1+\lambda_2)-\bar{S}(s)\left[\bar{U}(s)+\bar{V}(s)+\bar{W}(s)\right]} \tag{48}$$

$$\bar{P}_1(s) = \frac{(\lambda c_1+\lambda c_2)}{s+\lambda c_1+\lambda c_2+\lambda_1+\lambda_2}\bar{P}_0(s) \tag{49}$$

$$\bar{P}_2(s) = \frac{\lambda_2(\lambda c_1+\lambda c_2)}{(s+\lambda c_1+\lambda_1)(s+\lambda c_1+\lambda c_2+\lambda_1+\lambda_2)}\bar{P}_0(s) \tag{50}$$

$$\bar{P}_3(s) = \frac{\lambda_1(\lambda c_1+\lambda c_2)}{(s+\lambda c_2+\lambda_2)(s+\lambda c_1+\lambda c_2+\lambda_1+\lambda_2)}\bar{P}_0(s) \tag{51}$$

$$\bar{P}_4(s) = \frac{\lambda_2}{s+\lambda c_1+\lambda c_2+\lambda_1}\bar{P}_0(s) \tag{52}$$

$$\bar{P}_5(s) = \frac{\lambda_2\,\lambda c_2}{(s+\lambda c_1+\lambda_1)(s+\lambda c_1+\lambda c_2+\lambda_1)}\bar{P}_0(s) \tag{53}$$

$$\bar{P}_6(s) = \frac{\lambda_1}{s+\lambda c_1+\lambda c_2+\lambda_2}\bar{P}_0(s) \tag{54}$$

$$\bar{P}_7(s) = \frac{\lambda_1\,\lambda c_1}{(s+\lambda c_2+\lambda_2)(s+\lambda c_1+\lambda c_2+\lambda_2)}\bar{P}_0(s) \tag{55}$$

$$\bar{P}_8(s) = \frac{\lambda c_2(\lambda c_1+\lambda c_2)}{(s+\lambda c_1+\lambda c_2+\lambda_1+\lambda_2)}\left(\frac{1-\bar{S}(s)}{s}\right)\bar{P}_0(s) \tag{56}$$

$$\bar{P}_9(s) = \frac{\lambda c_1(\lambda c_1+\lambda c_2)}{(s+\lambda c_1+\lambda c_2+\lambda_1+\lambda_2)}\left(\frac{1-\bar{S}(s)}{s}\right)\bar{P}_0(s) \tag{57}$$

$$\bar{P}_{10}(s)=\frac{\lambda_1\lambda_2(\lambda c_1+\lambda c_2)}{(s+\lambda c_1+\lambda_1)(s+\lambda c_1+\lambda c_2+\lambda_1+\lambda_2)}\left(\frac{1-\bar{S}(s)}{s}\right)\bar{P}_0(s) \quad (58)$$

$$\bar{P}_{11}(s)=\frac{\lambda c_1\lambda_2(\lambda c_1+\lambda c_2)}{(s+\lambda c_1+\lambda_1)(s+\lambda c_1+\lambda c_2+\lambda_1+\lambda_2)}\left(\frac{1-\bar{S}(s)}{s}\right)\bar{P}_0(s) \quad (59)$$

$$\bar{P}_{12}(s)=\frac{\lambda_1\lambda_2(\lambda c_1+\lambda c_2)}{(s+\lambda c_2+\lambda_2)(s+\lambda c_1+\lambda c_2+\lambda_1+\lambda_2)}\left(\frac{1-\bar{S}(s)}{s}\right)\bar{P}_0(s) \quad (60)$$

$$\bar{P}_{13}(s)=\frac{\lambda c_2\lambda_1(\lambda c_1+\lambda c_2)}{(s+\lambda c_2+\lambda_2)(s+\lambda c_1+\lambda c_2+\lambda_1+\lambda_2)}\left(\frac{1-\bar{S}(s)}{s}\right)\bar{P}_0(s) \quad (61)$$

$$\bar{P}_{14}(s)=\frac{\lambda_1\lambda_2}{(s+\lambda c_1+\lambda c_2+\lambda_1)}\left(\frac{1-\bar{S}(s)}{s}\right)\bar{P}_0(s) \quad (62)$$

$$\bar{P}_{15}(s)=\frac{\lambda_1\lambda_2}{(s+\lambda c_1+\lambda c_2+\lambda_1)}\left(\frac{1-\bar{S}(s)}{s}\right)\bar{P}_0(s) \quad (63)$$

$$\bar{P}_{16}(s)=\frac{\lambda c_2\,\lambda_1\,\lambda_2}{(s+\lambda c_1+\lambda_1)(s+\lambda c_1+\lambda c_2+\lambda_1)}\left(\frac{1-\bar{S}(s)}{s}\right)\bar{P}_0(s) \quad (64)$$

$$\bar{P}_{17}(s)=\frac{\lambda c_2\,\lambda c_1\,\lambda_2}{(s+\lambda c_1+\lambda_1)(s+\lambda c_1+\lambda c_2+\lambda_1)}\left(\frac{1-\bar{S}(s)}{s}\right)\bar{P}_0(s) \quad (65)$$

$$\bar{P}_{18}(s)=\frac{\lambda_1\,\lambda_2}{(s+\lambda c_1+\lambda_1)(s+\lambda c_1+\lambda c_2+\lambda_1)}\left(\frac{1-\bar{S}(s)}{s}\right)\bar{P}_0(s) \quad (66)$$

$$\bar{P}_{19}(s)=\frac{\lambda_1\,\lambda c_2}{(s+\lambda c_1+\lambda c_2+\lambda_2)}\left(\frac{1-\bar{S}(s)}{s}\right)\bar{P}_0(s) \quad (67)$$

$$\bar{P}_{20}(s)=\frac{\lambda c_1\lambda_1\,\lambda_2}{(s+\lambda c_2+\lambda_2)(s+\lambda c_1+\lambda c_2+\lambda_2)}\left(\frac{1-\bar{S}(s)}{s}\right)\bar{P}_0(s) \quad (68)$$

$$\bar{P}_{21}(s)=\frac{\lambda c_2\lambda_1\,\lambda c_1}{(s+\lambda c_2+\lambda_2)(s+\lambda c_1+\lambda c_2+\lambda_2)}\left(\frac{1-\bar{S}(s)}{s}\right)\bar{P}_0(s) \quad (69)$$

