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Construction of a Situation Awareness Influencing Factor System for Manned Submersibles in Dynamic Complex Underwater Operations

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Abstract:

To bolster the marine economy and strengthen maritime power, China's manned submersible program faces the challenge of managing the inherent complexity of underwater operations and the need for synchronized device interactions. This paper presents a novel situational awareness information system designed specifically for these complex environments. This system integrates multiple factors such as equipment status, task requirements, environmental variables, and human behavior to provide a holistic view. Subsequently, the system effectively organizes and categorizes this diverse information into a structured taxonomy. Furthermore, by utilizing the Analytic Network Process (ANP), the information elements are prioritized, offering a nuanced analysis that underscores the system's critical role in enhancing decision-making capabilities for divers and improving the efficiency and safety of underwater operations. Ultimately, the effectiveness of this system is demonstrated, showcasing its superiority in managing the complexities of manned submersible operations.

Keywords: manned submersibles, situational awareness system, interactive information network.

BRIEF INTRODUCTION

The ocean is Earth's largest ecosystem, covering over 70% of the planet's surface, with the deep-sea accounting for 90% of the world's ocean area [1]. The deep sea, as a largely unexplored frontier on Earth, harbors abundant resources, some of which have not yet been discovered or fully utilized [2]. These resources include biological, mineral, oil, and natural gas reserves, which are of great significance not only for national economic development but also for national defense strategies [3]. This has spurred major maritime nations around the globe to begin focusing on ocean space development, deep-sea resource exploration, marine environmental protection, and other issues, while actively developing new technologies and equipment to propel the deep-sea domain into a new stage of development.

Manned deep-sea submersibles are underwater operational vehicles piloted by navigators, carrying engineers and scientists for research and exploration. Within their spherical cabins, there is an array of equipment and component-related information distributed across systems such as propulsion, energy, observational navigation, acoustic sonar systems, life support, hydraulics, ballast and trim regulation [4]. Since 2002, when China's Ministry of Science and Technology included the development of manned deep-sea submersibles in the national high-tech research and development program, China has gradually placed emphasis on the development and research of deep-sea submersibles. Under the strategic goal of expanding the maritime economy and building a strong maritime country, significant achievements have been made in the development of manned submersibles [5]. For instance, some scholars have focused on the application of human-machine ergonomics in the cabin design of manned submersibles. The focus of these studies is the human-machine system inside the submersible's cabin, with the core issue being physiological comfort and cognitive reliability during human-machine interaction. An in-depth analysis of factors influencing physiological comfort and potential cognitive behavioral errors during use informs the optimization of the submersible's interior design [6-13]. Other scholarly research has mainly targeted the optimization of information display on the human-machine interaction interface of manned submersibles, interface digitalization design, cognitive mechanisms, and decision-making rules [14-19], involving the optimization of human-machine interaction information and digital upgrading. It is worth mentioning that Academician Xu Qinan pointed out in his article "Current Status and Prospects of Manned Deep Diving Technology and Applications" that intelligent control is one of the main trends in the development of manned equipment [20].

The cockpit system of manned submersibles is complex, with various subsystems interrelated. During the piloting operations, navigators must manage and monitor various types of task-related information resources within the cabin, in addition to mechanical operations, making it an intensive human-machine interaction process [21]. As ocean exploration advances, the underwater operations of manned submersibles become more complex, and new missions impose stricter requirements on the submersibles. However, large-scale and time-sensitive tasks make reliance on a single submersible impractical. Due to the development and maturity of different submersible technologies, the coordinated operation of multiple submersibles to accomplish tasks has emerged as a new application form. The existing deep-sea multi-platform joint operation models can be categorized into three types: joint operations based on a surface mother ship, joint operations based on an unmanned surface platform, and joint operations based on an underwater lander [22]. These three modular joint operational modes enable different types of submersibles to be flexibly combined to meet the needs and complexities of various tasks.

In the context of the big data and artificial intelligence era, the quantity and complexity of information are expanding swiftly, while human capacity for information perception has not experienced a significant breakthrough [23]. Moreover, given that deep-sea operations are stratified into multiple stages, the situational information required by divers differs across these stages, posing a considerable challenge for divers to swiftly and accurately locate necessary information elements amidst a flux of data. This issue is accentuated on the submersible's human-machine interface, which presents a multitude of parameters, encompassing depth, water temperatures, currents, oxygen levels, among others. Divers need to promptly and effectively access and utilize these pieces of information for decision-making throughout the execution of varying tasks.

In this study we introduce a situational awareness information system specifically designed for complex and variable underwater missions, which includes a structured taxonomy of situational awareness information pertinent to manned submersibles. To further this endeavor, we employ the Analytic Network Process (ANP) for the quantitative analysis and assessment of the interrelatedness and importance of information gleaned through situational perception. By refining the interplay among various informational elements, we prioritize the impact factors on situational awareness. This refinement is intended to alleviate the cognitive load on navigators during the exchange of information with machines, thus bolstering the mission's overall reliability and operational efficiency.

