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Determining the Riskiest Production Area Using Integrated Criteria Weights

Gülin Feryal Can[1*], **Pelin Toktaş**[1]

[1]Industrial Engineering Department, Engineering Faculty, Başkent University, Ankara, Turkey

[*]**Correspondence to: Gülin Feryal Can**, PhD, Associate Professor, Industrial Engineering Department, Engineering Faculty, Başkent University, Eskişehir Yolu 20. Km, Etimesgut, Ankara 06790, Turkey; Email: gfcan@baskent.edu.tr

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Abstract

Objective: This study aims to prioritize seven production areas in an automotive glass manufacturing firm considering their risk levels by using integrated multi-criteria decision-making approach.

Methods: The proposed approach includes two phases as determining risk criteria weights and ranking production areas according to their risk levels. In determining risk criteria weights, Criteria Importance through Inter-criteria Correlation (CRITIC), Entropy and Preference Selection Index (PSI) methods are used. Then, the different criteria weights obtained from these three approaches are aggregated with geometric mean operator. In ranking production areas, Multi-objective Optimization on the Basis of Simple Ratio Analysis is utilized and the production area which has the lowest risk level is determined considering the aggregated criteria weights obtained in the first phase.

Results: The least risky and the riskiest areas were obtained as autoclave and tunnel kiln areas respectively for four different weighting approaches. CRITIC, PSI and Aggregated Weighting methods gave the same rankings of production areas. There are small differences between the rankings of Entropy and Aggregated Weighting Method for the third and sixth production areas.

Conclusion: The data used in the analysis is obtained by real measurements. For this reason, the results obtained from the study are more accurate compared to the subjective weighting methods. The proposed approach provides authorities to see the results of the different approaches and aggregated rankings. Thus, authorities can decide for which production area measures should be taken first in a more flexible way.

Keywords: CRITIC, Entropy, PSI, aggregated weighting, production area

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1 INTRODUCTION

The production systems of companies typically deal with a number of "threats" that can create a set of risks for themselves and their workers. In order to meet regulatory and commercial requirements, companies must identify all threats of their activities that determine the safety and healthiness of their production areas. It is essential for workers to manage all hazards, at every step of the production (design, production, storage, transport, distribution) to guarantee their and production area's safety. For this reason, risk management is required reducing the related risks. Risk management is a "challenge" for companies but also for the authorities who have to decide which production area has an "acceptable" risk level and which doesn't. For this decision, authorities should consider many risk criteria for different production areas. This decision provides authorities to see which production area has the highest risk level that is extremely important to formulate an improvement plan. This type of plan is necessary because companies have limited economic, labor and time sources. As it were, to determine the riskiest production area has multi-criteria decision making (MCDM) structure.

MCDM is expressed as the process of assigning performance values to alternatives by evaluating many criteria together. The aim of MCDM is to ensure that the best among the alternatives is selected. In a rational decision-making environment, the selection of the best alternative usually takes place within the constraints and objectives. In determining the riskiest production area, production area form alternatives, risk criteria form considered criteria in MCDM.

In MCDM methods, the preferences of the decision makers are also of great importance, which also bring about the subjectivity of the results. This is especially true for MCDM methods applied based on subjective evaluations. However, the importance weights of the criteria taken into account in the selection also play a major role in the selection of the best alternative. As the importance weights of the criteria change in MCDM approaches, there are also changes in alternative rankings. Therefore, it is not appropriate to reach a decision based on the alternative rankings obtained by applying a single weighting method. To eliminate this disadvantage, it is necessary to reflect the results of more than one different weighting approach into the process of obtaining alternative rankings. For this reason, in the study, the importance weights of the criteria were obtained by using three different objective criterion weighting approaches selected from the literature. Then, the rankings of the alternatives were determined by combining the related weights. Additionally, for computing criteria weights and ranking alternatives using real measurement values provide more accurate results than subjective approaches.

In this context, in determining the criteria weights, Criteria Importance through Inter criteria Correlation (CRITIC), Entropy, and Preference Selection Index (PSI) methods have been used. Alternatives were prioritized with the Multi-objective Optimization on the Basis of Simple Ratio Analysis (MOOSRA) method. CRITIC, Entropy and PSI methods were utilized with real measurement data. Additionally, MOOSRA can work with the same data and criteria weights obtained from these three weighting approaches.

CRITIC was developed by Diakoulaki et al[1]. It is used to find the objective weights of the criteria. It considers the strength and direction of the relationship between criteria, and determines the standard deviation in terms of the performance values taken by the alternatives according to the criteria and uses it in the process, without considering the evaluations of the decision makers. CRITIC aims at the computing of objective weights of criteria in MCDM problems, and is structured based on the analytical evaluation of the initial decision matrix to extract all information belonging to the evaluation criteria. This method facilitates the decision maker to express his/her view of the relative importance of the criteria. CRITIC decreases the subjectivity in the decision process, by constituting subjective and objective weights in a composite value of overall importance. It can allocate inconspicuous criteria, in a primary weighting evaluation of the criteria.

The concept of Entropy was first put forward by Clausius in 1865[2]. It is known as a criterion of disorder and dispersion in thermodynamics, and was given a different use by Shannon and became information Entropy[3]. According to information theory, Entropy is a measure of uncertainty about random variables[4]. In the Entropy method, the initial decision matrix is sufficient to obtain the criteria weights and it is highly useful due to no need of decision makers to evaluate the criteria. The strength of Entropy is that it provides more objective results on scores of alternatives without the need for decision makers' evaluations. In this method, the uncertainty is higher in the data group with high Entropy value. The greater the degree of Entropy dispersion, the greater the degree of differentiation and the more information available. The criteria values with this feature should have higher importance weights for the Entropy method.

PSI was developed by Maniya and Bhatt in 2010[5]. It is an objective criterion weighting method. It determines the criteria weights according to the convergence in the performance values of the alternatives. There is no need to assign relative importance to the criteria. If there is a conflict in deciding the relative importance between attributes, PSI is an effective approach for computing criteria weights, with simple and short computation steps.

