VSB TECHNICAL UNIVERSITY OF OSTRAVA | FACULTY OF MECHANICAL ENGINEERING

MM Science Journal | www.mmscience.eu
ISSN 1803-1269 (Print) | ISSN 1805-0476 (On-line)
Special Issue | TEAM 2024
Transdisciplinary and Emerging Approaches to Multidisciplinary Science
11.9.2024 – 13.9.2024, Ostrava, Czech Republic
DOI: 10.17973/MMSJ.2024_12_2024130

MM SCIENCE JOURNAL

TEAM2024-00043

SELECTING WELDING SAFETY GOGGLES BY MULTI-CRITERIA DECISION-MAKING APPROACHES— A COMPREHENSIVE EVALUATION

Kanak Kalita[1,2,*], R Balaji[1], Lenka Cepova[3], S P Samal[4], Pradeep Jangir[5,6,7,8]

[1] Department of Mechanical Engineering, Vel Tech Rangarajan Dr, Sagunthala R&D Institute of Science and Technology, Avadi 600062, India. drkanakkalita@veltech.edu.in.

[2] Jadara Research Center, Jadara University, Irbid 21110, Jordan.

[3] Department of Machining, Assembly and Engineering Metrology, Faculty of Mechanical Engineering, VSB-Technical University of Ostrava, 70800 Ostrava, Czech Republic. lenka.cepova@vsb.cz.

[4] Department of Biosciences, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Chennai 602105, India. spsamal24@gmail.com.

[5] University Centre for Research and Development, Chandigarh University, Mohali 140413, India. pkjmtech@gmail.com.

[6] Applied Science Research Center, Applied Science Private University, Amman 11931, Jordan.

[7] Department of CSE, Graphic Era Hill University, Dehradun 248002, India.

[8] Department of CSE, Graphic Era Hill University, Graphic Era Deemed to Be University, Dehradun 248002, India.

*Corresponding author; e-mail: drkanakkalita@veltech.edu.in

Abstract

This paper presents a comprehensive application of the Multi-Criteria Decision-Making (MCDM) approach to evaluate and rank different models of welding goggles. The study uses both the Mean Weight and Entropy Weight methods in conjunction with five different MCDM techniques—TOPSIS, CODAS, COPRAS, SAW, and MOORA. These methods provide an insightful comparison and robust ranking of various goggle models. The analysis consistently highlighted $'ArcOne\ The\ Fly\ Safety\ Goggles'$ and $'3M\ Speedglas\ 100\ Series'$ as superior performers across multiple criteria.

Keywords:

TOPSIS, MCDM, Safety, Decision making, Industrial Engineering

1 INTRODUCTION

Occupational safety and health (OSH) are an essential aspect of any workplace, as it ensures the well-being and productivity of employees. Employers and organizations have a moral, legal, and financial responsibility to ensure a safe and healthy working environment. A crucial aspect of OSH is the appropriate selection and use of safety equipment, which can prevent accidents, injuries, and fatalities. The process of selecting the appropriate safety equipment is a complex task that requires the consideration of multiple factors like type of hazard, severity of the risk, effectiveness of the equipment, ease of use, and cost. This is especially true when we consider safety glasses or welding goggles, as they are crucial in protecting workers from potential hazards associated with welding operations, such as intense light, infrared and ultraviolet radiation, sparks, and metal debris. Traditionally, safety equipment selection has been a subjective process based on the experience and judgment of safety professionals. However, this approach can be prone to errors, biases, and inconsistencies.

The introduction of multi-criteria decision-making (MCDM) approaches offers an opportunity to address these challenges by providing a systematic and objective framework for evaluating and selecting safety equipment. MCDM approaches can integrate various criteria and enable decision-makers to make informed choices based on quantifiable evidence [Machida 2001]. Welding goggles come with numerous variations in design, material, comfort, lens shading, durability, and cost. Each of these factors serves as a decision criterion in the MCDM approach. What makes it challenging is that each criterion should be given adequate weightage depending on the specific context of the work and the welder's preferences. For instance, a welding operation that primarily involves exposure to intense light might require goggles with a higher emphasis on lens shading, while one involving a lot of sparks might demand goggles with better physical coverage. In the literature, no such work on application of MCDM in selection of welding goggles is seen.