CONSTRUCTION OF SITUATIONAL AWARENESS SYSTEM AND INFORMATION NETWORK IN MANNED SUBMERSIBLE

The concept of Situation Awareness (SA) emerged in the 1980s within the United States military, characterized by three principal elements: perception, comprehension, and projection, and was formally defined by Endsley M. R in 1988[24]. SA embodies the dynamic and comprehensive capacity to interpret the immediate context through environmental cues, originally leveraged for pilot training to ensure they could assimilate ample information for accurate maneuvering [25]. The SA framework has since been extensively adopted in battlefield operations, advancing abilities to uncover, discern, comprehend, and react to security hazards, thereby aiding in the execution of decisive actions [26]. Moreover, SA constitutes a crucial segment of human information processing — a temporal and spatial internal representation of the individual’s awareness and predictive faculties regarding the states and dynamics of the environment and entities, a pivotal determinant for an operator's strategic choices and efficacy [27]. Overall, Situation Awareness (SA) involves the cognitive process of perceiving, comprehending, and anticipating the evolution of an entity within a given timeframe, and discerning its implications for both the current situation and future outcomes [28].

Complex Operational Scenarios Faced by the Manned Submersible Situation Awareness System

Situation Awareness is essential in large and intricate dynamic environments or systems requiring human engagement. The complex and unpredictable nature of the deep-sea environment faced by manned submersible cooperative tasks (Figure 1) demands the support of a robust Situation Awareness system. Manned submersible operations are characterized by lengthy durations, confined workspaces, significant task difficulty, and adverse environmental conditions [29]. In such a complex deep-sea setting, swiftly grasping the prevailing environmental status and executing accurate decision-making is of utmost importance. The complexity of the environmental data renders sole reliance on the submariners' judgment unfeasible, underscoring the importance of Situation Awareness in these operations.

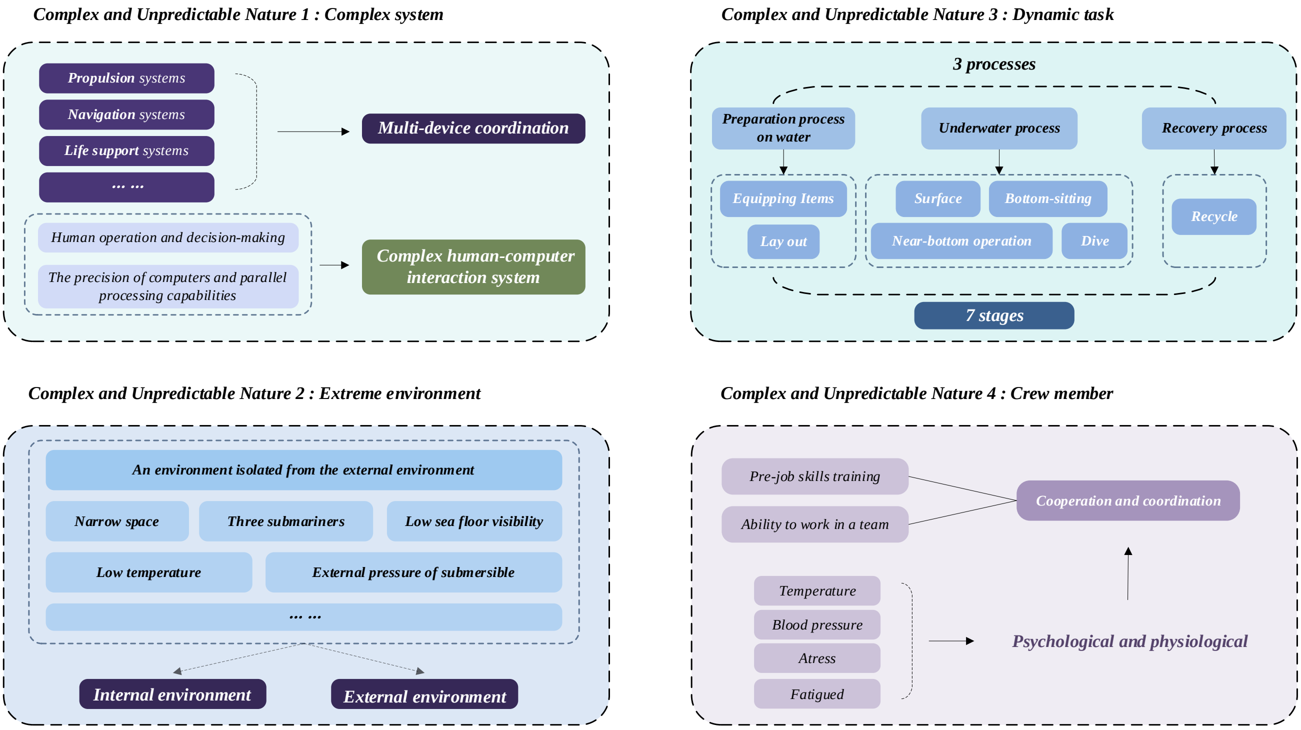

Figure 1. Complex scenarios of deep-sea operations

Complex system.

The manned submersible represents a multifaceted system [30]. Its design and manufacturing process incorporate multidisciplinary knowledge. The human-machine interaction system is a pivotal element of the manned submersible's intricate framework (Table 1).