The probabilities of up and down states are as follows:

$$\bar{P}_{up}(s)=\bar{P}_0(s)\left[\begin{array}{l}1+\frac{\lambda c_1+\lambda c_2}{(s+\lambda_1+\lambda c_1+\lambda c_2+\lambda_2)}\left\{1+\frac{\lambda_2}{(s+\lambda_1+\lambda c_1)}+\frac{\lambda_1}{(s+\lambda_2+\lambda c_2)}\right\}+\frac{\lambda_2}{(s+\lambda_1+\lambda c_1+\lambda c_2)}\\ \left\{1+\frac{\lambda c_2}{(s+\lambda_1+\lambda c_1)}\right\}+\frac{\lambda_1}{(s+\lambda_2+\lambda c_1+\lambda c_2)}\left\{1+\frac{\lambda c_1}{(s+\lambda_2+\lambda c_2)}\right\}\end{array}\right] \quad (70)$$

$$\bar{P}_{down}(s)=\bar{P}_0(s)\left(\frac{1-\bar{S}(s)}{s}\right)\left[\begin{array}{l}\frac{\lambda c_1+\lambda c_2}{(s+\lambda_1+\lambda c_1+\lambda c_2+\lambda_2)}\left\{\begin{array}{l}\lambda c_1+\lambda c_2+\frac{\lambda_1\lambda_2}{(s+\lambda_1+\lambda c_1)}+\frac{\lambda c_1\lambda_2}{(s+\lambda_1+\lambda c_1)}+\\ \frac{\lambda_1\lambda_2}{(s+\lambda_2+\lambda c_2)}+\frac{\lambda c_2\lambda_1}{(s+\lambda_2+\lambda c_2)}\end{array}\right\}+\\ \frac{\lambda_2}{(s+\lambda_1+\lambda c_1+\lambda c_2)}\left\{\lambda_1+\lambda c_1+\frac{\lambda c_2\lambda_1}{(s+\lambda_1+\lambda c_1)}+\frac{\lambda c_1\lambda c_2}{(s+\lambda_1+\lambda c_1)}\right\}+\\ \frac{\lambda_1}{(s+\lambda_2+\lambda c_1+\lambda c_2)}\left\{\lambda_2+\lambda c_2+\frac{\lambda c_1\lambda_1}{(s+\lambda_2+\lambda c_2)}+\frac{\lambda c_1\lambda c_2}{(s+\lambda_2+\lambda c_2)}\right\}\end{array}\right] \quad (71)$$

where,

$$\bar{U}(s)=\frac{(\lambda c_1+\lambda c_2)}{(s+\lambda c_1+\lambda c_2+\lambda_1+\lambda_2)}\left\{\begin{array}{l}\lambda c_1+\lambda c_2+\frac{\lambda_1\lambda_2}{(s+\lambda c_1+\lambda_1)}+\frac{\lambda c_1\lambda_2}{(s+\lambda c_1+\lambda_1)}\\ +\frac{\lambda_1\lambda_2}{(s+\lambda c_2+\lambda_2)}+\frac{\lambda c_2\lambda_1}{(s+\lambda c_2+\lambda_2)}\end{array}\right\}$$

$$\bar{V}(s)=\frac{\lambda_2}{(s+\lambda c_1+\lambda c_2+\lambda_1)}\left\{\lambda_1+\lambda c_1+\frac{\lambda_1\lambda c_2}{(s+\lambda c_1+\lambda_1)}+\frac{\lambda c_1\lambda c_2}{(s+\lambda c_1+\lambda_1)}\right\}$$

$$\bar{W}(s)=\frac{\lambda_1}{(s+\lambda c_1+\lambda c_2+\lambda_2)}\left\{\lambda_2+\lambda c_2+\frac{\lambda_2\lambda c_1}{(s+\lambda c_2+\lambda_2)}+\frac{\lambda c_1\lambda c_2}{(s+\lambda c_2+\lambda_2)}\right\}$$

4. Numerical Calculations

For computing the reliability measures of the proposed railway communication system, following failure and repair rates will be assumed as given by Table 2.

Table 2. Assumed failure and repair rate of proposed railway communication system.

Failure and repair rate/per hour
$\lambda_1 = 0.009$
$\lambda c_1 = 0.06$
$\lambda_2 = 0.007$
$\lambda c_2 = 0.03$
$\mu = 1$

4.1. Availability

The availability of the proposed system is computed by substituted the values of failure and repair rates as given in Table 2, in Equation (70), after putting these values, availability of the proposed RCS in terms of time t is given as follows:

$$A(t) = -0.01158e^{(-0.9887t)}+0.05608e^{(-0.2075t)}-0.00085e^{(-0.0779t)}-0.00277e^{(-0.0439t)}+0.95911 \quad (72)$$

Now after varying time from 0 to 50 with the interval of 5 units of time, one can get the numerical values of availability of the proposed system which are demonstrates by table 3.

