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Ergonomic Performance Evaluation in Turkey's Metal Industry: Occupational Health and Safety Indicators Through VIKOR Methodology

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Abstract: In the quest to reduce occupational accidents and diseases, the ergonomic performance levels of industries remain pivotal. Within this context, the metal industry in Turkey, notorious for ergonomic challenges, was scrutinised regarding its occupational health and safety (OHS) indicators. Five pivotal criteria were employed to delineate the industry's performance: the incidence of occupational accidents, the occurrence of fatal occupational accidents, the reporting rate of occupational diseases, the cumulative days of temporary incapacity, and the overall count of insured individuals obtaining permanent incapacity benefits. A decadal period, spanning 2013-2022, served as the temporal backdrop for this examination. Utilising the VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method, an esteemed Multiple-Criteria Decision-Making (MCDM) technique, an assessment was conducted to ascertain the years marred by sub-optimal ergonomic performance. Notably, 2014, 2013, and 2020 were identified as the most critical years, whereas 2022 emerged as the least problematic. This investigation underscores the imperative for strategic planning to augment ergonomic conditions in professional settings in light of OHS, particularly in recent times.

Keywords: Ergonomics; Occupational health and safety; Multiple-Criteria Decision-Making (MCDM); VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR); Metal industry

1 Introduction

Ergonomics, recognised as a multidisciplinary domain, plays an instrumental role in safeguarding employees' health, safety, and overall well-being. The absence of ergonomic interventions has been observed to culminate in adverse ramifications, including occupational accidents and illnesses. For the mitigation of such detrimental health and safety outcomes, systematic and precise ergonomic implementations are deemed imperative within workplaces. Commencement of this pivotal endeavour is typically marked by a thorough analysis of an industry's current ergonomic standing.

Numerous criteria reportedly influence the ergonomic performance across industries. An annual evaluation of industries based on these criteria, coupled with an exposition of their accomplishments in ergonomic practices, is believed to be essential for the accurate formulation of related objectives and strategies [1]. The metal industry, globally and in Turkey, has been highlighted for its strategic significance, underpinning various sectors such as defence and transportation [2]. Nevertheless, considerable ergonomic challenges, leading to detrimental health implications for many, are persistently associated with this sector [3]. Thus, the ergonomic performance of the metal industry warrants a meticulous examination, ensuring the instigation of appropriate preventative measures.

In existing literature, scant attention has been afforded to the delineation of ergonomic risk levels specific to sectors. Ayrım and Can [4] investigation into 14 distinct sectors for 2016 utilised the Criteria Importance Through Intercriteria Correlation (CRITIC) method. In a parallel vein, Can and Kargı [5] embarked on identifying the sector bearing the highest risk through the CRITIC-Estimation of Distribution Algorithms (CRITIC-EDAs) model, examining 17 sectors based on 2016 data. Elmas-atay and Yildirim [6] deployed the CRITIC-based Grey Relational Analysis method to discern the sectors with the highest and lowest risks for 2020. Toptancı [1], employing the

Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) method, achieved similar determinations based on data spanning 2013-2020.

Diverging from prevalent literature, the current study endeavours to appraise the ergonomic performance of a singular industry, namely the metal industry, through the lens of OHS criteria, juxtaposed against a chronological backdrop. An innovative solution approach is introduced, elucidating the metal industry's ergonomic performance trajectory in Turkey over the years. This study is poised to furnish a comprehensive chronology of the metal industry's ergonomic performance vis-à-vis OHS, whilst also proffering preliminary insights to scholars regarding periods of ergonomic sub-optimality. Such insights are envisaged to catalyse in-depth inquiries into the origins of these health and safety setbacks, fostering improvements in ergonomic paradigms.

2 Methodology

Evaluating ergonomic performance is characteristically framed as a decision-making quandary. This encompasses the appraisal and sequential ranking of alternatives as per predefined criteria. Historically, the MCDM methods have been employed in literature to address such problems. Within this section, both the computational steps inherent to the VIKOR method and the envisaged approach for the study are elucidated.

