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Using wearable technological devices to improve workplace health and safety: An assessment on a sector base with multi-criteria decision-making methods

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ABSTRACT

In occupational health and safety, it is important to use personal protective equipment that reduces or prevents injury to employees during an accident. Advanced sensors and computing technologies that can be worn on the body to create, store and transmit data during daily activities are wearable technology products. These products also make significant contributions to employee health and safety. The use of wearable technologies, which are very important in creating a safe work environment, is seen as a promising solution in contributing to the reduction of accidents and increasing industrial efficiency by increasing employee safety, reducing hazards and risks in sectors where occupational accidents are common.

The study, it is aimed to prioritize the use of wearable technology devices in sectors that have potential risks that may cause fatigue, injury, error, and accident of employees due to labor-intensive and challenging tasks. Within the scope of this target, five alternatives and eight criteria were determined in line with the literature research and expert opinions. The criteria weights were determined by the AHP method, and the ranking of the alternatives was made by the AHP and PROMETHEE methods. Alternatives are listed as construction, mining, agriculture, textile, and chemistry. The increase in the use of wearable technology devices in the leading sectors in terms of work accidents and occupational diseases will open a new door to occupational safety and health management in the sectors and will significantly reduce health and safety problems.

1. Introduction

According to the latest research of the International Labor Organization (ILO), 2.78 million workers die annually due to work and occupational accidents. 2.4 million of those who died are due to disease. 374 million workers suffer from occupational accidents that do not cause death [1]. The most critical priority for employers is to ensure high job security for employees. Because working in an industrial environment is dangerous, accidents regularly occur in workplaces, and workers are injured because of this. Ensuring workers wear appropriate personal protective equipment (PPE) is an important factor in protecting them from hazards [2]. Recently, the development of personal portable devices has taken its place among the subjects of special importance for the monitoring of occupational safety and health. Fabric-integrated smart garments based on strain sensors for real-time measurement of physiological endpoints stand out as a promising solution [3].

Technologies such as smart wearable devices are user-worn in the form of an accessory with integrated electronics and computing technologies, retrieving or reporting data. These devices are; It can collect and store data from the user's physical activity, movement, heat rate, and even voice data. All or any of these data can be analyzed at any time [4]. By expanding the scope of wearable technology applications, it has gained the feature of tracking the user's position and movements by adding a Global Positioning System (GPS), an Inertial Measurement Unit (IMU), or an accelerometer to the sensor systems [5]. In addition, the development of wearable chemical sensors attracts great attention due to their great potential applications in the fields of medicine, occupational safety, health, and sports [6]. In today's technology-driven environment, the market for connecting everything to the local network or the cloud often focuses on wearable electronic devices that can report environmental and biometric data and detect security trends. However, some of the very common injuries on the job can be avoided

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by offering an immediate and practical approach, thanks to advances in the familiar personal protective equipment, gloves, and shoes [7].

With the latest developments in technology, wearable devices may emerge as a promising solution in the management of occupational health and safety in real working conditions [8]. Wearable technology usage scenarios in the workplace; providing enhanced instruction to identify and respond to safety hazards or risks, monitor productivity, facilitate health and wellness and improve task management [9]. Monitoring of body condition and the surrounding environment, combined with real-time data detailing, allows hazards to be identified to quickly take action against potential damage. The collected information can also be shared and evaluated by expert operators [10].

Clothing for work is often a matter of comfort, and perhaps even style, for many. For others, routinely wearing the right equipment in heavy machinery, high voltage, or constantly harsh environments can mean the difference between staying comfortable and completing a shift safely or sustaining an injury that can have a significant impact on a worker's future employment options and quality of life [7]. In this study, it is considered as a decision-making problem in which field the wearable technological devices are used the most in five alternative study areas determined as mining, construction, textile, agriculture, and chemistry. The criteria weights were found with the Analytical Hierarchy Process (AHP) method, and the alternatives were ranked with the PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation, PROMETHEE) and AHP methods.

The study consists of five chapters, and a literature review was conducted in the second chapter following the introduction, which is the first chapter. In the third chapter, information about the methods used, AHP and PROMETHEE, is given. The application of the problem is made in the fourth chapter, and at the end, information about the results is given, and future work is presented.