The reason for choosing three different weighting methods is that all three can make objective weighting. In the study, it was aimed to prioritize production areas according to risk levels, considering different criteria. Each production area has performance values according to nine criteria and these values are real, measured values. For this reason, objective weighting methods that work with real values were preferred while determining the criteria weights.

MOOSRA was developed by Das et al.[6] in 2012. According to methods such as Analytical Hierarchy Process, Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Vıse Kriterijumsa Optimizacija I Kompromisno Resenje (VIKOR), Elemination and Choice Translating Reality English and The Preference Ranking Organization Method for Enrichment Evaluation, it has been determined that the computation time is shorter[6]. It is a practical method in terms of mathematical operations[6], as well as a reliable method in terms of the results it produces, as it allows the proportional comparison of benefit-cost values[6]. MOOSRA is a multi-objective optimization method, so it can offer optimum rankings for alternatives. The reason for preferring MOOSRA to rank production areas is that MOOSRA can provide optimal rankings considering conflict criteria.

This study aims to provide objective evaluation to determine risk level of different production areas considering different criteria. In this context, real and measured data for alternatives according to criteria were considered. Different criteria weighting methods were used to reflect different perspectives of the related methods. Finally, an aggregation was proposed to determine final criteria weights. Criteria weights are important for any decision process. As determining the riskiest production area is a decision, it is useful to benefit from the proposed approach for executives, in which they can acknowledge different ranking results and aggregated ranking results provided by different criteria weights and they can decide which method provides logical result for their firm or they can make a work plan according to aggregated rankings. Nevertheless, it is not possible to reduce the risk level in all production areas simultaneously due to the required substantial capital, labor and time. In this regard, ongoing studies should be started from the riskiest production area. With the proposed approach, it will be possible to make a work plan in terms of improvement works. All criteria need to be optimized when determining the riskiest production area. Considering that the criteria considered are of a conflicting nature, it is important to optimize the values taken from these criteria in the ranking of the production areas. With the proposed integrated approach, the related optimization is also realized.

To the best of our knowledge, this study is the first one in term of determining the riskiest production area with MCDM approaches. Additionally, this study provides more accurate view point to make this type of analysis by using real measurement data for production areas according to risk criteria. Finally, this study can present a path to authorities to make a decision for this type of process.

The rest of the study is organized as follows. Second section includes a brief literature review for CRITIC, Entropy, PSI and MOOSRA methods. Third section includes recommended approach and implementation for determining the riskiest production area. Results and conclusion are taken place in the fourth section.

2 MATERIALS AND METHODS

2.1 Literature Review on CRITIC Method

In this section to reflect current literature knowledge, the studies related to CRITIC implementation performed between the years 2020-2022 are briefly reviewed.

Wu et al.[7] developed a two-level index system based on the cloud model index system and CRITIC to evaluate urban rail transit operation safety. The cloud model index system was used to obtain the evaluation set and cloud. An improved CRITIC method was adopted to compute weights of all criteria. Peng et al.[8] implemented Pythagorean fuzzy CRITIC and The Combined Compromise Solution (CoCoSo) for 5G industry evaluation. Simić et al.[9] conducted a study which implies defining the level of safety of a total of nine sections of two-lane roads by using CRITIC, Fuzzy Full Consistency Method (Fuzzy FUCOM), Fuzzy Data Envelopment Analysis (Fuzzy DEA), and Fuzzy Measurement Alternatives and Ranking according to the Compromise Solution (Fuzzy MARCOS) methods to determine the level of traffic safety on road sections under the conditions of uncertainty[9]. Pan et al.[10] evaluated the suitability of each intersection for heavy traffic requirements using the CRITIC method. Krishan et al.[11] advanced a modified version of the CRITIC method, namely the Distance Correlation-based CRITIC (D-CRITIC) to evaluate weights of five smartphone criteria. Lai and Liao[12] proposed linguistic D numbers, double normalization-based multiple aggregation (DNMA) method, and CRITIC integration for block chain platform evaluation process. Jati et al.[13] determined the rankings of criteria that affect the visibility of a website on a search engine by using CRITIC. Rani et al.[14] aimed to select the most appropriate food waste treatment method by combining CRITIC and Multi-objective Optimization based on Ratio Analysis with the full multiplicative form (MULTIMOORA) methods with single-valued neutrosophic sets (SVNSs). Dhara et al.[15] used CIRITIC and TOPSIS to choose the most suitable very light business aircraft based on the view of the passengers in terms of effectiveness and aesthetic comfort. Peng et al.[16] performed CRITIC and interval-valued fuzzy soft decision-making algorithm-based CoCoSo for intelligent healthcare management evaluation. Mishra et al.[17] carried out a hybrid methodology based on CRITIC and EDAS methods with Fermatean fuzzy sets (FFSs) to select third-party reverse logistics providers. Simić et al.[18] integrated CRITIC and multi-attributive border approximation area comparison MABAC based on type-2 neutrosophic model for public transportation pricing system selection problem. Wang et al.[19] suggested Grey Relational Projection (GRP) method for probabilistic uncertain linguistic Multi Attribute Group Decision Making based on the CRITIC for site selection of hospital constructions. The criteria weights were computed by CRITIC. Additionally, the probabilistic uncertain linguistic positive ideal solution (PULPIS) and probabilistic uncertain linguistic negative ideal solution (PULNIS) were determined. Then, the optimal scheme was found through figuring up the value of GRP from PULPIS as well as PULNIS[19]. Kahraman et al.[20] advanced a novel spherical fuzzy CRITIC method for prioritizing supplier selection criteria. Lei et al.[21] structured the probabilistic double hierarchy linguistic EDAS (PDHL-EDAS) method. CRITIC was introduced to compute objective weights and the cumulative prospect theory was performed to obtain the cumulative weight of PDHLTS. In addition, PDHL-EDAS method was applied to the select high-quality 3D printer[21].

