ORIGINAL RESEARCH (AR) DOI: 10.4274/jems.2022.47550

Journal of ETA Maritime Science 2022;10(2):108-123

Indoor Positioning Technology Selection Using a Combined AHP and PROMETHEE Method at SEDEF Shipyard

Ibrahim Cil[1], Fahri Arisoy[2], Ekrem Özgürbüz[3], Ahmet Yunus Cil[4], Hilal Kılınç[2]

[1]Sakarya University, Department of Industrial Engineering, Sakarya, Türkiye
[2]SEDEF Shipyard, Research and Development Center, İstanbul, Türkiye
[3]Sistematik OTVT, İstanbul, Türkiye
[4]Kocaeli University, Department of Industrial Engineering, Kocaeli, Türkiye

Abstract

Shipyard 4.0 refers to the application of Industry 4.0 principles to shipyards. To keep up with the challenges, the shipyard industry, like other industries, strives to realize Shipyard 4.0 in its industry. The goal of this study is the creation of an indoor positioning system (IPS) to determine the positions of all assets in the shipyards, such as employees, welding machines, cranes, and carriers, and track their movements using an IPS. Users can use positioning systems to find and track the location of a particular object. The most well-known position tracking system is the Global Positioning System, which is widely used in determining the location and position of objects in the external environment. The GPS for locating and tracking an object indoors is not recommended for indoor use, as indoor signals transmitted from a satellite to a device are weakened by indoor obstructions. Many different IPSs are in development that track and position objects indoors. Choosing the most suitable IPS for a shipyard is a multicriteria decision problem. A combined AHP and PROMETHEE method is proposed in this study to determine which IPS technologies would be most suitable in shipyards. In the literature review, it is shown that the AHP and PROMETHEE methods are used separately or together in solving problems in many areas. However, no study has been conducted in which the AHP and PROMETHEE methods are used together for the IPS selection problem. For this purpose, an application of the proposed method in IPS selection and evaluation was carried out at the SEDEF shipyard, and the most suitable technology was determined by evaluating different IPS technology options.

Keywords: Shipyard, Indoor positioning systems, MCDM, AHP, PROMETHEE

1. Introduction

Positioning systems can be classified into two main types: indoor and outdoor technologies [1]. Although GPS has been used successfully in outdoor environments for a long time, satellite-based positioning systems cannot be used indoors with the desired performance. Heavy metals and obstacles such as walls weaken the signal strength and drastically reduce its performance in areas such as shipyards and construction sites. Thus, the reliable service expected from positioning systems falls short of meeting the requirements as positioning accuracy is drastically reduced. There has recently been an increase in research on the use of IPS technologies in open environments. Most of the technologies developed in outdoor environments are used successfully. However, they cannot be considered fully successful indoors. Various technologies based on Radio Frequency, Infrared, Ultrasound, Magnetic, Optical, and computer vision are proposed in this context to improve indoor positioning [2]. Shipyards, ports, airports, warehouses, hospitals, hotels, and shopping malls all need IPS [3]. Currently, various IPS technologies such as Radio Frequency, Haptic Ground, Ultrasonic Sound, and High Sensitivity GPS technologies are applied independently in different fields. Indoor solutions that are currently available are highly dependent on the environment and the target application [4]. Sound-based IPS cannot provide the desired performance because

Address for Correspondence: Ibrahim Cil, Sakarya University, Department of Industrial Engineering, Sakarya, Türkiye
E-mail: icil@sakarya.edu.tr
ORCID ID: orcid.org/0000-0002-1290-3704

Received: 09.12.2021
Accepted: 29.03.2022

To cite this article: I. Cil, F. Arisoy, E. Özgürbüz, A.Y. Cil, H. Kılınç, “Indoor Positioning Technology Selection Using a Combined AHP and PROMETHEE Method at SEDEF Shipyard.” *Journal of ETA Maritime Science*, vol. 10(2), pp. 108-123, 2022.

shipyards are also noisy environments [5]. On the other hand, the presence of magnetic interference in the shipyard environment makes magnetic-based IPS an unsuitable high-performance alternative [6]. Considering these facts, radio frequency (RF)-based IPS seems to be more suitable for shipyard environments. In this context, the problem of determining which RF-based IoT technologies such as Wi-Fi, Bluetooth, RFID, ZigBee, UWB, NFC, SigFox, and LoRa is most suitable for shipyards is an important research topic [7].

It will be possible to build the shipyards of the future with IoT-based digital transformation, and IPS will provide many advantages to the shipyards. The shipyard will be fundamentally restructured as a result of digital transformation; without digitalization, the necessary new shipyard business models cannot be created, applications cannot be implemented, and the right technologies cannot be developed. First of all, the IPS not only reduces shipbuilding costs but also reduces design time by enabling engineers to test their capabilities in a matter of hours and days instead of weeks or months. Therefore, choosing the right IPS technology creates an infrastructure for all these works and increases success. It will strengthen close cooperation between all fields, integrating processes and ensuring end-to-end continuity by sharing real-time information. Through data-based processes and decision-making, efficiency will be increased productivity will be increased and profitability will be secured. The IPS detects the location of people and objects indoors. The obtained location information is transferred to the application software via servers, providing for real-time asset monitoring and asset management.

In the presence of dense metal blocks in the shipyard environment, presence of water, high probability of exposure to acids or other corrosive substances, possible signal reflections and communication interference, exposure to high temperatures from welding machines, high pressure in the environment, in terms of all factors such as time and cost, none of the existing IPS technology can meet the needs of shipyard environments. For example, while technology may show high performance in terms of energy use, it may be insufficient in terms of accuracy. In such a case, the multi-criteria-decision-making (MCDM) methodology is a very suitable and convenient method for solving this problem. Considering that there is not enough work done in the selection of IPS for shipyards, as can be seen from the literature research, this study provides an original contribution by presenting innovation in the analysis, evaluation, and selection of suitable IPS technologies in the shipyard sector.

This article proposes an MCDM model based on combined the AHP and PROMETHEE methods that can fully characterize an IPS and assist stakeholders in determining which IPS technology is suitable for shipyards thereby improving the design phase of IoT ecosystems in shipyards. This approach allows decision-makers to make better reasoning and more informed analyses of various and often conflicting criteria. With the help of experts, the necessary technologies, evaluation criteria, and all kinds of judgment situations are determined. Evaluations are often complex decision situations involving new technologies such as IPS and focus on examining a large number of different conflicting criteria. As a result, the main innovation of this article, which deals with the selection of the most suitable positioning technology for the shipyard environment to cope with the challenges, is that it provides decision support using the combined AHP and PROMETHEE methods. The combination of AHP and PROMETHEE has been used effectively in different fields [8-11], but has never been studied in advance for the evaluation of IPS for shipyards. This article also contributes significantly in this respect. This study aims to create a model that combines the strengths of the AHP and ROMETHEE methods and then uses that model to select the most suitable IPS for the SEDEF shipyard. The proposed model was used in the selection of IPS technologies at the SEDEF shipyard in Tuzla, Istanbul. While AHP defines the criteria weights, the alternatives are ranked and the most suitable one is determined by the ROMETHEE method. The reason for choosing the combined model is that AHP is very effective and easy to use in pairwise comparison and ROMETHEE in ranking options [12]. Methods are used separately, but hybrid use in this way is not common [13]. The selection measures should be first determined to be able to decide the most suitable IPS technologies among the mentioned technologies. From the point of view of users, the most important factors for IPS are accuracy, coverage, cost, power consumption, and privacy [14].

MCDM is one of the most widely used decision methodologies in science, business, government, and engineering. MCDM methods help to improve the decision-making process by being more clear, rational, and efficient and can help improve the quality of decisions. According to authors Hwang and Yoon [15], the term MCDM refers to making decisions based on multiple criteria, which are often contradictory. There are various techniques in MCDM. Some of the most well-known are AHP, ANP, MAUT, MAVT, SMART, SMARTER, PROMETHEE, ELECTRE, TOPSIS, and VIKOR [16,17].

The AHP is the most widely used and best known of these techniques. AHP is an MCDM technique that uses pairwise comparisons based on a numerical scale to systematize and structure the decision-making process [18,19]. Many studies have used AHP to support decision-making both alone and in combination with other techniques. AHP has been used all over the world and has been applied in many fields [20,21]. With its systematic and mathematical approach, AHP supports decision-making. As a result, it is widely used in research on practical applications. Yazıcı et al. [22] propose an MCDM approach for choosing a machine learning method for the IPS. The study uses AHP to select the appropriate machine learning algorithm for an IPS [22]. Ficco et al. [23] recommend GlobalPreLoc, a multi-purpose strategy for the selection of dynamic and optimal IPS technologies. The study is based on a multi-objective meta-heuristic for the optimal selection of mobile terminal location providers [23]. Mileo et al. [24] present an informed MCDM approach to support positioning. Basiri et al. [25] evaluate IPS Technologies for Pedestrian Navigation Services with AHP.