2. Scientific literature review

Setz et al. [11] analyzed in their study that cognitive load is different from stress by using electrodermal activity (Electrodermal Activity, EDA) in an office environment. Kritzler et al. [2] investigated the idea and application of a security system for PPE based on wireless technology and wearable sensors. The aim of the system was to ensure that the correct PPE required for a particular task was worn. They obtained the approval of field experts by stating that wearable sensing can increase workplace safety in their studies. Teizer [12] investigated the potential of Self-Monitoring Alert and Reporting Technology for Hazard Avoidance and Training (SmartHat) system, which is a wearable technology for workers working in the construction industry, to provide warning in hazardous situation conditions. Lee et al. [13] investigated the usability and reliability of wearable sensors in roofing workers while performing their duties and off-duty. In their case study, Hwang and Lee [14] investigated the use of physical demand measurement in 19 workers working at the construction site using a wristband. In the analysis, they searched in-depth information about factors affecting physical demands such as individual, environmental, job tasks, etc. They aimed to demonstrate the potential of continuous measurement in identifying the most significant variation in physical demand. Results; revealed that the physical demands of workers vary significantly due to indirect and direct work, the combined effects of work tasks, and individual work. They concluded that this research will have a curative effect on the construction industry as it predicts health and safety issues before physical demands, loss of productivity. Kim et al. [15] conducted a study proposing a hazard avoidance system related to crash safety issues at construction sites. In their work, they use computer vision techniques to identify dangerous situations on the site and display the results on the screen of "Google Glass," a commercial wearable eyewear product. Direction information for hazard direction, distance, and safety level are calculated and evaluated by processing images captured by global cameras at construction sites, and hazard information is displayed on the worker's wearable screen using Augmented Reality (AR). They stated that the safety information provided by the proposed system can increase the safety of the construction site by reducing the hazards. Choi et al. [16] in their study, investigated the determinants of wearable technology adoption in occupational safety and health of construction workers with a wrist-type activity tracker wearable physiological sensor and a smart vest for location tracking with embedded indoor GPS. They developed models to determine the factors that affect workers' adoption of devices and made inferences for wearable technological devices to be more useful. Their studies concluded that the appropriate and continuous use of wearable technology devices in occupational health and safety management should be ensured by providing important information to encourage workers to adopt each device. In their article, Mardonova and Choi [17] presented a research on their widespread and potential distribution in the mining industry, taking into account the existing conditions in wearable device technology. They proposed a wearable security management system for miners and other possible applications. As a result of their research, they stated that worker safety in mining sites will increase with the use of wearable device technology. Awolusi et al. [18] aimed to make a comprehensive review of wearable technological device applications in providing personalized construction safety. They revealed that current wearable technologies applied in different industrial sectors can also be used in the construction industry to monitor and measure various safety performance measures. Schall et al. [19] conducted research on the potential benefits of using wearable sensor types (especially personal activity monitors) used by OHS experts and the reasons that hinder their widespread adoption in the industry. Bowen et al. [20] made a physiological data measurement by expressing that New Zealand's forestry industry has one of the highest death and injury rates among all industrial sectors in the country and to determine appropriate ways to detect fatigue in the forestry workplace to successfully manage it. Gualandi et al. [10] discussed the role of CPs (Conductive Polymers) and the main challenges in the development of textile electrochemical sensors specially designed for real-time sweat monitoring. Hwang et al. [21] in their study, along with the increasing concerns about occupational health, the early detection of health risk factors, especially in physically demanding workplaces such as construction sites, is critical for improving worker health, so the wearable activity tracker embedded in the wristband type tracker, ready to use, is used in construction investigated its use. Their results revealed that a PPG (photoplethysmography) based sensor can be used effectively in the heart rate monitoring of construction workers. Sandoval and Kwon [4] analyzed the use of wearable devices as a response method to reduce accident risk, monitor, and improve construction safety. They stated that improper actions and behaviors are two of the main causes of safety problems in the construction industry, and these causes often lead to injury and even death of the worker. In the face of this situation, placing wearable devices in the working environment; They concluded that it can help monitor business processes, create a safer and healthier workplace, and increase staff productivity. Jakops et al. [22] identified the factors that predicted employees' acceptance of wearable devices in their study. A survey of 1273 working adults on line surveyed demographics, experience with wearables, job and organizational characteristics, beliefs, and willingness to use wearables. Actively using wearable technology in the workplace, but; They concluded that use and user behavior depend heavily on employee acceptance for wearable technology to realize its potential benefits, and employees will need to adopt and adhere to the technology. In their study, Xie and Chang [23] aimed to show that the wearable safety assurance system, which can predict the risk of personal safety accidents caused by unsuitable physical conditions, can evaluate the life situations of employees in the working environment in real time. Kiehl et al. [24] proposed a new system for remote monitoring of confined space entrances in aircraft maintenance operations in order to reduce the risk factors associated with confined space. They explained how human sensing technology is transforming the nature of work in aircraft maintenance, increasing