2.2 Literature Review on Entropy Method

As seen from the literature, there are many studies carried out using the Entropy method. In this section, studies conducted between years 2020-2022 were investigated to cover current studies using the Entropy method. These studies are briefly given below.

The concept of Entropy measure belonging to picture fuzzy sets was first introduced by Thao[22], and some similarity measures used in Entropy measurements were also investigated. These Entropy and similarity assessments were applied in supplier selection. Li et al.[23] proposed a new hybrid MCDM model for machine tool selection. In the proposed method, firstly, a comprehensive weighting approach was used, combining subjective weights were obtained using the Fuzzy Decision Making Trail and Evaluating Laboratory (Fuzzy DEMATEL-FDEMATEL) and the objective weights were computed using Entropy; secondly, the “Later Defuzzification Vise Kriterijumsa Optimizacija I Kompromisno Resenje” method was applied to rank the alternatives[23]. Goswami et al.[24] aimed to investigate the adequacy and applicability of two MCDM methods, namely Additive Ratio Assessment (ARAS) and Complex Proportional Assessment (COPRAS). In the study, three real-time material handling equipment selection problems (conveyor selection, automatic guided vehicle selection and robot selection) are discussed. In these three MCDM problems, the alternatives were ranked using ARAS and COPRAS, and the objective criteria weights were obtained by the Entropy method. The resulting rankings were evaluated using six different MCDM methods and validated by comparison with the findings of previous researchers[24]. Salehi et al.[25] aimed to evaluate the crisis management systems of five petrochemical plants from three aspects: organizational aspects, human aspects and technical aspects. In the study, the Entropy method was used to weight the identified 34 criteria, and management systems were prioritized with the TOPSIS. Yazdani et al.[26] used the Shannon Entropy method for the criteria weights determination to prioritize renewable energy technologies, within the scope of the evaluation of five renewable energy sources (solar PV, Solar thermal, wind energy, geothermal and biomass) from an economic, technical, social and environmental aspects. On the other hand, Evaluation based on Distance from Average Solution (EDAS) was performed to obtain rankings of these sources[26]. Chodha et al.[27] used Entropy-TOPSIS integration to select an industrial robot for arc welding process. It was aimed by Seker and Aydın[28] to select the most suitable location in northern Turkey to establish a hydrogen-sulfide separation plant. In this context, Entropy and TOPSIS methodologies have been integrated and implemented under the interval-valued Pythagorean fuzzy environment to better handle uncertain information. Lam et al.[29] utilized the Entropy and F-VIKOR integration to evaluate the financial performance of construction companies. Sahoo and Chodhury[30] evaluated the electric wheelchair options available in the market by applying the Entropy, COPRAS and EDAS methods. Chaurasiya and Jain[31] combined Pythagorean fuzzy set with Entropy and COPRAS methods to determine the most appropriate method for the disposal of wastes resulting from health services. Deveci et al.[32] used the Entropy-based Weighted Aggregated Sum Product Assessment (WASPAS) method and “interval type-2 hesitant fuzzy sets” in order to select the most suitable aircraft type for a particular route.

2.3 Literature Review on PSI Method

Since the PSI method is a widely used method, it has been preferred in many studies in the literature. For this reason, in order to reflect current literature knowledge, the studies carried out between the years 2020-2022 are briefly mentioned below.

Ulutaş[33] selected a stacker, one of the material handling equipment, by using an integrated MCDM model consisting of PSI and Weighted Euclidean Distance Based Approach (WEDBA). In the study, the criteria weights were found by PSI, and the prioritization of manual stackers was carried out with the WEDBA method[33]. By using Gray Entropy, PSI and ARAS methods, Akbulut compared the performance levels of the 10 largest deposit banks operating in Turkey in terms of asset size in 2018. In this context, criteria weights were calculated with the Gray Entropy and PSI methods, and the performance ranking of the banks was made by using the weights obtained in PSI and ARAS methods[34]. Ulutaş et al. implemented Fuzzy Pivot Pairwise Relative Criteria Importance Assessment (Fuzzy-PIPRECIA), Fuzzy PSI and Fuzzy CoCoSo in order to select the appropriate company for retailers in Turkey, within the scope of ready-made clothing transportation. The subjective weights of the criteria taken into account were obtained with the Fuzzy-PIPRECIA method, the objective weights of the criteria were determined with the Fuzzy PSI method, and alternative transportation companies were ranked according to their performance using Fuzzy CoCoSo[35]. Chen et al. carried out a study by integrating rough numbers, Shannon Entropy, TOPSIS and PSI methods for a product design concept evaluation. The criteria importance weights were determined with the integration of rough numbers and Shannon Entropy, and then the design concepts were compared with the integration of TOPSIS with rough numbers. Then, criteria weights were determined again by rough numbers and PSI integration, and alternatives were listed with TOPSIS and rough numbers integration. In the last step, the concept rankings obtained from both approaches were compared[36]. Amin et al. applied the PSI method in the selection of baby creams for sensitive skin in children under the age of three[37]. Reddy et al. compared predicted combinations of composites with optimal mechanical and wear levels using PSI[38]. Reddy obtained the weights of the parameters with the PSI method in the selection of products with high sound quality, and they performed the product selection with the TOPSIS method[39].

2.4 Literature Review on MOOSRA Method

In the literature, there is limited number of studies carried out using the MOOSRA method. The related studies carried out between the years 2018-2022 are briefly mentioned below.

Kılıç and Organ performed Entropy and MOOSRA methods to rank private shopping websites in the online sales group[40]. Narayanamoorthy et al. implemented HF-MOORSA method to the site selection of electronic waste recycling plant[41]. Özdemir implemented MOORA and MOOSRA methods and the results were interpreted for smartphone selection[42]. Feizi et al. advanced two novel hybrid MCDM techniques in the mineral potential mapping (MPM), called FUCOM-MOORA and FUCOM-MOOSRA, as robust computational frameworks for MPM to apply a set of exploration targeting criteria of skarn[43]. Narayanamoorthy et al. carried out a new methodology based on Hesitant Fuzzy Subjective and Objective Weight Integrated Approach and Hesitant Fuzzy MOOSRA to find the most suitable bio-medical waste disposal methods[44]. Dorfeshan et al. introduced extension of MULTIMOORA methods under IT2FS. They applied the proposed approach for critical paths determination for project time considering time, cost, risk, quality and safety. Additionally, a new TPOP method under IT2FS performed to aggregate rankings[45].