However, MCDM has been applied to other areas of protective gear selection. For example, Seçkiner and Ünal [Seçkiner 2021] used FAHP select the most efficient personal protective equipment, including protective shoes, helmets, earmuffs, and dust masks, for an effective workplace safety program. Jin and Goodrum [Jin 2021] developed a fuzzy multi-criteria decision-making model to analyze the performance of fall protection plans in construction projects, considering safety, productivity, and economy factors to minimize fall risks, improve labour productivity, and save costs. Boris et al. [Boris 2019] applied MCDM methods to workplace equipment selection, showing the importance of criteria weighting for safety decisions in varying contexts. Burcu et al. [Burcu 2016] used AHP and fuzzy PROMETHEE to select gas measurement devices, highlighting the role of universal design for usability. Aamir et al. [Aamir 2021] developed a fuzzy-TOPSIS model to evaluate safety equipment, integrating risk assessments for comprehensive decision-making. Nilufer et al. [Nilufer 2022] employed AHP to select PPE, with safety features prioritized over comfort and design in hazardous environments. Robert et al. [Robert 2024] emphasized optimizing wearable sensor selection through accuracy and usability, improving safety in critical situations.

Despite the potential benefits of applying MCDM approaches to safety equipment selection, there is limited research in this area. This paper aims to bridge this gap by providing a comprehensive study on the use of MCDM approaches for selecting occupational safety equipment. The primary problem addressed in this paper is the lack of a systematic and objective approach to selecting occupational safety equipment that accounts for multiple criteria. Traditional safety equipment selection relies on the experience and judgment of safety professionals, which can lead to errors, biases, and inconsistencies. The application of MCDM approaches offers an opportunity to overcome these limitations and make informed decisions based on quantifiable evidence. The problem can be summarized as follows: How can MCDM approaches be applied to select occupational safety equipment, considering multiple criteria?

2 DESCRIPTION OF CASE STUDY

2.1 Problem Description

Welding produces intense light and heat, and sparks fly in all directions. Moreover, some welding processes emit harmful infrared and ultraviolet radiation. Welding goggles protect the eyes from these risks. Welding produces a high intensity of UV and infrared radiation. Long-term or even short-term exposure to these radiations can lead to conditions such as "welder's flash," cataracts, and other eye injuries. Welding often produces sparks and metal spatter that can cause serious eye injuries if not protected. Some welding processes involve the use of chemicals which, if they come into contact with the eye, can cause chemical burns or other injuries.

Shade Range: Welding goggles come with different shade numbers, which refer to the level of darkness of the lenses. For example, gas welding generally requires shades 4-8, while arc welding often requires shades 9-14.

Lens Material: Polycarbonate (PC) lenses are highly impact-resistant and protect against UV and IR radiation, while glass (G) lenses can handle higher temperatures.

Frame Material: Goggles should be made of sturdy, durable materials that can withstand the harsh environment of welding.

Ventilation: To prevent fogging, some welding goggles have ventilation systems.

Auto-Darkening: It is a feature that auto darkens the google where there is too much flash.

Comfort Features: Since welding often requires long hours, the goggles must be comfortable to wear.

Safety Standards: Goggles should meet national and international safety standards like American National Standards Institute (ANSI) or the European Standard (EN).

Price Range: The cost of the google.

2.2 Dataset description

For this case study, 6 different pairs of welding google are selected, as shown in Tab. 1. The dataset was compiled by the authors using information available on their respective manufacturer's/seller's website.

As seen from the above dataset in Tab. 1, the welding google data is in categoric format. To convert this qualitative data into quantitative data for applying MCDM, some form of conversion must be carried out. However, it should be noted that this conversion is a subjective process and will largely depend on the preferences and the specific needs of the project. To do the conversion, a scale is assigned for the qualitative data based on general considerations, but this can be adjusted by the decision makers based on specific criteria. To conduct this analysis, first numerical values is assigned to the qualitative data.