2.1 VIKOR Method

The VIKOR method stands as a frequently utilised MCDM technique. This method facilitates the ranking and subsequent selection of alternatives, taking multiple criteria into account. The cornerstone of this method lies in pinpointing a compromise solution to which consensus is attained, with a central focus on its "proximity to the ideal solution. Emphasis is placed on maximising the "group utility" of the "majority" whilst minimising the individual regret of the "opponent" [7]. Several advantages, notably its straightforwardness in application and computation, render the VIKOR method particularly apt for the context of this study. The general steps associated with the VIKOR method have been delineated as follows [7]:

Step 1: An initial decision matrix is constructed:

$$X_{DM} = [x_{ji}]_{mxn} = \begin{array}{c} \\ A_1 \\ \vdots \\ A_m \end{array} \begin{bmatrix} C_1 & \dots & C_n \\ x_{11} & \dots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \dots & x_{mn} \end{bmatrix} \tag{1}$$

In Eq. (1), m, n and x_{ji} are characterised as the number of alternatives, the number of criteria, and the numeric value the j-th row alternative assumes for the i-th column criterion (with parameters $i = 1, \dots, n$, and $j = 1, .., m$), respectively.

Step 2: Both the optimal (f_i^*) and sub-optimal $\left(f_i^-\right)$ values for each criterion are identified. The nature of the criteria, specifically whether they symbolise benefits or costs, is pivotal in this determination. For a model wherein the i-th criterion is deemed beneficial, Eq. (2) is adopted. Conversely, for cost criteria, Eq. (3) is employed.

$$f_i^* = \max_j x_{ji}, f_i^- = \min_j x_{ji} \text{ for benefit criteria} \tag{2}$$

$$f_i^* = \min_j x_{ji}, f_i^- = \max_j x_{ji} \text{ for cost criteria} \tag{3}$$

Step 3: By utilising Eq. (4), the initial decision matrix X_{DM} undergoes normalisation, producing the standardised decision matrix N_{DM}.

$$r_{ji} = \frac{f_i^* - x_{ji}}{f_i^* - f_i} \tag{4}$$

$$N_{DM} = [r_{ji}]_{mxn} = \begin{array}{c} \\ A_1 \\ \vdots \\ A_m \end{array} \begin{bmatrix} C_1 & \dots & C_n \\ r_{11} & \dots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \dots & r_{mn} \end{bmatrix} \tag{5}$$

Step 4: Every matrix element within N_{DM} undergoes weighting, achieved by multiplying each with the corresponding criterion weights.

$$v_{ji} = r_{ji} \times w_i \tag{6}$$

$$V_{DM} = [v_{ji}]_{mxn} = \begin{array}{c} \\ A_1 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & \cdots & C_n \end{array} \\ \begin{bmatrix} v_{11} & \cdots & v_{1n} \\ \vdots & \ddots & \vdots \\ v_{m1} & \cdots & v_{mn} \end{bmatrix} \end{array} \tag{7}$$

where, w_i symbolises the criterion's significance weights.

Step 5: Values S_j and R_j for each alternative are ascertained.

$$S_j = \sum_{j=1}^{n} v_{ji} = \sum_{j=1}^{n} r_{ji} \times w_i \tag{8}$$

$$R_j = \max_j v_{ji} = \max_j (r_{ji} \times w_i) \tag{9}$$

Step 6: The value of Q_j for every alternative is computed.

$$S^* = \min_j S_j, \quad S^- = \max_j S_j, \quad R^* = \min_j R_j, \quad R^- = \max_j R_j \tag{10}$$

$$Q_j = \frac{q \times (S_j - S^*)}{S_j - S^*} + \frac{(1-q) \times (R_j - R^*)}{R_j - R^*} \tag{11}$$

where, q signifies the weight of the maximal group utility, whereas $(1-q)$ denotes the weight of the minimal regret. Moreover, consensus is usually achieved through compromise, employing a majority when $q > 0.5$, consensus with $q = 0.5$, or a veto for $q = 0.5$. Typically, a weightage of $q = 0.5$ is attributed to maximal group utility. Accordingly, for the purpose of this study, $q = 0.5$ has been assumed.