2.5 Recommended Approach and Implementation for Determining the Riskiest Production Area

The proposed approach consists of two stages. In the first stage, the importance weights of the considered criteria were calculated with CRITIC, Entropy and PSI methods with the help of a geometric mean operator. In the second stage, the ranking of the alternatives was carried out using the MOOSRA method, taking into account the importance weights of the criteria obtained from the first stage.

In the study, a risk analysis was carried out using the integrated MCDM method, which is proposed to cover seven different production areas of a company that produces automotive glass. The risk analysis showed that the production area with the highest risk level was determined among the sections in question.

2.6 First Stage: Obtaining Criteria Weights by Three Different Methods

At this stage, importance weights of the criteria are obtained by using CTIRIC, Entropy and PSI methods.

Step 1. Create the initial decision matrix.

The initial decision matrix denoted as [B] presents performance values of alternatives (A$_i$; i=1, ...m) for considered criteria (C$_j$; j=1, ...n). Each element of [B] is indicated as b_{ij}.b_{ij} shows the performance value of the ith alternative for the jth criterion. When considered from the point of view of the automobile glass producing company, the alternatives are seven production areas (A$_i$; i=1, ...7), and the criteria are the nine risk factors used in the comparison of these production areas in terms of risk levels (C$_j$; j=1, ...9). These seven production areas are autoclave area (A_1), tunnel kiln area (A_2), dye house (A_3), cutting and processing area (A_4), forge (A_5), bus oven (A_6),vinyl room (A_7). Criteria are the number of work accidents in the night shift for the last one year (C_1), average age of workers who had an occupational accident (C_2) (year), average experience of workers (C_3) (year), number of machine-related occupational accidents for the last one year (C_4), number of work-related accidents for the last one year (C_5), number of work accidents resulting in death for the last one year (C_6), number of work accidents resulting in injury for the last one year (C_7), number of unsafe conditions observed for the last one year (C_8), lost time for the last one year (C_9) (hour).

The criteria that make up the initial decision matrix can have benefit or cost structure. It is expected that the performance values of the alternatives will be high for the criteria with benefit structure and low performance values for the criteria with cost structure. [B], which consists of the values of seven different production areas in the company where the application is made, in terms of nine risk factors, is given in Table 1. The elements of [B], (b_{ij}; i=1, ...,7; j=1, ..., 9) are determined as the average of the Occupational Health and Safety records of the production areas for the last five years. Among the criteria considered in the study, other criteria except the average experience of workers (C_3) criterion are cost-based, since the risk levels of production areas are desired to be reduced.

Table 1. Initial Decision Matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	7	42	19	2	3	1	2	13	32
A_2	9	31	8	5	4	2	1	11	89
A_3	5	28	12	3	2	4	3	15	156
A_4	8	45	23	2	6	3	5	8	96
A_5	13	38	20	1	1	5	4	17	56
A_6	11	36	14	4	5	6	6	9	74
A_7	12	48	22	1	7	8	7	7	65

Step 2. Apply the CRITIC, Entropy and PSI methods.

In this step, using the $[B]$ created in the first step, the implementing procedure of each weighting method is applied.

Step 2.1. Normalize the initial decision matrix according to the CRITIC method.

$[B]$ is normalized for the benefit and cost type criteria by using Equation (1) and Equation (2) respectively. In this way, normalized initial decision matrix for CRITIC denoted as $[N]_C$ is structured. Each element of $[B]$ is indicated as ($n_{i_j}{}^{c}$; i=1, ...,7; j=1, ..., 9).

$$n_{i_j}{}^{c} = \frac{b_{i_j} - b_{j_{min}}}{b_{j_{max}} - b_{j_{min}}} \quad (1)$$

$$n_{i_j}{}^{c} = \frac{b_{j_{max}} - b_{i_j}}{b_{j_{max}} - b_{j_{min}}} \quad (2)$$

In Equation (1) and Equation (2), b_{jmin} and b_{jmax} show the minimum and maximum values of the jth criterion for alternatives, respectively. $[N]_C$, including seven different production areas and nine criteria, was created in Table 2 using Equation (1) and (2).

Step 2.2. Build the correlation matrix and calculate the standard deviation of the performance values of the alternatives.

In this step, it is decided which of the Spearman or Pearson correlation coefficients will be calculated according to the data structure. In practice, the Spearman Correlation coefficient between the performance values (ρ_{jk}) was calculated as in Equation (3), since the data obtained did not comply with the normal distribution and the number of data was small.

$$\rho_{jk} = 1 - \frac{6\sum_{i=1}^{m} d_i^{2}}{m(m^2-1)} \quad (3)$$

In Equation (3), d_i denotes the difference between the ranks of jth criterion and th criterion, m is the number of alternatives. The Spearman correlation coefficient values (ρ_{jk}) between the nine criteria and standard deviation values for all criteria (SD_j) considered in the application are presented in Table 3. SPSS 17.1 was used to calculate the correlation coefficients.

Step 2.4. Calculate the total information for each criterion.

In the CRITIC method, the total information for each criterion denoted as S_j is calculated by Equation (4). S_j values are given in Table 4.

$$S_j = SD_j \sum_{k=1}^{9} \left(1 - \rho_{jk}\right) \quad (4)$$

Step 2.5. Calculate the importance weight for each criterion.

According to the CRITIC method, the importance weight of each criterion indicated as w_j^c is obtained using Equation (5).

$$w_j{}^{c} = \frac{S_j}{\sum_{j=1}^{9} S_j} \quad (5)$$

As seen in Table 5, the most important criterion affecting the risk level of production areas according to the CRITIC method was determined as the number of unsafe conditions (C_8). The rankings of criteria were obtained as $C_8 > C_3 > C_4 > C_2 > C_1 > C_5 > C_7 = C_9 > C_6$.