As in AHP, the PROMETHEE technique has been used effectively in many areas of MCDM, especially in recent years [26-29]. PROMETHEE is also combined with different weighting methods such as AHP to cope with criterion weights and strengthen the model [30-34]. Budak and Ustundag [35] developed a fuzzy decision model for the selection of real-time location systems, which was applied to a hospital in Istanbul by considering three types of systems: RFID hybrid, UHF RFID, and Active RFID. Silva and Jardim-Goncalves [36] propose a decision methodology for the selection of IoT hardware platforms in which AHP, ELECTRE, and PROMETHEE methods are used separately. Çil et al. [37] developed an MCDM model to determine which RF-based technologies will be used as IPS technologies in shipyards, and the problem is evaluated with Fuzzy MULTIMOORA and Fuzzy COPRAS Methods in the study. Kecek and Yüksel [38] researched the order of preference of the young people between the ages of 18-25 for the current alternatives in the smart mobile phone sector by using AHP and PROMETHEE in the study. Lee et al. [39] presented a comparative study of protocols consisting of Wireless Bluetooth, UWB, ZigBee, and Wi-Fi. Dukyil [40] presented an artificial intelligence and MCDM approach for a Cost-Effective RFID-powered tracking management system. Turcksin et al. [30] used the AHP method to assign weights between criteria based on pairwise comparison and PROMETHEE to rank the appropriate policy scenario from three possible scenarios. Oztaysi et al. [41] evaluated data collection technologies using the fuzzy TOPSIS method. Doulos et al. [42] others proposed a methodology based on the ELECTRE method to determine the optimal location of a suitable photosensor.

The rest of the article is organized as follows: First, information and explanations about the IPS and IPS in shipyards are presented. In this study, the proposed methodology and the MCDM methods used in the methodology are then explained in detail. And then, a case study is presented and a comparative analysis is conducted. The article ends with comments on the results obtained and future work suggestions.

2. Indoor Positioning Systems

Positioning systems are an emerging technology that detects the location of objects and guides them in real-time [2]. Satellite-based positioning systems such as GPS are used to detect the location of an object in open areas. The object to be determined by satellites must be in the line of sight for GPS to detect its true position. GPS cannot be used indoors because structures such as roofs and walls prevent satellite vision. Therefore, independent of satellite-based systems, Wi-Fi, Bluetooth, ZigBee, UWB, RFID, etc., wireless technologies have been used in various studies. Although there is not yet a standardized IPS for closed areas, the basic expectations from a system are high accuracy, high security, low cost, low-power consumption, and low maintenance need. With the developments in technology, wireless devices can be produced cheaper and with lower energy consumption. Easy installation is essential for an IPS to become widespread. As a result, systems that benefit from existing infrastructures without the need for additional hardware are one step ahead. However, depending on the targeted usage areas, a certain sensitivity target is also necessary.

Some references must be calculated and well defined in terms of cost, accuracy, precision, scalability, coverage, and limitations to constructing a successful IPS. References such as different dimensions, money, time, and space will affect the system. IPS integrated into building-dependent Wi-Fi technology is considered excellent in terms of cost. Because for the installation of technologies such as RFID, purchasing any tools and equipment, applying them, and integrating them into the system while maintaining their quality requires a long time and cost for system installation. Since the IPS works in real-time environments, it must perform with high precision. Ensuring this situation is ensured by accuracy testing. Accuracy is ensured as a result of the correct entry of the location notification and tracking system that is considered for the system or intended to be implemented, successful data acquisition with high sensitivity, and the result of many program analyses of the location determination and the same results. Accuracy is ensured by determining the same results by making many trials of the desired results from the system, and by increasing the performance effect of the system in indoor environments, it is ensured to give us an accurate result. This gives an idea that the installed system is working. In this respect, accuracy is critical for system performance and obtaining correct information from the system. For example, as a result of trials, the distance of the object or person determined for the IPS is determined as 20 cm with 95% accuracy. In this case, the system gave us the correct answer 95% of the time. Different technology-based IPSs have recently been developed [43].

2.1. Shipyards and IPS

The digital transformation within the scope of Industry 4.0 deeply affects all industries, as well as the shipbuilding industry, and creates revolutionary innovations in shipyards as well. The shipbuilding industry is a slow-moving industry that faces many challenges that need to be addressed to improve the efficiency of processes. In this context, IPS refers to technologies used to track the location of an entity or person in real or near-real time, usually in a restricted area. Shipyards need to install IPS to obtain data on the location of people and other assets in shipbuilding. Shipyards are mostly indoor spaces made up of large metal blocks, and most shipbuilding activities are carried out indoors. The IPS offers new opportunities for shipyards to make faster and better decisions based on real-time data. With modern IPS, shipyards can increase the productivity and safety of their people, equipment, and workplaces. Therefore, by focusing more on value-added activities, preventing misplacement of assets, reaching assets faster, increasing capacity utilization, enabling better shipyard workflows and utilization, responding more efficiently to shipyard emergencies or evacuations, and minimizing workplace injuries and accidents. It provides many benefits, such as downloading. IPS at the shipyard is particularly useful for many things, such as attendance, pandemic workplace applications, warehousing, logistics, and forklift operations. With the ability to quickly monitor and compare data, the IPS provides the infrastructure and convenience to find, monitor, and take effective action on all critical resources to improve processes and optimize workflows. The IPS provides insights on how to get the most value from resources, increase efficiency, and reduce costs.

Asset tracking with the IPS eliminates the time to search and find assets, reducing lost and misplaced assets. With employee tracking and value-added activities, workflows are improved and inefficiencies are eliminated. In the field, the use of multiple cranes, forklifts, and similar machinery and equipment maximizes workflows. With maintenance tracking, maintenance procedures are reduced and maintenance flow is optimized. Every aspect of shipbuilding processes is controlled for efficiency, quality, and traceability through process tracking. Material-handling processes, safety, and work safety are improved, and full control of the site is ensured by the shipyard site management. Workflow optimization identifies and eliminates bottlenecks using real-time and accurate data, and workforce and asset usage are effectively managed. Full traceability of assets is ensured. Every aspect of the production process is controlled for quality and traceability with more effective quality control. Solutions developed for shipyard environments allow monitoring of unsafe conditions, alerting of potential hazards, and enforcing geofencing rules and security restrictions. Everywhere, security rules are effectively enforced, with instant breach alerts. In emergencies, it ensures that the number of employees is determined accurately and quickly. Better risk management is achieved through monitoring of equipment and working in hazardous environments and immediate detection of unsafe conditions. Data is stored and reports are created in compliance with all security regulations. They can be used to generate detailed reports on asset usage and movement within the shipyard during working hours. In the case of workplace accidents and injuries, these reports constitute evidence in case of any claim. Based on location data, the IPS allows shipyard managers to monitor material flow, flow times, and other key statistics to gain meaningful insights about their equipment and workers. In summary, the IPS provides a faster and more effective response to emergencies, a high level of security, simplified processes, the avoidance of human factor problems, and many other advantages.

In recent years, some researchers have studied and made recommendations on the implementation of technological solutions in the direction of digitizing tasks in shipbuilding. Kim and others presented a study suggesting the use of automatic welding machines to be used by intelligent robots in shipyards [44]. In positioning the people inside the shipyard, Kawakubo et al. [45] conducted a study. In this article, the authors use Bluetooth technology. There are some review articles related to real-time positioning in areas such as shipyards and construction sites. Li et al. [46] analyzed ten different IPS technologies. As can be seen in the literature review below, studies discussing and comparing IPS techniques, especially for IPS applications in shipyards, are insufficient. More specific development for the construction of ships and offshore platforms in a shipyard is detailed in [47]. Here the authors consider sensor networks, virtual reality, and RFID technologies to improve the procurement process. RF communication is affected in environments with a high metal presence. This effect has been tested in a series of experiments with various labels. The signal strength has been found to decrease when tags are placed on a copper metal plate. Cil et al. [48] analyze the feasibility of affixing passive RFID tags on bent metal pipes in an environment close to the shipyard. To overcome harsh environments, multiple tags and components have been designed to enable RFID communication in metallic environments [49,50]. RF communication becomes even more complex if conditions such as high temperatures are added to the presence of metals. Therefore, components need to be adapted to demanding communication scenarios.

2.2. IPS Technology Alternatives

In this study, the following five alternative IPS technologies are evaluated to whether are suitable or not for shipyards.

Wi-Fi Technology: A Wireless Local Area Network connects different types of devices over high-frequency radio waves instead of cables. The devices are equipped with an IEEE 802 WLAN adapter. Moreover, WLAN technology has become widespread in the whole building, hospitals, shopping malls, and similar structures. It becomes possible for mobile devices to follow these transmitters by processing the reference signals emitted from them or by forming a network with other devices. Bluetooth is one step ahead of other wireless technologies with its high security, low cost, adjustable power, and small size. Indoor technologies such as BLE and Wi-Fi can provide a more reliable and precise location. Computable propagation characteristics may seem like they are easy to locate, but looking at actual outputs, their greater sensitivity means they are more susceptible to interference. In addition to these effects, the dynamism and inconsistency of environmental factors make it difficult to achieve an applicable structure in every field.

Bluetooth Technology: The Bluetooth-based systems need more hardware devices, unlike the Wi-Fi-based system. It can achieve high accuracy from these devices. Other advantages are low cost, low-power consumption, small size, and easy deployment. The Bluetooth-based IPS mainly uses proximity sensing and fingerprints. With the Bluetooth standard, which is common in many advanced smart devices today, these devices can communicate with smart devices around them. The most obvious difference between Bluetooth and other solutions is that with Bluetooth, multiple devices can communicate with each other at the same time. With the RF connection in Bluetooth technology, there is no need for visual contact as in infrared communication technology. Like other standards, Bluetooth also uses the 2.45 GHz, ISM band. The frequency hopping method is used to prevent interference to a great extent. Devices in the Bluetooth network are within 10-100 meters, 400 kbps symmetrical, or 700-150 kbps. It provides asymmetrical data transmission.