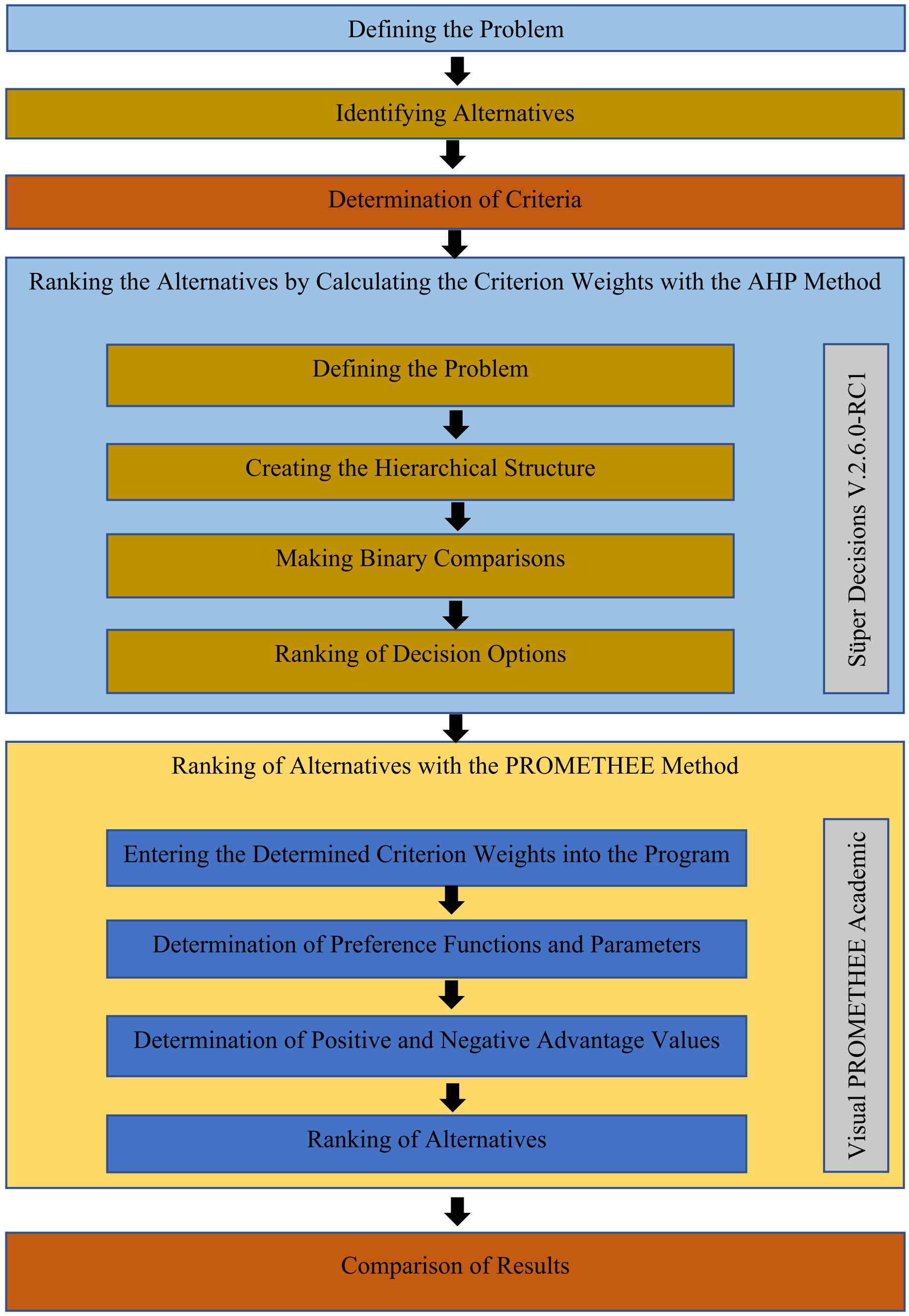


Fig. 1. Flow Chart of the Problem.

work efficiency, as well as optimizing health and safety monitoring. Häikiö et al., [25] obtained the data of their study through an online survey of 4385 construction workers and investigated the perceptions of construction workers in using the Internet of Things (IoT) technology in terms of occupational safety. Participants stated that they had concerns that these devices would violate privacy and security. They concluded that the use of IoT technology in occupational safety and health solutions is the most important component of user acceptance and building trust. Niknejad et al. [26] aimed to review the latest developments and future challenges of smart wearable devices in their literature study. According to the findings, they have reached the conclusion that smart wearable device studies have increased dramatically in recent years. Marra et al. [3] developed a new strain sensor from graphene nanoplatelets (GNPs), which were suitably dispersed in water-based transparent ink and then deposited on a synthetic fabric by screen printing technique. Banguru et al. [27] proposed an automatic construction worker activity recognition method based on ANN (Artificial Neural Network) that can recognize different construction activities. The proposed methodology; discusses ANN model development, data collection, and data fusion. They presented the research to validate the feasibility of the proposed methodology with a case study in scaffolding construction activities, as well as to evaluate performance against other available methods.

In the literature review, no study was found in which sectors primarily use MCDM methods regarding the use of wearable technology devices. The fact that it opens a new door to occupational safety and health management, especially for those who work in physically demanding and dangerous tasks, and is among the first studies on this subject will contribute to the literature.