Step 2.6. Normalize the initial decision matrix according to the Entropy method.

According to the Entropy method, $[B]$ is normalized by using Equation (6) for benefit type criteria and Equation (7) for cost type criteria, and the normalized initial decision matrix for Entropy $[N]_e$ is obtained. The element of $[N]_e$ is denoted as $n_{ij}{}^{e}$, $i=1,2,\ldots,7$; $j=1,2,\ldots,9$.

$$n_{i_j}{}^{e} = \frac{b_{i_j}}{b_{j_{max}}} \quad (6)$$

$$n_{i_j}{}^{e} = \frac{b_{j_{min}}}{b_{i_j}} \quad (7)$$

Table 2. Normalized Initial Decision Matrix for CRITIC

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	0.750	0.300	0.733	0.750	0.667	1.000	0.833	0.400	1.000
A_2	0.500	0.850	0.000	0.000	0.500	0.857	1.000	0.600	0.540
A_3	1.000	1.000	0.267	0.500	0.833	0.571	0.667	0.200	0.000
A_4	0.625	0.150	1.000	0.750	0.167	0.714	0.333	0.900	0.484
A_5	0.000	0.500	0.800	1.000	1.000	0.429	0.500	0.000	0.806
A_6	0.250	0.600	0.400	0.250	0.333	0.286	0.167	0.800	0.661
A_7	0.125	0.000	0.933	1.000	0.000	0.000	0.000	1.000	0.734

Table 3. Multiple Correlation Matrix and Standard Deviation Values

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	1.000	0.357	-0.321	-0.436	0.143	0.643	0.500	-0.143	-0.464
C_2	0.357	1.000	-0.893	-0.727	0.607	0.214	0.571	-0.607	-0.464
C_3	-0.321	-0.893	1.000	0.800	-0.429	-0.286	-0.643	0.429	0.250
C_4	-0.436	-0.727	0.800	1.000	-0.018	-0.364	-0.473	0.018	0.509
C_5	0.143	0.607	-0.429	-0.018	1.000	0.321	0.607	-1.000	0.143
C_6	0.643	0.214	-0.286	-0.364	0.321	1.000	0.857	-0.321	0.000
C_7	0.500	0.571	-0.643	-0.473	0.607	0.857	1.000	-0.607	-0.036
C_8	-0.143	-0.607	0.429	0.018	-1.000	-0.321	-0.607	1.000	-0.143
C_9	-0.464	-0.464	0.250	0.509	0.143	0.000	-0.036	-0.143	1.000
SD_j	0.359	0.364	0.374	0.378	0.360	0.344	0.360	0.374	0.317

Table 4. Total Information Values for all Criteria

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
S_j	2.770	3.252	3.401	3.285	2.746	2.388	2.601	3.875	2.597

Table 5. Criteria Importance Weights for CRITIC

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
w_j^c	0.103	0.121	0.126	0.122	0.102	0.089	0.097	0.144	0.097

The $[N]_e$ is shown in Table 6.

Step 2.7. Calculate the Entropy values for the criteria.

The Entropy values of the criteria denoted as e_j are calculated using Equation (8).

$$e_j = -k \sum_{j=1}^{9} n_{i_j} ln\left(n_{i_j}\right) \quad (8)$$

In Equation (8), k is the Entropy coefficient and it is computed as $k=(ln(n))^{-1}$.The Entropy values of the nine criteria considered in the application are given in Table 7.

Step 2.8. Calculate the Entropy removal value for each criterion.

The Entropy removal value of the criteria is expressed as d_j, and high d_j values indicate that the differentiation between the performance values of the alternatives is high. d_j is obtained using Equation (9).

$$d_j = 1 - e_j \quad (9)$$

d_j values for nine criteria are given in Table 8.

Step 2.9. Compute criteria importance weights.

The importance weights of the criteria (w_j^e) are calculated using Equation (10).

$$w_j^e = \frac{d_j}{\sum_{j=1}^{9} d_j} \quad (10)$$

The criteria importance weights calculated according to the Entropy method are given in Table 9.

Table 6. Normalized Decision Matrix Created For Entropy

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	0.714	0.667	0.826	0.500	0.333	1.000	0.500	0.538	1.000
A_2	0.556	0.903	0.348	0.200	0.250	0.500	1.000	0.636	0.360
A_3	1.000	1.000	0.522	0.333	0.500	0.250	0.333	0.467	0.205
A_4	0.625	0.622	1.000	0.500	0.167	0.333	0.200	0.875	0.333
A_5	0.385	0.737	0.870	1.000	1.000	0.200	0.250	0.412	0.571
A_6	0.455	0.778	0.609	0.250	0.200	0.167	0.167	0.778	0.432
A_7	0.417	0.583	0.957	1.000	0.143	0.125	0.143	1.000	0.492

Table 7. Entropy Values for All Criteria

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
e_j	-0.888	-0.634	-0.606	-0.786	-0.891	-0.883	-0.891	-0.753	-0.951

Table 8. Entropy Removal Values for All Criteria

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
d_j	1.888	1.634	1.606	1.786	1.891	1.883	1.891	1.753	1.951

Table 9. Criteria Importance Weights According to Entropy

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
w_j^e	0.116	0.100	0.099	0.110	0.116	0.116	0.116	0.108	0.120

According to the Entropy method, the most important criterion is the lost time (C_9) criterion. Criteria rankings according to their importance are obtained as $C_9>C_7=C_6=C_5=C_1>C_4>C_8=C_2>C_3$.

Step 2.10. Normalize the initial decision matrix according to the PSI method.

According to the PSI method, the normalized decision matrix $[N]_p$ is constructed using Equation (6) for criteria with benefit structure and Equation (7) for criteria with cost structure as in Entropy. The element of $[N]_p$ is denoted as $n_{ij}{}^p$. The $[N]_p$ is presented in Table 6.