ZigBee Technology: ZigBee features proximity sensing and multi-sided positioning. Wireless technology based on the ZigBee standard wireless technology has many advantages, such as low cost and low power. Safety, reliability, robustness, and low data rates are other characteristics. ZigBee technology is widely used in IPS due to its advantages. ZigBee, an IEEE 802.15.4 standard, is a new generation of communication technology with a low data transfer rate, a battery life that can be sufficient for months or years, and low complexity. It operates in the frequency band without an international license. It uses 16 channels in the 2.4 GHz band, and the maximum data transfer rate for each band is 250 kbps. The disadvantages of ZigBee include a low data transfer rate and an insufficient number of compatible devices. The most important advantages of this technology are that it can be used for years with low-power consumption and that it supports a wide variety of network topologies.

RFID Technology: An RFID system consists of a reader that uses its antenna to listen for nearby active receivers or passive tags. Data can be transmitted from RFID tags to the reader via radio waves using RFID technology. Generally, this data consists of the unique identification number of the tag associated with the current location information of the RFID tag. The system for detecting the presence of a person wearing an RFID tag, also known as the Principal Cell, is the most commonly used positioning method based on the proximity principle. In this respect, the positioning accuracy of an RFID system is highly dependent on the density of the placed tags and the furthest reading distance. While it is preferred in indoor areas with RFID, it is preferred for its system simplicity, low cost of devices, portability, ease of maintenance, positioning, and diagnostic capacity, coverage up to approximately 1000 meters and variable tag sizes; one-sided communication, multipath disruptors, and unstable RSS values make widespread use difficult.

UWB Technology: UWB is a wireless technology that transmits large amounts of data over a wide range of low-power and short-range frequency bands as it have a bandwidth of more than 500 MHz. Also, in UWB, the duration of the pulses is short. It makes it possible to filter the reflected signal from the original, thus guaranteeing a high-precision system. The advantages of the UWB system are that it effectively penetrates walls and passes through obstacles, is isolated from any existing RF signals, and does not cause any interference (if any). Finally, UWB-based IPS is a very high-precision system. The disadvantage of this system is that it is costly and liquid and metallic materials cause interference. This interference condition prevents the system from operating with the correct sensitivity.

2.3. Evaluation Criteria

For an IPS to be widely adopted, it must be issued with a cost clearance, be issued with an energy clearance, have a large reception area, high accuracy, low latency, and high measurability. However, it is a well-known fact that it depends on the implementation of the systems and remains sufficient to meet all these measurements. These criteria are discussed briefly below [51].

Cost: The cost of an IPS should not be high. Ideally, the system should be able to install any infrastructure materials and be easy to maintain. It must be used by any high-end user device or system that does not use it as a broadcast. Operating costs should be low as well.

Accuracy: Accuracy is measured by the reliability of the technology. Accuracy is obtained by how accurately housing information is given by the openness of interior accommodation technologies. Different systems provide different accuracies. For example, the Wi-Fi system is 1.5 m of medium-level accurate health, and RFID technology is 1-5 m of high-level accurate health in the IPS.

Energy Efficiency: The energy efficiency of displacement systems is very important for their adoption everywhere. As of now, many of the current IPSs use relatively higher energy to provide higher accuracy and better range. For IPSs, it is extremely difficult to achieve high accuracy without straining the device battery. This is because its device, which is used for improved performance, must periodically take for certain signal messages or signals. Devices that use less energy should be selected.

Coverage area: Coverage area is the main key factor when the IPS needs to be reviewed in the ranking of interior technology selection. Different technologies have different characteristics for coverage. Therefore, its short-range technology may need more devices to cover the same area. The range of existing systems can vary from 5-50 meters.

3. Methodology

The most important point to be underlined here is that IPS technology selection is an MCDM problem [15,16]. It is a very difficult decision to choose since different alternatives stand out in terms of various criteria. For this reason, there is a need to use methods that will support decision-making and lead to correct and effective decisions. In summary, it can be said that the MCDM method is the most appropriate tool for evaluating IPS technologies. The idea of integrating AHP and PROMETHEE principles has previously been explored by other researchers [30]. This section provides detailed descriptions of the AHP and ROMETHEE techniques used for analysis in this study. It aims to propose an integrated approach in which AHP and PROMETHEE methods are used together, which can help with the selection of IPS technologies for shipyards more objectively and realistically. The proposed approach should be applied to any other project of IPS for different sectors.

3.1. Integration of AHP and PROMETHEE Methods

In MCDM, AHP is a method based on priority values determined through a pairwise comparison of criteria or alternatives, taking into account the judgments of the decision-maker. On the other hand, PROMETHEE is an outranking method. There are strengths and weaknesses in these two methods. This study aims to combine the strengths of these two methods to obtain a combined method that will also give a good ranking to find the best option among the options. The literature mentioned the weaknesses and advantages of these two methods. In the AHP method, since the problem is divided into sub-components and expressed hierarchically, even very complex problems can be expressed very easily. When the number of criteria in the PROMETHEE method exceeds seven, the problem becomes extremely difficult. There is no concrete weight calculation method proposed by the PROMETHEE method. The emphasis on the criteria is entirely left to the personal opinions of the experts who have defined the problem. This work is done more scientifically in the AHP method. Because all the criteria are pairwise compared, the relative importance becomes clearer. In the AHP method, since the problem consists of too many subsystems and pairwise comparisons are made for each criterion, too much data is generated to be studied. In the PROMETHEE method, the result can be achieved with fewer data. Data loss does not occur since the PROMETHEE method avoids tradeoffs. But since AHP and PROMETHEE are also evaluated on cumulative results, some data are lost. In the AHP method, a scale of 1-9 is used for relative importance when making a decision comparison between criteria. But this sometimes creates logical restrictions. The PROMETHEE method result can be expressed as high visual insight according to the AHP method, and the effect of each criterion on the result can be expressed more clearly. The use of the Geometric Analysis for Interactive Aid (GAIA) notation technique in the PROMETHEE method has a large share in this regard.

The AHP and PROMETHEE methods were used together in the IPS selection, taking into account the above-mentioned considerations. The combined AHP and PROMETHEE approach proposed in this study consists of eight steps, as follows:

1. Definition of the problem and collection of data.
2. The alternatives are selected and the criteria by which the alternatives will be evaluated are determined.
3. The creation of the hierarchy was done with AHP.
4. The criterion weights are calculated using AHP.
5. Creation of a rubric for PROMETHEE and determination of preference functions.
6. Performing partial ranking operations with PROMETHEE I and full ranking operations with PROMETHEE II, and conducting sensitivity analysis with Visual PROMETHEE.
7. Alternatives are evaluated and ranked via the GAIA plane.
8. Suggestions for the best compromise are determined.

It is possible to see the proposed solution method visually in Figure 1.

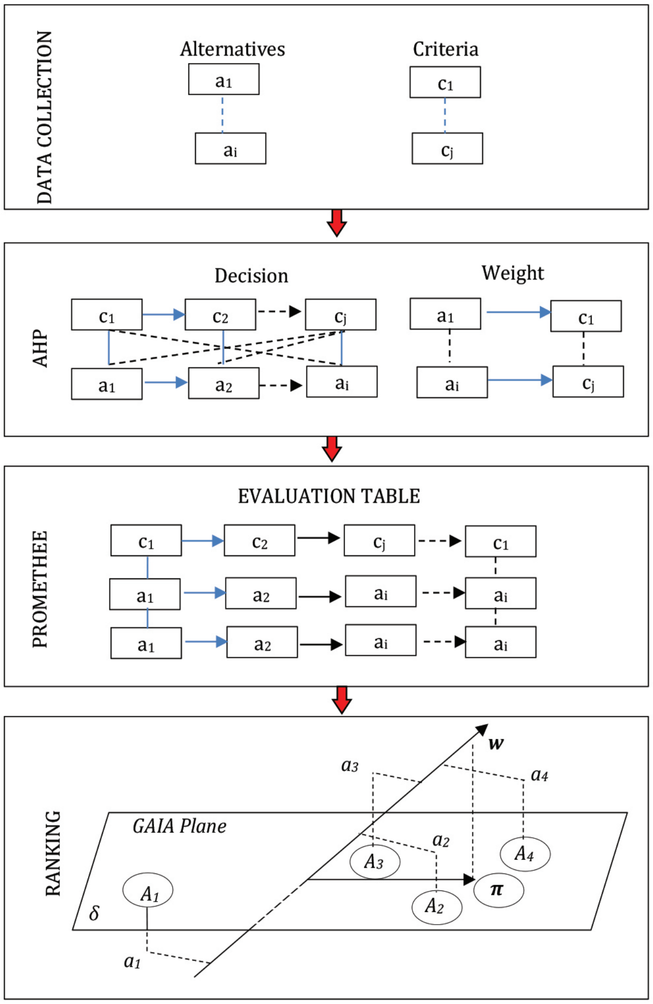


***Figure 1.** The combined AHP and PROMETHEE approach*

3.2. Analytical Hierarchy Process

The AHP is a powerful decision-making methodology developed by Saaty [52] based on the ranking of alternatives by pairwise comparison of multiple conflicting criteria. The AHP methodology consists of three stages [53].

Stage 1: Model Building and Formulation of the Problem: In AHP, the hierarchical structure combines all the components that will contribute to the purpose of a problem to be solved. The goal is at the top of the hierarchical structure. The lower level contains the main criteria for the problem. At the bottom of the hierarchy, options related to the problem are placed (Figure 2).

