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Application of combined SWOT and AHP (A'WOT): A case study for maritime autonomous surface ships

SWOT ve AHP (A'WOT) yöntemlerinin birlikte uygulanması: otonom yüzey gemileri çalışması

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ABSTRACT

Increasing operational costs, the growth in ship tonnage, loss of lives, and the human factor in maritime accidents have driven the inevitable emergence of Maritime Autonomous Surface Ships (MASSs) in the world's seas. However, the universal establishment of laws and regulations for autonomous ships is still pending. Moreover, challenges arise due to the scarcity of personnel for immediate response to mitigate the impact of ship accidents and uncertainties linked to the absence of commercial autonomous voyages in international waters. Utilizing SWOT analysis as a strategic management approach enables the identification of strengths and weaknesses in a situation, awareness of related opportunities for leveraging those strengths, examination of threats, and formulation of measures against potential risks. This study encompasses a comprehensive evaluation of the positive and negative aspects of autonomous surface vehicles, encompassing their capabilities, advantages, challenges, and disadvantages. It employs SWOT analysis and the Analytic Hierarchy Process (AHP) method to facilitate strategic planning necessary for the widespread adoption of autonomous ships.

Keywords: Autonomous ship, MASS, SWOT analysis, AHP, A'WOT.

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ÖZET

Artan işletme maliyetleri, büyüyen gemi tonajları, can kayıpları, gemi kazalarında insan faktörünün büyük etkisi gibi nedenler otonom yüzey gemilerinin (MASS) yakın gelecekte kaçınılmaz olarak dünya denizlerinde seyir yapacak olmasını tetikleyen başlıca faktörlerdir. Ancak henüz otonom teknelerle ilgili yeterli uluslararası kanun ve yönetmeliklerin olmayışı, gemi kazaların sonuçlarının büyüklüğünü ve kazanın etkilerini azaltacak ilk müdahaleyi yapacak personel olmayışı, halihazırda otonom gemilerin uluslararası sularda ticari seferler yapmaması nedeniyle mevcut olan belirsizlikler ve otonom gemilere duyulan güvensizlik günümüzde otonom su üstü araçlarının yaygınlaşması önündeki en büyük engellerdir. SWOT analizi ile ele alınan bir durumun ya da konunun güçlü ve zayıf yönlerini keşfetmek, bunlarla ilgili fırsatların farkına varmak ve bu fırsatlardan yararlanmak, tehditleri incelemek ve ortaya çıkabilecek risklere karşı önlem almak mümkün olmaktadır. Bu çalışmada otonom su üstü araçlarının yetenekleri, sundukları fırsatlar, avantajları, doğurabileceği sorunlar, dezavantajları gibi olumlu ve olumsuz yönleri bir bütün olarak ele alınmış, uzman görüşlerine göre geliştirme stratejileri önerilmiştir. Otonom gemilerin yaygın olarak benimsenmesi için gerekli olan stratejik planlamayı kolaylaştırmak amacıyla SWOT analizi ve Analitik Hiyerarşi Süreci (AHP) yöntemleri kullanılmıştır.

Anahtar sözcükler: Otonom gemiler, MASS, SWOT analizi, AHP, A'WOT

1. INTRODUCTION

Numerous studies underscore that maritime transport should be viewed as a "human system" and treated accordingly (Hetherington *et al.*, 2006). Human error often plays a role in maritime accidents, and its consideration tends to emerge only after a loss has occurred (Harati-Mokhtari *et al.*, 2007; Yildiz *et al.*, 2021). Recently, examining human contributions to maritime accidents has gained paramount importance in the industry. Similar to aviation and other transportation sectors, human error is a primary factor in preventable maritime accidents. Research, statistics, and investigations into accident causes reveal that human error, whether directly or indirectly, accounts for 70% to 96% of accidents (Ugurlu and Cicek, 2022). There's a consensus among researchers that the human factor is the primary cause and predominant influence behind maritime accidents. Over time, the impact and proportion of the human factor in maritime accidents have remained largely consistent (O'Neil, 2003). One of the most effective strategies to mitigate accidents stemming from human error and subsequently enhance ship safety involves increasing automation to support decision-making processes where appropriate (S. Yang *et al.*, 2007). This is particularly pertinent in the context of unmanned and autonomous ships, which are less prone to human-specific circumstances that might lead to accidents.

Strategic management involves the systematic utilization of an organization's resources to accomplish its defined goals and objectives. Crafting a strategy includes a range of assessments involving risks and resources, counteracting potential risks, and optimizing resource allocation in pursuit of significant goals. This strategic management process unfolds through three key stages: strategy formulation, strategy implementation, and strategy evaluation (David, 2011). The SWOT analysis stands as a pivotal tool within strategic planning, serving as a linchpin for both strategy formulation and evaluation. SWOT analysis is a strategic planning technique employed to assess the strengths, weaknesses, opportunities, and threats facing organizations. This analysis extends two critical advantages to organizations: Firstly, it acts as a diagnostic tool, offering insights into the present status of the organization. The initial components of the analysis, designated by the letters S and W, facilitate self-awareness by uncovering the organization's strengths and weaknesses. Strengths signify the organization's internal capacities that set it apart from competitors, while weaknesses denote the internal aspects where the organization lags behind its rivals. On the other hand, external factors—namely opportunities and threats—evaluate how the organization can navigate the industry landscape. Opportunities involve external factors that can yield positive outcomes for the organization, while threats comprise external factors that pose risks to the organization's continued existence. Consequently, the subsequent phase of the analysis delves into situational assessments with a forward-looking perspective, centered on potential future developments rather than the current state. This aspect inherently relies more on subjective data and estimations.