Table 3. Availability of the proposed system

Time (t)	Availability
0	1.00000
5	0.97611
10	0.96398
15	0.95991
20	0.95867
25	0.95838
30	0.95829
35	0.95815
40	0.95811
45	0.95808
50	0.95801

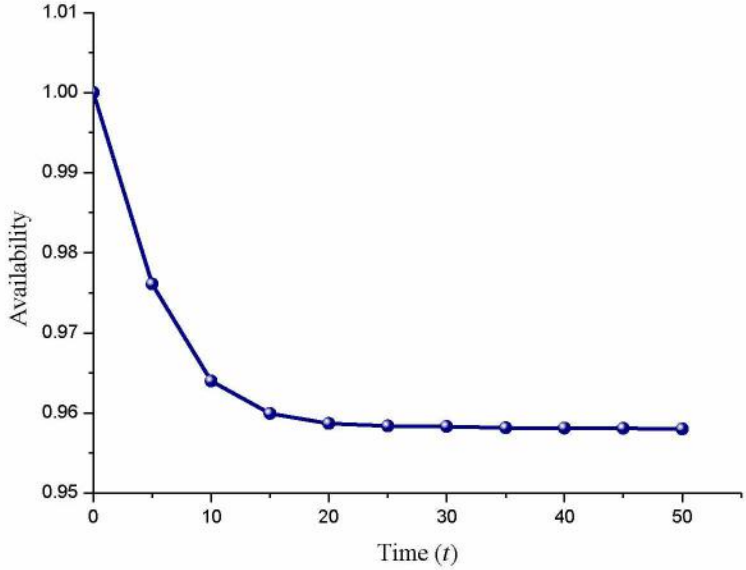

Figure 3. Availability of the proposed system as time vary from 0 to 50 units

4.2. Reliability

For the proposed system, reliability is calculated by substitute the values of failures as given in Table 2 and repair rate equal to zero in Equation (70), after substitute these failures and repairs values, the reliability function in terms of t is given by

$$R(t) = 0.30057e^{(-0.0370t)} + 0.64938e^{(-0.6900t)} + (0.06123t + 0.05005)e^{(-0.1060t)} \quad (73)$$

Now varying time t from 0 to 10 unit with an interval of 1 unit, one can analyzed the reliability behavior of proposed system as tabulated in Table 4 and shown in Figure 4.

Table 4. Reliability of the system

Time (t)	Reliability
0	1.00000
1	0.91938
2	0.76281
3	0.60074
4	0.45978
5	0.34658
6	0.25947
7	0.19404
8	0.14553
9	0.10976
10	0.08341

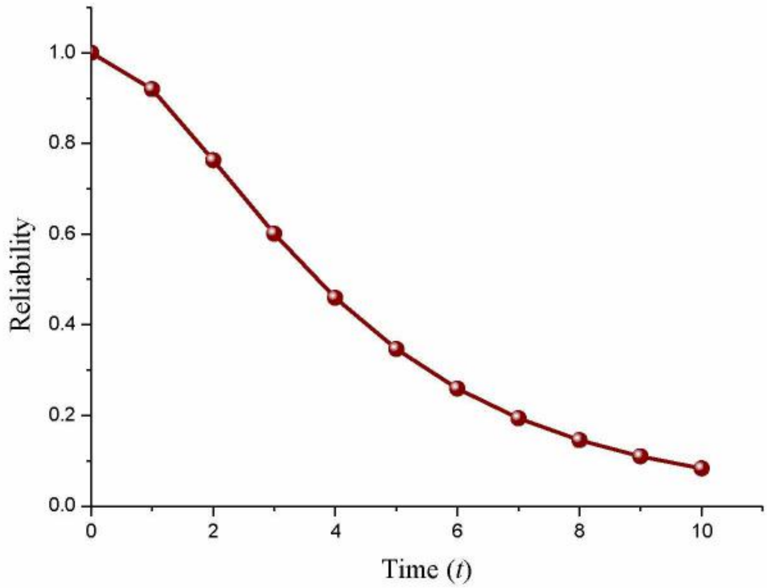

Figure 4. Reliability of the system w.r.t. time

4.3. Mean time to system Failure

The mean time to failure is calculated by taking μ = 0 and limit $s \to 0$ (Tyagi et al., 2021) in Equation (70). So, the MTTF of the proposed system in terms of failure rate is given by Equation (74).

$$MTTF = \frac{1}{(\lambda c_1 + \lambda c_2 + \lambda_1 + \lambda_2)} \left[\begin{array}{l} 1 + \frac{\lambda c_1 + \lambda c_2}{(\lambda_1 + \lambda c_1 + \lambda c_2 + \lambda_2)} \left\{ 1 + \frac{\lambda_2}{(\lambda_1 + \lambda c_1)} + \frac{\lambda_1}{(\lambda_2 + \lambda c_2)} \right\} + \frac{\lambda_2}{(\lambda_1 + \lambda c_1 + \lambda c_2)} \\ \left\{ 1 + \frac{\lambda c_2}{(\lambda_1 + \lambda c_1)} \right\} + \frac{\lambda_1}{(\lambda_2 + \lambda c_1 + \lambda c_2)} \left\{ 1 + \frac{\lambda c_1}{(\lambda_2 + \lambda c_2)} \right\} \end{array} \right] \quad (74)$$

Now setting all failure rates values as given by Table 2 and vary each failure rate one by one from 0.001 to 0.04 in Equation (74) to get the MTTF of the proposed system with respect to variation in the failure rates. The variation in MTTF can be seen from Table 5 and corresponding Figure 5 shows the behaviour of MTTF regarding variation in failure rates.