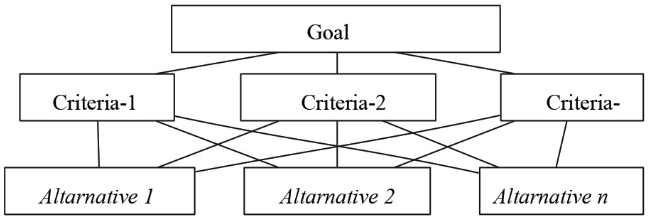


***Figure 2.** The hierarchical structure of AHP*

Stage 2: Creating the Pairwise Comparison Matrix: After the hierarchical structure is established, pairwise comparison matrices are obtained by using Saaty's 1-9 point preference scale, given in Table 1.

In the pairwise comparison matrix, the term w_i/w_j expresses how important criterion *i* is to criterion *j* to achieve the goal. For example, if this judgment value is 5, it is understood that the *i*th criterion is very important compared to the *j*th criterion. In this case, the *j*th criterion is also important at the 1/5 level compared to the *i*th criterion.

In the decision process, since there is a goal and a finite set of alternatives, $X = \{x_1,\dots,x_n\}$, the decision-maker is usually asked to choose the best option (Equation 1).

$$X = \{x_1,\dots,x_n\} \tag{1}$$

That is, given a set of alternatives, $X = \{x_1,\dots,x_n\}$ creates a decision-making weight vector (Equation 2).

$$w = (w_1,\dots,w_n)^T, \tag{2}$$

where w_i is a value that consistently predicts the score of the alternative x_i. Weight vectors are a rating, and their components w_i's are the weights of the decision elements.

To determine the weights, pairwise comparisons are made and the pairwise comparison matrix $A = (a_{ij})_{n\times n}$ structured as follows, is created (Equations 3).

***Table 1.** Preference Scale with 1–9 Points*

Scale	Description	Description
1	Equally Important	Both factors are equally important.
3	Moderately Important	One factor is slightly more important than the other.
5	Strongly Important	One factor is strongly more important than the other.
7	Very Strongly Important	One factor must be strongly favored over another.
9	Absolutely Important	One factor is very important to the other.

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \tag{3}$$

with $a_{ij} > 0$ expressing the degree of preference of x_i to x_j. More precisely, according to Saaty's theory, each entry is supposed to approximate the ratio between two weights (Equations 4).

$$a_{ij} \approx \frac{w_i}{w_j} \ \forall_{i,j} \tag{4}$$

This means that, if the entries exactly represent ratios between weights, then the matrix A can be expressed in the following form (Equations 5),

$$A = (w_i/w_j)_{n\times n} \begin{bmatrix} w_1/w_1 & \cdots & w_1/w_n \\ \vdots & \ddots & \vdots \\ w_n/w_1 & \cdots & w_n/w_n \end{bmatrix} \tag{5}$$

Note that, as soon as we account for (Equations 4) and consider (Equations 5), a condition of multiplicative reciprocity $a_{ij} = 1/a_{ji} \ \forall_{i,j}$ holds, and *A* can be simplified and rewritten (Equations 6).

$$A = \begin{bmatrix} 1 & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ \frac{1}{a_{n1}} & \cdots & 1 \end{bmatrix} \tag{6}$$

At this stage, the priority vector needs to be calculated. The most popular method for estimating a priority vector is that proposed by Saaty himself, according to which the priority vector should be the principal eigenvector of *A*. The method stems from the following observation: Taking a matrix *A* whose entries are exactly obtained as ratios between weights and multiplying it by *w,* one obtains (Equations 7).

$$Aw = \begin{bmatrix} w_1/w_1 & \cdots & w_1/w_n \\ \vdots & \ddots & \vdots \\ w_n/w_1 & \cdots & w_n/w_n \end{bmatrix} \begin{bmatrix} w_1 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} nw_1 \\ \vdots \\ n\,w_n \end{bmatrix} = n\,w_n \tag{7}$$

We know from linear algebra that for a formulation of the type Aw = nw, n and w are an eigenvalue and an eigenvector of *A*, respectively. From this, vector w can be determined from any pairwise comparison matrix *A* as the solution to the following system of equations (Equation 8),

$$Aw = \begin{cases} Aw = \lambda_{max} w \\ w^T 1 = 1 \end{cases} \tag{8}$$

where λ_{max} is the maximum eigenvalue of *A*, and $1 = (1,\ldots,1)^T$. After the weights are obtained in this way, the consistency of the comparison matrix should be checked using Equations 9 and 10. These weights cannot be used in the comparison matrix and are not consistent. For this, Saaty proposed the Consistency Index [52]. The accepted upper limit for the consistency ratio is 0.10. To calculate the consistency ratio, first of all, the consistency index (CI) is calculated using Equation 9. After the CI is found, the consistency ratio (CR) is calculated by Equation 10 using the Random Consistency values in Table 2.

$$\text{CI (A)} = CR = \frac{\lambda_{max} - m}{m-1} \tag{9}$$

$$CR\ (A) = \frac{CI(A)}{RI_n} \tag{10}$$

Stage 3: Determining the Weights of the Criteria and Scoring of the Alternatives: The entire construction of the AHP is done separately according to the alternatives. The decision score of each alternative is multiplied by a simple matrix multiplied eigenvector, namely: matrix, *A*, transmitter, W^T.

3.3. PROMETHEE

The PROMETHEE method is based on pairwise comparisons of decision points according to evaluation factors. Its main difference from other multiple decision-making methods is that, in addition to the importance weights indicating the level of relationship between the evaluation factors, each evaluation factor also takes into account its internal relationship. As a result of comparing alternatives based on established criteria using the PROMETHEE I method, it is possible to determine partial priorities (partial ranking) and net priorities (full ranking) as a result of comparing alternatives based on established criteria using the PROMETHEE II method [55].

The algorithm of the processes of application of the PROMETHEE method consists of seven steps. These;

1. Creation of a Dataset
2. Determination of Preference Functions
3. Creation of Common Preference Functions
4. Determination of Preference Indices for Decision Points
5. Determination of Positive and Negative Superlatives
6. Partial ranking with PROMETHEE I

Table 2. *Values of RIn [54]*

n	3	4	5	6	7	8	9	10
RIn	0.5247	0.8816	1.1086	1.2479	1.3417	1.4057	1.4499	1.4854

7. The Exact Sequence of Decision Points with PROMETHEE II

Step 1: The determined alternatives, criteria, criterion weights, and the values obtained by the alternatives according to the relevant criteria are tabulated in a data matrix. In the following data matrix, a data matrix is created as given in Table 3 for alternatives A= (a, b, c,...) evaluated by the criterion k with weights w= (w_1, w_2,..., w_k) c= (f_1, f_2,..., f_k).

Step 2: Preference functions are defined for the criteria. Preference functions are determined depending on the structure of the criterion and the characteristics sought based on the criterion in alternatives.

Step 3: Pairwise comparisons of decision points are made for each evaluation factor, taking into account preference functions. Common preference functions are determined. If A and B denote two decision points, the following Equation 11 is used for the joint preference function.

$$P(A,B) = \begin{cases} 0 & f(A) \leq f(B) \\ p[f(A) - f(B)] & f(A) > f(B) \end{cases} \tag{11}$$

Step 4: Preference indices for decision points compared using common preference functions are determined using Equation 12. The value of k in this formula indicates the number of evaluation factors.

$$\pi(A,B) = \sum_{i=1}^{k} w_i . P_i(A,B) \tag{12}$$

Step 5: The positive (φ+) and negative (φ-) superlatives are determined for the alternatives. The positive superiority is calculated by Equation 13, and the negative superiority is calculated by Equation 14.

$$\varphi^{+}(a)=\frac{1}{n-1}\sum_{b}\pi(a,b) \tag{13}$$

$$\varphi^{-}(a)=\frac{1}{n-1}\sum_{b}\pi(b,a) \tag{14}$$

Step 6: Partial priorities are determined with PROMETHEE I. Partial priorities allow you to determine the preference of alternatives included in the alternative set relative to each other, alternatives that are no different from each other, and alternatives that cannot be compared with each other. While A and B are the two alternatives in the alternative set, there are the following situations in determining partial priorities:

If any of the following situations is provided, alternative A is preferred over alternative B.

$$\begin{cases} \phi^{+}(A) > \phi^{+}(B) & and & \phi^{-}(A) < \phi^{-}(B) \\ & or & \\ \phi^{+}(A) > \phi^{+}(B) & and & \phi^{-}(A) = \phi^{-}(B) \\ & or & \\ \phi^{+}(A) = \phi^{+}(B) & and & \phi^{-}(A) < \phi^{-}(B) \end{cases}$$

If the following situation is provided, alternative A is no different from alternative B.

$$\phi^{+}(A) = \phi^{+}(B) \quad and \quad \phi^{-}(A) = \phi^{-}(B)$$

If any of the following situations are provided, alternative A cannot be confused with alternative B.

$$\begin{cases} \phi^{+}(A) > \phi^{+}(B) & and & \phi^{-}(A) > \phi^{-}(B) \\ & or & \\ \phi^{+}(A) < \phi^{+}(B) & and & \phi^{-}(A) < \phi^{-}(B) \end{cases}$$

Step 7: The priorities for alternatives with PROMETHEE II are calculated according to Equation 15, given below. With the calculated net priority value, the exact ranking covering all alternatives is determined by evaluating all the alternatives in the alternative set in the same plane.

$$\varphi = \varphi^{+}(a) - \varphi^{-}(a) \tag{15}$$

The decisions given below are taken depending on the net priority value calculated when there are two alternatives in the alternative sets a and B.

$\phi(A) = \phi(B)$ if a is the alternative, it is superior.