Step 2.11. Calculate the preference variation value for each criterion.

The preference variation value (PV) for each criterion denoted as PV_j, j=1,2,...9 is computed using Equation (11) and (12).

$$PV_j = \sum_{j=1}^{9} (n_{ij}{}^p - \overline{n_j{}^p})^2 \quad (11)$$

$$\overline{n_j{}^p} = \frac{\sum_{j=1}^{9} n_{ij}{}^p}{m} \quad (12)$$

PV_j values for risk criteria are presented in Table 10.

Step 2.12. Calculate the preference value for each criterion.

Preference value for each criterion is denoted as φ_j and it is calculated using Equation (13).

$$\varphi_j = 1 - PV_j \quad (13)$$

φ_j values are given in Table 11.

Step 2.13. Compute criteria importance weights.

The importance weights of the criteria indicated as $w_j{}^p$ are obtained using Equation (14).

$$w_j{}^p = \frac{\varphi_j}{\sum_{j=1}^{9} \varphi_j} \quad (14)$$

The impact degree of the criteria considered in terms of the risk levels of the production areas was determined by their importance weights. The related importance weights are given in Table 12.

As seen in Table 12, the most important criterion affecting the risk levels of the production areas according to the PSI method is the average age (C_2) criterion of the workers who had a work accident. Rankings of criteria were determined as $C_2>C_1>C_8>C_3>C_9>C_7=C_5>C_6>C_4$.

Step 3. Combine the criteria weights obtained by

Table 10. The Preference Variation Value of All Criteria

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
PV_j	0.276	0.138	0.357	0.669	0.551	0.560	0.551	0.289	0.393

Table 11. Preference Values for All Criteria

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
φ_j	0.724	0.862	0.643	0.331	0.449	0.440	0.449	0.711	0.607

Table 12. Criteria Importance Weights for PSI

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
w_j^p	0.139	0.165	0.123	0.063	0.086	0.084	0.086	0.136	0.116

CRITIC, Entropy and PSI methods.

The criteria weights obtained from the CRITIC, Entropy and PSI methods are combined using Equation (15) and the final importance weight (W_j) for each criterion is obtained.

$$W_j = \frac{(w_j{}^c \times w_j{}^e \times w_j{}^p)^{1/3}}{\sum_{j=1}^{9}(w_j{}^c \times w_j{}^e \times w_j{}^p)^{1/3}} \quad (15)$$

The final importance weights for the criteria considered in application are given in Table 13.

According to Table 13, the ranking of the criteria according to their final importance weights was obtained as $C_8>C_2>C_1>C_9>C_3>C_4>C_5>C_6=C_7$.

2.7 Second Stage: Obtaining Alternative Rankings

At this stage, using the MOOSRA method, the priority order of seven production areas is obtained in terms of their risk levels. The implementation steps of MOOSRA method are given below.

Step 1. Form initial decision matrix.

The initial decision matrix [B] including the performance values of the alternatives according to the criteria (Table 1) is used to compute the criteria importance weights in the first stage. The same matrix is utilized here to implement MOOSRA.

Step 2. Normalize initial decision matrix.

According to the MOOSRA method, the [B] is normalized using Equation (16) and the normalized initial decision matrix [C] is obtained. Each element of [C] is symbolized as c_{ij}.

$$c_{ij} = \frac{b_{ij}}{\sqrt{\sum_{j=1}^{9}\left(b_{ij}\right)^2}} \quad (16)$$

The normalized values of 7 production areas according to 9 criteria are shown in Table 14.

Step 3. Structure weighted normalized initial decision matrix.

In this step, the weighted normalized decision matrix [Z] is obtained by multiplying the final weights W_j and c_{ij} values of the criteria obtained at the end of the first step. [Z] is presented in Table 15. The element of [Z] is denoted as z_{ij}.

Step 4. Compute performance scores of alternatives.

The performance score of each alternative is defined by y_i and calculated as in Equation (17).

$$y_i = \frac{\sum_{j=1}^{g} z_{ij}}{\sum_{j=g+1}^{n} z_{ij}} \quad (17)$$

Where, $j=1, ..., g$ presents benefit type criteria and $j=g+1, ..., n$ shows cost type criteria. Table 16 shows y_i values. In the case study, only C_3 is the benefit type criterion, for this reason g=3.

As can be seen from Table 16, the riskiest production area is the autoclave area defined by A_1.

3 RESULTS

In the study, an integrated approach is proposed that can combine the results of different criteria weighting methods and reflect them on alternative rankings. Thus, a more sensitive approach has been developed in which different perspectives can be included according to the alternative rankings obtained by considering the results of a single weighting method.

As a result of the proposed approach, the criterion with the highest impact on the risk levels of production areas was determined as the number of unsafe conditions observed (C_8). The result in question is a logical conclusion in terms of the risk levels of the production areas. Because, as the number of unsafe conditions in production areas increases, the probability of occupational accidents increases and the risk level increases.

However, the fact that the three different criteria weighting methods applied in the study gave different

Table 13. Final Importance Weights of Criteria

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
W_j	0.132	0.139	0.101	0.088	0.079	0.069	0.069	0.199	0.124

Table 14. Normalized Initial Decision Matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	0.274	0.408	0.407	0.258	0.254	0.080	0.169	0.412	0.136
A_2	0.352	0.301	0.171	0.645	0.338	0.161	0.085	0.348	0.378
A_3	0.196	0.272	0.257	0.387	0.169	0.321	0.254	0.475	0.663
A_4	0.313	0.438	0.493	0.258	0.507	0.241	0.423	0.253	0.408
A_5	0.509	0.369	0.429	0.129	0.085	0.402	0.338	0.538	0.238
A_6	0.430	0.350	0.300	0.516	0.423	0.482	0.507	0.285	0.315
A_7	0.470	0.467	0.471	0.129	0.592	0.643	0.592	0.222	0.276