Table 1. The complexity performance of the human-computer interaction system of manned submersible

Complexity performance	content
Multiple input and output	The man-machine system needs to visually output the information in diversified information output ways, to help the submersible to receive the information better and more quickly.
Complex task execution	The human-computer interaction system needs to provide flexible and diversified operation interface and interaction modes to meet the needs of different tasks and ensure that submersible pilots can easily and accurately perform tasks.
A lot of information processing	The human-computer interaction system needs to have strong information processing ability, which can integrate, analyze and visually display the data to help the submersible pilots understand and use this information.
adaptive capacity to environment	The deep-sea environment poses unique challenges to the human-computer interaction system, including high pressure, low temperature, humidity and other extreme conditions.

Dynamic task

Deep-sea operations conducted by manned submersibles are intricate, multi-faceted, and extended in duration (Figure 2). Each stage features unique operational tasks, necessitating variable distributions of functions between humans and machines depending on the specific task at hand.

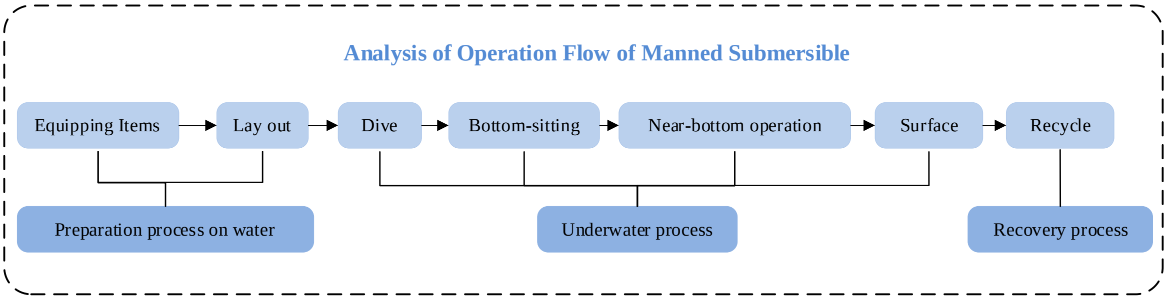

Figure 2. Analysis of the operation process of manned submersible

Extreme environment

Manned submersibles operate within the bounds of two primary extreme environments: internal and external (Table 2).

Table 2. Extreme environment performance of manned submersible

Extreme environment category	Extreme performance
Internal extreme environment	Small cabin space
	High personnel density
	Special physical environment [31]
External extreme environment	Deep sea high pressure
	Dark environment
	Variable hydrological conditions
	Biological interference

Crew member

The interior of a manned submersible is engineered to host a trio comprising one pilot and two observers, with each individual bearing distinct responsibilities and tasks. Symbiotic cooperation and coordination among them are essential to the seamless execution and fulfillment of the submersible's operational tasks.

In complex deep-sea operation environment, depth optimization of the manned submersible situational awareness system, for submersible provides a comprehensive understanding, receiving and assessment environment, make them through the situational awareness system, multi-channel perception of deep-sea operation information, quickly understand the current state and quickly make correct judgments and decisions. The situational awareness system in the manned submersible has five unique characteristics (Table 3).

Table 3. Characteristics of the situational awareness system

	Characteristic	Ask
1	On-demand interconnection	Timely acquisition, synchronization, processing and transmission of all kinds of information and data, to achieve the real-time information transmission between equipment and man-machine, to ensure the smooth progress of the task.
2	Flexible display	According to the specific task needs, adjust the way and content of the information display, to provide the most intuitive and effective information.
3	Natural interaction	It should have an intuitive interactive interface to interact with divers in an intuitive and convenient way, to reduce the operation difficulty and improve work efficiency.
4	Convenient coordination	Support the requirements of multi-body cooperative operation, effectively realize the coordination and command scheduling between each submersible and between human and submersible and optimize the operation process.
5	Efficient perception	Ability to quickly and accurately obtain and analyze environment and task information to provide accurate operational information for submersible pilots.

Construction of Information Network in the Situational Awareness System of Manned Submersible

The primary goal of the situation awareness system in manned submersibles is the intricate task of distilling a vast array of complex maritime data into tangible information elements. By weaving connections among these elements, the system aims to forge an integrated network of deep-sea situational intelligence. This facilitates real-time gathering, processing, integration, and presentation of diverse data pertinent to the submersible and its environmental context, simplifying intricate datasets into clear, user-friendly information. Such a system is crucial for enabling submariners to grasp the immediate conditions of the submersible, assess the environmental situation, and recognize potential perils and opportunities.

Through rigorous analysis of the sophisticated operational scenarios encountered by manned submersibles, alongside corresponding national and industry standards, a collection of over one hundred valid information elements has been distilled. Given the extensive nature of this data, it is essential to manage information meticulously and process it effectively to uplift the caliber of decision-making. Consequently, these elements are segregated into four principal categories according to their distinct utility (Table 4):

Table 4. Information description on the 4 main categories of manned submersible

Information category	definition
System mode	The technical status and performance parameters of the manned submersible itself
Task information	The mission information involves the specific details of the submersible's mission execution
environmental information	Environmental information includes data on the Marine environment around the submersible
Personnel status	Information related to the submersible pilots

To enhance the orderliness and efficiency of information handling, a more sophisticated and integrated approach to information management is essential. Building upon this, the four main categories have been meticulously subdivided into 14 subcategories (Table 5). This categorization approach, underpinned by the underlying attributes and applications of the data, meticulously structures the intricate information system, bolstering the safety, efficiency, and result-driven performance of submersible operations.