$\phi(A) > \phi(B)$ alternatives A and B are no different.

4. Case Study

SEDEF Shipyard, which is the largest private shipyard in Turkey in terms of area and capacity, has a total of 270,000

Table 3. *Representation of the data matrix*

f_1		**Criteria**				
		f_2	f_3	---	f_k	
Alternatives	A	$f_1(A)$	$f_2(A)$	$f_3(A)$	---	$f_k(A)$
	B	$f_1(B)$	$f_2(B)$	$f_3(B)$	---	$f_k(B)$
	C	$f_1(C)$	$f_2(C)$	$f_3(C)$	---	$f_k(C)$
	---	---	---	---	---	---
	Z	$f_1(Z)$	$f_2(Z)$	$f_3(Z)$	---	$f_k(Z)$
Weights		v1	v2	v3	---	vk

m^2 of shipbuilding area, with a Tuzla campus of 194,000 m^2 of which 51,000 m^2 is closed-area, and a 76.000 m^2 Orhanlı support area of 12.000 m^2 closed-area. SEDEF Shipyard, in terms of competence and equipment; provides services in the fields of military and commercial new shipbuilding, ship conversion projects, special steel constructions, and industrial projects. With nearly fifty years of knowledge and equipment, SEDEF Shipyard is a pioneer in the sector with the projects it has realized [56]. Other project partners are software and hardware companies that develop and prepare the necessary software and hardware for the IPS and the SEDEF shipyard, whose main field of activity is shipbuilding. In addition, the coordination and consultancy of the project are academics from different universities. In this study, all the necessary information, expert judgments, and evaluations were made by these stakeholders according to expert opinions. Stakeholders whose expert opinions were sought are as follows: SEDEF shipyard R&D department, IT department and senior managers and staff, Systematic OTVT company experts who developed the software, Experts from SADE Technology Company, which develops IoT hardware, and academics from Sakarya University and Yaşar University. In this context, both IPS technologies, evaluation criteria, and all judgments were determined through regular and repeated meetings.

The SEDEF shipyard, which is the subject of this study, faces a decision-making problem in choosing IPS. The SEDEF shipyard should select the technologies that are most suitable for its goals and prioritize them following its criteria. It is possible to classify the options to be evaluated by the shipyard under the following different headings. These;

1. Wi-Fi
2. Bluetooth
3. RFID
4. ZigBee
5. UWB

Seven main criteria stand out in the selection of IPS for the SEDEF Shipyard. These;

1. Accuracy
2. Coverage Area
3. Energy consumption
4. Cost
5. Scalability
6. Response Time
7. Robustness

IPS technologies have been implemented using the "Expert Choice" and "Visual PROMETHEE" software using the combined model described in detail above.

4.1. Calculation of Criterion Weights Using the Expert Choice

Seven main criteria have been determined by experts among many criteria when evaluating technologies that will be subjected to evaluation by the SEDEF Shipyard. The weights of these criteria were determined by AHP. The AHP, as described above, is based on the pairwise comparison. The weights of the criteria were determined using the "Expert Choice" software. Figure 3 shows the criterion weights formed as a result of the calculation performed.

The weights of the criteria used in the selection of IPS are ordered from largest to smallest as shown in Figure 3: "Energy consumption, Accuracy, Coverage Area, Cost, Scalability, Response Time, Robustness." In addition, the consistency of the matrix was checked and the inconsistency ratio was calculated to be less than 0.1, that is, Overall Inconsistency=0.02.

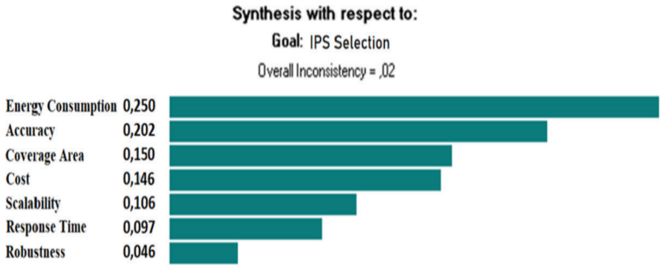
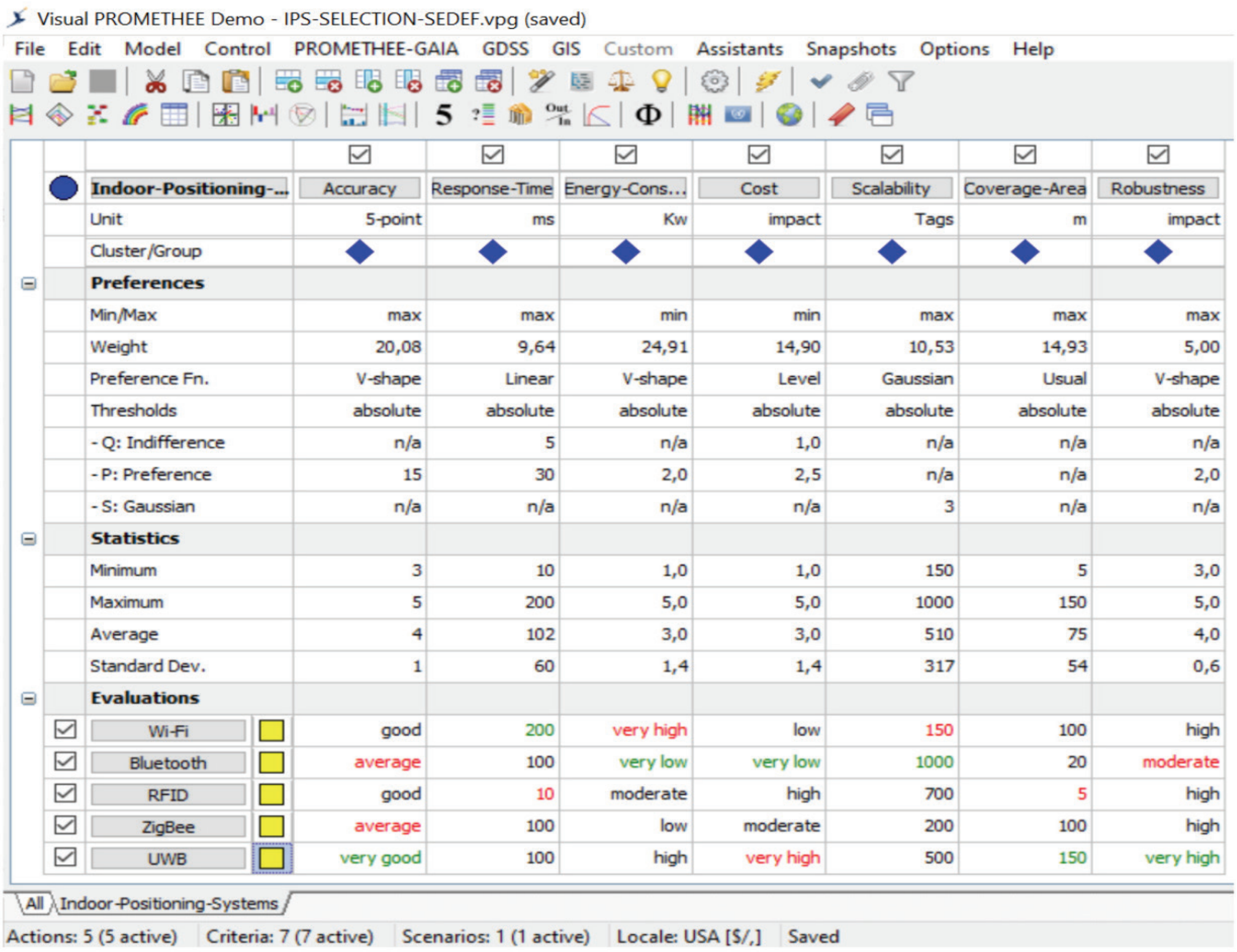


Figure 3. *The weights of the criteria used in the selection of IPS*

After calculating the weights of the criteria, we can now proceed to the outranking of IPS technologies using the PROMETHHE method.

4.2. Evaluation of alternatives using the Visual PROMETHEE

The "Visual PROMETHEE" software was used to perform the IP selection process. Five technologies have been evaluated for the best IPS selection. These have been compared based on seven criteria, and the data used in the selection of IPS is given in Figure 4. As shown in Figure 4, the evaluation table containing the determined alternatives, criteria, weights of the criteria, and data collected from the alternatives about the relevant criteria were created in Visual PROMETHEE software. For all the criteria, Preference functions were determined. The evaluation was made with the V-Shape function was used to evaluate Accuracy, Energy consumption, and Robustness, linear function for Coverage, Level function for Cost, Guassian function for Scalability, and Response Time function. The functions and parameters used are also given.