1.1. Motivations

As human beings, we all possess certain capabilities and limitations. For instance, humans excel in the discernment and recognition of patterns. No machine worldwide can interpret graphics and data on a radar screen as proficiently as a trained individual. Conversely, our memory capacity and the swiftness and precision with which we calculate numbers are somewhat restricted, whereas computers outperform us significantly in these aspects. In addition to these inherent characteristics, human performance is influenced by internal factors such as motivation and fatigue, alongside the knowledge and skills we acquire. The physical work environment directly impacts an individual's performance. For instance, the human body functions optimally within a specific temperature range. Performance tends to decline when temperatures deviate from this range and ceases entirely under extreme conditions (Wu *et al.*, 2020). Given the geographical and meteorological conditions of our planet and the ability of ships to navigate all the world's seas, achieving an ideal physical work environment is often unattainable. Adverse sea conditions and ship vibrations can impede movement and dexterity, leading to stress and fatigue. Constrained economic circumstances may also heighten the propensity for risk-taking (Rothblum, 2000).

In spite of the prevailing reservations surrounding autonomous ships due to the inherent uncertainty, valuable insights can be gleaned from incidents involving autonomous surface vehicles, as well as the lessons derived from accidents caused by human factors. Regardless of the terminology employed (autonomous), it remains the case that the design, software, and decision-making mechanisms of these systems are ultimately developed by humans. Furthermore, autonomous ships offer the distinct advantage of being operable in three distinct modes: manned, remote-controlled, and fully autonomous (Dittmann *et al.*, 2021). Over the course of a voyage, it is feasible to alter the autonomy levels through dynamic autonomy. For instance, when approaching a congested port, an autonomous surface vehicle can be under the control of an operator onshore, with the capacity to switch to full autonomy upon entering low-traffic waters. By minimizing the subjective human elements in maritime navigation and substituting them with an intelligent Decision-Making (DM) system for navigation and collision avoidance, it is plausible to reduce maritime accidents and their associated causes. A substantial proportion of mishaps and erroneous decisions at sea can result in the loss of life and environmental catastrophes (L. P. Perera, 2009). In a study conducted by (Mokhtari and Khodadadi, 2013), involving over 1,800 Iranian officers, queries were posed to identify strategies for mitigating human errors. Based on the obtained findings, the following measures were selected as potential remedies for negligence:

- Increasing the automation level,
- More control and surveys,
- More usage of alert signs,
- More accurate working standards, and
- More accurate Programming Maintenance Services (PMS)

The findings undeniably demonstrate that officers engaged in conventional maritime operations also share the belief that autonomous systems hold the potential for enhanced safety. The adoption of autonomous ships has the capacity to reduce the frequency of maritime accidents attributed to human error, owing to reduced human participation in the operational processes, albeit with the introduction of new risks and challenges (Utne *et al.*, 2017).

The aforementioned scenarios have precipitated an accelerated shift towards autonomy. The circumstances conducive to the emergence of economically viable solutions for unmanned and fully autonomous cargo and passenger vessels are ripening. It has been clearly articulated that the objective is to surpass the safety standards of autonomous surface vessels in comparison to their manned counterparts (Ahvenjärvi, 2016). Over the past quarter-century, the heightened capabilities in computational power and communication technologies, the advent of more advanced sensor systems, and reduced costs have spurred the utilisation of MASSs in novel domains such as mine clearance, environmental data collection and monitoring, naval exploration, as well as surface and submarine military applications. Prominent ongoing and large-scale research and development initiatives in Europe within this domain encompass the EU-funded MUNIN project (MUNIN, 2016) and DNV GL's Norwegian ReVolt project, which receives support from Transnova (DNV, 2017). Furthermore, a significant European undertaking is the AAWA project (Laurinen, 2019), backed by a consortium of Finnish enterprises and the Finnish Innovation Finance Agency TEKES. Additionally, the companies Yara and Kongsberg have jointly constructed an autonomous and fully electric container ship named 'Yara Birkeland' (Yara, 2021).

The existing body of literature offers valuable contributions comprising various facets of safety concerning autonomous ship operations, including security and cyber threats (Issa *et al.*, 2022), risk models and their management (Utne *et al.*, 2020), and risk assessments (Wróbel *et al.*, 2017). In particular, numerous studies within the domain of autonomous ships have concentrated their efforts on the enhancement of technical systems to avoid collisions. These enhancements encompass target detection (Zhang *et al.*, 2023), path planning (C. Yang *et al.*, 2023), collision avoidance algorithms (Yuan and Gao, 2022), and the adaptation of COLREGs for application to autonomous ships (Du *et al.*, 2022). However, given the anticipated expansion of MASSs into more intricate missions and diverse weather conditions, these platforms necessitate a heightened degree of autonomy to prevent an escalation of operator workload while simultaneously upholding elevated safety standards.