Step 7: The values S_j, R_j and Q_j are arranged in ascending order. The alternative with the minimal value Q_j is recommended as the compromise solution, granted the subsequent conditions are met:

$Condition\,1$: Acceptable advantage;

$$Q(A_2) - Q(A_1) \geq DQ, \quad DQ = 1/(m-1) \tag{12}$$

where, A_2 symbolises the second-ranked alternative and A_1 represents the top-ranked alternative in the ordering of Q_j.

$Condition\,2$: Acceptable stability in decision making;

The alternative A_1 must concurrently occupy the highest rank within the listings of S_j and/or R_j. Consequently, the compromise solution is deemed stable within the decision-making procedure.

If either of the aforementioned conditions is unmet, the compromise solution set is structured as follows:

• In instances where only the second condition is unfulfilled, both alternatives A_1 and A_2 are jointly regarded as compromise solutions.

• If the first condition remains unfulfilled, all alternatives $A_1, A_2, \ldots, A_m$ feature within the optimum compromise solution set, with A_m being discerned through the relation $Q(A_m) - Q(A_1) < DQ$ at its maximum m.

2.2 Proposed Approach

In an endeavour to ascertain the ergonomic performance of the metal industry with respect to OHS, a systematic approach was devised. The subsequent steps elucidate the methodology adopted, wherein analyses were conducted utilising the Python programming language.

Step 1: Criteria for assessing ergonomic performance in the context of OHS were delineated. Concurrently, the years subject to evaluation, termed as 'alternatives', and the segments of the metal industry operating in Turkey, in alignment with the Statistical Classification of Economic Activities in the European Community, were pinpointed.

Step 2: Data encompassing the span of 2013-2022, detailing occupational accidents and diseases, as disseminated by the Social Security Institution (SSI), was assimilated for the evaluation process.

Step 3: By harnessing the capabilities of the VIKOR method, performance metrics and their corresponding rankings for each individual year were derived.

Step 4: To corroborate the authenticity of the ratings procured, a sensitivity analysis was executed, specifically probing varying values of $\boldsymbol{q}$.

3 Results

Within this study, the ergonomic performance pertaining to the metal industry in Turkey, in light of OHS indicators, was meticulously examined using the previously proposed methodology. In the Statistical Classification of Economic Activities in the European Community (Nomenclature statistique des Activites economiques dans la Communaute-NACE Rev.2), two distinct classifications underpin the metal industry: 'Manufacture of Basic Metals' and 'Manufacture of Fabricated Metal Products (excluding machinery and equipment)'. Data amalgamated from these classifications were thus employed to deduce performance metrics for the metal industry annually. The derived ergonomic performance criteria in the realm of OHS, based on an extensive literature review, are illustrated in Table 1.

Table 1. OHS-based ergonomic performance criteria

Code	Criteria	Description	Target	Source(s)
C1	The incidence of occupational accidents	The total count of insured individuals exposed to occupational mishaps	Min	(Elmas Atay ve Kuzu Y1ldirm [5]; SGK [8])
C2	The occurrence of fatal occupational accidents	The aggregate number of insured individuals who succumbed as a direct result of occupational incidents	Min	(Elmas Atay ve Kuzu Y1ldrim [5]; SGK [8])
C3	The reporting rate of occupational diseases	The prevalence of insured personnel diagnosed with occupationally-induced diseases	Min	(Elmas Atay ve Kuzu Y1ldrim [5]; SGK [8]);
C4	The cumulative days of temporary incapacity	The cumulative days for which insured employees, having endured workplace accidents, were registered as inpatients and outpatients	Min	[8]
C5	The overall count of insured individuals obtaining permanent incapacity compensation	The sum of insured workers granted permanent incapacity compensation within a given year, attributable to work-related accidents and diseases	Min	[8]

The employed criteria predominantly focus on cost implications, reflecting the overarching objective of gauging performance metrics. Furthermore, the importance weightage attributed to each criterion was uniformly distributed, with every criterion being assigned a value of 0.20 (1/5).