Shade Range: Since the shade range can be a range or a fixed number, we can calculate this as the width of the range. For a fixed shade, the range is 0. So, for instance, for 3M Speedglas 100 Series, the range is 13 - 8 = 5. The broader the shade range, the more versatile the goggles are for different welding processes. Thus, this is a maximization type criterion.

Lens Material: Here, Polycarbonate was assigned 2 (due to its high impact resistance and UV protection) and Glass as 1 (higher temperature resistance, but less impact resistance). A higher score here indicates a more desirable lens material. Thus, this is a maximization type criterion.

Frame Material: Here, Nylon was assigned 3 (due to its strength and resistance to many environmental factors), Rubber was assigned 2 (for its flexibility and resistance to certain chemicals), PVC was assigned 1 (durable, but less resistant to certain chemicals and conditions), and Thermoplastic was assigned 2 (it offers a balance between flexibility and rigidity). A higher score here indicates a more durable and suitable frame material, indicating maximization type criterion.

Ventilation: Here, Direct was assigned 2 and Indirect was assigned 1 (since direct ventilation might offer better air circulation). A higher score here suggests better ventilation and therefore, potentially less fogging. Thus, this is a maximization type criterion.

Auto-Darkening: Here, googles with auto-darkening was assigned 2 and without was assigned 1. Auto-darkening is a preferred feature, thus the higher the value, the better. Thus, this is a maximization type criterion.

Comfort Features: Here, 1 point was awarded for each feature mentioned. If only an adjustable strap is mentioned, it gets a 1. If there is an adjustable strap and additional padding, it gets a 2. This is also a maximization type criterion.

Safety Standards: Since all meet the googles met ANSI Z87.1 standard, a standard score of 2 was assigned.

Price Range: For low, moderate and high cost 3, 2 and 1 was assigned respectively. A lower price is generally more desirable, so we would want to minimize this value. However, during the transformation process we assigned Low = 3, Moderate = 2, and High = 1, so in terms of Tab. 2, this criterion can be treated as maximization type i.e., score 3 is more desirable as compared to 1.

After assigning these numbers, Tab. 1 would be transformed numerical values as shown in Tab. 2.

Tab. 1. Dataset on Welding Goggles

Goggle Model	Shade Range	Lens Material	Frame Material	Ventilation	Auto-Darkening	Comfort Features	Safety Standards	Price Range	Data source (Retrieved on 5th July 2024)
3M Speedglas 100 Series	8-12	PC	Nylon	Indirect	Yes	Adjustable headband	ANSI Z87.1	High	https://www.3mindia.in/3M/en_IN/p/d/b00040423/
Miller Electric Shade 5.0	Fixed 5	PC	Rubber	Indirect	No	Adjustable headband	ANSI Z87.1	Moderate	https://www.millerwelds.com/safety/safety-glasses/safety-glasses-m00483
ArcOne The Fly Safety Goggles	5-13	PC	Nylon	Indirect	Yes	Foam padding, Adjustable	ANSI Z87.1	High	https://arc1weldsafe.com/index.php/products/head-face/goggles/the-fly
Hobart 770095 Oxy/Acetylene	Fixed 5	G	PVC	Indirect	No	Adjustable strap	ANSI Z87.1	Low	https://www.hobartwelders.com/safety/goggles-face-shields/goggles/2-x-425-lens-oxyacetylene-goggles-with-flip-front-770095
Jackson Safety 15979	Fixed 5	PC	Thermoplastic	Direct	No	Adjustable strap	ANSI Z87.1	Low	https://www.jacksonsafety.com/product-page/cutting-goggle-iruv-shade-5-1
Lincoln Electric KH976	Fixed 5	G	PVC	Indirect	No	Adjustable headband	ANSI Z87.1	Low	https://www.amazon.com/Lincoln-Electric-KH976-Goggles-Black/dp/B0148DRNRW