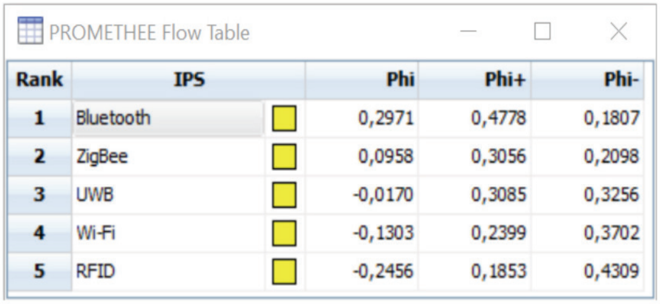


	☑	☑	☑	☑	☑	☑	☑
Indoor-Positioning-...	Accuracy	Response-Time	Energy-Cons...	Cost	Scalability	Coverage-Area	Robustness
Unit	5-point	ms	Kw	impact	Tags	m	impact
Cluster/Group	◆	◆	◆	◆	◆	◆	◆
Preferences							
Min/Max	max	max	min	min	max	max	max
Weight	20,08	9,64	24,91	14,90	10,53	14,93	5,00
Preference Fn.	V-shape	Linear	V-shape	Level	Gaussian	Usual	V-shape
Thresholds	absolute	absolute	absolute	absolute	absolute	absolute	absolute
- Q: Indifference	n/a	5	n/a	1,0	n/a	n/a	n/a
- P: Preference	15	30	2,0	2,5	n/a	n/a	2,0
- S: Gaussian	n/a	n/a	n/a	n/a	3	n/a	n/a
Statistics							
Minimum	3	10	1,0	1,0	150	5	3,0
Maximum	5	200	5,0	5,0	1000	150	5,0
Average	4	102	3,0	3,0	510	75	4,0
Standard Dev.	1	60	1,4	1,4	317	54	0,6
Evaluations							
☑ Wi-Fi 🟨	good	200	very high	low	150	100	high
☑ Bluetooth 🟨	average	100	very low	very low	1000	20	moderate
☑ RFID 🟨	good	10	moderate	high	700	5	high
☑ ZigBee 🟨	average	100	low	moderate	200	100	high
☑ UWB 🟨	very good	100	high	very high	500	150	very high

Actions: 5 (5 active) | Criteria: 7 (7 active) | Scenarios: 1 (1 active) | Locale: USA [$/,] | Saved

Figure 4. *Data used during the selection of the best IPS*

Considering the preference functions, pairwise comparisons of the alternatives were made for each criterion, and common preference functions were calculated based on this. While making this evaluation, minimization and maximization were taken into account. Preference indices for alternatives were determined by using common preference functions. As shown in Figure 5, positive Phi (ϕ+) and negative Phi (ϕ-) values were determined for each alternative.



Rank	IPS		Phi	Phi+	Phi-
1	Bluetooth	🟨	0,2971	0,4778	0,1807
2	ZigBee	🟨	0,0958	0,3056	0,2098
3	UWB	🟨	-0,0170	0,3085	0,3256
4	Wi-Fi	🟨	-0,1303	0,2399	0,3702
5	RFID	🟨	-0,2456	0,1853	0,4309

Figure 5. *Positive, Negative and Net superiority values*

The partial ranking is done. The results obtained as a result of partial ranking by the POMETHEE I method are given in Figure 6. Based on this result, it is seen that the positive superiority value of Bluetooth is the biggest (best) and the negative superiority value is the lowest (again, the best).

As shown in Figure 7, the results obtained according to the full ranking were the most suitable option. Then ZigBee, RFID, UWB, Wi-Fi, and RFID are listed. The ranking of the alternatives and the Phi (Φnet) value is given in Figure 7.

4.3. GAIA Plane Analysis

The geometric plane showing the distribution of the criteria according to the values of the options is shown in Figure 8. It can be easily seen that the criteria are distributed on the side of the options that are leading in the ranking. After obtaining partial and complete rankings, the result values can be displayed geometrically in the GAIA plane, where the alternatives are represented by squares and the criteria are represented by vectors. While the vectors

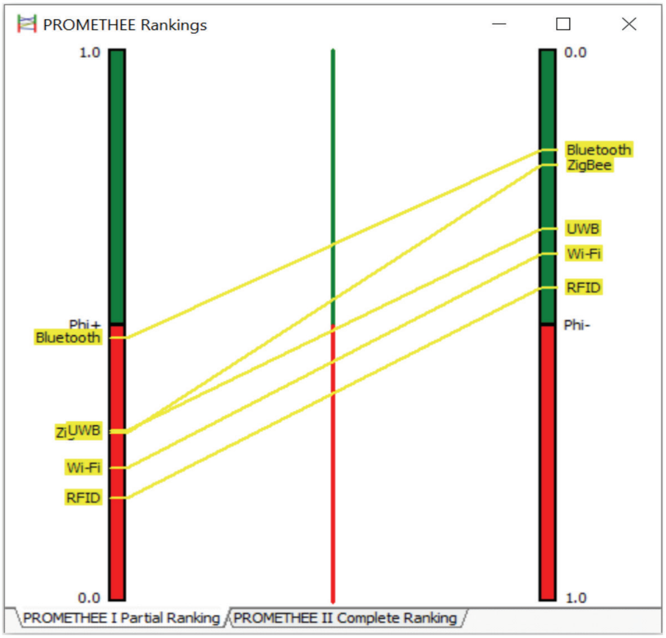


***Figure 6.** Partial ranking by PROMETHEE I result*

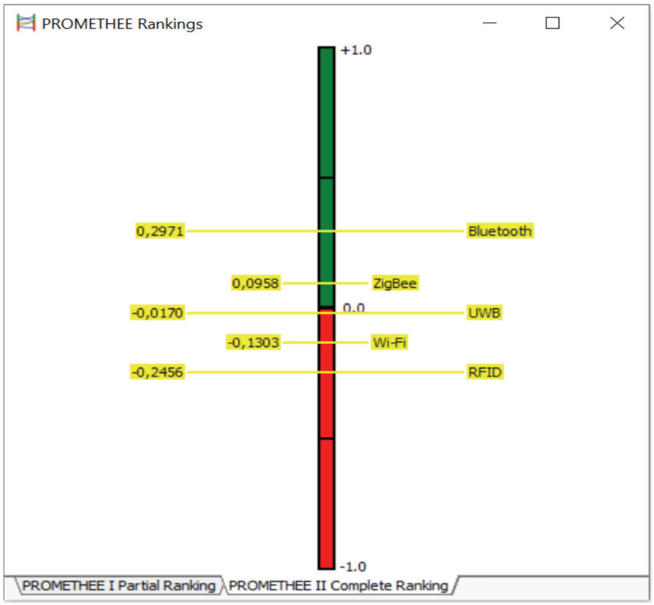


***Figure 7.** Full ranking results as a result of PROMETHEE II*

representing the criteria showing similar preferences on the data are in the same direction, the vectors belonging to the conflicting criteria show different directions. In addition, the length of the vector belonging to a criterion shows the effect of that criterion on alternative IPS. The obtained GAIA plane also shows the quality value, which is 93% for this case. This quality value indicates the accuracy of the calculated values. As this value approaches 100%, the accuracy of the analysis increases. The GAIA plane is given in Figure 8; accordingly, Bluetooth has been successful in terms of "Energy consumption" and "Cost." RFID has been successful in "Scalability." UWB, on the other hand, has been successful in terms of "Accuracy," "Robustness" and "Coverage Area."

4.4. Sensitivity Analysis

It is often difficult to determine a solid conclusion because of the variability in the relative importance of a given criterion. In response to this problem, an interactive tool called "walking weights" is used to control the precision of the result. The Walking Weights window allows you to change the weights of the criteria and see their effect on the analysis. The window is divided into two parts: At the top is a bar chart showing the full ranking. The bottom part is a bar chart showing the weights of the criteria. For example, if the relative importance of any criterion is increased by a certain %, how this will be reflected in the result is easily done in Figure 9. In this context, several sensitivity analyses were performed.