An initial decision matrix, encompassing the metal industry across the five criteria, is presented in Table 2. The table also displays the apex and nadir values across the various columns.

Table 2. Initial decision matrix

Alternatives (Years)	C1	C2	C3	C4	C5
w_i	0.20	0.20	0.20	0.20	0.20
2013	27760	69	15	371460	210
2014	30886	45	26	329018	206
2015	31750	58	55	445767	428
2016	33697	57	33	469314	500
2017	39297	65	77	533189	465
2018	43119	91	98	332718	395
2019	40498	50	151	480161	402
2020	38528	52	92	470936	270
2021	52467	71	134	638027	281
2022	56545	66	94	633723	374
f_i^*	27760	45	15	329018	206
f_i^-	56545	91	151	638027	500

The normalization of the initial decision matrix was executed using Eq. (4). By juxtaposing the importance weights of the criteria with the normalized decision matrix through Eq. (6), the weighted normalized decision matrix was subsequently derived, as showcased in Table 3.

Table 3. Weighted normalized decision matrix

Alternatives (Years)	C1	C2	C3	C4	C5
2013	0.0000	0.1043	0.0000	0.0275	0.0027
2014	0.0217	0.0000	0.0162	0.0000	0.0000
2015	0.0277	0.0565	0.0588	0.0756	0.1510
2016	0.0413	0.0522	0.0265	0.0908	0.2000
2017	0.0802	0.0870	0.0912	0.1321	0.1762
2018	0.1067	0.2000	0.1221	0.0024	0.1286
2019	0.0885	0.0217	0.2000	0.0978	0.1333
2020	0.0748	0.0304	0.1132	0.0919	0.0435
2021	0.1717	0.1130	0.1750	0.2000	0.0510
2022	0.2000	0.0913	0.1162	0.1972	0.1143

Upon procuring the weighted normalized decision matrix, the S_j and R_j values were extrapolated through the application of Eqs. (8) and (9), respectively. The subsequent performance value Q_j, representative of each year, were computed through the methodologies delineated in Eqs. (10) and (11). These findings are encapsulated in Table 4.

Table 4. S_j, R_j and Q_j values

Alternatives (Years)	S_j	R_j	$Q_j(q = 0.5)$
2013	0.1345	0.1043	0.303
2014	0.0379	0.0217	0.000
2015	0.3697	0.1510	0.606
2016	0.4107	0.2000	0.774
2017	0.5666	0.1762	0.821
2018	0.5597	0.2000	0.883
2019	0.5414	0.2000	0.870
2020	0.3539	0.1132	0.489
2021	0.7107	0.2000	0.994
2022	0.7190	0.2000	1.000

The evolution of ergonomic performance in the metal industry over the years is detailed in Table 5.

Table 5. Yearly ergonomic performance rankings

Alternatives (Years)	S_j	R_j	$Q_j(q = 0.5)$
2013	2	2	2
2014	1	1	1
2015	4	4	4
2016	5	6	5
2017	8	5	6
2018	7	6	8
2019	6	6	7
2020	3	6	3
2021	9	6	9
2022	10	6	10

From the analysis presented by ranking result Q_j, the year 2014 emerges as the predominant position, whilst the year 2022 is discerned at the extremity. It is imperative to note, however, the relevance of satisfying a duo of conditions for a comprehensive interpretation. Upon examination, it has been discerned that both stipulated conditions are met in the context of $q = 0.5$ since $Q(A_2) - Q(A_1) \geq DQ \quad \left(0.303 - 0.000 \geq \frac{1}{10-1}\right)$, and the year 2014 is also corroborated by the ranking lists of both S_j and R_j. To bolster the credibility and precision of these rankings, a sensitivity analysis was undertaken. The findings derived from this rigorous analysis are articulated in Table 6 and visually represented in Figure 1.