Table 5. MTTF of the system

Variation in Failure rates	MTTF			
	λ_{C1}	λ_{C2}	λ_1	λ_2
0.001	68.6161	51.82156	22.35057	24.79149
0.003	62.38204	45.53850	21.65165	24.28984
0.005	57.63895	41.19976	21.29690	23.84834
0.007	53.85080	37.98025	21.12371	23.45672
0.009	50.71749	35.46688	20.45672	23.10686
0.02	39.53540	27.40036	19.61863	21.69336
0.04	29.23630	20.75466	19.01606	20.24722
0.06	23.45672	17.10419	17.34855	19.39883
0.08	19.65024	14.65523	17.21551	18.81630
0.1	16.92906	12.85991	16.70574	18.37954

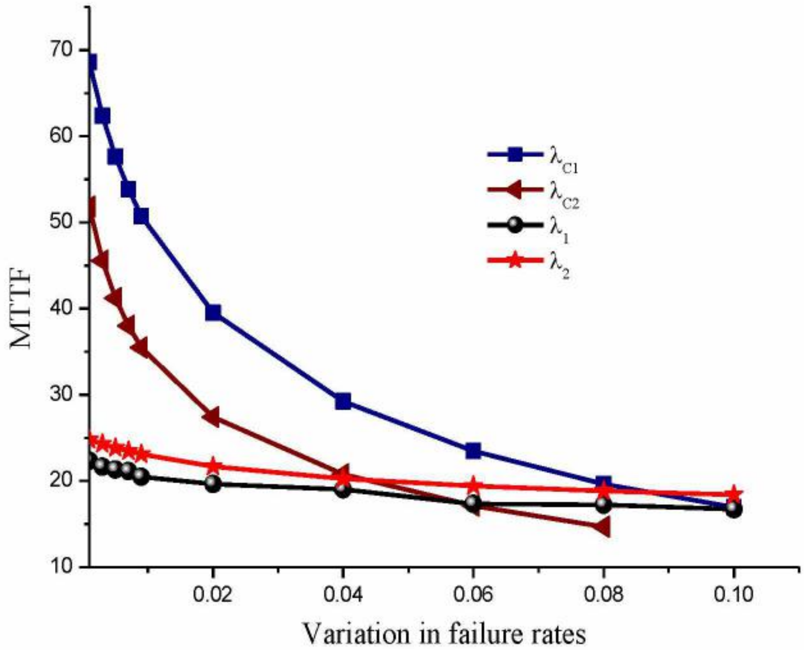

Figure 5. MTTF with respect to variation in failure rates

4.4. Sensitivity of reliability

In reliability sensitivity study, the effect of failure rates on reliability has been studied. The reliability function is the dependent variable. It's dependent because it depends on failures rates. Those failure rates are the independent variable. Sensitivity of reliability is obtained by partial differentiation of reliability function with respect to all the failure rates. Now putting all failure rates as given by Table 2 and repair rate equal to zero in these derivatives, one can get the Table 6 and corresponding Figure 6.

Table 6. Sensitivity of reliability of the proposed communication system

Time (t)	Sensitivity of reliability			
	$\frac{\partial R(t)}{\partial \lambda c_1}$	$\frac{\partial R(t)}{\partial \lambda c_2}$	$\frac{\partial R(t)}{\partial \lambda_1}$	$\frac{\partial R(t)}{\partial \lambda_2}$
0	0	0	0	0
1	-0.08468	-0.08575	-0.01886	-0.03526
2	-0.30679	-0.31133	-0.06439	-0.12756
3	-0.62535	-0.636	-0.123	-0.25976
4	-1.00731	-1.02689	-0.18454	-0.41824
5	-1.42634	-1.45771	-0.24159	-0.59228
6	-1.86164	-1.90766	-0.28897	-0.77354
7	-2.29709	-2.36052	-0.32325	-0.95566
8	-2.72038	-2.80387	-0.34243	-1.13384
9	-3.12234	-3.22838	-0.34555	-1.3046
10	-3.49642	-3.62729	-0.33251	-1.4655

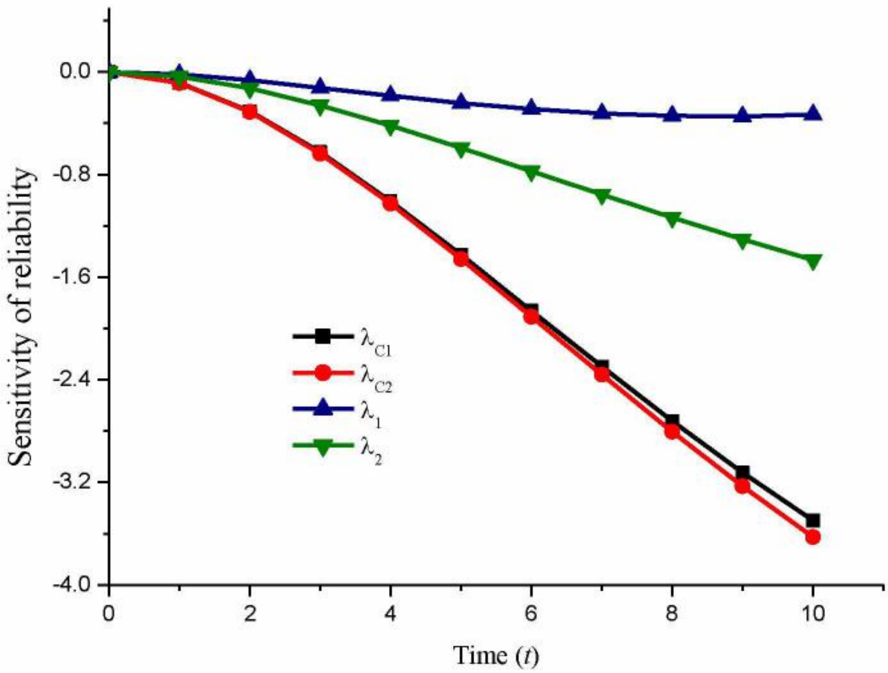

Figure 6. Sensitivity of reliability with respect to time

5. Result Discussion

In this paper, different reliability characteristics have been calculated and analysed for the railway communication system. Some results related to these reliability characteristics are given below:

(i) From Table 3 and Figure 3, one can see the behaviour of the availability of the proposed RCS. Availability of the RCS decreases with increases in the value of time t. At initially, i.e., time t = 0, availability is 1 and after 50 units of time, system availability is 0.9580. From Figure 3, one can see that the availability graph is constant for the time period 35 units to 50 units.

