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Neutrosophic MCDM Methodology for Risk Assessment of Autonomous Underwater Vehicles

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Abstract: Due to its usefulness in several industries and the military, researchers have concentrated on developing autonomous underwater vehicles (AUVs). However, AUV navigation continues to be a difficult challenge to solve owing to the variety of underwater settings. The usage of AUVs, or autonomous underwater vehicles, is not without dangers like malfunction, ecological risks, loss of communications, cybersecurity risks, collisions, and others. There are many criteria to assess these risks technical, operational, economic, and regulatory. So, the methods of multi-criteria decision-making (MCDM) is used to deal with these various criteria. The analytical hierarchy process (AHP) method is an MCDM methodology, that can be used to compute the weights of criteria. The AHP is integrated with the single-valued neutrosophic set (SVNS) to deal with uncertain data in the assessment process. The risks of AUVs are ranked after computing the weights of the criteria. The results show that malfunctions are the highest risk.

Keywords: Neutrosophic Set; Autonomous Underwater Vehicles; Risks Analysis; MCDM.

1. Introduction

Many nations and people throughout the globe have taken an interest in the ocean and its inhabitants in recent years. As a result, it's crucial to learn more about these places and the lessons they can teach us. Since the oceans and seas cover most of the surface of the planet, their significance for resource extraction, scientific inquiry, and economic gain should come as no surprise. From a scientific perspective, the ocean offers a plethora of study options for a deeper comprehension of our planet, which may help several research sectors and scientific organizations [1, 2].

Moreover, due to the high worth of the ocean's resources, many scholars and researchers have put in long hours undertaking in-depth research to find the best uses for them. As part of this shift, nations have been racing to perfect maritime monitoring tools that can operate at different depths and in different environments, including the air. One such tool is the autonomous underwater vehicle (AUV), which is used for surveillance and other forms of crucial surveillance. In 1957, Stan Murphy, Bob Francois, and Terry Ewart from the University of Washington in the United States created the first AUV at the university's applied physics laboratory.

Among the many applications for AUVs are maritime rescue, data collecting, seafloor discovery, and the search for objects underwater. In order to preserve and safeguard our oceans as one of our most important natural assets, these types of boats have grown more popular for a variety of uses, including mapping seabed geography, evaluating marine pastures, and checking undersea oil pipelines. The emergence of the AUV sector is a direct result of the proliferation of cutting-edge technology. Examples of recent developments that have contributed to the growth of the AUV sector include improvements in software and design elements [3, 4].

Think about how AUVs have improved their data collection and processing thanks to new and improved sensors and software. Because of these developments, AUVs may now carry out activities including underwater visualization, pipeline assessment, and rescue efforts. AUVs have also advanced in design thanks to the incorporation of new technologies in areas like propulsion, navigation, and connectivity. These developments in technology have made AUVs safer in operation, as well as more flexible and able to adjust to different environments.

The AUV market is expected to expand at a rapid clip of 22.8% CAGR during 2022 and 2027 as a direct consequence of these developments. Demand for AUVs in industries such as offshore oil and gas development, oceanographic research, and military surveillance is projected to be a major factor in this expansion. It is anticipated that this expansion will be fueled in part by the AUV industry's commitment to technological advancement, which in turn will open up promising new avenues of business [5, 6].

Since the introduction of the fuzzy theory by Zadeh, several methods have been created to cope with ambiguity. Atanassov introduces intuitionistic fuzzy sets, a generalization of fuzzy sets that takes truth and falsity participation into account. To better deal with ambiguity, Smarandache devised neutrosophic logic. Incorporating the "ambiguity" that comes with making any kind of human judgment, "Neutrosophic Logic" has recently emerged [7, 8].

Constraints are passed on to the choice. The need to limit the total number of trainees is a key limitation. This restriction might be based on available funds or the greater work burden experienced because of an absence. This component also has to be included. It is crucial to the technique to define the factors that will be taken into account. The Analytic Hierarchy Process (AHP) has been shown in recent research to be an effective, rigorous, and stable technique for generating and measuring subjective judgments in MCDM. The benefits of AHP, however, are reduced due to the bi-comparison of parameters and possible discrepancies, as stated in the same research. Potential solutions include hybrid techniques that combine AHP with other methodologies [9, 10].

This study proposed the single-valued neutrosophic AHP MCDM method to rank the AUVs risks and compute the weights of the list of criteria.