Table 6. Variations in Q_j-values as a function of different q-values

	***q*-values**										
Alternatives (Years)	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
2013	0.463	0.431	0.399	0.367	0.335	0.303	0.271	0.238	0.206	0.174	0.142
2014	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2015	0.725	0.701	0.678	0.654	0.630	0.606	0.582	0.559	0.535	0.511	0.487
2016	1.000	0.955	0.909	0.864	0.819	0.774	0.728	0.683	0.638	0.593	0.547
2017	0.866	0.857	0.848	0.839	0.830	0.821	0.812	0.803	0.794	0.785	0.776
2018	1.000	0.977	0.953	0.930	0.906	0.883	0.860	0.836	0.813	0.790	0.766
2019	1.000	0.974	0.948	0.922	0.896	0.870	0.844	0.817	0.791	0.765	0.739
2020	0.513	0.508	0.503	0.499	0.494	0.489	0.484	0.479	0.474	0.469	0.464
2021	1.000	0.999	0.998	0.996	0.995	0.994	0.993	0.992	0.990	0.989	0.988
2022	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

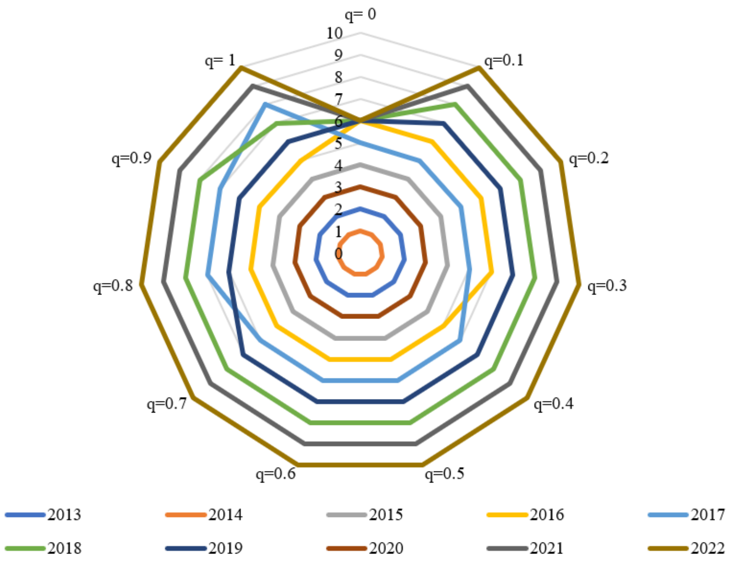

Figure 1. Visual representation of yearly rankings based on varied q-values

Note: Figure was furnished by the author

Through this rigorous analysis, it was determined that both VIKOR method conditions were consistently met across all q-values. The ergonomic performance of 2014 remained superior in comparison to other considered years. Furthermore, negligible variations were observed in the ranking of alternatives upon modulation of the q-values.

4 Conclusions

Ergonomic performance optimisation in the metal industry is paramount to substantially diminishing, if not entirely eradicating, adverse OHS conditions in the workplace. In the context of Turkey's metal industry, this study is recognised as a pioneering endeavour, quantitatively analysing the prevailing conditions. This analysis hinges on the ergonomic performance metrics of OHS spanning the years 2013 to 2022, drawing upon data published by the SSI.

When evaluated through the VIKOR method (for $q = 0.5$), the annual ergonomic performance hierarchy within the metal industry emerges as follows: $2014 > 2013 > 2020 > 2015 > 2016 > 2017 > 2019 > 2018 > 2021 > 2022$. It is hypothesised that these performance values might be influenced by the fluctuating counts of employees and establishments in corresponding years. However, to furnish actionable insights for ergonomic enhancements, a meticulous investigation, particularly focused on years earmarked as high-risk due to inferior ergonomic outcomes, is recommended. Such investigations could elucidate the underlying risk factors within these workplaces.

By embarking on such rigorous studies, it becomes conceivable to mitigate the economic ramifications induced by suboptimal ergonomic practices. Furthermore, an avenue worthy of future research exploration involves ascertaining the significance of ergonomic evaluation metrics through varied methodologies, subsequently juxtaposing the resultant yearly rankings with those derived from alternative MCDM techniques.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The author declares that they have no conflicts of interest.

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