(ii) Table 4 and corresponding Figure 4 give an idea about the behaviour of the reliability of proposed railway communication system regarding time *t* for various system failure rates. From Table 4 and Figure 4, it is easily seen that the reliability of the proposed system decreases rapidly as increment in time *t*. At initially, reliability is one and after 10 units of time, reliability is 0.08341.

(iii) From Table 5, it is easily seen that the MTTF of the proposed system continuously decreases as all the failure rates λ_1, λc_1, λ_2, λc_2 increases. With respect to all stations failure rates MTTF is decreases in a uniform manner but with respect to control centre failure rates it decreases rapidly. Figure 5 demonstrates that the MTTF is high with variation in the failure rate of the first control centre and lowest regarding failure rates of path 1 stations which means failure rate of all stations of path 1 has more frequent downtime and disruption as compare to other failure rates.

(iv) Further, From Table 6 and Figure 6, one can see the behaviour of the failure rates on system reliability. The reliability of the RCS is more influenced by the variation in the second control centre failure rate which means second control centre failure rate causes the stronger change in reliability of the proposed system as time increases.

6. Conclusion

The present study discussed the performance of a railway communication system regarding sits component failure, and a procedure to evaluate the system's reliability measures. In order to numerically analyzed the performance of the composed system, Markov process has been applied. In the proposed railway communication system, the reliability is more influenced by failure rate of second control centre, thus the system reliability can be increased by a slight improvement in the failure rate of second control centre. In future work one can extend this investigation by using Link-Lk between switches so that communication is available even if there are multiple failures.

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VISION-BASED WEIGHTING SYSTEM (VIWES) IN PROSPECTIVE MADM

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Abstract: *Policy-making is an undeniable decision-making process in every company where different kinds of decisions are taken based on different goals and preferences in each vision. "Prospective Multiple Attribute Decision Making (PMADM)" is one of the well-known decision-making frameworks that have been used as a flexible decision-making tool for developing policies and making future decisions over different periods. This study presents a multi attribute problem with three different visions where a decision-making process is required for each vision in order to prioritize the potential set of alternatives. Evaluation Based on the Distance from the Average Solution (EDAS) is used as a MADM model to show the applicability and feasibility of the PMADM framework. A vision-based weighting system (ViWeS) prepares a new opportunity to take proper decisions in different visions and time requirements. This research is analyzed three-time vision (Current, 2025, and 2030) and showed by changing the time, the rank of the alternatives also is changed. In numerical example is indicated in the current vision, Alternative 5 gets rank one and alternative six get rank 2, for 2025 vision, the rank one and two don't change, and in vision 2030, the rank of one does not change, but the rank of second change from Alternative 6 to 3.*

Key words: *Prospective Multiple Attribute Decision Making (PMADM), Vision-based weighting system (ViWeS), Evaluation Based on the Distance from the Average Solution (EDAS), Policy-Making, Weighting system*

1. Introduction

Multiple Attribute Decision Making (MADM) models are considered reliable decision-making models that can help decision-makers and policymakers address

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complex evaluation problems such as supplier selection problems. Logistics provide problem, waste management, location selection problem considering multiple attributes (Ignatius *et al.* 2016; Yazdani *et al.* 2017; Ebadi Torkayesh *et al.* 2019; Hashemkhani Zolfani *et al.* 2020). MADM models such as BWM (Fazlollahtabar *et al.* 2021; Pamučar and Savin, 2020), SWARA (Radović and Stević, 2018), AHP (Alosta *et al.* 2021), FUCOM (Durmić et al. 2020) are applied to determine the importance of decision criteria, while models such as EDAS (Stević et al 2016), CoCoSo (Biswas *et al.* 2019), CODAS (Badi *et al.* 2018), TOPSIS, MARCOS (Đalić *et al.* 2021) are applied to evaluate alternatives of a multi attribute problem (Mardani *et al.* 2016; Kumar *et al.* 2017). MADM models are able to address a complex problem with *n* criteria and *m* alternatives for a specific time. However, the decision-making process can be due to several changes in weight of criteria and then an evaluation framework, considering a decision maker's or a company's visions and goals for different periods. Therefore, the decision-making process and obtained results from traditional MADM models may not be reliable in the following years. So, nonexistent a MADM model which considers the future makes more sense than previously.

Prospective MADM (PMADM) is a new framework that can be used to process different companies' visions. The MADM models make decisions in a steady and stable state (fix situation), but PMADM expands this decision environment and considers the time that hasn't happened. The PMADM uses two items for studying the future, limiters and boosters. These items in the different situations given different values to alternatives in evaluation.

Companies can facilitate their policy-making process using PMADM, where several visions can be defined based on companies' goals. By this method, managers can survey and evaluate their future outcomes and modify their decisions and plan.