2. Autonomous Underwater Vehicle Building

The AUV's bodywork construction is crucial because it protects the vehicle's mechanical and electrical parts from water damage. The fluid-structure relationship between the AUV and the water influences its motion dynamics. AUVs take their torpedo shapes directly from boats.

Extremely maneuverable, UVs can swiftly navigate intricate routes and reach out-of-the-way places. In addition to these straightforward designs, AUVs are now also being built in sophisticated forms with hydrofoil shapes to boost performance and decrease drag. AUV P-SURO Similar AUVs include those described by Li et al. and the ones provided by Alam et al. These many AUVs have a common waterproof close-frame construction despite their varying body forms. Due to the lower drag force at low speeds, open-frame constructions are often used by AUVs.

In addition to these man-made devices, AUVs have also been designed to seem like fish or other marine life. These bio-mimetic AUVs are not only useful for exploration and other submerged tasks but also for studying and understanding marine creatures in their natural habitat. Among the bio-mimetic AUVs, fish robots have proven to be the most well-liked [11, 12].

Modular body construction is becoming more common in modern AUVs. The entire AUV is made up of modular components, including the engine and sensor modules, that can be rapidly and easily swapped out in the event of a malfunction or upgraded to meet new mission needs. These AUVs are more cost-effective to maintain and have a high degree of adaptability.

As it moves through the water, an AUV encounters drag and lift forces from the friction between its body and the water. These forces are significantly impacted by the framework of the body. Predicting drag and lift requires studying the fluid-structure relationship between the AUV and the nearby water. The performance of the AUVs may be improved by minimizing these loads utilizing various numerical and optimization techniques. The creation of a reliable dynamic framework for steering and control benefits from estimates of drag and lift as well.

3. Autonomous Underwater Systems

AUVs are autonomous underwater systems that are not tied to the surface, unlike manned undersea robots and remotely controlled vehicles. Costs associated with operations and issues of human safety (such as mine reconnaissance) may be minimized with the use of untethered and unmanned characteristics. In 1957, researchers at the University of Washington created the first AUV, dubbed the Self-Propelled Underwater Research Vehicle (SPURV). The SPURV resembles a torpedo in design. It has a range of up to 3000 meters, a maximum speed of 2.3 meters per second, and a working time of roughly 4 hours. The use of AUV technology has grown exponentially during the last 60 years. Some specifics of AUV methods are shown below.

Due to their autonomous navigation and control capabilities, AUVs can complete missions without human intervention. The sensors aboard collect data from the settings in which these devices operate. Most AUVs need a few fundamental systems, including navigation, power, and sensor technology [13, 14].

4. Navigation System of AUVs

One of the most crucial components of an AUV is its navigation system. The following is a presentation of navigational systems, which includes navigational methods and navigational hardware:

Due to the quick degradation of GPS signals in the ocean, navigation presents a difficult difficulty. Researchers have proposed a number of navigation approaches over the last several decades to address this issue. In order to function, some antiquated methods need surface boats or beacons to be pre-positioned in a certain area. Different lengths of baseline are used for each of these methods: ultrashort (USBL), short (SBL), and long (LBL). Both USBL and SBL setups have a vessel on the surface. The LBL network relies on stationary beacons. A beacon is an instrument that sends out periodic signals to direct autonomous underwater vehicles.

Both a transceiver and an antenna are components of a USBL system. A transceiver is an item with the ability to send and receive electromagnetic waves. Three or more signal-generating transducers are included in a USBL transceiver, and their baseline separation is less than 10 centimeters. Distances between transducers serve as the baseline. A transponder is an item that takes in one signal and immediately sends out another. Transceiver and transponder are both mounted on autonomous underwater vehicles. A USBL technology monitors relative orientations and distances between the outermost vessel and the AUV to determine its location. The variation in phase of acoustic signals measured at the transducer array is used to calculate relative orientations. The distance between two points may be determined by timing the travel time of a sound wave from its source to its destination [15, 16].

5. Communication System of AUVs

The acoustic communicators used by AUVs make underwater interaction possible. Sound signals are sent and received by acoustic modems, which transform electrical power into sound energy and back again. Designers of modems work hard to boost data transfer rates and ensure consistent connectivity. Increasing time delays among frames decreases interference from multipath, and certain companies use spread-spectrum methods to improve the proportion of packets delivered in multipath surroundings, leading to higher processing speeds in those cases. We summarise a variety of modern modem solutions from various vendors to provide a general understanding of the capabilities of acoustic modems.