Tab. 2. Dataset on Welding Goggles after transformation

Goggle Model	Shade Range	Lens Material	Frame Material	Ventilation	Auto-Darkening	Comfort Features	Safety Standards	Price Range
3M Speedglas 100 Series	5	2	3	1	2	1	2	1
Miller Electric Shade 5.0	0	2	2	1	1	1	2	2
ArcOne The Fly Safety Goggles	8	2	3	1	2	2	2	1
Hobart 770095 Oxy/Acetylene	0	1	1	1	1	1	2	3
Jackson Safety 15979	0	2	2	2	1	1	2	3
Lincoln Electric KH976	0	1	1	1	1	1	2	3

3 RESULTS AND DISCUSSION

3.1 Weight Assignment

The process of assigning weights in the MCDM approach is pivotal as it provides a quantitative measure of the importance of each criterion. In our study, we used both Mean weight and Entropy method to determine these weights for each criterion in the selection of welding goggles.

As seen in Tab. 3, each criterion is assigned an equal mean weight of 0.125, implying an initial assumption that all factors are of equal importance. However, given the intricacies of practical scenarios, all criteria may not hold equal relevance in all contexts. Therefore, to introduce a sense of relativity, we supplement this with the Entropy method. The entropy method, rooted in information theory, is employed to provide a measure of the diversity or "disorder" associated with each criterion. The larger the entropy value, the higher the uncertainty or variability associated with a criterion, suggesting that it could have a wider range of potential outcomes or effects. Conversely, a lower entropy value implies less uncertainty or variability.

From Tab. 3, it is clear that 'Shade Range' has the highest entropy value of 0.747907, indicating a considerable degree of variability. This could be attributed to the diverse range of shades available in welding goggles, corresponding to different types and intensities of welding operations. Therefore, it becomes a highly variable criterion based on the specific welding task and the individual welder's comfort. On the other hand, 'Safety Standards' has an entropy value of 0, indicating no variability. This suggests that 'Safety Standards' is a universally required feature in all welding goggles, irrespective of the type of welding operation. It's a non-negotiable criterion, always expected to be in place for any pair of welding goggles.

Tab. 3. Calculated weight Mean weight and Entropy method

Objectives	Mean weight	Entropy
Shade Range	0.125	0.747907
Lens Material	0.125	0.029641
Frame Material	0.125	0.059162
Ventilation	0.125	0.029776
Auto-Darkening	0.125	0.039952
Comfort Features	0.125	0.029776
Safety Standards	0.125	0
Price Range	0.125	0.063787

3.2 Ranking with various MCDMs

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is a useful method in multi-criteria decision-making as it identifies solutions that are closest to the ideal and furthest from the negative-ideal solutions. By applying TOPSIS to our set of criteria for the selection of welding goggles, we aim to provide a comprehensive ranking system that prioritizes the optimal balance of safety, comfort, and cost-effectiveness. As per Fig. 1(a), 'ArcOne The Fly Safety Goggles' ranks first, suggesting that this model offers a well-rounded performance across all criteria when considering the mean weight of each criterion. However, when taking the entropy into account, the same model still holds the first rank, implying that this model can handle the variability associated with the criteria effectively. However, there's a variation in the ranking of other models when we switch from mean weights to entropy weights. For example, 'Miller Electric Shade 5.0' drops from the 4th rank to the last in the entropy-TOPSIS analysis, indicating that this model's performance may not be as robust in the face of variability and uncertainty.

Combinative Distance-based Assessment (CODAS) is an MCDM method that provides a comprehensive and reliable tool for ranking alternatives based on multiple criteria. Unlike TOPSIS, CODAS uses the concept of Euclidean and Taxicab (Manhattan) distances, making it a robust method for decision-making.