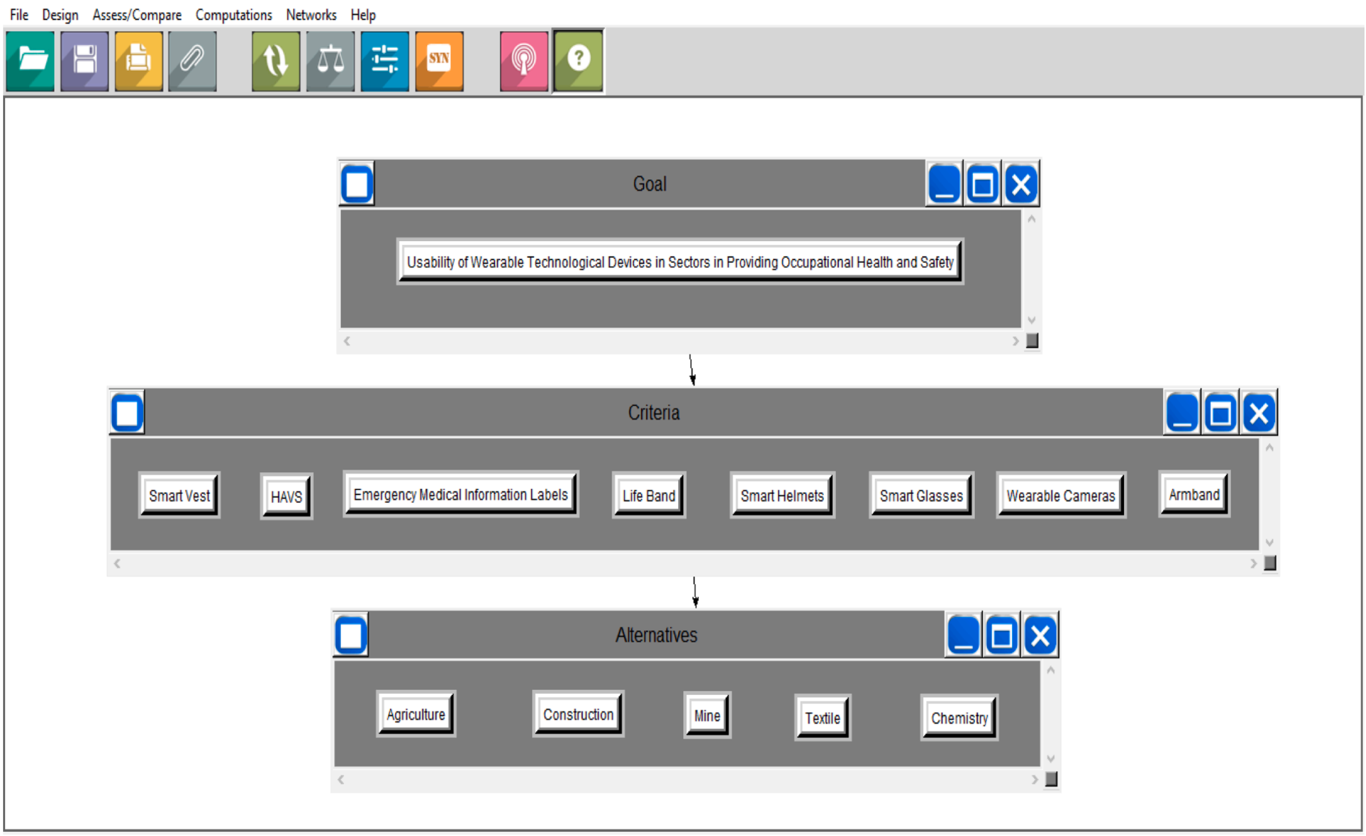


Fig. 2. Hierarchical Structure of the Decision Problem.

Here are the priorities.

Icon	Name	Normalized by Cluster	Limiting
No Icon	Construction	0.36657	0.183284
No Icon	Chemistry	0.09122	0.045608
No Icon	Mine	0.30406	0.152028
No Icon	Agriculture	0.14437	0.072186
No Icon	Textile	0.09379	0.046894
No Icon	Usability of Wearable Technological Devices in~	0.00000	0.000000
No Icon	Emergency Medical Information Labels	0.03671	0.018356
No Icon	Smart Glasses	0.10148	0.050742
No Icon	Smart Helmets	0.29128	0.145640
No Icon	Smart Vest	0.13102	0.065510
No Icon	Wearable Cameras	0.05218	0.026088
No Icon	HAVS	0.22817	0.114085
No Icon	Armband	0.09887	0.049434
No Icon	Life Band	0.06029	0.030146

Fig. 3. Calculation of Criterion Weights with AHP and Ranking of Alternatives.

3. Materials and methods

In the study, in which the priority order of use of wearable technology devices according to the sectors was determined, alternatives and criteria were determined in line with the literature review and expert opinion. Criteria weights were calculated with AHP, one of the multi-criteria decision-making methods. Alternatives determined by AHP and PROMETHEE methods were ranked and compared.

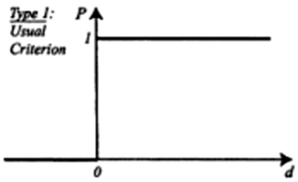
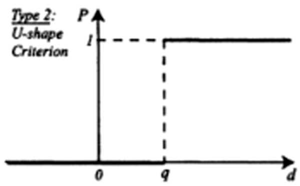
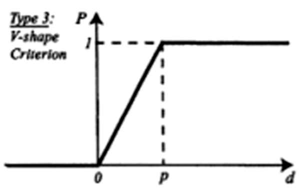
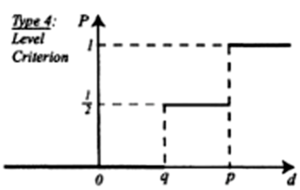
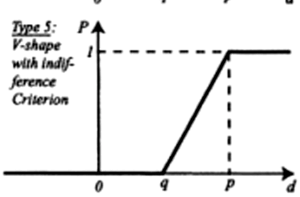
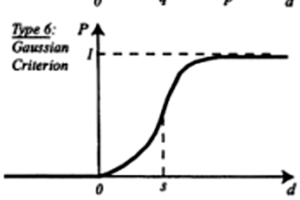
3.1. AHP method

AHP is a measurement theory. When applied to decision making, it decomposes a complex problem into a multilevel hierarchical structure of objectives, criteria, sub-criteria, and alternatives to help define the overall decision process [28]. AHP includes comparison and rating methods. In order to find the best choice among the options, it is necessary to establish a reliable feedback network or hierarchical structure that covers the various types of impacts with the criteria of the stakeholders and decision alternatives. Policymakers at all levels of organizations use multi-criteria thinking to facilitate decision-making and analyze complex problems in this way [29].