Batteries dominate AUV power systems. Lead-acid and silver-zinc batteries are the two most common kinds of conventional batteries. Lead-acid batteries are less expensive than silver-zinc ones, although the latter can store twice as much energy. AUVs, like mobile phones and laptops, now often employ lithium batteries. Recharging is possible with lithium batteries. Using this function can save a ton of money.

However, there is still a restriction due to insufficient battery life. Some AUVs are designed with removable batteries to get around this problem, allowing for quick battery swaps and subsequent return to duty [17, 18].

AUVs may serve as sensor systems, allowing for the installation of a wide variety of sensors. Images may be captured using digital cameras, digital video recorders, synthetic aperture sonars, and side-scan sonars. Swath bathymetry seabed overlays are possible with the use of sub-bottom investigators and multi-beam sonars. Distances may be determined using tools like echo sounders and underwater laser scanners. Avoiding danger is made easier with forward-looking sonars. The electrical conductivity, temperature, and stress of saltwater may be measured using a conductivity temperature thickness. There is already a plethora of sensors available to do a wide range of tasks [19, 20].

6. Risks Analysis of AUVs

The distinctions between a malfunction, a problem, and an error are crucial. When a part or system stops working as it should, we call it a failure. A fault is any anomalous situation or flaw that has the potential to cause a failure. The term "error" is used to describe a deviation from the expected value, situation, or human action. It often happens when actual performance falls short of expectations, which may lead to failure.

There has been a progressive movement towards human operator risk assessment as AUV technology has developed. Human variables, which are crucial but somewhat difficult to measure, are garnering more interest in the AUV risk control method as a means to thoroughly limit the risk of AUV installations. When people become involved, AUVs lose some of their independence. We may categorize how much control a system has over its own actions on a scale from totally human-operated to entirely human-assisted to fully human-delegated to completely human-supervised to a fully human-mixed initiative to fully human-operated again. The degree of autonomy indicates how little interference from humans there will be throughout the operation. The current generation of AUV systems falls under level (ii), level (iii), and level (iv), with level (v) and degree (vi) possible in the not-too-distant future. While modern AUV systems have some degree of autonomy, employees are still necessary in a supervisory capacity. Human beings are primarily involved in the design process (figuring out mission plans), the deployment and retrieval of the vehicle, decision-making in the face of crises, and so on [21, 22].

Underwater habitats where AUVs are often used include open ocean, sea ice or shelf ice, and coastal regions. Subsea settings are dynamic and dangerous, making it difficult to guarantee a safe installation. Thus, it is critical to determine what aspects of the underwater environment pose threats to AUVs and to learn how to mitigate such risks. In this part, we draw on previous research to examine four important environmental elements connected to risk: sea ice or shelf ice; underwater currents; the surrounding temperature; and water density [23, 24].