Table 15. Weighted Normalized Initial Decision Matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	0.037	0.066	0.051	0.018	0.021	0.006	0.013	0.070	0.015
A_2	0.047	0.049	0.021	0.044	0.028	0.011	0.007	0.060	0.041
A_3	0.026	0.044	0.032	0.027	0.014	0.023	0.020	0.081	0.072
A_4	0.042	0.071	0.061	0.018	0.042	0.017	0.033	0.043	0.044
A_5	0.068	0.060	0.053	0.009	0.007	0.028	0.026	0.092	0.026
A_6	0.058	0.057	0.037	0.036	0.035	0.034	0.040	0.049	0.034
A_7	0.063	0.076	0.059	0.009	0.049	0.045	0.046	0.038	0.030

Table 16. Performance Scores of Alternatives and Their Rankings

Alternatives	y_i	Ranking
A_1	0.206	1
A_2	0.074	7
A_3	0.104	6
A_4	0.198	2
A_5	0.168	3
A_6	0.109	5
A_7	0.165	4

results showed how problematic it can be to make a decision based on a single weighting approach.

In the study, the most important criterion according to the CRITIC method was the number of unsafe conditions (C_8), while according to the Entropy method, it was determined as the lost time (C_9). PSI, on the other hand, determined the most important criterion as the mean age of the workers (C_2) who had a work accident. The ranking of the criteria according to three different weighting methods and aggregated weighting method is shown in Table 17.

As seen in Table 17, three different weighting methods produced different ranking results. The main reason for this is that each method evaluates the performance values of the alternatives from different aspects. For example, the CRITIC method takes into account the standard deviation, strength and direction of the relationships between the performance values, while the Entropy method models the uncertainty in the information. PSI, on the other hand, focuses on variation between preference values. In this context, the importance of calculating criteria weights by combining different perspectives becomes evident. As seen from ranking results obtained by aggregating weighting method, it is evaluated that these results are the rank values between the criteria rankings obtained from the other three

Table 17. Criteria Rankings Obtained by CRITIC, Entropy, PSI, and Aggregated Weighting Method

Criteria	Criteria Rankings			
	CRITIC	Entropy	PSI	Aggregated Weighting Method
C_1	5	2	2	3
C_2	4	5	1	2
C_3	2	6	4	5
C_4	3	3	8	6
C_5	6	2	6	7
C_6	8	2	7	8
C_7	7	2	6	8
C_8	1	4	3	1
C_9	7	1	5	4

weighting methods.

The results obtained from CRITIC shows that C_8 is the most important criterion.This is a logical result because C_8 has the highest total information value and it has one of the biggest standard deviation value. According to Entropy method, C_9 is at the first rank. This is also an expected result because C_9 has the smallest Entropy value and highest Entropy removal value. For PSI, C_2 is at the first rank because, it has the smallest preference variation value and highest preference value.

Different criteria weights cause different alternative rankings. In this study three different weighting approaches and one aggregated weighting approach were performed. Table 18 shows obtained alternative rankings considering criteria weights obtained from these four different weighting approaches.

As seen from Table 18, the least risky area was obtained as autoclave area for four different weighting approaches. In the same manner, the riskiest production area was determined as tunnel kiln area for four different weighting approaches. CRITIC, PSI and Aggregated Weighting methods gave the same alternative rankings. There are small differences between the rankings of Entropy and Aggregated Weighting Method. Only, the rankings of A_3 and A_6 alternatives are different for these two approaches.

According to the results obtained, the autoclave area was determined as the least risky production area. The last step of the automobile glass manufacturing process is the lamination process of automobile glass inside the autoclave in the form of a high pressure and temperature chamber. For this, the pressure and temperature of the autoclave are firstly increased. Then, the process is completed by cooling and then expelling the air. All processes are completed in 110min to 160min, depending on the type of product, the fill rate of the autoclave and the season, and the heating and cooling times. Automobile glass is basically divided into two as "tempered" and "laminated". While laminated glass is mainly used as the windshield of automobiles, tempered glass forms the door, butterfly and rear windows. Laminated automobile glasses are produced by combining two glass plates with flat or curved form, with the help of a material called "Polivnly Butraly" (PVB). The process of heating the PVB placed between two glass plates to a temperature of approximately 80-100 C and then sticking it to the glass plates by the press method that is called "pre-lamination". Transparency and permanent adhesion of PVB, which is actually opaque in color, takes place in the autoclave, which is the last step of the laminated glass production process.

The autoclave is a pressure vessel and there is a risk of explosion. Annual periodic tests of pressure vessels should be carried out in accordance with the regulation. However, there are two safety valves and these should also be tested. Also, steam may escape from the door gasket and cause a burn. For this reason, daily checks and periodic maintenance should be done. Compared to other production areas considered in the study, it is an expected result that the least risky production area will emerge as a result of the proposed method, since there is a risk of explosion. In this context, high security measures are taken in this area and serious periodic controls are carried out. In addition, no workers are employed in this area who do not have any training in the work being done.

Water and air inlets are checked at the beginning of each shift and the steam generator is expected to warm up for 20min. When the generator manometer is 3.5 bar and the wall pressure is 2 bar, the device starts to operate. This instruction is posted in an area where it can be seen by the workers who will work in the autoclave. The sterilizer is controlled by the touch screen. First, the pin code is entered on the screen and the confirmation button is pressed, the main menu appears on the screen. Vacuum leak test is performed by pressing the test program from the main menu. If the result is positive, the device printout is attached to the "Steam autoclave loading form" and the

Table 18. Alternative Rankings Obtained by Considering Criteria Weights for CRITIC, Entropy, PSI, and Aggregated Weighting Method