Table 5. Manned submersible 14 small category

Information category 1	Information Category 2	definition
System mode	Run the information	Basic dynamic features during navigation and movement
	Device status information	Operating status and performance data of the main equipment and systems
	Emergency and life support system information	Involving emergency communications, warnings, and prompts
	Communication system information	Communication facilities inside and outside the submersible
Task information	Subsubmersible basic operation information	Time, place and other basic information
	Underwater operation information	Information requiring feedback during an underwater navigation mission
	Window to watch for job information	Information related to the observation activities conducted through the submersible window
	Sit bottom homework information	Information about the submersible operating on the sea floor
	Collaborative operation information	Collaborative-related operations and communication information
Environmental information	In-cabin environmental information	Information about the internal environment of the submersible
	Outside the cabin environmental information	Information on the external environment of the submersible
Personnel status	Physiological information	The physiological state of the submersible pilot, such as heart rate, blood pressure, oxygen saturation, etc
	Psychological information	Involving the psychological state and stress level of the submersible pilot
	Training experience	Information on operational training, safety training, and emergency response training

Guided by the four principal and 14 sub-category classification, we have meticulously categorized over a hundred specific data points, culminating in the comprehensive construction of the data spectrum architecture for the situation awareness system dedicated to manned submersibles (Table 6). (We take the example that each subclass table shows two)

Table 6. Information pedigree architecture of manned submersible situational awareness system

Information pedigree architecture of the situational awareness system		
System mode	Run the information	Azimuth
		Speed of a ship or plane
		...
	Device status information	Projector status
		State of electrical equipment
		...
	Emergency and life support system information	Emergency communication
		Warnings and prompt information
		...
	Communication system information	Acoustic positioning
		Water sound communication.
		...
Task information	Submersible basic operation information	Date
		Working hours
		...
	Underwater operation information	Voltage...
		Current
		...
	Window to watch for job information	Geological structure
		Topography
		...
	Sit bottom homework information	Deep detection in Haiti
		Deep sea image photography
		...
	Collaborative operation information	Position
		Degree of completion
		...
Environmental information	In-cabin environmental information	Oxygen content
		Carbon dioxide content
		...
	Outside the cabin environmental information	Sea weather
		Geodetic coordinates
		...
Personnel status	Physiological information	Heart rate
		Blood pressure
		...
	Psychological information	Pressure
		Load
		...
	Training experience	...

ANALYSIS AND EVALUATION MODEL OF INFORMATION ELEMENTS FOR SITUATION AWARENESS IN MANNED SUBMERSIBLES

In this section, we present a multi-criteria decision-making methodology predicated upon the network hierarchy analysis approach to resolve the optimization issue related to the importance and temporal distribution of information elements within the situation awareness system under complex underwater collaborative operations.

Construction of the ANP Network Structure for the Situational Awareness Information System

The Analytic Network Process (ANP), first introduced in 1996 by Thomas L. Saaty [32], is a scientifically effective decision-making approach conceived to assist decision-makers in navigating a plenitude of complex alternatives. By generating comparative matrices between elements via direct and indirect dominance [33], and using the "super matrix" to analyze the contributing facets, it derives both local and global weight decision analysis methodologies that can manage the intricacies of mutually influential factors.

Following the previously laid-out framework for the manned submersible situational awareness system information spectrum, we managed to create an assessment structure for the influential factors within the manned submersible situational awareness system (Table 7).

Table 7. Impact factor evaluation system of the situational awareness system of manned submersible

Target layer	Standard layer (primary indicator)	Elemental layer (secondary indicator)
The situation awareness information of the manned submersible	(S)System mode	(S1) Run Information
		(S2) Device status information
		(S3) Emergency and Life Support System Information
		(S4) Communication system information
	(R)Task Information	(R1) Submersible basic operation information
		(R2) Underwater navigation operation information
		(R3) Window observation job information
		(R4) Sitting bottom job information
		(R5) Co-operation information
	(E)Environmental information	(E1) In-cabin environmental information
		(E2) Outside the cabin environmental information
	(H)Personnel status	(H1) Physiological information
		(H2) Psychological information
		(H3) Training Experience

On the foundations of the intricate spectrum of situational awareness influencing factors in manned submersibles, this study employs the manned submersible's situational awareness information system as the controlling layer. Additionally, it incorporates the system, task, environment, and individual factors as the primary influencing indicators of the network layer. Consequently, we assembled the ANP hierarchical structure for the manned submersible's situational environment, which can be viewed in Figure 3.