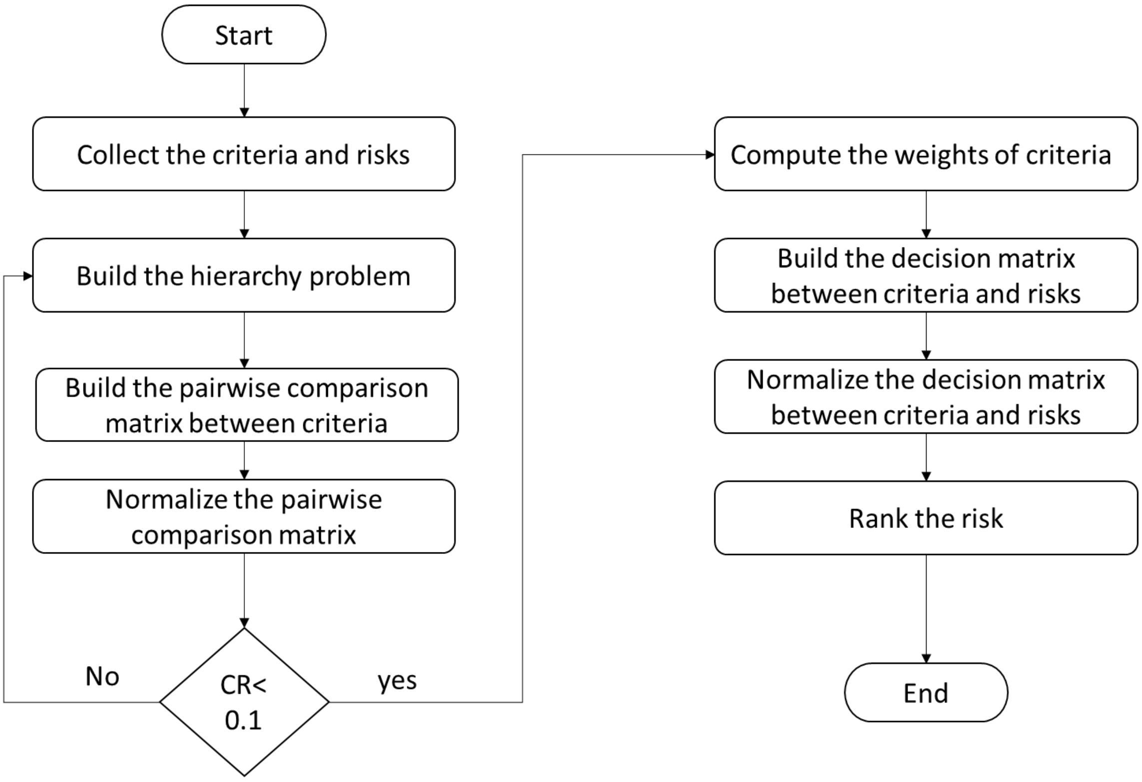

Figure 1. The steps of the neutrosophic AHP method.

7. Neutrosophic MCDM Methodology

In AHP, the decision-makers' past actions are translated into values for the criterion. AHP is a technique that maps the expertise of decision-makers onto the relative importance of certain criteria. The outputs of an AHP analysis are the relative values of the various criteria. Each condition has a weight, and their total is 1. crisp is the original AHP.

However, humans make judgements with a certain amount of fuzziness. Therefore, FAHP is produced by combining fuzzy logic with AHP. Van Laarhoven and Pedrycz provide the first way to combine fuzzy logic with AHP. The purpose of using AHP in making decisions is to account for the ambiguity that comes with using human reasoning. Fuzzy theory is included into AHP in FAHP[25], [26]. The suggested approach incorporates a novel model that combines Neutrosophic Sets with AHP. Figure 1 shows the steps of the neutrosophic AHP method.

Step 1. Build the pairwise comparison matrix between criteria.
Step 2. Normalize the pairwise comparison matrix.
Step 3. Compute the consistency ratio.

$$CR = \frac{CI}{RI}$$

$$CI = \frac{\lambda_{max}-n}{n-1}$$

Step 4. Compute the weights of criteria.

$$w_j = \frac{x_j}{n}$$

Step 5. Build the decision matrix between criteria and risks.

Step 6. Normalize the decision matrix between criteria and risks.

Step 7. Rank the risk.

The risks are ranked with the highest value in multiplying the weights of criteria by the normalization matrix.

8. Results of AUVs Risks Analysis

This section introduces the assessment the risks analysis of the AUVs. This section introduces the application of the single-valued neutrosophic AHP method. The AHP is used to compute the weights of criteria. The AHP is used to rank the risks of the AUVs. There are seven risks are introduced is this paper. AUVs pose hazards similar to those of any other technological advancement. Threats associated with AUVs include:

In the event of a failure, the AUV may become unresponsive or unable to carry out its mission since it relies on a number of complicated electrical and mechanical components. Dangers in the Natural World: Underwater currents, rocks, and other barriers may all pose a threat to the AUV's health and safety. Disconnection: AUVs depend on their communication systems to receive instructions from their operators and relay any collected data back to them. If the AUV loses contact with its base, it may get disoriented and unable to continue its mission. Hacking, a kind of cyberattack, is one example of how AUVs' data and control systems might be jeopardized by their increasing interconnectedness with other systems. Accidental collisions with other vehicles, marine creatures, or submerged objects pose a significant threat to the health and safety of AUVs. Remote AUV operations provide room for human error in mission planning, navigation, and data interpretation, increasing the risk of the AUV being lost, destroyed, or unable to perform its intended purpose. The use of AUVs may have negative consequences for the marine ecosystem, such as the destruction of habitats and the introduction of foreign objects and contaminants.