Various motivations, aside from the human factor, drive the transition towards autonomous ships. The absence of accommodation in unmanned vessels can yield cost savings, reduce tonnage and save space, consequently allowing ships to provide a greater cargo capacity (Laurinen, 2016). As living quarters become superfluous, vessels can become smaller, giving rise to more adaptable transportation solutions that can supplant road and rail transport for short to medium distances (Rødseth and Nordahl, 2017). Furthermore, it can enhance access to potentially dangerous maritime regions and diminish the occurrence of piracy incidents, as personnel cannot be held as ransom (AGCS, 2017). Additionally, the utilisation of MASSs can contribute to environmentally friendly shipping by reducing energy consumption. For instance, the unmanned, fully autonomous, electrically powered ReVolt concept ship is anticipated to offer substantial cost savings exceeding one million Euros annually when compared to a diesel-powered vessel (Alfheim *et al.*, 2018).

The unique strengths of a human operator in managing a complex system lie in their adaptability and creativity. The human capacity to respond effectively to unforeseen situations positively influences system safety. In contrast, a pre-programmed computer system possesses limited adaptability to handle exceptional and unanticipated scenarios. This could be considered a vulnerability of autonomous ships when compared to conventional vessels operated by human personnel. However, this drawback of autonomous surface vehicles is gradually diminishing as technological advancements enable computer systems to learn and adapt (Cui *et al.*, 2022). This adaptability becomes particularly crucial in challenging situations for autonomous ships. For instance, scenarios involving multiple simultaneous sensor failures or deliberate disruption of communication equipment by hackers can result in undesirable consequences. Another advantage of conventional ships is their capability to execute immediate onboard responses in the event of an accident. (Wróbel *et al.*, 2017) conducted an examination of maritime accidents across eight distinct categories and found that autonomous

surface vehicles reduce the likelihood of accidents. However, upon scrutinizing the outcomes of these accidents, it becomes evident that their impact exceeds that of conventional ships. Furthermore, the response of autonomous ships to potential accidents remains uncertain.
In light of the information presented herein and derived from the conducted studies, it becomes evident that all other prerequisites have matured, except for the comprehensive legal procedures and international regulations necessary for the deployment of autonomous surface vehicles in maritime navigation, as well as the capacity to initiate immediate responses in the event of an accident. The insights gleaned from these studies highlight that even the officers serving aboard vessels are now cognizant of the imperative need for MASSs.
The principal objective of this research is to assess the competitiveness of autonomous ships within the maritime industry and to recommend strategic planning approaches for their enduring sustainability. To achieve this, a comprehensive methodological approach is utilised, incorporating SWOT analysis and the Analytical Hierarchy Process (AHP) for conducting the analysis. The remainder of the study is organized as follows: The second section focuses on identifying SWOT factors and development strategies based on a review of existing literature. In the third section author presents the application of the SWOT-AHP method to the proposed factors and strategies. The results and discussions stemming from the study are presented in the fourth section. Finally, the fifth section contains the conclusions drawn from the study.

2. SWOT-AHP (A'WOT) METHOD

A seven-step methodology was adhered to in the study. The flowchart illustrating the quantified SWOT analysis (A'WOT) is depicted in Figure 1.

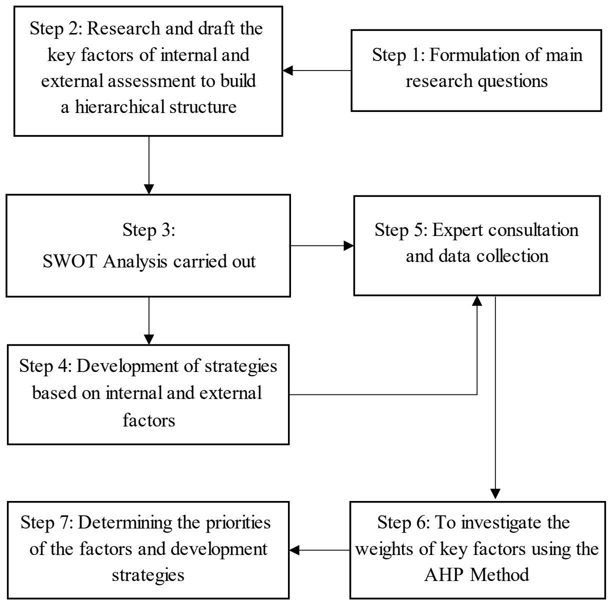

Figure 1. Flowchart of the A'WOT analysis pattern.

2.1. Describing SWOT Factors

Utilizing SWOT analysis, an effective strategy should be devised by amplifying strengths, mitigating weaknesses, capitalizing on opportunities, and safeguarding against threats (Shinno *et al.*, 2006). Given the significance of SWOT analysis in the context of strategic planning within the maritime sector, the objective of this section's study is to assess MASSs through SWOT analysis on the global stage. The aim is to sustain and enhance their strengths, address and rectify their weaknesses, prioritize opportunities, and proactively mitigate threats.
To assess the competitiveness of autonomous vessels, the following four primary research questions were formulated for SWOT analysis.
Question 1: What are the strengths that can encourage its development?
This question was formulated to ascertain the advantages that MASS possess, enabling them to establish competitiveness.
Question 2: What weaknesses will hinder its development?
This question investigates the shortcomings that MASS may exhibit, that is, the areas where MASS is deficient and requires enhancement.
Question 3: What opportunities are there to contribute to development?