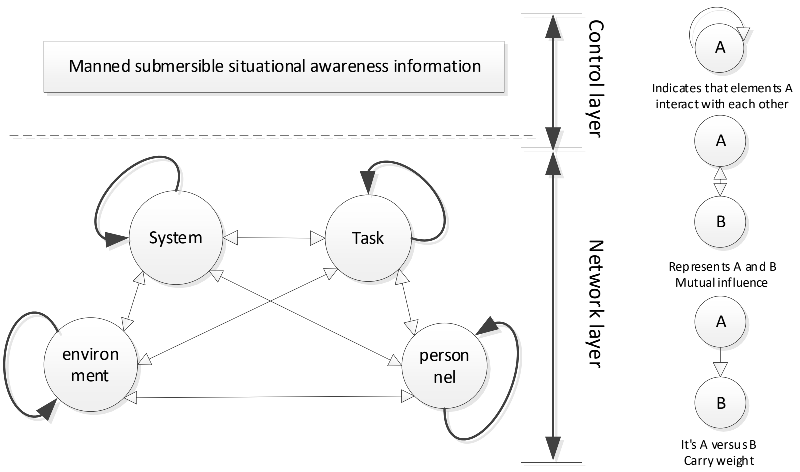

Figure 3. The situation awareness of manned submersible affects the information ANP network structure

We utilized the Super Decision [34] software to establish an ANP model reflecting the impact of information on the manned submersible's situational awareness, as depicted in Figure 4.

Figure 4. The situation awareness of manned submersible in SD affects the network structure of information ANP

Count

To gather information on the influential and dominant relationships amongst the indicator elements, we devised and distributed a survey. The survey was given to 15 participants, all of whom submitted a completed form, yielding a 100% response rate. According to the structure of ANP, we obtained a digraph of the influencing factors of situational awareness of manned submersible (Figure 5).

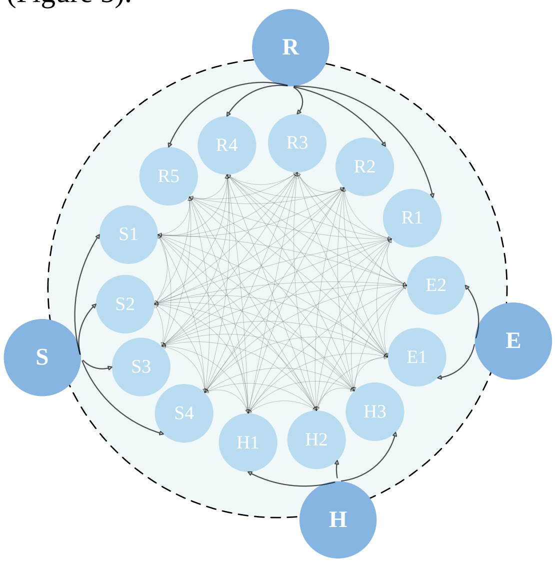

Figure 5. The relationship between the influencing factors of situational awareness of manned submersible is a digraph

In this stage, we accorded each an equal weight of 0.25. A team of eight specialists from a research institute affiliated to China Shipbuilding Industry Corporation, was invited to form an expert panel. Using the Delphi method [35], they conducted an assessment on the 14 secondary metrics in the informational spectrum for situational awareness, thus determine the type of control and the weight of each information element. Subsequently, with the use of the 1-9 scale method, a pairwise comparison and grading of the importance of the i, j indicators in each matrix were conducted, which ultimately allowed us to construct a judgment matrix depicted (Table 8). Customarily, CR$\leqslant$0.1 is indicative of successful validation. As the consistency check results for all comparative matrices also fall below 0.1, the data validation is deemed to have successfully passed.

Table 8. Pairwise contrast matrix of S elements with S1

S1	S1	S2	S3	S4	Feature Vector W
S1	1.00	3.00	5.00	2.00	0.4731
S2	0.33	1.00	3.00	0.50	0.1696
S3	0.20	0.33	1.00	0.25	0.0728
S4	0.50	2.00	4.00	1.00	0.2845

After the SD operation, the final limit hypermatrix is shown as follows (Table 9):

Table 9. Extreme supermatrix.

	S1	S2	S3	S4	R1	R2	R3	R4	R5	E1	E2	H1	H2	H3
S1	0.0650	0.0650	0.0650	0.0650	0.0650	0.0650	0.0650	0.0650	0.0650	0.0650	0.0650	0.0650	0.0650	0.0650
S2	0.0468	0.0468	0.0468	0.0468	0.0468	0.0468	0.0468	0.0468	0.0468	0.0468	0.0468	0.0468	0.0468	0.0468
S3	0.0742	0.0742	0.0742	0.0742	0.0742	0.0742	0.0742	0.0742	0.0742	0.0742	0.0742	0.0742	0.0742	0.0742
S4	0.0640	0.0640	0.0640	0.0640	0.0640	0.0640	0.0640	0.0640	0.0640	0.0640	0.0640	0.0640	0.0640	0.0640
R1	0.0532	0.0532	0.0532	0.0532	0.0532	0.0532	0.0532	0.0532	0.0532	0.0532	0.0532	0.0532	0.0532	0.0532
R2	0.0454	0.0454	0.0454	0.0454	0.0454	0.0454	0.0454	0.0454	0.0454	0.0454	0.0454	0.0454	0.0454	0.0454
R3	0.0424	0.0424	0.0424	0.0424	0.0424	0.0424	0.0424	0.0424	0.0424	0.0424	0.0424	0.0424	0.0424	0.0424
R4	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453	0.0453
R5	0.0637	0.0637	0.0637	0.0637	0.0637	0.0637	0.0637	0.0637	0.0637	0.0637	0.0637	0.0637	0.0637	0.0637
E1	0.1256	0.1256	0.1256	0.1256	0.1256	0.1256	0.1256	0.1256	0.1256	0.1256	0.1256	0.1256	0.1256	0.1256
E2	0.1244	0.1244	0.1244	0.1244	0.1244	0.1244	0.1244	0.1244	0.1244	0.1244	0.1244	0.1244	0.1244	0.1244
H1	0.0864	0.0864	0.0864	0.0864	0.0864	0.0864	0.0864	0.0864	0.0864	0.0864	0.0864	0.0864	0.0864	0.0864
H2	0.0795	0.0795	0.0795	0.0795	0.0795	0.0795	0.0795	0.0795	0.0795	0.0795	0.0795	0.0795	0.0795	0.0795
H3	0.0840	0.0840	0.0840	0.0840	0.0840	0.0840	0.0840	0.0840	0.0840	0.0840	0.0840	0.0840	0.0840	0.0840