Thera are six criteria to assess the AUVs risks. The parameters used to evaluate the dangers posed by AUVs may be broken down into numerous classes, such as: In terms of technological criteria, we'll be looking at things like how well the AUV's sensors, navigation, communication, and propulsion systems work and how long they last. Evaluating the AUV's software and control systems, such as its level of autonomy and any built-in redundancies, is another technical criterion. Environmental criteria include taking into account the water depth, temperature, and current, as well as any other environmental parameters that may have an effect on the AUV's performance and safety, while it is in operation. The possible effect of the AUV's operation on marine life and ecosystems must also be considered among the environmental requirements. In terms of operational criteria, we'll be looking at things like how well the mission was planned and carried out, how well the AUV was maintained, and how well the AUV was equipped with safety features to prevent accidents. Cybersecurity Criteria: This includes assessing the likelihood of cyber-attacks, data breaches, and other cybersecurity threats in relation to the AUV's operation. Compliance with safety and environmental legislation, as well as industry standards and best practices, are all part of the regulatory criteria that must be considered while operating an AUV. Evaluating the economic hazards of operating an AUV, such as the cost of development and operation and the potential for financial losses due to system failures, accidents, or other unanticipated occurrences, is part of this criterion.

Table 1. AUVs data between criteria and alternatives.

	AUVC$_1$	AUVC$_2$	AUVC$_3$	AUVC$_4$	AUVC$_5$	AUVC$_6$
AUVR$_1$	(0.90, 0.10, 0.10)	(0.30, 0.75, 0.70)	(0.20, 0.85, 0.80)	(0.10, 0.90, 0.90)	(0.30, 0.75, 0.70)	(0.90, 0.10, 0.10)
AUVR$_2$	(0.10, 0.90, 0.90)	(0.20, 0.85, 0.80)	(0.10, 0.90, 0.90)	(0.30, 0.75, 0.70)	(0.10, 0.90, 0.90)	(0.90, 0.10, 0.10)
AUVR$_3$	(0.20, 0.85, 0.80)	(0.10, 0.90, 0.90)	(0.30, 0.75, 0.70)	(0.20, 0.85, 0.80)	(0.20, 0.85, 0.80)	(0.10, 0.90, 0.90)
AUVR$_4$	(0.90, 0.10, 0.10)	(0.20, 0.85, 0.80)	(0.90, 0.10, 0.10)	(0.30, 0.75, 0.70)	(0.90, 0.10, 0.10)	(0.20, 0.85, 0.80)
AUVR$_5$	(0.10, 0.90, 0.90)	(0.30, 0.75, 0.70)	(0.10, 0.90, 0.90)	(0.30, 0.75, 0.70)	(0.20, 0.85, 0.80)	(0.10, 0.90, 0.90)
AUVR$_6$	(0.20, 0.85, 0.80)	(0.20, 0.85, 0.80)	(0.30, 0.75, 0.70)	(0.20, 0.85, 0.80)	(0.30, 0.75, 0.70)	(0.10, 0.90, 0.90)
AUVR$_7$	(0.90, 0.10, 0.10)	(0.10, 0.90, 0.90)	(0.30, 0.75, 0.70)	(0.10, 0.90, 0.90)	(0.20, 0.85, 0.80)	(0.90, 0.10, 0.10)

Table 2. AUVs data normalization between criteria and alternatives.

	AUVC$_1$	AUVC$_2$	AUVC$_3$	AUVC$_4$	AUVC$_5$	AUVC$_6$
AUVR$_1$	0.2641	0.2032	0.0997	0.0721	0.1362	0.2731
AUVR$_2$	0.0354	0.1471	0.0516	0.1924	0.051	0.2731
AUVR$_3$	0.0685	0.0761	0.1376	0.1393	0.0987	0.0366
AUVR$_4$	0.2641	0.1471	0.3844	0.1924	0.3806	0.0708
AUVR$_5$	0.0354	0.2032	0.0516	0.1924	0.0987	0.0366
AUVR$_6$	0.0685	0.1471	0.1376	0.1393	0.1362	0.0366
AUVR$_7$	0.2641	0.0761	0.1376	0.0721	0.0987	0.2731

The experts are evaluated the criteria and risks of the AUVs by using linguistic terms of single valued neutrosophic set. Then we used the single valued neutrosophic numbers instead of the linguistic terms as shown in Table 1. Then apply the steps of the AHP method on the single valued neutrosophic numbers to compute the weights of criteria and rank the risks. Then normalize the pairwise comparison matrix. Then compute the weights of criteria. Figure 2 shows the highest importance criteria. Then compute the rank of the risks by normalize the data between criteria and risks as shown in Table 2. Then multiply the weights of criteria by the normalization data. Then sum of each row as shown in Figure 3. The malfunction is the highest risk in all risks.