The three principles of the AHP method are decomposition, synthesis, and measurement of preferences. In parsing, a problem is handled one by one and divided into manageable items. The problem begins with the implicit descriptors (purpose) and progresses logically to the criteria by which the results are evaluated. From pairwise comparisons of items at the hierarchy level, a relative ratio scale is derived according to the impact of an item. Pairwise comparisons are made about the strength (importance or probability) of one element numerically represented over another on an absolute scale, with judgments provided as verbal statements. The local priority vector is derived in a matrix framework using the estimation of the relative magnitudes in relation to the items being compared. When priority vectors are derived for all comparisons in the hierarchy, local priorities are synthesized to derive a global priority measure that is used to make the final decision. The result of the synthesis is a nonlinear form whose complexity depends on the number of levels and elements in the hierarchy at each level [30].

In order to make an organized decision to establish priorities, it is

Table 1
Preference Functions [35].

Generalised criterion	Definition	Parameters to fix
	$P(d) = \begin{cases} 0 & d \le 0 \\ 1 & d > 0 \end{cases}$	–
	$P(d) = \begin{cases} 0 & d \le q \\ 1 & d > q \end{cases}$	q
	$P(d) = \begin{cases} 0 & d \le 0 \\ \frac{d}{p} & 0 \le d \le p \\ 1 & d > p \end{cases}$	p
	$P(d) = \begin{cases} 0 & d \le q \\ \frac{1}{2} & q < d \le p \\ 1 & d > p \end{cases}$	p, q
	$P(d) = \begin{cases} 0 & d \le q \\ \frac{d-q}{p-q} & q < d \le p \\ 1 & d > p \end{cases}$	p, q
	$P(d) = \begin{cases} 0 & d \le 0 \\ 1 - e^{-\frac{d^2}{2s^2}} & d > 0 \end{cases}$	s

necessary to break the decision down into the following steps.

1. By defining the problem, the type of information sought is determined.
2. The decision hierarchy is structured from above with the goal of the decision, then through the middle levels (criteria on which the next items depend) to the lowest level (usually a set of alternatives), goals are structured from a broad perspective.
3. A series of pairwise comparison matrices are created, and the higher-level items are compared with the items below.
4. Priorities from comparisons are used to weight priorities at the level immediately below for each item. Then, weighted values are added for each element in the following level, and its global or global priority is taken. This weighting and addition process continues until the final priorities of the lowest alternatives are achieved [31].