This question explores the favourable circumstances that can facilitate a positive impact on the future development of MASS. This includes considering how MASS can contribute to society and the potential benefits it can deliver.

Question 4: What are the threats to be considered in future planning?

This question examines the challenges and obstacles that MASS may encounter. This includes assessing potential consequences that could pose threats to the environment and society, as well as identifying factors that may impede its development.

Using these questions SWOT analysis matrix is developed to identify the strengths, weaknesses, opportunities, and threats of the MASSs in the maritime sector. A total of 31 SWOT factors are finalized for the competitiveness evaluation and for deriving four future strategies (Table 1).

Utilizing these questions, a SWOT analysis matrix has been constructed to identify the strengths, weaknesses, opportunities, and threats associated with MASS within the maritime sector. A comprehensive set of 31 SWOT factors has been determined for the assessment of competitiveness and the formulation of four prospective strategies (Table 1).

To ensure the objectivity of the study, a comprehensive review of the literature was conducted to investigate the various scenarios, advantages, disadvantages, and future prospects pertaining to autonomous ships. Based on this literature research, SWOT factors were identified. In the selection of SWOT factors associated with autonomous ships, careful consideration was given to factors documented in the pertinent studies within the literature (Table A1- Appendix I).

The SWOT approach entails systematic and comprehensive examination of factors associated with management, technology, or planning. SWOT analysis involves the comparison of strengths, weaknesses, opportunities, and threats, combining these four elements to suggest SO (Strengths-Opportunities), WO (Weaknesses-Opportunities), ST (Strengths-Threats), and WT (Weaknesses-Threats) components. Subsequently, after summarising the issues within these four strategic directions, these matters are incorporated into the context of strategic planning for implementation. A development strategies model for autonomous ships, involving diverse interpretations and the formulation of strategies through SWOT evaluation, taking into account the factors outlined in Table 1, is presented in Figure 2.

SWOT analysis, when used effectively, can serve as a robust foundation for strategy development. However, SWOT analysis exhibits certain limitations in the evaluation and measurement phases within the strategic decision-making process. Most articles addressing SWOT analysis offer merely descriptive accounts of the analysis, with only a few employing quantified assessments. This may result in an under utilisation of the analytical method, given the inherent complexity of planning processes, which often involve a multitude of criteria and interdependencies. In the conventional SWOT analysis framework, a significant limitation lies in the inability to quantitatively measure the importance of decision factors, rendering it exceedingly challenging to gauge which factors exert the most profound influence on strategic decision-making (Shrestha *et al.*, 2004). Consequently, SWOT analysis may not provide a comprehensive evaluation of the strategic decision-making process. To address this shortcoming, the Analytical Hierarchy Process (AHP) methodology is employed to ascertain weights and quantitatively assess the relative significance of each factor within the SWOT analysis development strategy.

2.2. AHP Method

The Analytical Hierarchy Process (AHP) represents a potent tool for structuring and modelling, particularly in scenarios involving multi-criteria decision-making. AHP is a methodology that takes into account both objective and subjective assessment criteria when determining the optimal choice, relying on priorities derived from pairwise comparisons of the evaluation criteria. Successfully applied across various management domains (Li and Yuen, 2022), AHP dissects complex problems into constituent parts and subsequently

Table 1. Factors identified through the SWOT approach

SWOT Group	Abbreviation	SWOT Factors
(S)	S.1	Safer than manned ships (for human-related cases)
	S.2	Being resistant to human biological and emotional changes (i.e., cold, hot, fatigue, stress)
	S.3	Ability to make quick decisions
	S.4	Ability to evaluate data from many sources and perform multiple analyzes
	S.5	Ability to determine risk priority
	S.6	Ability to act under COLREG and local navigational rules
	S.7	Ability to learn
	S.8	24 hours of continuous monitoring of the environment and targets
	S.9	Easy to test their reaction to events
	S.10	Remote and easy troubleshooting of software errors and deficiencies
(W)	W.1	Still requires human intervention (i.e., in case of an accident)
	W.2	Limited remote intervention in case of technical failure
	W.3	Still in the testing phase and not yet applied to commercial ships
	W.4	Difficult to develop software at the infrastructure stage
	W.5	Inability to interpret and adapt to events in unexpected situations
(O)	O.1	Promising more environmentally friendly transportation (i.e., no crew-related pollution, fuel savings, and use of renewable energy)
	O.2	The maturation of technological developments for autonomy day by day
	O.3	Reduced ship size and increased carrying capacity due to lack of living quarters
	O.4	Lower operating cost (i.e., no personnel expenses)
	O.5	Ability to access dangerous and unsafe marine areas
	O.6	Effective use for minesweeping, research, data collection, and military purposes
	O.7	More and more people and institutions are interested in the subject
	O.8	Uncover new workforce areas related to operations and software
(T)	T.1	Prejudice towards autonomous vehicles
	T.2	Possible reactions as people will replace
	T.3	Skilled workforce and training gap for management and operation
	T.4	The immaturity of its legal and regulatory status
	T.5	Unknown interaction with manned ships
	T.6	Being vulnerable to cyber attacks
	T.7	Potential for job loss for existing seafarers
	T.8	The potential for new types of risks to emerge