The computed weights of the influential factors for the manned submersible situational awareness information system are presented in Table 10.

Table 10. The final weight and ranking of the evaluation indicators

Level 1 indicators	weight	Level 2 indicators	Within-group weights	Group sorting	Total weight	Total ranking
(S)System mode	0.25	(S1) Run Information	0.2600	2	0.0650	7
		(S2) Device status information	0.1872	4	0.0468	11
		(S3) Emergency and Life Support System Information	0.2968	1	0.0742	6
		(S4) Communication system information	0.2560	3	0.0640	8
(R)Task Information	0.25	(R1) Submersible basic operation information	0.2128	2	0.0532	10
		(R2) Underwater navigation operation information	0.1816	3	0.0454	12
		(R3) Window observation job information	0.1696	5	0.0424	14
		(R4) Sitting bottom job information	0.1812	4	0.0453	13
		(R5) Co-operation information	0.2548	1	0.0637	9
(E)Environmental information	0.25	(E1) In-cabin environmental information	0.5024	1	0.1256	1
		(E2) Outside the cabin environmental information	0.4976	2	0.1244	2
(H)Personnel status	0.25	(H1) Physiological information	0.3456	1	0.0864	3
		(H2) Psychological information	0.3180	3	0.0795	5
		(H3) Training Experience	0.3364	2	0.0840	4

The weights within each group are shown in the Figure 6:

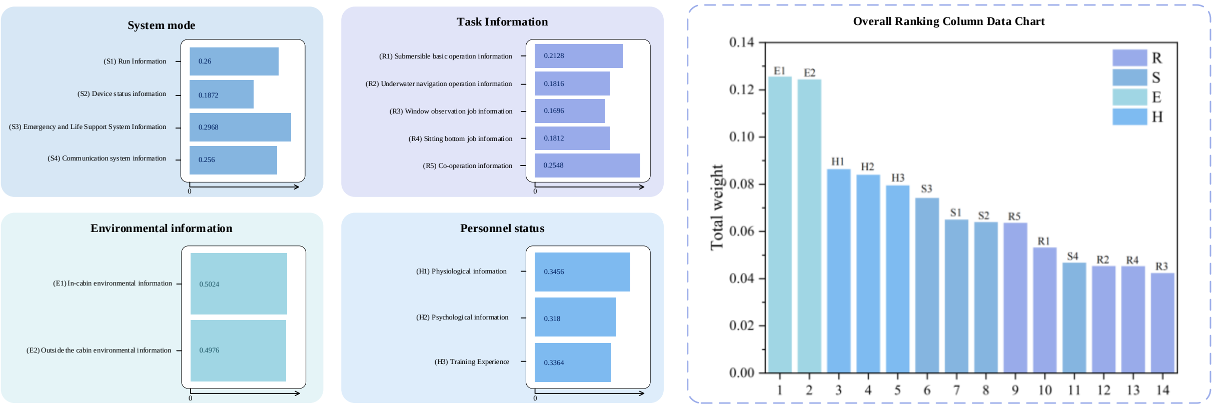

Figure 6. Histogram of elemental specific gravity analysis within each group

DISCUSS

Interpretation of Result

In the third section, we employed the Analytic Network Process (ANP) to present a quantitative study on the correlated influential factors. This allowed us to ascertain the weight proportions for each risk factor index, providing a quantified evaluation of the importance and efficiency of information transmission for manned submersibles in deep-sea operations. The findings are as follows:

The ANP impact factor evaluation model of the manned submersible situational awareness information system aligns with practical conditions. By quantifying each impact factor index, the impact level of each information element on the situational awareness system of the manned submersible was established.

Assuming individual primary indicators bear equal importance, the secondary indicators under the primary of personal information and environmental information have relatively greater weights. The decisive impact of specific factors such as the physiological and psychological status of divers on the safety and performance of submersible operations is highlighted. For instance, when assessing the state of a diver, the high weight assigned to changes in the operator's physiological state emphasizes its importance in maintaining operational accuracy and decision-making quality.

In the primary indicator of system status, the emergency and life support system information had the highest weightage in the internal indicator analysis. This indicates that within the evaluation of the submersible's system status, responding to and managing emergencies are considered the most crucial tasks.