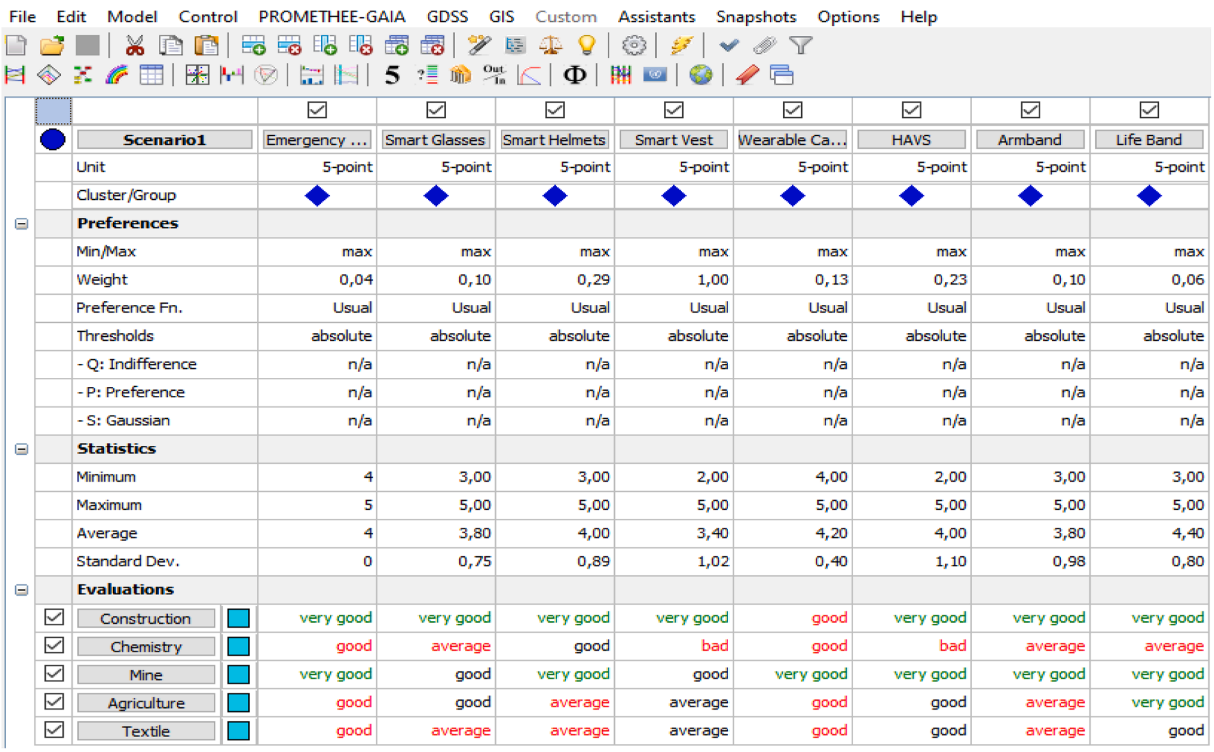
3.2. PROMETHEE method

The PROMETHEE method is the priority method used in solving MCDM problems, developed based on the difficulties of other prioritization methods in the literature, which are easy to implement and effective [32]. Advantages of this method over others; ability to determine qualitative quantities, structuring the problem, good software support, data quantities that can be processed, and presentation on the GAIA plane [33]. Disadvantages; It does not provide a clear method for assigning weights and requires assigning values [34].

A significant number of successful applications have been handled with the PROMETHEE methodology in various fields such as manpower planning, banking, investments, industrial location, chemistry, water resources, medicine, ethics in the operating room, tourism, health services, dynamic management. The success of the methodology is mainly due to its ease of use and mathematical features [35].

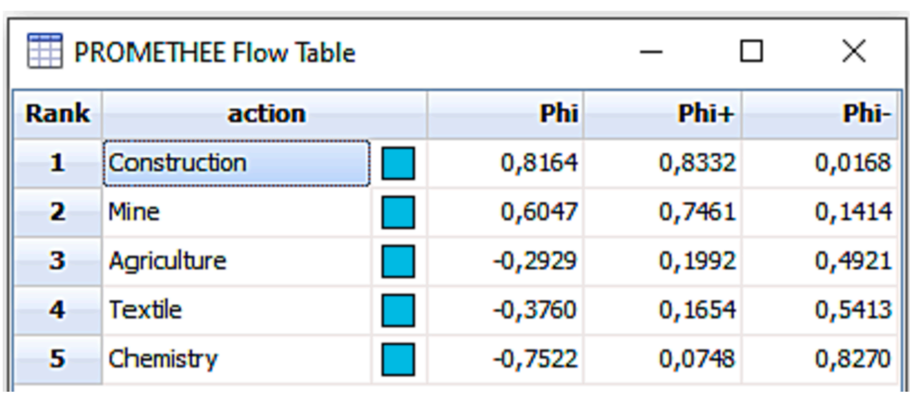
The method consists of 7 steps [36].

Step 1: The importance weights of the criteria are determined by defining the criteria and alternatives.
Step 2: Preference functions are defined depending on the interrelationship and structure of the criteria.



Scenario1	Emergency ...	Smart Glasses	Smart Helmets	Smart Vest	Wearable Ca...	HAVS	Armband	Life Band
Unit	5-point	5-point	5-point	5-point	5-point	5-point	5-point	5-point
Cluster/Group								
Preferences								
Min/Max	max	max	max	max	max	max	max	max
Weight	0,04	0,10	0,29	1,00	0,13	0,23	0,10	0,06
Preference Fn.	Usual	Usual	Usual	Usual	Usual	Usual	Usual	Usual
Thresholds	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute
- Q: Indifference	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
- P: Preference	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
- S: Gaussian	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Statistics								
Minimum	4	3,00	3,00	2,00	4,00	2,00	3,00	3,00
Maximum	5	5,00	5,00	5,00	5,00	5,00	5,00	5,00
Average	4	3,80	4,00	3,40	4,20	4,00	3,80	4,40
Standard Dev.	0	0,75	0,89	1,02	0,40	1,10	0,98	0,80
Evaluations								
Construction	very good	very good	very good	very good	good	very good	very good	very good
Chemistry	good	average	good	bad	good	bad	average	average
Mine	very good	good	very good	good	very good	very good	very good	very good
Agriculture	good	good	average	average	good	good	average	very good
Textile	good	average	average	average	good	good	average	good

Fig. 4. PROMETHEE Data Entry.



PROMETHEE Flow Table

Rank	action	Phi	Phi+	Phi-
1	Construction	0,8164	0,8332	0,0168
2	Mine	0,6047	0,7461	0,1414
3	Agriculture	-0,2929	0,1992	0,4921
4	Textile	-0,3760	0,1654	0,5413
5	Chemistry	-0,7522	0,0748	0,8270

Fig. 5. Ranking of Alternatives by PROMETHEE Method.

Table 2
Comparison of AHP and PROMEETHE Rankings.

Ranking	AHP Ranking of Alternatives	PROMETHEE Ranking of Alternatives
1	Construction	Construction
2	Mine	Mine
3	Agriculture	Agriculture
4	Textile	Textile
5	Chemistry	Chemistry

Step 3: Considering the preference functions for each criterion, pairwise comparisons of the alternatives are made, and common preference functions are determined.
Step 4: Preference indices are determined for each pair of alternatives using common preference functions.
Step 5: Negative and positive superiority values are determined for alternatives.
Step 6: Partial priorities are set with PROMETHEE I.
Step 7: Exact priorities for each alternative are determined by PROMETHEE II.