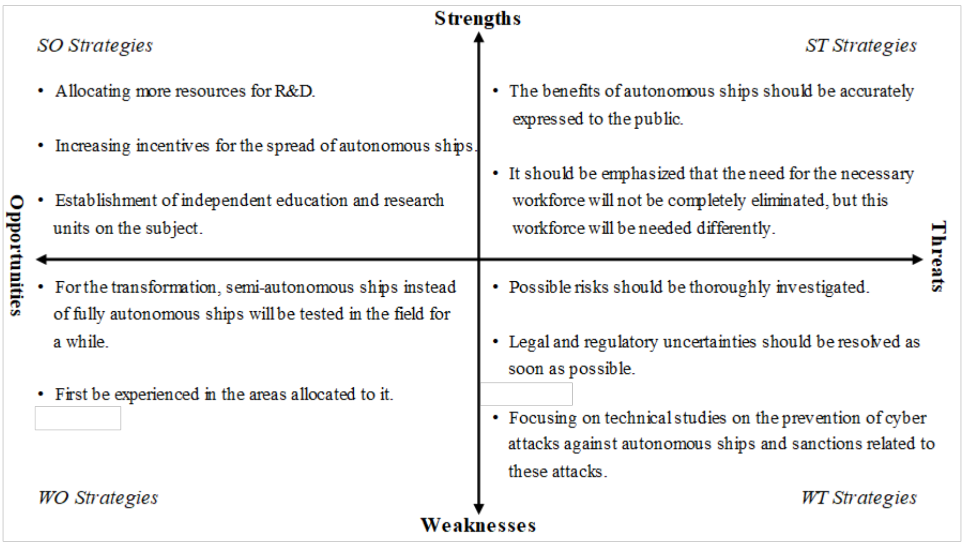

Figure 2. Four-quadrant development strategy model for autonomous ships

integrates all the solutions derived for these components. By amalgamating intuition, emotions, judgement, and rationality, AHP explain all the factors influencing a decision and streamlines the decision-making process. The advantages of AHP encompass its capacity to analyse decision attributes both qualitatively and quantitatively, along with its adaptability in goal-setting (Mahapatra *et al.*, 2021). However, AHP has certain disadvantages, which include its high computational demands even for small-scale problems. It also possesses a subjective nature, relying on individuals to translate their emotions and preferences into numerical judgments. Additionally, as the number of alternatives and criteria increases, the method requires a larger amount of pairwise comparisons, which can lead to increased time and effort. Moreover, over time, the inconsistency of the matrices may increase due to a loss of focus and concentration on the subject. The AHP Method consists of five stages. These are: 1-hierarchy construction, 2- pairwise comparison, 3- deriving relative weights, 4- checking the consistency ratio and 5- synthesizing results.

3. IMPLEMENTATION OF AHP-SWOT (A'WOT) METHOD

The next stage for prioritizing SWOT factors and development strategies obtained from the literature is to use the AHP Method to assess and rank them based on their relative importance.

3.1. Hierarchy construction

In the study, AHP was employed to establish priorities among the SWOT factors. The problem was structured into a four-stage hierarchical process, which involves the identification of SWOT factors, the categorization of these factors, the derivation of strategies through the combination of these groups, and ultimately the formulation of recommended development strategies (Figure 3) to enable measurement of the strategic factor groups and fundamental strategies identified through SWOT analysis via AHP. The inherent complexity of this approach can present implementation challenges; however, the fortunate availability of software tools designed to automate the mathematically intensive aspects has alleviated these difficulties. For this study, Microsoft Excel was chosen and utilised to quantitatively assess all the factors and strategies.

3.2. Pairwise comparison

Pairwise comparisons are conducted among the SWOT factors within each respective SWOT group. During these pairwise comparisons,