As per Fig. 1(b), 'ArcOne The Fly Safety Goggles' ranks first, demonstrating a balanced performance across criteria. '3M Speedglas 100 Series' follows in the second rank, indicating it as another reliable alternative. On the other hand, 'Hobart 770095 Oxy/Acetylene' and 'Lincoln Electric KH976' share the last rank, suggesting they may not be optimal choices given the current set of criteria. Additionally, Entropy-CODAS also suggests 'ArcOne The Fly Safety Goggles' as the first rank, highlighting the model's consistent performance in diverse conditions. The '3M Speedglas 100 Series' maintains its second rank, while 'Miller Electric Shade 5.0' drops to the last position, reflecting its poor performance in handling uncertainties compared to other alternatives.

The Complex Proportional Assessment (COPRAS) is a MCDM method that ranks alternatives based on their weighted normalized values across various criteria. It considers the relative importance of each criterion by using a comprehensive and robust decision matrix. For the Mean Weight-COPRAS (Fig. 1(c)), 'ArcOne The Fly Safety Goggles' secure the top spot, followed by '3M Speedglas 100 Series' at second, and 'Jackson Safety 15979' at third place. This ranking reflects their general performance across all criteria with equal weights. Interestingly, 'Hobart 770095 Oxy/Acetylene' and 'Lincoln Electric KH976' share the last position, implying a lower overall performance based on the current criteria. A similar trend is seen in the Entropy-COPRAS (Fig. 1(c)), with 'ArcOne The Fly Safety Goggles' maintaining the lead. This consistency suggests that the 'ArcOne' model's performance is not only robust under normal conditions but also remains relatively stable under varying or uncertain conditions. Meanwhile, the '3M Speedglas 100 Series' retains its second position. The 'Miller Electric Shade 5.0' drops to the fourth rank in this assessment, indicating that it might not be as efficient under uncertain conditions as the 'ArcOne' and '3M' models.

Simple Additive Weighting (SAW), also known as weighted sum model, is a popular and straightforward multi-criteria decision-making method. SAW computes the sum of the weighted performance scores for each alternative, thereby providing a global score which can be used to rank the alternatives. Fig. 1(d) provides the SAW rankings based on the mean weighted decision matrix. Similar to previous analyses, 'ArcOne The Fly Safety Goggles' tops the list, followed by '3M Speedglas 100 Series' and 'Jackson Safety 15979'. This ranking once again highlights the overall strong performance of 'ArcOne The Fly Safety Goggles' across all the considered features. The entropy-weighted SAW method also results in the same ranking as the mean-weighted one, which confirms the robustness of 'ArcOne The Fly Safety Goggles' and '3M Speedglas 100 Series' as top performers. Interestingly, 'Hobart 770095 Oxy/Acetylene' and 'Lincoln Electric KH976' tie at the last spot in both assessments, suggesting that these models may not be as effective or balanced across the considered criteria compared to the other alternatives.

Multi-Objective Optimization on the basis of Ratio Analysis (MOORA) is an advanced MCDM method. The primary goal of MOORA is to rank alternatives based on a ratio system and a reference point, thereby allowing for more objective and comprehensive comparisons. Fig. 1(e) shows the MOORA ranking based on the mean weighted decision matrix. The 'ArcOne The Fly Safety Goggles' again tops the list, followed by '3M Speedglas 100 Series' and 'Jackson Safety 15979'. Interestingly, in this analysis, 'Jackson Safety 15979' ranks higher than 'Miller Electric Shade 5.0', unlike in the SAW analysis. The entropy-weighted rankings mirror those in the mean-weighted analysis, further reinforcing the leading positions of 'ArcOne The Fly Safety Goggles' and '3M Speedglas 100 Series'. Additionally, 'Hobart 770095 Oxy/Acetylene' and 'Lincoln Electric KH976' rank last, consistent with previous findings from the SAW method. From the MOORA analysis, it is clear that 'ArcOne The Fly Safety Goggles' and '3M Speedglas 100 Series' stand out in their performance across multiple criteria. This demonstrates the usefulness of the MOORA method in providing clear and consistent ranking of alternatives, which can greatly aid decision-makers in their selection process.