4. Application

The flow chart of the problem is as shown in Fig. 1.

4.1. Defining the problem

It is very important to develop portable personal technological devices, especially in the follow-up of occupational safety and health. For real-time measurement of physiological endpoints based on fabric-integrated strain sensors, smart clothing has emerged as a promising solution [3]. Physically demanding and dangerous construction [25,16,18] agriculture caused by exposure to pesticides [37,38] mining with inadequate safety conditions [17] chemicals that cause accidents by harming people and the environment due to socio-environmental-technical systems and toxic products [39], textile sectors where industrial accidents occur [40] were selected. The use of wearable technologies is of key importance in creating a safer work environment, especially in these sectors where occupational accidents are common. The aim of the study is to prioritize the wearable technological device needs of the sectors where the working conditions are the most difficult, and the employees are exposed to the most dangers and risks during the work process. In this way, it will contribute to the reduction of accidents by increasing the safety of employees and also increasing industrial efficiency.

4.2. Identifying alternatives

Mining, construction, agriculture, textile, and chemistry sectors, which are the places where the working conditions are the most difficult and the workers are exposed to the most dangers during the work process, have been determined as alternatives. It is important to choose the appropriate wearable technologies to reduce or eliminate risks in order to prevent workplace injuries, employee diseases, or health damage. Creating good health and safety conditions for employees; will lead to the recognition and decision-making of problems and better organizational processes.

4.3. Determination of criteria

Wearable device; It can collect and store data from the user's movement, heat rate, physical activity, and even voice data, any or all of which can be analyzed later [4]. The criteria of the study consisted of the wearable technology devices listed below.

Smart Vest: Recent wearable devices can track a user's location and movements by adding a GPS, accelerometer, or an IMU to their sensor systems, expanding the scope of wearable technology applications [5]. Such potentials of wearable technology can occupy an important place in the management of occupational health and safety in real working conditions, together with the latest technological developments in terms of cost reduction and wearability, and sensing capacity. These garments can play an important role in detecting the worker's position in the hazardous work area, identifying work-related musculoskeletal disorders, near-miss risks inferred from IMU signals, and preventing workers from accessing hazardous locations on construction sites [16].

HAVS: HAVS (Hand-Arm Vibration Syndrome, HAVS) is a groundbreaking wearable technology designed to prevent hand-arm vibration syndrome. Generally, vibrations damage the blood vessels, muscles, and joints, nerves of the hand, wrist, and arm due to prolonged use of power tools. The user-installed tool, with the support of analytics platform reporting software, provides continuous monitoring with automatic reporting to identify any exposure risk. Equipment; It is designed to identify personal exposure points and thresholds for the tool operator with the system, aiming to raise awareness about exposure, to train workers while using tools. HAVS provides clear, concise, and tailor-made reliable data analysis to help reduce and design causes of exposure to vibration. Each tool user has a separate module that attaches to a wrist strap. The module has a screen showing vibration exposure and tool information, and sounds an audible alert, and vibrates to indicate the exposure level for the person to take action later. The system transmits all data to generate cloud-based reports in real-time [41].

Emergency Medical Information Labels: Emergency Medical Information (Emitags) are intelligent, life-saving devices that can be secured to a hard hat, cardholder, or other flats, clean surface and retain an employee's emergency information, including allergies, and provide health conditions, medications, and emergency contact information. Ideal for construction workers, other professionals such as the oil and gas industry, aviation, and retail, wearing an Emitag gives team members the peace of mind they can take in an emergency when they can't speak for themselves [41].

Life Band: A flexible lanyard that can be worn alone or placed inside a variety of hats, it is used to alert and monitor operators of apparent fatigue and decreased alertness. Reading users' brain waves, alerting operators determines the riskiest hours and micro-sleep. It helps prevent fatigue-related accidents by allowing users to monitor their fatigue levels at any time via the Bluetooth connection of a dedicated smartphone app [7].

Smart Helmets: It is designed to actively monitor users' heart rate, body temperature, location, and work environment. It provides a holistic view of the work environment, providing instant alerts in the event of each user's fall, locked areas and proximity to moving equipment, exposure to toxic gases. Helmets are especially effective in minimizing the risk of falling. It helps to prevent those who do not have the necessary equipment for the job from working at height by detecting from the ground whether the workers at height are wearing appropriate safety equipment while working. If a worker falls from a considerable height, the hat's communication system immediately notifies security operators and emergency services. A wearable PVCD (Personal Voltage and Current Detector) is attached to the mouth of the helmet and detects magnetic electrical felts emitted from sources around the user in a 360° region. LED proximity alerts are triggered long before the user comes into contact with an energized source. After the device detects the first proximity alert, it displays the approximate direction of the source. The device, which has an automatic sensitivity feature, allows the user to silence unnecessary warnings by pressing the middle button [7].

Smart Glasses: A screen that displays important notifications (notifications are sent to the glasses via Bluetooth via the mobile phone), the screen used as a camera for taking videos and photos can also be used as a navigation screen for location. In order to achieve these goals with smart glasses, there is a software package that securely and freely exchanges data with applications on the mobile phone, connects its components in the system, and stores the data obtained from them for further processing and analysis [17].