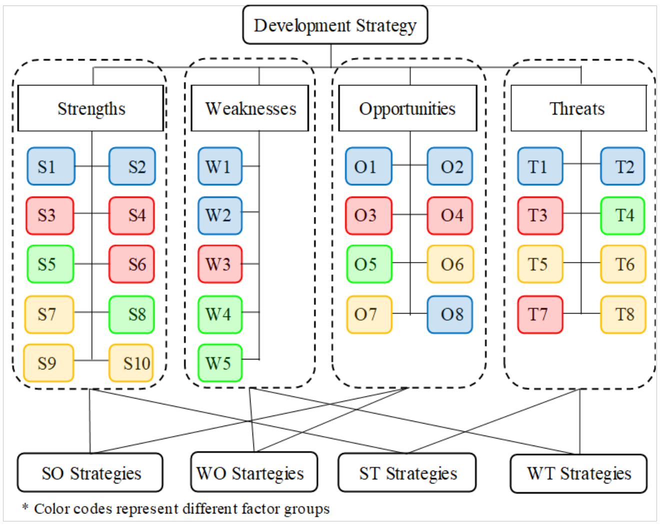

Figure 3. Hierarchical structure of A-WOT analysis

individuals tasked with evaluating the factors in the questionnaire are asked to provide judgements based on two key questions: 1) 'Which factor is more preferred (important) when comparing factor 1 with factor 2?' and 2) 'How much more preferred is one factor over the other factor?' At each stage, the criteria are assessed through pairwise comparisons according to their levels of influence. In the AHP, these multiple pairwise comparisons are made using Saaty's standardized comparison scale (Table 3), which encompasses nine levels (Saaty, 1987). Subsequent to these comparisons, the relative priorities of the SWOT factors are calculated using the eigenvalue approach within the framework of the AHP technique. Expert opinions were sought to establish the weights for the factor groups. As a criterion for selecting the experts whose opinions were solicited, having a minimum of two studies on autonomous surface vehicles was stipulated. Insights were gathered from 10 researchers engaged in the field of MASS, including individuals from the private sector and predominantly academics affiliated with universities. Recognizing the significance of diverse perspectives, experts with expertise in various domains such as law, technology, maritime, shipbuilding, and environmental matters relevant to autonomous ships were specially chosen. The occupational backgrounds of these experts encompassed master mariners, shipbuilders, lawyers, software developers, and engineers.

Table 3. Pairwise comparison scale

Importance	Explanation
1	Two criteria contribute equally to the objective
3	Experience and judgment slightly favor one over another
5	Experience and judgment strongly favor one over another
7	Criterion is strongly favored and its dominance is demonstrated in practice
9	Importance of one over another affirmed on the highest possible order
2, 4, 6, 8	Used to represent a compromise between the priorities listed above

Despite identifying a total of 31 SWOT factors, we have restructured these factors into 15 coherent groups to enhance clarity regarding our objectives. Opinions from all experts are collected in a single matrix by taking the geometric mean. The pairwise comparison matrix (referred to as the A matrix), a square matrix with dimensions 15x15, is presented in the Appendix II.

Comparisons are conducted for values located above the diagonal of the comparison matrix. For comparisons below the diagonal, the following formula is employed.

$$a_{ij} = 1 / a_{ji} \tag{3.1}$$

3.3 Deriving relative weights

To determine the weights of the factors in their entirety, 15 column vectors, each comprising 15 components, and B-column vectors are constructed from the column vectors constituting the comparison matrix.

$$B_i = \begin{bmatrix} b_{11} \\ b_{21} \\ b_{31} \\ . \\ . \\ . \\ b_{151} \end{bmatrix}, \quad b_{ij} = a_{ij} / \sum_{i=1}^{n} a_{ij} \tag{3.2}$$

When the 15 B-column vectors are consolidated in matrix form, the normalized matrix C is constructed and displayed in Appendix III.

Utilising the equation below, the arithmetic mean of the row elements within the C matrix is computed to determine the relative importance (weight) of values for the factors in relation to each other, subsequently yielding the W column vector, commonly referred to as the priority vector.

$$w_i = \sum_{j=1}^{n} c_{ij} / n \tag{3.3}$$

$$W = \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ . \\ . \\ . \\ w_{15} \end{bmatrix} \tag{3.4}$$

Within the SWOT Matrix, established through SWOT analysis to assess the position of autonomous ships within the sector, the weights for four factors each in the categories of strengths, opportunities, and threats, and three factors in the category of weaknesses were determined. The weight values for the complete set of 15 factors are presented in Table 4. Following the decomposition of the problem and the construction of the hierarchy, the prioritisation process commences to define the relative importance of each criterion as outlined in Table A2 (Appendix IV).

3.4 Checking consistency ratio

To compute the eigenvalue (λ), denoted as such, the D column vector is generated by multiplying the comparison matrix A with the priority vector

W. The λs for each evaluation factor are derived by dividing the reciprocal elements of the D vector by the W vector as per equation (3.5). Using the formula below, the λ for the comparison is calculated.

$$E_i = d_i / w_i \ (i = 1, 2, 3, \ldots 15) \tag{3.5}$$

$$\lambda = \sum_{i=1}^{n} E_i / n \tag{3.6}$$

After determining λ, the Consistency Index (CI) can be computed using the equation provided below. In our study, this value was determined to be 0.0439.

$$CI = \frac{\lambda - 1}{1 - n} \tag{3.7}$$

The CI is divided by the standard correction value referred to as the Random Index (RI), as detailed in Table 5, to yield the Consistency Ratio (CR). The CR, as a result of calculations, was determined to be 0.0276.

$$CR = CI / RI \tag{3.8}$$

Table 5. Random consistency index

Size of Matrix (n)	Random Consistency Index (RI)
1	0
2	0
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51
12	1.54
13	1.56
14	1.57
15	1.59

A CR value below 0.10 signifies that the comparisons are consistent. If the CR value exceeds 0.10, it implies the presence of a computational error within the AHP or inconsistency in the comparisons. The CR serves as a means to examine the consistency of the one-to-one comparisons made between the factors. The result is within the acceptable compliance rate limits, as it is below 10%. Therefore, the inconsistency is considered acceptable.