Fig. 2 presents a comparative assessment of the similarity in ranking of the various MCDMs. It is seen that in general, there is a high correlation in the ranking. In fact, in most cases the exactly similar rankings are derived by different methods. This high correlation further builds additional confidence in the derived rankings, indicating that the google selection problem can solved with high degree of reliability

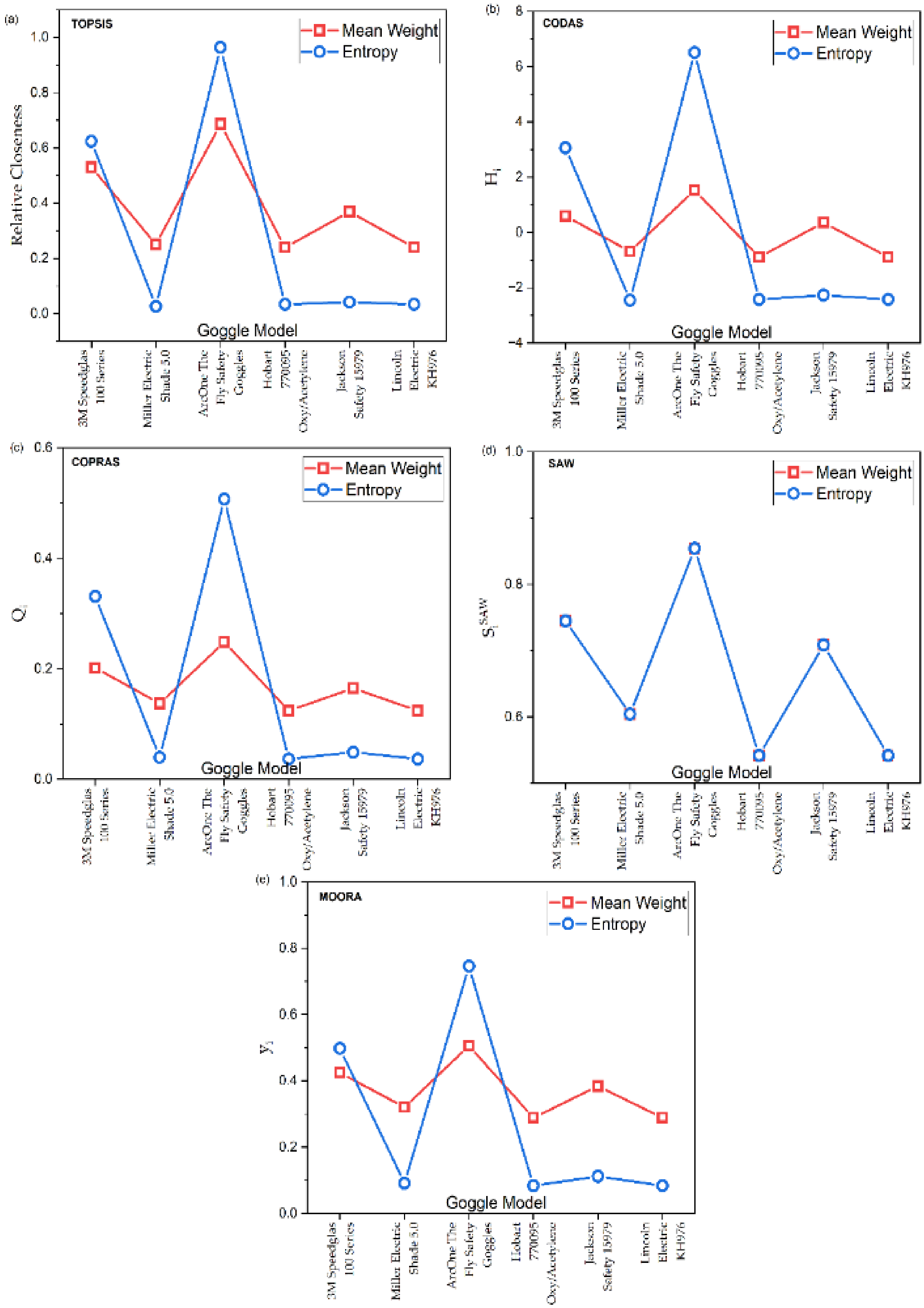

Fig. 1. Comparison of performance measure of various MCDMs for mean weight and entropy. (a) TOPSIS (b) CODAS (c) COPRAS (d) SAW (e) MOORA