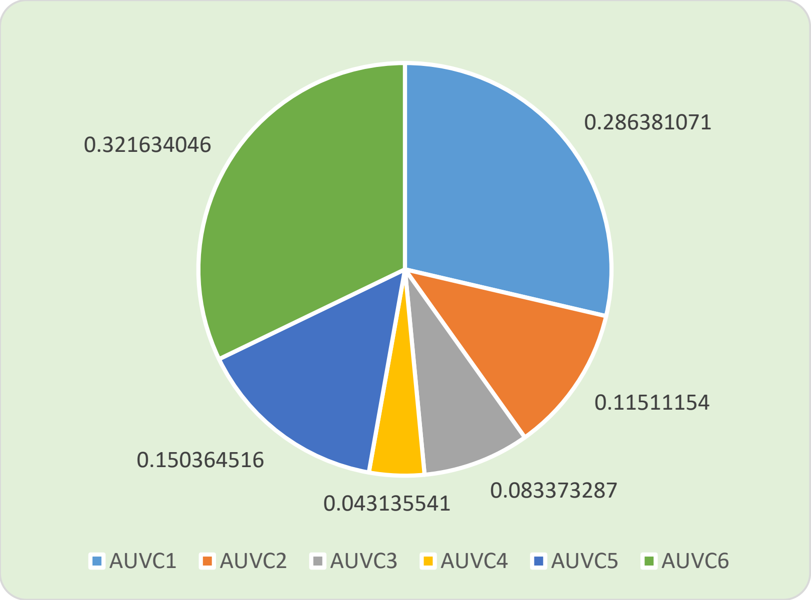

Figure 2. The importance criteria risks of AUVs.

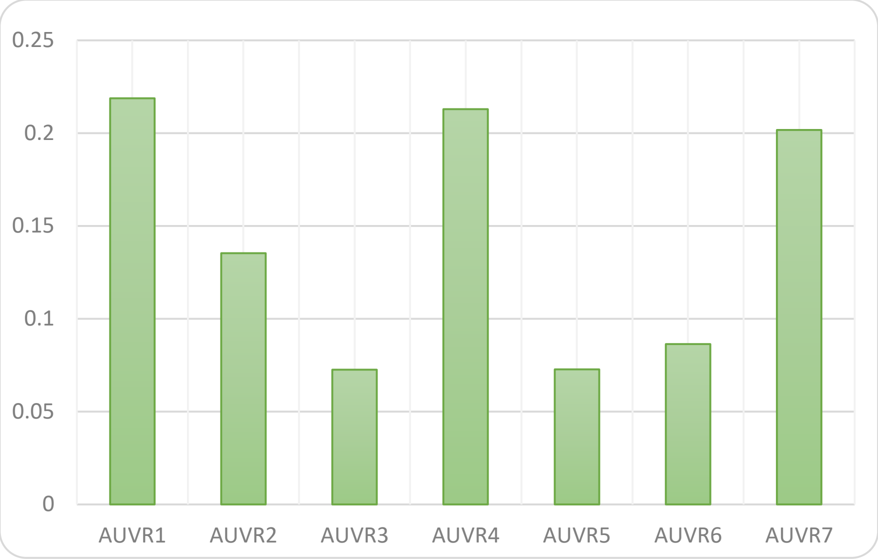

Figure 3. The rank of seven risks of AUVs.

9. Conclusion

AUVs are useful platforms for taking automated measurements without human involvement in harsh environments like the ocean or beneath the ice. But the AUVs have many risks threat it. So, this study collected and ranked these risks based on various criteria by using the concept of the MCDM method. The AHP method is used to compute the weights of criteria and rank the risks. The AHP is integrated with the single-valued neutrosophic set to deal with uncertain data. The malfunctions are the highest risk. The possibility of malfunction is a major threat while using AUVs. The sensors, navigation, communication, and propulsion systems of the AUV are all susceptible to failure. If the AUV has a problem, it may become unresponsive or unable to fulfill its mission, leading to either the loss of the AUV or the information it has gathered.

Data availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Conflict of interest

The authors declare that there is no conflict of interest in the research.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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