3.5. Synthesizing results

The distribution of importance percentages among the decision points is ascertained by iteratively repeating the comparisons and matrix operations, equating to the number of factors (15 times). Following each comparison operation, mx1 dimensional S column vectors are generated, illustrating the percentage allocations to the decision points of the factors. The resulting mx15 dimensional K decision matrix, comprising 15m x 1 dimensional S column vectors, is presented below.

$$K = \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{115} \\ s_{21} & s_{22} & \cdots & s_{215} \\ . & & & . \\ . & & & . \\ . & & & . \\ s_{m1} & s_{m2} & \cdots & s_{m15} \end{bmatrix} \tag{3.9}$$

By performing matrix multiplication between the decision matrix and the W column vector, the L column vector, referred to as the 'Priority Vector Matrix,' is generated. This vector depicts the percentage allocation of the decision points and establishes their order of significance.

$$L = \begin{bmatrix} 0.735 \\ 1.395 \\ 1.155 \\ 1.005 \\ 0.81 \\ 0.495 \\ 0.585 \\ 0.705 \\ 0.96 \\ 0.735 \\ 1.395 \\ 1.245 \\ 1.005 \\ 0.9 \\ 1.905 \end{bmatrix}$$

The results obtained indicate which factors should receive the most attention. In order of

priority, it was found that T4, S2, O4, and T1 are the factors that need to be considered the most. The factors in order of priority, along with their descriptions, are as follows:
T4- Threats related to unknown issues, security, and risks.
S2- Strengths in data processing speed and analysis capability.
O4- Opportunities related to safety and security.
T1- Threats of negative reactions and prejudice.
The procedure carried out earlier for the SWOT factor groups was applied to derive the development strategies as follows:

$$A = \begin{bmatrix} 1.000 & 1.568 & 2.167 & 1.431 & 1.888 & 0.826 & 2.543 & 0.987 & 1.159 & 1.284 \\ 0.638 & 1.000 & 1.097 & 1.135 & 1.134 & 0.728 & 1.625 & 0.503 & 0.964 & 0.885 \\ 0.461 & 0.691 & 1.000 & 1.196 & 1.038 & 0.768 & 1.661 & 0.515 & 0.738 & 0.872 \\ 0.699 & 0.881 & 0.836 & 1.000 & 1.175 & 0.851 & 2.491 & 0.530 & 0.608 & 0.749 \\ 0.530 & 0.882 & 0.963 & 0.851 & 1.000 & 0.777 & 2.666 & 0.441 & 0.538 & 0.671 \\ 1.210 & 1.374 & 1.338 & 1.175 & 1.287 & 1.000 & 3.640 & 0.746 & 1.170 & 1.131 \\ 0.393 & 0.616 & 0.609 & 0.402 & 0.375 & 0.275 & 1.000 & 0.322 & 0.454 & 0.545 \\ 1.013 & 1.987 & 1.940 & 1.888 & 2.267 & 1.340 & 3.108 & 1.000 & 1.669 & 1.710 \\ 0.863 & 1.038 & 1.356 & 1.644 & 1.858 & 0.855 & 2.203 & 0.599 & 1.000 & 0.768 \\ 0.779 & 1.129 & 1.147 & 1.311 & 1.491 & 0.884 & 1.835 & 0.585 & 1.302 & 1.000 \end{bmatrix}$$

$$C = \begin{bmatrix} 0.132 & 0.140 & 0.174 & 0.119 & 0.140 & 0.099 & 0.112 & 0.158 & 0.121 & 0.134 \\ 0.084 & 0.090 & 0.088 & 0.094 & 0.084 & 0.088 & 0.071 & 0.081 & 0.100 & 0.092 \\ 0.061 & 0.062 & 0.088 & 0.099 & 0.077 & 0.092 & 0.073 & 0.083 & 0.077 & 0.091 \\ 0.092 & 0.079 & 0.067 & 0.083 & 0.087 & 0.103 & 0.109 & 0.085 & 0.063 & 0.078 \\ 0.070 & 0.079 & 0.077 & 0.071 & 0.074 & 0.094 & 0.117 & 0.071 & 0.056 & 0.070 \\ 0.160 & 0.123 & 0.107 & 0.098 & 0.095 & 0.120 & 0.160 & 0.120 & 0.122 & 0.118 \\ 0.052 & 0.055 & 0.049 & 0.033 & 0.028 & 0.033 & 0.044 & 0.052 & 0.047 & 0.057 \\ 0.134 & 0.178 & 0.156 & 0.157 & 0.168 & 0.161 & 0.136 & 0.161 & 0.174 & 0.178 \\ 0.114 & 0.093 & 0.109 & 0.137 & 0.137 & 0.103 & 0.097 & 0.096 & 0.104 & 0.080 \\ 0.103 & 0.101 & 0.092 & 0.109 & 0.109 & 0.106 & 0.081 & 0.094 & 0.136 & 0.104 \end{bmatrix}$$

The development strategies with the highest weight, in order of priority, are WT1, SO1, WO1 and WT2. These strategies have been identified as the most important for our study's development based on their respective weights (Table 6). In general, it appears that the WT values have the highest weight in the analysis, suggesting that addressing weaknesses and mitigating threats is a crucial aspect of this study's development strategy.
The CR value of 0.099, although it is at the limit, indicates that the generated AHP model is relatively consistent. While it's close to the threshold of 0.1, the fact that it's below this limit suggests that the expert opinions and the model's calculations are reasonably consistent and reliable for this study analysis. After analyzing the consistency ratio of the results, priority values were ultimately determined and are presented with L vector. Therefore, the top three development strategies that should receive the highest emphasis are WT1, SO1, and WO1, respectively. This highlights the significance of concentrating on aspects where internal weaknesses and external threats exist in order to enhance and safeguard the outcomes of the study.