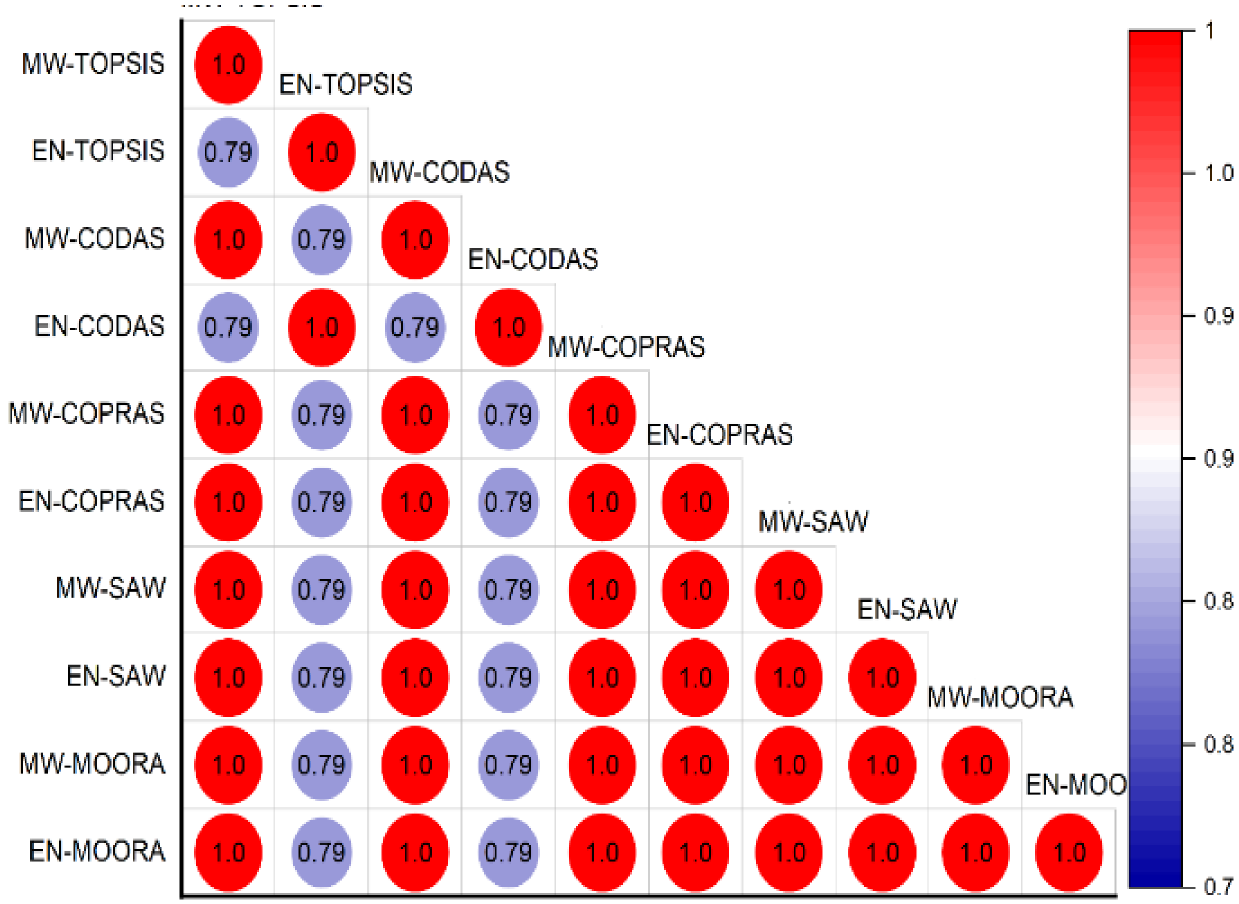

Fig. 2. Comparison of Spearman correlation coefficient of all MCDM methods

.