There are many MADM methods like PROMETHEE (Brans 1982) and VIKOR (Opricovic, 1988), and TOPSIS (Hwang and Yoon in 1981), but they don't consider the future, and this shortage of them causes managers less willing to use them. In contrast, these methods could help them make better policy decisions. For developing and make more efficient methods, this idea formed in our minds that using the PMADM framework can promote their performance and activities. The PMADM approach considers future vision and changes the value of criteria. This conversion affects the rank of alternatives. The researchers who study in the MADM context usually consider the current time in their studies - considering the future in decision making expressed by the PMADM method. But, researchers don't use this method in their studies. This paper considers the future in decision-making by the use of the PMADM method.

In this paper, we develop a PMADM framework and define three visions for a numerical decision-making example where weights of criteria are different in each vision based on goals and preferences and possible events that may happen in the future. For the evaluation part, the EDAS model, as a reliable and frequently used tool, is applied to prioritize the alternatives for each vision.

2. Literature review

As said before, most of the time, Managers concentrate on future actions and goals and make plans to reach them. Due to a lot of factors, managers are confused about set or ranking company priorities. Therefore head manager or an administrator needs to see the future more clearly and make an appropriate decision. To determine the direction and guide policymakers or officers to make a better decision. This section first reviewed the PMADM model and its uses in various contexts and then described a MADM model. Because according to the subject of the article and for futuristic decisions, researchers want to use the PMADM framework for a MADM model.

Hashemkhani Zolfani *et al.* (2016) developed a new framework for MADM problem, called Prospective MADM, which not only facilitate the decision-making process at the moment but also enables decision-makers to consider future visions and extend the decision making process using different sets of inputs based on possible events or goals that are planned for each vision. Later, Zolfani *et al.* (2018) studied the prospective MADM framework for sustainability assessment problems, focusing on a multi-aspect set of criteria that can be used for multi-attribute problems. They consider futures sustainability an umbrella for sustainability, which consists of the future economy, environment, and social position. As to the importance of development in sustainability, they introduced a trend for Exergy, which consists of energy, environment, and sustainable development. In this trend, energy is presented as a core item.

Zolfani and Masaeli (2020) presented a comprehensive framework for the prospective MADM approach and its application for the health device industry of Iran, considering several visions during sanctions. By the PMADM, they achieved their goal to increase the medical device market share ten times more like a sustainable market for the country. In this research, Max capacity, ideal directed scenario, and supportive backup criteria are used in the PMADM framework.

Hashemkhani Zolfani *et al.* (2020) used a text-mining tool, latent semantic analysis, as a criteria selection and weighting system in prospective MADM. They use this for machine tool selection and introduce five criteria as (1) Cost and Serviceability; (2) Technical Features and Safety; (3) Size and Precision; (4) Flexibility; and (5) Productivity. After calculating and ranking them, they report that Cost and Serviceability have the highest priority among these criteria.

After explaining the uses of PMADM in various contexts, it talks about a MADM method and its uses in articles or case studies. Evaluation Based on the Distance from the Average Solution (EDAS) is one of the recently developed MADM models that is used to prioritize a set of alternatives concerning multiple factors (Keshavarz Ghorabee *et al.* 2015). Kahraman *et al.* (2017) proposed a new extension of the EDAS model under fuzzy set theory to evaluate the waste disposal location selection process. In this research, they determined three alternatives and three criteria. The criteria uses are water pollution (w), distance to residential areas (D), and slope (S). For solving, they decided to use the interval-valued intuitionistic fuzzy EDAS (IVIF EDAS) method. In the IVIF method, membership and non-membership function and unknown degree (hesitancy degree) are calculated.

Ecer (2018) integrated AHP and EDAS models under fuzzy set theory to address third-party logistics (3PLs) provider selection problems. First, fuzzy AHP was used to determine the importance of decision criteria, and then fuzzy EDAS was used to prioritize alternatives. He determined that cost, quality, and professionalism are the most critical factors for 3PLs provider selection.

Li et al. (2019) developed another extension of the EDAS method using a neutrosophic set to consider the uncertainty that may happen in the decision-making process. They proposed a convex weighted average operator of multivalued neutrosophic numbers (MVNNs) to calculate the average solution of criteria.

Torkayesh *et al.* (2020) proposed an integrated MADM model using the Shanon Entropy and EDAS methods. The proposed decision-making model has applied a neighborhood selection problem for a new international student who wants to be located in Istanbul, Turkey. The usability and capacity of five renewable resources: solar PV, Solar thermal, wind power, geothermal, and biomass concerning economic, technical, social, and environmental aspects are measured. By EDAS method are ranked these resources and showed wind power is the most suitable energy for their case study.

Behzad *et al.* (2020) used a hybrid decision-making model by using BWM and EDAS models to make an evaluation framework in order to assess waste management status in Nordic countries. They use seven criteria as waste generation, composting waste, recycling waste, landfilling waste, recycling rate, waste to the energy rate, and greenhouse gas emissions from waste. Comparing these criteria concludes that Sweden has the best waste management profile.

2.1. Main contribution

In this article, researchers are trying to develop a decision-making policy to consider the future in decision-making furthermore to the current time. In most conventional decision-making methods, only the present time is considered. This paper attribute to this issue attempt to introduce a vision-based weighting system that facilitates the decision processes. This system is a combination of the PMADM framework with the MADM method. The ViWeS helps administers or managers decide by considering time vision. Finding or verdict in current time is different from the future because the weight of criteria to time vision changes. For example, suppose someone has a plan for reaching a specific goal in two years and wants to determine his alternative priorities; if he doesn't consider the future vision, he may gain the wrong rank of alternatives and doesn't reach his aim. In the numerical example section, this rank changing by time vision changing is shown by an example.