Each of the five secondary indices under the primary index of task information holds relatively lower global weights. Although this information is crucial for successful task execution during descent, bottoming out and bottom-adjacent operations, its relevance is stage-specific, resulting in less weightage overall. Rather than reducing the criticality of these sets of information, it underscores an assessment system that considers the needs and characteristics of each stage, ensuring a logical allocation of resources and attention.

Limitations and Subsequent Research Content Outlook

Manned submersible underwater operations are characterized by unique environments, specific tasks, and high-complexity operations. This paper tackles the complex operational situations encountered by manned submersibles. However, the situational awareness information elements extracted per relevant national and industry standards are incomplete. With the development of manned submersibles and the changing ways of joint operations, the elements of situational awareness information will continue to increase. The author postulates a few issues warranting further in-depth examination, as follows:

Refining situational awareness information elements: With sustained advancement of manned submersible technology and underwater operation methods, it is imperative continuously to update and refine situational awareness information elements.

Evaluation and prioritization of tertiary indicators: The spectral structure of situational awareness system information has myriad tertiary indicators under each secondary indicator. For each tertiary indicator, ANP computations should be performed to construct a more detailed ANP network structure for the manned submersible situational awareness information system, to provide a more scientific evaluation.

Dynamic adjustment of weight allocation during operations: The four primary indicators may indeed be necessary to dynamically adjust these weights according to the specific tasks and environment at each stage to ensure that the weight distribution aligns more closely with actual circumstances.

CONCLUSION

As the core component of human information processing, Situational Awareness (SA) has led to the construction of Situational Awareness Information Systems using the principles of SA, which have been widely used in complicated environments with high difficulty such as flight training and operations. Due to the severe challenges of the deep-sea environment, designing and building a SA Information System that can assist manned submersibles to deal with these complex factors in real-time and accurately has become all the more important.

In this research, this system's main characteristic is its ability to dynamically acquire and analyze multiple pieces of information, such as the working status of the submersible's equipment, task requirements, deep-sea environmental conditions, and the real-time behavior of the divers. Such design endows the system with comprehensive perceptual ability of the entire operational environment, ensuring constant awareness of submarine personnel concerning the global state of deep-sea tasks. Furthermore, the system prompt provision of feedback concerning collected information and instantaneously created operational data keeps submarine staff abreast of the present functioning state and reaction requirements. Concurrent with this, the system's early detection feature anticipates prospective issues or threats, supplying submarine personnel with a well-prepared basis for decision-making. This potent forewarning capability dramatically bolsters the safety factor inherent in dive operations. The attributes and capabilities of this system denote a substantial progression relative to traditional manned submersible systems. Conventional systems often can only process limited information, lack sufficient perception of complex environments and lack timely feedback mechanisms and warning functions. The new system breaks these limitations, this system has clear advantages in fully and dynamically "perceiving" information and providing real-time feedback and early warnings. These advantages enable the system to adapt and handle the complex changes of deep-sea operational environment more accurately and swiftly, greatly improving operational efficiency.

And we have discovered several issues worth further deliberation and resolution, such as incomplete information elements, unclear data details, and insufficient segmentation of informational factors. Thus, we intend to scrutinize these problems in subsequent research, enhancing and refining the information elements, with the goal of achieving a more comprehensive and in-depth situational awareness in future information systems. Concurrently, we will streamline the strategies for data collection and processing to yield more precise, higher-resolution data. Furthermore, we'll increase the granulation of information factors, facilitating our in-depth understanding and accurate appraisal of the situational awareness capacity of manned submersibles.

In a broader view, in-depth research into situation awareness information systems can promote more extensive interdisciplinary innovation centered around efficient information management and adaptive decision support systems. Such exploration may have significant implications for the future course of marine science, particularly in providing advanced data acquisition and processing methods for increasingly deeper and more dangerous marine explorations. The potential and significance of this system are noteworthy. We will continue striving to optimize and improve the situation awareness information system of manned submersibles, hoping to provide more effective support for marine exploration.

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REFRENCES

[1] Xu W Z, Qingyon Z. 2016 Overview of present status and development trend of full ocean depth submersibles. Shipbuilding of China. 57(2) pp 206-211

[2] Jiang Z, Cui W C 2015. A review of the latest progress in research on hydrodynamic performance of full ocean depth submersibles. Shipbuilding of China. 56(4) pp 188-199

[3] Ren Y, Liu B, Ding Z, et al. 2018 Research on the current status and development trend of manned submersibles. Journal of Marine Technology. 37(2) pp 114-122

[4] Minzhuo G, Dengkai C. 2022 Study on the theory and method of the layout design of manned submersible capsule (2014 paper compilation of Shaanxi Mechanical Engineering Society). CNC Automation Branch of Shaanxi Mechanical Engineering Society. pp 24-28

[5] Cao J, Hu Z, Liu T. 2020 Current situation and development of deep-sea submersible equipment. Shipbuilding of China. 61(01) pp 204-218

[6] Chen D, Zhu M, Qiao Y, Wang J, Zhang X. 2023 An ergonomic design method of manned cabin driven by human operation performance. Advanced Design Research. 1(1) pp 12-20

[7] Zhang S, He W, Chen D. 2019 Compound evaluation method for the space comfort of manned submersible. Journal of Harbin Institute of Technology. 51(10) pp 83-89