Wearable Cameras: Wearable cameras are particularly well suited to creating first-person photos and videos in real-time. It can be used in supply chain management and security monitoring, dust monitoring, process control, and field inspection [17].

Armband: The wearable device carries multiple sensors and slips into an armband that an employee wears during a shift. The device will then record the environmental conditions experienced by the worker during the shift. Throughout the shift, the sensor sends feedback to the cloud platform, which can be monitored to determine conditions on-site. Diagnosis may include visibility range, temperature, noise, air quality, and environmental conditions such as an employee tripping or tripping [42].

4.4. Ranking the alternatives by calculating the criterion weights with the AHP method

The weighting of the criteria determined by the literature review and expert opinions was made with the AHP method. SuperDecion V.2.6.0-RC1 program was used to solve the problem. The hierarchical structure of the decision problem is shown in Fig. 2. Calculations of criterion weights and ranking of alternatives are given in Fig. 3.

4.5. Ranking of alternatives by PROMETHEE method

In our study, in which mining, construction, agriculture, textile, and chemistry sectors were determined as alternatives, the PROMETHEE method was used to rank the alternatives. First of all, the criteria weights obtained in the AHP method were entered into the Visual PROMETHEE Academic Version Program used for the solution. The preference functions to be used in the solution of the problem are given in Table 1 [35]. There are six kinds of preference functions Usual (Type One), U-Type (Type Two), V-Type (Third Type), Fourth Type (Level), Linear (Fifth Type), Gaussian (Sixth Type). In this study, the First Type (Usual) function from preference functions was used. While the login screen is given in Fig. 4, the order of the alternatives is given in Fig. 5.

In ordering the alternatives, Phi + gives the positive superiority value, and Phi- gives the negative superiority value. The difference between the positive and negative superiority values gives the Phi net priority value. According to the net priority value, construction ranks first as the usage area of the wearable technological products available here, followed by mining, agriculture, textile, and chemistry.

4.6. Comparison of results

The ranking of priority sectors suitable for using wearable technological products determined as criteria by using the AHP and PROMETHEE methods is given in Table 2. In both methods, alternatives are listed as construction, mining, agriculture, textile, and chemistry. In the ranking made with the PROMETHEE method, the positive and negative superiority values in the construction and mining sectors were close to each other. This situation shows us that the need for wearable technological devices in these sectors is very important in both sectors. The fact that the ranking results of the alternatives according to the AHP and PROMETHEE methods are the same shows that the evaluation made is consistent. The development of digital solutions by using wearable technology devices in the field of occupational health and safety is very important in providing a safer work environment.

5. Conclusion

It is aimed to prioritize the sectors according to the need for the use of wearable technology devices in sectors where work accidents are common, employees are exposed to dangers and risks, and working conditions are difficult. Within the scope of this target, five alternatives and eight criteria were determined. According to expert opinions, in order of weight, smart helmets (0.29128), HAVS (0.22817), smart vest (0.13102), smart glasses (0.10148), armband (0.09887), life band (0.06029), wearable cameras (0.05218) and emergency medical information labels (0.03671). Alternative ranking made by AHP and PROMETHEE method has come as construction, mining, agriculture, textile, and chemistry. Lee et al. [13] emphasized that it is very important to adopt applicable technologies based on practical limitations, to obtain meaningful sensor data in the field, to process sensor data based on occupational health principles, to understand the construction industry and task demands, and to transform the obtained data into meaningful interpretations for the construction industry. Choi et al. [16] stated that the use of wearable devices has the potential to reduce the project cost related to the health and safety of workers in construction. Mardonova and Choi [17] suggest that more effective use of wearable devices in the mining industry has the potential to transform health and safety problems in mining sites into a modern and safe "innovative workplace" with high efficiency and increased production, instead of a traditional "dangerous mine" concept with communication difficulties. They said it would be effective.

Wearable technological products, which directly prevent injuries and increase worker safety and productivity, will play an even greater role in the life of employees in the near future, in the field of occupational safety, which is approached with great care by both the public and companies. These products, which draw attention with their contribution to employee health and work safety, are of key importance for a safer work environment. With the study, the use of wearable technology devices in the leading sectors in terms of work accidents and occupational diseases will relatively reduce the health and safety problems that occur in these areas. The fact that it opens a new door to occupational safety and health management, especially for those who work in dangerous, risky, and physically demanding tasks, and is among the first studies on this subject will contribute to the literature.

In the future, research on the usability of wearable technological devices related to occupational health and safety in other fields such as food, military, fire, education, tourism, museums, etc., can be carried out using different MCDM methods.

CRediT authorship contribution statement

Güler Aksüt: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. **Tamer EREN:** Conceptualization, Data curation, Investigation, Methodology, Validation, Writing – review & editing. **Hacı Mehmet ALAKAŞ:** Conceptualization, Investigation, Methodology, Validation, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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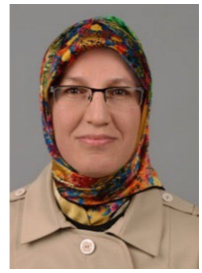

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