3. Methodology

This section describes the EDAS model that can be applied for PMADM problems that consider different types of weighting visions based on events that may happen in the future and affect the decision-making process. One of the reasons which opt EDAS method is it needs fewer computations concerning most of the other multi-attribute decision-making methods. At the same time, it can produce the same ranking of alternatives (Kahraman et al. (2017)).

3.1. Evaluation Based on the Distance from the Average Solution (EDAS)

Keshavarz Ghorabaee et al. 2017 proposed a new brand Multiple Attribute Decision Making (MADM) method, called EDAS, to address multi-attribute problems such as supply chain management, transportation problem, waste management, etc. By measuring the distance from ideal and nadir solutions, is determined the best alternative. After calculating these distances, the one that has a lower distance from the ideal solution and a higher distance from the nadir solution is our perfect answer. The EDAS method calculating these distances from the average solution (AV). This method defines the positive distance from average (PDA) and negative distance from average (NDA) and specified the best alternative after comparing these distances. For more detail of this method in continuing to explain the steps of this.

The steps of the EDAS method are explained below.

Step 1. In this step, the decision-maker constructs the initial decision matrix.

$$X = \left[X_{ij}\right]_{n*m} = \begin{bmatrix} X_{11} & X_{12} & \dots & X_{1m} \\ X_{21} & X_{22} & \dots & X_{2m} \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ X_{n1} & X_{n2} & \dots & X_{nm} \end{bmatrix} \tag{1}$$

Step 2. The average solution for each criterion is calculated based on equations.

$$AV = \left[AV_j\right]_{1*m} \tag{2}$$

$$\text{AV}_j = \frac{\sum_{i=1}^{n} X_{ij}}{n} \tag{3}$$

Step3. Positive distance from average (PDA) and negative distance from average (NDA) are calculated.

$$PDA = \left[PDA_{ij}\right]_{n*m} \tag{4}$$

$$\text{NDA}=\left[NDA_{ij}\right]_{n*m} \tag{5}$$

if j th criterion is beneficial,

$$\text{PDA}_{ij} = \frac{\max(0,(X_{ij} - AV_j))}{AV_j}, \tag{6}$$

$$\text{NDA}_{ij} = \frac{\max(0,(AV_j - X_{ij}))}{AV_j}, \tag{7}$$

if j th criterion is non-beneficial,

$$\text{PDA}_{ij} = \frac{\max(0,(AV_j - X_{ij}))}{AV_j}, \tag{8}$$

$$\text{NDA}_{ij} = \frac{\max(0,(X_{ij} - AV_j))}{AV_j}, \tag{9}$$

Step 4. We calculate the weighted sum of PDA and NDA for all alternatives which are denoted as SP and SN.

$$SP_i = \sum_{j=1}^{m} w_j * PDA_{ij}; \tag{10}$$

$$SN_i = \sum_{j=1}^{m} w_j * NDA_{ij}; \tag{11}$$

Step 5. We normalize the obtained values in step 4. These values are then added and construct a new vector, called NSP (normalized weighted sum of PDA) and NSN (normalized weighted sum of NDA).

$$NSP_i = \frac{SP_i}{\max_i(SP_i)}; \tag{12}$$

$$\mathrm{NSN}_i = 1 - \frac{SN_i}{\max_i(SN_i)}; \tag{13}$$

Step 6. Finally, appraisal score (AS) for each alternative is calculated.

$$AS_i = \frac{1}{2}(NSP_i + NSN_i), \tag{14}$$

4. Numerical example

In this part, define a numerical example in order to show the applicability and feasibility of the EDAS based PMADM framework. A multiple attribute problem is considered in the numerical example, which includes five decision criteria and six alternatives that should be evaluated accordingly. Weight of decision criteria is proposed for three different visions as current vision, vision 2025, and vision 2030. The importance of decision criteria varies in each vision due to the possible changes that may happen and affect the decision-making process. For each set of weights, the EDAS model is used to solve the decision-making problem and identify the ranking order of alternatives for each time vision. In Table 1, the initial decision matrix including scores of alternatives concerning each criterion is reported. The weight of criteria for each time vision is also reported in Table 1.

Table 1. Initial decision matrix

Criteria	C_1	C_2	C_3	C_4	C_5
Max/Min	Max	Min	Max	Max	Max
			Weights		
Current vision	0.2	0.25	0.2	0.15	0.2
Vision 2025	0.22	0.21	0.18	0.2	0.19
Vision 2030	0.25	0.18	0.18	0.24	0.15
A_1	7	6	8	6	7
A_2	6	7	8	7	8
A_3	8	6	7	6	7
A_4	7	7	7	7	8
A_5	8	7	8	7	7
A_6	6	5	8	6	7

In the next step, the EDAS model is used based on the steps explained in the previous section to solve the decision-making process. For this purpose, the SP, SN, NSP, NSN, AS, and the final ranking of each alternative for each set of weights for each time vision is calculated. In Table 2, the results for EDAS parameters and the corresponding ranking order of each alternative are reported. Alternatives A_5 and A_6 are selected as the most preferred alternatives with respect to the current vision. In table 3, the results of the EDAS model for vision 2025 are reported. As same as the current vision, alternatives A_5 and A_6 are selected as the most preferred alternatives. For vision 2030, the results of the EDAS model are reported in table 4. Alternatives A_5 and A_3 are selected as the most preferred alternatives.