4 CONCLUSION

The primary focus of this paper is to apply MCDM methods to evaluate and rank various goggle models based on multiple criteria. This approach assists in making more informed decisions in the realm of product selection, where there are often trade-offs to consider among multiple important features. This research included the application of both the Mean Weight and Entropy Weight methods in the context of TOPSIS, CODAS, COPRAS, SAW and MOORA, providing a comprehensive comparative evaluation of the different goggle models. Based on the extensive numerical experiments the following conclusion can be drawn—

- The models 'ArcOne The Fly Safety Goggles' and '3M Speedglas 100 Series' were consistently ranked high across all methods, indicating their superior performance on the considered criteria.
- It was observed that 'Jackson Safety 15979' showed an improved ranking in the MOORA analysis as compared to the SAW analysis, indicating that different MCDM methods can indeed result in different rankings.
- Both the Mean Weight and Entropy Weight methods were utilized to provide a comprehensive comparison and ensure the robustness of the rankings.
- The paper affirmed the importance of utilizing multiple criteria in decision-making, especially in scenarios where various important features or attributes are to be considered.

5 ACKNOWLEDGMENTS

This article was co-funded by the European Union under the REFRESH – Research Excellence For REgion Sustainability and High-tech Industries project number CZ.10.03.01/00/22_003/0000048 via the Operational Programme Just Transition and has been done in connection with project Students Grant Competition SP2024/087 "Specific Research of Sustainable Manufacturing Technologies“ financed by the Ministry of Education, Youth and Sports and Faculty of Mechanical Engineering VŠB-TUO.

6 REFERENCES

[Aamir 2021] Aamir, A. R., Musa, S. N., Ramesh, S., & Lim, M. K. (2021). Development of a fuzzy-TOPSIS multi-criteria decision-making model for material selection with the integration of safety, health and environment risk assessment. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science. https://doi.org/10.1177/1464420721994269

[Boris 2019] Boris, A., Hadzistevic, M., Budak, I., Moraca, S., & Vukelic, D. (2019). Comparison of approaches to weighting of multiple criteria for selecting equipment to optimize performance and safety. International Journal of Occupational Safety and Ergonomics. https://doi.org/10.1080/10803548.2017.1341126

[Burcu 2016] Burcu, Y. K., & Dagdeviren, M. (2016). Selecting Occupational Safety Equipment by MCDM Approach Considering Universal Design Principles. Human

Factors and Ergonomics in Manufacturing & Service Industries. https://doi.org/10.1002/HFM.20625

[Jin 2021] Jin, H., & Goodrum, P. M. (2021). Optimal Fall Protection System Selection Using a Fuzzy Multi-Criteria Decision-Making Approach for Construction Sites. Applied Sciences, vol. 11, p. 5296.

[Machida 2001] Machida, S., & Bachoo, P. (2001). Guidelines on occupational safety & health management systems. African news letter on occupational health and safety, vol. 11, pp. 68–69.

[Nilufer 2022] Kursunoglu, N., Önder, S., & Önder, M. (2022). Selection of an appropriate personal protective equipment using the analytic hierarchy process. Osmangazi Üniversitesi Mühendislik-Mimarlık Fakültesi dergisi. https://doi.org/10.31796/ogummf.1030448

[Robert 2024] Houghton, R., Martinetti, A., & Majumdar, A. (2024). A Framework for Selecting and Assessing Wearable Sensors Deployed in Safety Critical Scenarios. Sensors. https://doi.org/10.3390/s24144589

[Seçkiner 2021] Seçkiner, S. U., & Ünal, H. (2021). Comparing the alternatives for the most favourable personal protective equipment. International journal of occupational safety and ergonomics, vol. 27, pp. 921–927.