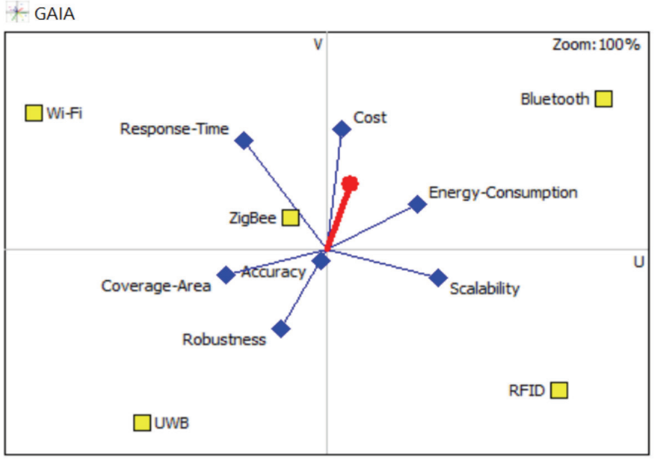


***Figure 8.** Distribution of criteria and options in the geometric plane of values*

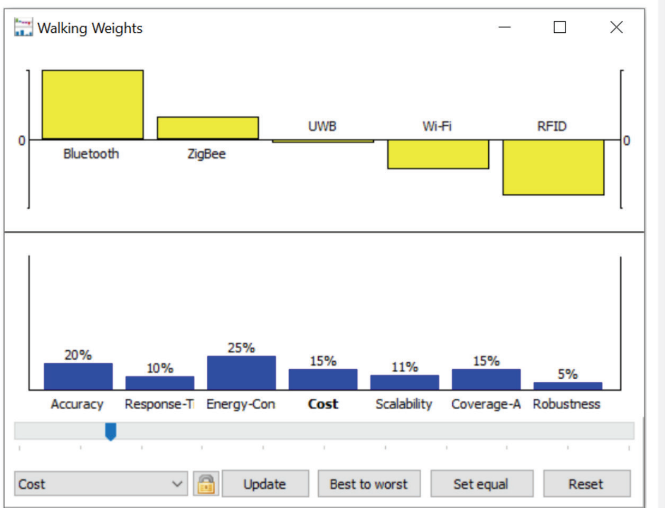


***Figure 9.** Performing sensitivity analysis in the window of the walking weight*

5. Conclusion

Two of these scientific methods, AHP and PROMETHEE, were used together in this study to select and rank the IPS for the SEDEF shipyard. In the literature review, it is shown that these two methods are used separately or together to solve problems in many fields. However, there has not been a study in which these two methods are used together for the IPS selection problem. With this feature, this study has an important contribution to the field. The AHP and PROMOTHEE method was used to determine which IPS is more suitable for the SEDEF Shipyard from several alternatives used in this study. Based on the developed model, the definition of the problem and the determination of the weights of the criteria were made with AHP. For the final ranking, the PROMETHEE method was used. The main reason why we use a combined structure, as mentioned in this article, is to make the most of the superior aspects of both methods and minimize errors caused by their weaknesses. For example, the PROMETHEE method for determining the problem structure and criterion weights has not yet produced a scientific proposal. The process of determining the weights of the criteria is completely left to the personal interpretation of specialists. There are criteria in the AHP method as a result of pairwise comparisons based on the opinions of experts. However, it can be checked whether it is consistent or not, and pairwise comparisons of the criteria can be expressed and seen very clearly due to the scale used. Since it is allowed to define the preference function based on each criterion in the PROMETHEE method, it is possible to make the alternatives that meet the criteria stand out a little more. In addition, the ranking of alternatives was even more meaningful because the PROMETHEE method avoided "compromising." With PROMETEE I, the advantages and weaknesses of the options to each other can be seen and analyzed without the problem of compromise. The results of the PROMETHEE method, thanks to the analysis tools, the strengths of the featured alternatives, the main criteria that make them stand out, and how the preference functions affect the results, have been analyzed very easily. Whether there is a contradiction between the criteria has been evaluated by experts using the GAIA plane. Again, these results were examined from different aspects, such as changing the weights and changing the conditions of the preference functions, and a very good parametric analysis was performed.

Expert Choice Software, which is very useful, was used to determine the criterion weights. The weight of each criterion is arranged graphically from the largest to the smallest, and visuality is provided. Visual PROMETHEE software is also very useful software for visualizing the computation process, which is a valuable tool for PROMETHEE analysis. The biggest advantage is that they allow the use of scenarios and all kinds of changes during the evaluation phase. Another advantage is that they provide eye-pleasing decision support with colorful graphics.

The following conclusions were reached by a comparative evaluation of the IPS considered here. Although the coverage area is very wide when positioning on the Wi-Fi network, the sensitivity is very low. Wi-Fi is a low-cost solution as it doesn't require extra devices. Variable signal strength may occur due to signal reflection and dynamic network structure in shipyard environments due to poor performance in multi-floor and very dense areas. On the other hand, the UWB has a wide range and high sensitivity. However, due to its high cost, it is suitable for applications where the location must be very precise. For closer distances, RFID, which is slightly different from these, can be preferred and is more suitable for use in stock counting door entry/exit applications. RFID is not easy to integrate into other systems. Low coverage and the inability of signals to pass through metal materials can cause problems in shipyard areas. ZigBee technology is widely preferred in applications that can be performed with small-scale data exchange because of its low cost, minimum power consumption principle, and easy and flexible installation. Thanks to this technology, it is possible to establish complex network structures, expand them, and enable these structures to communicate with other technologies. The disadvantage is that it cannot provide large data streams like Wi-Fi or Bluetooth. This means that ZigBee is mostly used in applications with small data flows. Compared in terms of power consumption, Bluetooth systems have the highest battery life and perform well in terms of energy use. Although the range is lower in Bluetooth technologies, positioning accuracy that can fall below 1 m can be achieved. Compared to other systems, Bluetooth has been seen as a good choice for reliable indoor positioning applications due to its higher sensitivity, lower cost, and ease of implementation. Bluetooth systems use the received signal strength indication technique, which is based on measuring the incoming signal strength among positioning techniques so that the farther the signal comes from, the weaker it will be.

This study's implementation is a case study for a single shipyard in the shipbuilding industry. Shipyard digitalization is still in the development stage. For this reason, the results obtained are only from an application-based study carried out at the SEDEF shipyard. As a result, the application results to be realized in other shipyards may not be the same as the evaluation results to be obtained with the approach implemented here. Similar applications can be made at other shipyards to make a more general recommendation for the sector, and more accurate decision support can be provided for the sector. Future researchers could focus on how the proposed integrated AHP and PROMETHEE method can be applied to the selection and evaluation of IPS technologies in other shipyards. The proposed integrated AHP and PROMETHEE method can be applied in the selection and evaluation of IPS technologies in other sectors other than shipyards. Furthermore, future studies can be conducted on the use of IPS technologies together.

6. Acknowledgment

This work is supported by TUBITAK with project number 1190128. The authors thank TEYDEB 1511 for its support.

Authorship Contributions

Concept design: I. Cil, F. Arisoy, E. Özgürbüz, Data Collection or Processing: F. Arisoy, E. Özgürbüz, H. Kılınç, Analysis or Interpretation İ. Cil, E. Özgürbüz, A. Y. Cil, H. Kılınç, Literature Review: İ. Cil, E. Özgürbüz, A. Y. Cil, Writing, Reviewing and Editing: I. Cil, A. Y. Cil, H. Kılınç.

Funding: The author(s) received no financial support for the research, authorship, and/or publication of this article.

7. References

[1] W. C. Simões, G. S. Machado, A. Sales, M. M. de Lucena, N. Jazdi, and V. F. de Lucena, “A review of technologies and techniques for indoor navigation systems for the visually impaired,” *Sensors*, vol. 20, 3935. 2020.

[2] I, Cil. F. Arisoy, H. Kilinc, and A. Y. Cil, “A Comparative Analysis of Indoor Positioning Technologies in Shipyard Digitalization Context,” *Journal of Marine Technology and Environment*, vol. 1, pp. 15-25, 2022.

[3] L. Dorji and T. Horanont, “Comparative Assessment of Indoor Positioning Technologies, Techniques, and Algorithms,” in *2018 International Joint Symposium on Artificial Intelligence and Natural Language Processing* (iSAI-NLP), pp. 1-6, 2018. doi: 10.1109/iSAI-NLP.2018.8692924.

[4] C. Liu, H. Wang, M. Liu and P. Li, “Research and Analysis of Indoor Positioning Technology,” *in 4th International Conference on Advanced Electronic Materials, Computers and Software Engineering* (AEMCSE), 2021, pp. 1212-17, 2021. doi: 10.1109/AEMCSE51986.2021.00248

[5] A. Giretti, A. Carbonari and M. Vaccarini, “Ultra wide band positioning systems for advanced construction site management,” *New Approach of Indoor and Outdoor Localization Systems*, InTech Open Access Publisher, pp. 89-112, 2012.

[6] T. Li, Gallagher, A.G. Dempster and C. Rizos, “How feasible is the use of magnetic field alone for indoor positioning?” in *2012 International Conference on Indoor Positioning and Indoor Navigation (IPIN)*, pp. 1-9, 2012. https://doi.org/10.1109/IPIN.2012.6418880

[7] I. Cil, F. Arisoy, and H. Kilinc, “An analysis on industrial internet of things in digital transformation of shipyard industry in Turkey,” *Global Journal of Computer Sciences: Theory and Research,* vol. 11, pp. 67-87, Oct 2021.

[8] K. Kabassi, S. Mpalomenou, and A. Martinis, “AHP and PROMETHEE II for the evaluation of websites of mediterranean protected areas??? managing boards*”. Journal of Management Information and Decision Sciences*, vol. 24, pp. 1-17, 2021.

[9] B. Vahid, B. Zahraie, and A. Roozbahani, “Comparison of AHP and PROMETHEE family decision making methods for selection of building structural system,” *American Journal of Civil Engineering and Architecture*, vol. 2, pp. 149-159, Sep 2014.

[10] S. S. Goswami, “Outranking Methods: Promethee I and Promethee II,” *Foundations of Management*, vol. 12, pp. 93-110, Jul 2020.

[11] A. Singh, A. Gupta, and A. Mehra, “Best criteria selection based PROMETHEE II method,” *OPSEARCH*, vol. 58, 160-180, March 2020.

[12] I. Cil, F. Arisoy, H. Kilinc, E. Özgürbüz and A. Y. Cil, “Fuzzy AHP-TOPSIS Hybrid Method for Indoor Positioning Technology Selection for Shipyards,” in *5th International Symposium on Multidisciplinary Studies and Innovative Technologies* (ISMSIT), 2021, pp. 766-771, doi: 10.1109/ISMSIT52890.2021.9604748. 2021.

[13] M. Ünver, and I. Cil, “Material selection by using fuzzy complex proportional assessment,” *Emerging Materials Research*, vol. 9, pp. 93-98, 2020.

[14] A. Basiri, P. Peltola, P. Figueiredo e Silva, ES Lohan, T. Moore and C. Hill, Indoor positioning technology assessment using analytic hierarchy process for pedestrian navigation services. In 2015 International Conference on Localization and GNSS (ICL-GNSS) (pp. 1-6). IEEE.

[15] C.L. Hwang, K. Yoon, “Multiple Attribute Decision Making”, *Lecture Notes in Economics and Mathematical Systems Springer*: Berlin/Heidelberg, Germany, Volume 186, ISBN 978-3-540-10558-9. 1981.

[16] C. Macharis and A. Bernardini, “Reviewing the use of multi-criteria decision for the evaluation of transport projects: time for a multi-actor approach,” *Transport Policy,* vol. 37, 177-186, Jan 2015.

[17] I. Cil, and Y.S. Turkan, “An ANP-based assessment model for lean enterprise transformation,” *The International Journal of Advanced Manufacturing Technology,* vol. 64, 1113-1130, 2013.