Table 2. EDAS values for current vision

	SP	SN	NSP	NSN	AS	Ranking
A_1	0.022	0.021	0.356	0.781	0.569	3
A_2	0.038	0.094	0.626	0.000	0.313	5
A_3	0.042	0.064	0.680	0.318	0.499	4
A_4	0.030	0.083	0.485	0.118	0.302	6
A_5	0.049	0.009	0.796	0.904	0.850	1
A_6	0.061	0.049	1.000	0.479	0.739	2

Table 3. EDAS values for vision 2025

	SP	SN	NSP	NSN	AS	Ranking
A_1	0.019	0.024	0.346	0.723	0.534	3
A_2	0.040	0.087	0.741	0.000	0.370	6
A_3	0.042	0.062	0.777	0.287	0.532	4
A_4	0.033	0.071	0.598	0.182	0.390	5
A_5	0.055	0.009	1.000	0.900	0.950	1
A_6	0.052	0.055	0.952	0.360	0.656	2

Table 4. EDAS values for vision 2030

	SP	SN	NSP	NSN	AS	Ranking
A_1	0.017	0.025	0.279	0.696	0.487	4
A_2	0.040	0.083	0.644	0.000	0.322	6
A_3	0.045	0.060	0.729	0.279	0.504	2
A_4	0.032	0.063	0.518	0.241	0.380	5
A_5	0.062	0.007	1.000	0.918	0.959	1
A_6	0.046	0.061	0.737	0.266	0.502	3

Figure 1 shows the ranking order of each alternative with respect to each time vision defined in this study. Alternative A_5 is selected as the top alternatives in all visions. Although alternative A_6 is selected as the second important alternative, it is ranked as the third one in vision 2030. The ranking order of other alternatives is also slightly changed concerning each time vision.

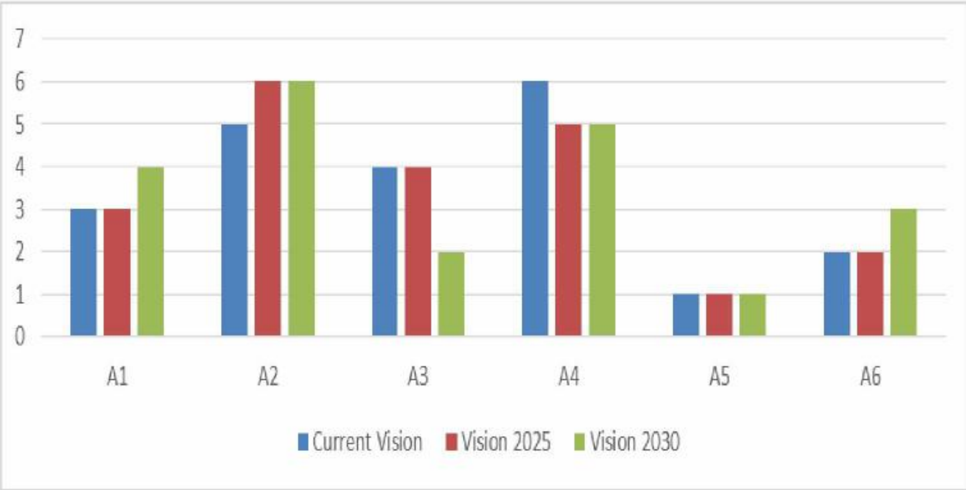

Figure 1. Ranking order of alternatives in different time visions

The main idea for this part is to show that essence could be changed in the current vision to future vision in a particular case. This numerical example is showing this issue of what a proper decision when considering the future is. This example shows in vision 2030, our alternative could be changed, and to reach the company's aim, this issue should be considered. The priorities in time vision could be changed. This issue helps decision-makers to set their decision by this long-term vision.

5. Managerial tips

Managers usually write the company's goals and attempt to reach them. For reaching goals and make a decision, a suitable plan should be set. This plan is consists of a set of alternatives and criteria, and managers should rank these alternatives and consider them according to priorities. Since in the real situation, various criteria involve in decision making, managers should use multiple criteria decision making for finding the best alternative. As previously mentioned, the future vision is one of the crucial issues managers should consider in their decision-making. If a multi-criteria decision-making method exists that considers the future vision, it helps stakeholders take a proper decision in the current time. The current decision that considers the future facilitates the way for achieving the company's goals.

6. Conclusions

Decisions need to be taken according to the current needs and strategic plans and situations. When a policymaker wants to decide by classic MADM form of study, everything must be considered fix in an acceptable primary evaluation. PMADM outline changes the previous games as a game-changer. New items have been developing the class MADM structure since 2016 by introducing PMADM. In this study, a new flexible weighting system, as Vision-based Weighting System (ViWes), presented shows how a decision can be made now but with proper preparation for all possible changes in the decisions.

Moreover, it can enhance this ability to show when we need to consider all the new changes in the priorities and alternatives due to the importance of the criteria in different periods and future visions. It is illustrated in the numerical example to see how the importance of alternatives can vary due to different criteria's expectations. As a suggestion for future studies, something can be mentioned as to how policymakers and decision-makers can make a flexible vision-based decision making when alternatives can be different when they agree to change according to the essential needs and rules. When decision alternatives want to be adopted by necessary changes, a dynamic situation will happen in the classic way of decision making, and that would be a new challenge in the field of MCDM and Prospective MADM. This research is used the PMADM structure for considering the future in the EDAS MADM model. Comparing table 1 to 4 found that in the current vision, Alternative 5 gets rank one and alternative six get rank 2, for 2025 vision, the rank one and two don't change, and in vision 2030, the rank of one does not change, but the rank of second change from Alternative 6 to 3. These conclusions show that makes the decision is changed over time and should consider the vision of time in decision making. The PMADM is a method that helps managers or stakeholders to consider time vision in their decision policy. By this, managers could reach their goals and plan.

The limitation of this study was there isn't an actual case study for this method, and future research, using the real case study is beneficial, and the combination of other MADM methods with PMADM could be actionable.

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