Criteria	Alternative Rankings			
	CRITIC	Entropy	PSI	Aggregated Weighting Method
A_1	1	1	1	1
A_2	7	7	7	7
A_3	6	5	6	6
A_4	2	2	2	2
A_5	3	3	3	3
A_6	5	6	5	5
A_7	4	4	4	4

process continues. Necessary safety precautions are taken to prevent the chemicals used in glass production from harming the workers. Material Safety Data Sheets of all chemicals used are obtained and these forms are taken as a guide during the use of chemicals. Local forced ventilation systems are used in the areas where toxic and inhaling chemicals are used. General ventilation systems are arranged in a way to renew the ambient air at appropriate intervals in the working area where chemical and heavy metal vapors are released. Suitable dust masks are used in cases where ventilation systems are not sufficient when working in dusty environments. Rotation is applied so that the noise does not adversely affect the employees. Thus, employees are prevented from staying in a noisy area for a long time. Earplugs are also used while working in this area. Employees are provided with the necessary protective clothing and shields to prevent them from being affected by radial heat. Again, work plans are made by including rotations and breaks in order to prevent employees from working in the heat for a long time. In this area, suitable ventilation and cooling systems are used. Precautions were also taken against the possibility of fire during the production of glassware. In the storage areas where chemicals are located, arrangements have been made in accordance with the Material Safety Data Sheets of the materials used. Combustible materials are not kept together. There are no flammable materials in the sections where the ovens and stoves are located. The fire extinguishing equipment necessary to respond to possible fires is also available at the workplace and fixed in the places determined according to the emergency plans.

4 CONCLUSION

As seen from the results, the riskiest area as determined as tunnel kiln area (A_2).Tunnel kilns are used when large quantities of glass production are required. A tunnel kiln is a type of centrally heated continuous kiln that is typically open at both ends. The gas used in industrial kilns presents a potential danger risk when large amounts accumulate in the air, as this can trigger a violent explosion. Due to this fact, gas leaks are a serious risk factor in tunnel kiln operations. When gas enters the burners, it can accumulate in hazardous areas rather than burn. Therefore, there are some considerations concerning the prevention of an explosion. Worker should make sure that they use only the correct type of valve, and conduct tests to confirm that kiln closes properly in the event of the valve not being closed. Before opening the gas and proceeding to ignition, it is necessary to purge the kiln or furnace with a semi-inert element such as air, so that the operators can ensure the elimination of any traces of accumulated gas[46]. In tunnel kiln operations, it is seen that the actions to be considered in order to prevent any accident from occurring normally require worker control. Worker-dependent processes accompany problems such as forgetfulness, inattention, and carelessness. Consequently, it is possible that the controls that should be carried out are not performed, which gives rise to risk of explosion in tunnel kilns. Based on this information, it is logical that the tunnel kiln area was identified as the production area with the highest risk as a result of the implementation of the proposed approach.

For the future studies, different criteria are warranted to be considered to evaluate different areas in glass production. The proposed approach is available for different production systems to evaluate risk levels of different areas in the related systems. Different weighting approaches can be used and different aggregation process to obtain final criteria weight can be implemented.

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Conflicts of Interest
The authors declared no conflict of interest.

Author Contribution
Can GF investigated the literature, Toktaş P prepared the Figures, tables. Can GF and Toktaş P wrote the main manuscript, made analysis together.

Abbreviation List
ARAS, Additive ratio assessment
CoCoSo, Combined compromise solution

COPRAS, Complex proportional assessment
CRITIC, Criteria importance through intercriteria correlation
D-CRITIC, Distance correlation-based CRITIC
DNMA, Double normalization-based multiple aggregation
EDAS, Evaluation based on distance from average solution
FFSs, Fermatean fuzzy sets
Fuzzy DEA, Fuzzy data envelopment analysis
Fuzzy DEMATEL, Fuzzy decision making trail and evaluating laboratory
Fuzzy FUCOM, Fuzzy full consistency method
Fuzzy MARCOS, Fuzzy measurement alternatives and ranking according to the compromise solution
Fuzzy-PIPRECIA, Fuzzy pivot pairwise relative criteria importance assessment
GRP, Grey relational projection
MCDM, Multi criteria decision making
MOOSRA, Multi-objective optimization on the basis of simple ratio analysis
MULTIMOORA, Multi-objective optimization based on ratio analysis with the full multiplicative form
PDHL-EDAS, Probabilistic double hierarchy linguistic EDAS
PSI, Preference selection index
PULNIS, Probabilistic uncertain linguistic negative ideal solution
SVNSs, Single-valued neutrosophic sets
TOPSIS, Technique for order preference by similarity to ideal solution
VIKOR, Vıse kriterijumsa optimizacija I kompromisno resenje
WASPAS, Weighted aggregated sum product assessment
WEDBA, Weighted Euclidean distance based approach
[B], Initial decision matrix
A_i, Alternatives
C_j, Criteria
b_{ij}, Performance value of the th alternative for the th criterion
[N], Normalized initial decision matrix
n_{ij}^{c}, Element of normalized initial decision matrix for CRITIC
b_{jmin}, Minimum value of the th criterion
b_{jmax}, Maximum value of the th criterion
$[N]_C$, Normalized initial decision matrix for CRITIC
ρ_{jk}, Correlation coefficient between the performance values
SD_j, Standard deviation values for all criteria
S_j, Total information for each criterion
w_j^{c}, Importance weight of each criterion for CRITIC
$[N]_e$, Normalized initial decision matrix for Entropy
n_{ij}^{e}, Element of normalized initial decision matrix for Entropy
e_j, Entropy values of the criteria
d_j, Entropy removal values for criteria
w_j^{e}, Importance weight of each criterion for Entropy
$[N]_P$, Normalized initial decision matrix for PSI
n_{ij}^{P}, Element of normalized initial decision matrix for PSI
PV_j, Preference variation value for each criterion
$\overline{n_j{}^P}$, Average of n_{ij}^{P}
φ_j, Preference value for each criterion
w_j^{P}, Importance weight of each criterion for PSI
W_j, Final importance weights of criteria
[C], Normalized initial decision matrix for MOOSRA
c_{ij}, Element of initial decision matrix for MOOSRA
[Z], Weighted normalized decision matrix for MOOSRA
z_{ij}, Element of weighted normalized decision matrix for MOOSRA
y_i, Performance score of each alternative

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