[18] E.G. Kavilal, S.P. Venkatesan, and S. Priyamvatha, “An integrated Fuzzy AHP and Fuzzy TOPSIS for prioritizing supply chain complexity drivers,” *International Journal of Operations and Quantitative Management,* vol. 22, pp. 39-51, March 2016.

[19] C. Zhang, and M. Chen, “Prioritising alternatives for sustainable end-of-life vehicle disassembly in China using AHP methodology,” *Technology Analysis & Strategic Management,* vol. 30, pp. 556-568, 2018.

[20] W. Ho and X. Ma, “The state-of-the-art integrations and applications of the analytic hierarchy process,” *European Journal of Operational Research,* vol. 267, pp. 399-414, June 2018.

[21] O. S. Vaidya and S. Kumar, “Analytic hierarchy process: an overview of applications,” *European Journal of Operational Research*, vol. 169, pp. 1-29, Feb 2006.

[22] A. Yazıcı, S. B. Keser, S. Günal, and U. Yayan, "A Multi-Criteria Decision Strategy to Select a Machine Learning Method for Indoor Positioning System," *International Journal on Artificial Intelligence Tools*, vol. 27, 2018.

[23] M. Ficco, R. Pietrantuono, and S. Russo, "Using multi-objective metaheuristics for the optimal selection of positioning systems," *Soft Computing,* vol. 20, pp. 2641-2664. 2016.

[24] A. Mileo, T. Schaub, D. Merico, and R. Bisiani, "Knowledge-based multi-criteria optimization to support indoor positioning," *Annals of Mathematics and Artificial Intelligence*, vol. 62, pp. 345-370, Aug 2011.

[25] A. Basiri, P. Peltola, P. F. Silva, E. S. Lohan, T. Moore, and C. Hill, "Indoor positioning technology assessment using analytic hierarchy process for pedestrian navigation services," in *2015 International Conference on Localization and GNSS (ICL-GNSS).* IEEE. 2015, pp. 1-6.

[26] N. Agrawal, "Multi-criteria decision-making toward supplier selection: exploration of PROMETHEE II method," *Benchmarking: An International Journal,* vol. ahead-of-print, pp. ahead-of-print. 2021.

[27] H. I. Caner and C. C. Aydin, "Shipyard site selection by raster calculation method and AHP in GIS environment," *Marine Policy*, vol. 127, pp. 104439, May 2021.

[28] K. Govindan, M. Kadziński, and R. Sivakumar, "Application of a novel PROMETHEE-based method for construction of a group compromise ranking to prioritization of green suppliers in food supply chain," *Omega,* vol. 71, pp. 129-145, Sep 2017.

[29] F. Samanlioglu, and Z. Ayağ, "A fuzzy AHP-PROMETHEE II approach for evaluation of solar power plant location alternatives in Turkey," *Journal of Intelligent and Fuzzy Systems*, vol. 33, pp. 859-871, July 2017

[30] L. Turcksin, A. Bernardini, and C. Macharis, "A combined AHP PROMETHEE approach for selecting the most appropriate policy scenario to stimulate a clean vehicle fleet," *Procedia - Social and Behavioral Sciences,* vol. 20, pp. 954-965, Sep 2011.

[31] F. Ikwan, D. Sanders, M. Haddad, "A Combined AHP-PROMETHEE Approach for Intelligent Risk Prediction of Leak in a Storage Tank," *International Journal of Reliability, Risk and Safety: Theory and Application*, vol. 3, pp. 55-61, July 2020.

[32] K. Baynal, T. Sarı, and V. Koçdağ, "A combined AHP-PROMETHEE approach for project selection and a case study in the Turkish textile industry," *European Journal of Business and Social Sciences*, vol. 5, pp. 202-216, Apr 2016.

[33] Alkan, A. Kasımoğlu, H. Ç. Çelik, C. and Z. Aladağ, "Supplier selection for a tire company with AHP and PROMETHEE methods," S*akarya University Journal of Science*, vol. 21, pp. 261-269, Apr 2017.

[34] Macharis, C. "PROMETHEE and AHP: The design of operational synergies in multicriteria analysis - Strengthening PROMETHEE with ideas of AHP," *European Journal of Operational Research,* vol. 153, pp. 307-317, Mar 2004.

[35] A. Budak, and A. Ustundag, "Fuzzy decision making model for selection of real time location systems," *Applied Soft Computing*, vol. 36, pp. 177-184, Nov 2015.

[36] Silva, E. M. and Jardim-Goncalves, R. "Multi-criteria analysis and decision methodology for the selection of internet-of-things hardware platforms," in *Doctoral Conference on Computing, Electrical and Industrial Systems*. Springer, Cham. 2017, pp. 111-121.

[37] İ. Çil, H. Kılınç, E. Özgürbüz, M. Ünver, and N. Özkurt, "Selection of indoor positioning technology in shipyards by fuzzy MULTIMOORA and Fuzzy COPRAS methods," *European Journal of Science and Technology,* pp. 248-254, Dec 2021.

[38] G. Keçek and R. Yüksel, "Smartphone selection with analytical hierarchy process (AHP) and PROMETHEE methods," *Dumlupınar University, Journal of Social Sciences,* vol. 49, pp. 46-62, July 2016.

[39] J. S. Lee, Y. W. Su and C. C. Shen, "A comparative study of wireless protocols: Bluetooth, UWB, ZigBee, and Wi-Fi," in *IECON 2007-33rd Annual Conference of the IEEE Industrial Electronics Society* IEEE. 2007, pp. 46-51.

[40] A. S. Dukyil, "Artificial intelligence and multiple criteria decision making approach for a cost-effective RFID-enabled tracking management system," *Doctoral dissertation, Brunel University,* London. 2018.

[41] B. Oztaysi, C. Kahraman, S. C. Onar, and I. Otay, "Indoor location tracking technology evaluation by using spherial fuzzy TOPSIS method," in *Developments of Artificial Intelligence Technologies in Computation and Robotics: Proceedings of the 14th International FLINS Conference (FLINS 2020).* 2020, pp. 173-181.

[42] L. Doulos, A. Tsangrassoulis and F. V. Topalis, "Multi-criteria decision analysis to select the optimum position and proper field of view of a photosensor". *Energy Conversion and Management*, vol. 86, pp. 1069-1077, Oct 2014.

[43] E. Ergen, D. A. İlter, I. A. Tekçe, B. Kula, and D. Dönmez, "Utilizing Indoor Localization Technologies For Occupant Feedback Collection," *Uluslararası Katılımlı 7. İnşaat Yönetimi Kongresi,* 06-07 Ekim 2017, Samsun.

[44] M.Y. Kim, H.S. Cho, and J. Kim, "Neural network-based recognition of navigation environment for intelligent shipyard welding robots," in *Proceedings of the 14th IEEE/RSJ International Conference on Intelligent Robots and Systems*, Maui, HI, USA, 29 October-3 November 2001 pp. 446-451.

[45] S. Kawakubo, A. Chansavang, S. Tanaka, and T. Iwasaki, "Wireless network system for indoor human positioning," in *Proceedings of the 1st International Symposium on Wireless Pervasive Computing*, Phuket, Thailand, 16-18 Jan 2006.

[46] C. T. Li, Cheng, J. C. and Chen, K. "Top 10 technologies for indoor positioning on construction sites," *Automation in Construction*, vol. 118, pp. 103309, 2020.

[47] R. F. Brena, J. P. García-Vázquez, C. E. Galván-Tejada, D. Muñoz-Rodriguez, C. Vargas-Rosales, and J. Fangmeyer, "Evolution of indoor positioning technologies: A survey". *Journal of Sensors*, 2017.

[48] I. Cil, F.Arisoy, and H. Kilinc, "Visibility of resources and assets in the shipyard through industrial internet of things," *Global Journal of Computer Sciences: Theory and Research*, vol. 11, pp. 88-101, Apr 2021.

[49] D. Lhakpa, and H. Teerayut. “Comparative assessment of indoor positioning technologies, techniques, and algorithms”, in *2018 International Joint Symposium on Artificial Intelligence and Natural Language Processing (iSAI-NLP),* 2018. https://ieeexplore.ieee.org/document/8692924

[50] P. Fraga-Lamas, D. Noceda-Davila, T. M. Fernández-Caramés, M. A. Díaz-Bouza, and M. Vilar-Montesinos, “Smart pipe system for a shipyard 4.0,” *Sensors*, vol. 16, pp. 2186, Dec 2016.

[51] F. Zafari, A. Gkelias, K. Leung, “A survey of indoor localization systems and technologies”, *IEEE Communications Surveys & Tutorials.* pp. 2568-2599, 2019. DOI 10.1109/CONTACT.2019.2911558.

[52] T. L. Saaty. The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation. McGraw-Hill, New York, 1980.

[53] M. Brunelli, “Introduction to the analytic hierarchy process”. Springer, 2014.

[54] J. A. Alonso and M. T. Lamata. “Consistency in the analytic hierarchy process: a new approach”. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems*, vol. 14, pp. 445-459, 2006.

[55] J. P. Brans, and Ph. Vincke, “A preference ranking organization method: The PROMETHEE method for multiple criteria decision-making,” *Management Science,* vol. 31, pp. 647-656, June 1985.

[56] I. Cil, F. Arisoy, H. Kilinc, E. Özgürbüz, A. Y. Cil and E. Uysal, “*Challenges and trends in shipbuilding industry: digitization of SEDEF shipyard in Turkey,*” in *5th International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT)*, pp. 799-804, 2021.