[8] Zhang S, He W, Chen D, et al. 2019 Thermal comfort analysis based on PMV/PPD in cabins of manned submersibles. Building and Environment. 148 pp 668-676

[9] Chen D, Li B, Ye C. 2018 Layout optimization design of manned submersible viewports based on JACK. Ship Mechanics. 40(8) pp 77-81

[10] Dengkai C, Yu F, Shuai Z, et al. 2018 Manned submersible working cabin layout design method under cabin function system constraints and ergonomic constraints. Chinese Journal of Ship Research. 13(2) pp 41-50

[11] Fan W, Yu S H, Wang J F. 2015 Evaluation method of DSV cabin layout based on human fatigue characteristics machine design. mechanical layout. 32(09) pp 105-110

[12] Licheng Z, He Z M, Yu S H. 2014 Experimental research of manned submersible′ s seat surface in energy optimi-zation method. Journal of Ship Mechanics. 18(07) pp 849-855

[13] Zong LC, Ye C, Yu S H, Chen D K. 2013 Research and application of intelligent layout method in DSV cabin equipment. Shipbuilding of China. 54(3) pp 147-154

[14] Wang H, Yu S H, Chen D K, et al. 2023 Mission-oriented human-machine interaction information importance assessment of deep-sea manned submersible. CIMS. pp 1-18

[15] Wang H, Yu S H, Chen D K, et al. 2022 Mission-oriented human-machine interaction information structure analysis of manned submersible. Journal of Harbin Institute of Technology. 54(12) pp 55-64

[16] Zhang Y C, Zhou X Y, Zheng Z H, et al. 2022 Design of Human-computer Interaction of Manned Submersible Navigation Console Hardware Based on Human Factors. Human ergonomics. 28(05) pp 7-13

[17] Zhang Y C, Sun G W, Ma X N, et al. 2022 Optimal design of navigation control interface for deep-sea manned submersible based on human factors. Ship Science and Technology. 44(01) pp 154-158

[18] Shi L, Xu W Z, Li Y Y, et al. 2022 All-sea human-computer interaction interface evaluation of deep manned submersible based on behavioral and eye movement data. Chinese navigation medicine and high air pressure medical magazine. 13(1) pp 345-351

[19] Liang R S, Zhang L H. 2012 Research on Interface Design of Manned Submersible User-centered. Packaging Engineering. 33(18) pp 31-34+53

[20] Xu Q A, Hu Z, Ye C, Wang S, Liu S, Cao J. 2022 Present Situation and Prospect of Deep-sea Manned Submersible. Technology and Its Application Prospective technology. 1(02) pp 36-48

[21] Ye C, Xu W Z, Liu S. 2021 Application of ergonomics to layout design of manned submersible. Journal of Northwestern Polytechnical University. 39(02) pp 233-240

[22] Yang L, Zhao S, Wang X, Shen P, Zhang T. 2022 Deep-Sea Underwater Cooperative Operation of Manned/Unmanned Submersible and Surface Vehicles for Different Application Scenarios. Journal of Marine Science and Engineering. 10(7) pp 909

[23] Wang Y H. 2022 Cognitive Mechanism and Evaluation Method of Human-machine Interaction in Intelligent Vehicle Cockpit Northwestern Polytechnical University.

[24] Endsley M R. 1988 Design and Evaluation for Situation Awareness Enhancement Proceedings of the Human Factors and Ergonomics Society Annual Meeting. 1988(2)

[25] Agli H, Bonnard P, Gonzales C, et al. 2016 Incremental Junction Tree Inference Proceedings of International Conference on Information and Management of Uncertainty in Knowledge-Based Systems. pp 326-337

[26] Hu H B, Guo H D. 2006 Architecture and Techniques of Common Operational Situation Picture Command and control and simulation. 2006(05) pp 28-32

[27] Endsley, Mica R. 1995 Toward a Theory of Situation Awareness in Dynamic Systems Human Factors. The Journal of Human Factors and Ergonomics Society. 1995(1)

[28] Wang L L. 2022 Research on Fusion Detection and Situation Awareness of Maritime Vessels University of the Inner Mongol.

[29] Shuai Z, Cong Y, et al. 2018 Research on method of human failure prediction in the process of landing manned submersibles. Journal of Harbin Engineering University. 39(02) pp 290-296

[30] Zheng D Y. 2019 Research on Topological Structure of Human-computer Interactive Information Network in Complex Task Environment Southeast China University.

[31] Jiang L, Jin F L, Hou D Y, et al. 2014 The application of the atmosphere control technology for the manned submersible. Jiaolong Ship Science and Technology. 36(08) pp 127-132

[32] Saaty T L. 2008 The analytic network process Iranian. Journal of Operations Research. 2008(1) pp 1-27

[33] Thomas L. Saaty 1986 Axiomatic Foundation of the Analytic Hierarchy Process Management Science. 1986(7)

[34] Lan F. 2018 Risk Evaluation of Software Project Development Based on FISM-ANP-Grey Clustering UESTC

[35] Wang C Z, Si Q. 2011 A Study of Data Statistical Processing Method of Delphi Method and Its Application. Journal of Inner Mongolia Institute of Finance and Economics (comprehensive edition). 9(04) pp 92-96