Table 6. Weight values of SWOT development strategies

Strategy Groups	Development Strategies	Local Weights	Global Weights
(SO)	1) Allocating more resources for R&D.	0.445	0.133
	2) Increasing incentives for the spread of autonomous ships.	0.291	0.087
	3) Establishment of independent education and research units on the subject.	0.264	0.079
(ST)	1) The benefits of autonomous ships should be accurately expressed to the public.	0.521	0.085
	2) It should be emphasized that the need for the necessary workforce will not be completely eliminated, but this workforce will be needed differently.	0.479	0.078
(WO)	1) For the transformation, semi-autonomous ships instead of fully autonomous ships will be tested in the field for a while.	0.731	0.122
	2) First be experienced in the areas allocated to it.	0.269	0.045
(WT)	1) Possible risks should be thoroughly investigated.	0.431	0.160
	2) Legal and regulatory uncertainties should be resolved as soon as possible	0.288	0.107
	3) Focusing on technical studies on the prevention of cyber attacks against autonomous ships and sanctions related to these attacks.	0.280	0.104

$$L = \begin{bmatrix} 1.33 \\ 0.87 \\ 0.79 \\ 0.85 \\ 0.78 \\ 1.22 \\ 0.45 \\ 1.60 \\ 1.07 \\ 1.04 \end{bmatrix}$$

4. RESULTS AND DISCUSSION

As a result, when analyzing the overall results of the study, it becomes evident that threats (33.7%) and strengths (28.6%) within the SWOT factors are areas that require more attention, as indicated by the examination of expert opinions. Additionally, the aspect of opportunities (25.3%) also holds a significant priority similar to the former two factor groups. Notably, the study's outcomes suggest that experts regard the weaknesses of MASSs (12.6%) as comparatively less critical than the other three factor categories. When assessing the SWOT factors based on expert opinions and ranked using the AHP method within their respective fields, the following priorities were observed:

a. Shipbuilders:
- The most important factors were T4, T1, S2, and T3, with priority values of 2.242, 1.919, 1.471, and 1.446, respectively.
- The least significant factors for shipbuilders were W2 and W3, with priority values of 0.363 and 0.375.

b. Technology Experts (MASS-related):
- T4, S4, O4, and S3 were emphasized as crucial factors, with priority values of 1.863, 1.582, 1.523, and 1.172, respectively.
- Factors O1 and S1 had the lowest priority values at 0.390 and 0.4, respectively.

c. Mariners:
- Significant factors for mariners included O4, S2, T4, and S3, with priority values of 2.059, 1.753,1.290, and 1.140, respectively.
- T3 and W2 were identified as the least important factors among mariners, with priority values of 0.454 and 0.608.

d. Legal Expert:
- Prioritized factors for the legal expert were W1, T4, T3, and T2, with priority values of 3.538, 2.915, 2.215, and 1.487, respectively.
- S3 and S4 were rated as the least significant factors for the legal expert, with a priority value of 0.315.

These results highlight the varying perspectives of experts from different fields regarding the importance of SWOT factors in the context of autonomous ships.

In summary, when considering the evaluations both in general and according to the fields of expertise, T4 emerges as the most crucial factor. Following T4, O4 holds significant importance. This indicates that experts believe that addressing unknown issues, security problems, and risks related to MASS should be the primary focus. Interestingly, despite these concerns, experts also see safety and security-related opportunities as highly significant, suggesting that the main preoccupation and aspiration within the field of MASSs revolve around safety and security issues. Furthermore, the analysis reveals that experts, except for lawyers, do not generally view the weaknesses of MASSs as major concerns. Legal gaps and infrastructure deficiencies, which pose significant obstacles to the widespread adoption of autonomous vessels, are not considered substantial issues by experts in fields other than law.

When analyzing the responses provided by experts with experience in MASSs, it becomes evident that professionals from different fields prioritize various aspects related to autonomous vessels. In the assessment of development strategies, shipbuilders assign the highest priority to strategies WT1, WO1, WT3, and SO1, with respective values of 0.227, 0.134, 0.130, and 0.123. On the other hand, engineers and academics specializing in autonomous ship technology emphasize strategies SO1, WO1, and WT1, with priority values of 0.176, 0.142, and 0.123, respectively. Mariners view strategies SO1, WT1, WO1, and SO2 as significant, with priority values of 0.141, 0.137, 0.122, and 0.118, respectively. Lastly, the legal expert highlights the importance of strategies WT1, WT2, and WT3, with a score of 0.183. Based on these evaluations, WT1 emerges as the most critical strategy, both overall and within specialized domains. SO1 and WO1 strategies closely follow. Interestingly, the strategy aimed at addressing the lack of a legal framework for autonomous ships, a significant barrier to their widespread adoption, is particularly emphasized by the legal expert.

5. CONCLUSION

In this research article, the study aimed to determine the strategic management of MASSs in comparison to manned ships, based on existing literature, and to propose strategies for their improvement and mitigation of weaknesses by leveraging expert opinions. To achieve this, a hybrid approach combining SWOT analysis, a strategic management method, and the AHP

Method, a technique commonly employed in multi-criteria decision making, was employed. Given the multifaceted literature of MASSs, experts from various domains were consulted to assess the factors influencing autonomous ships, and the gathered data underwent a comprehensive evaluation. This extensive analysis yielded several noteworthy findings:

- Experts highlighted the paramount importance of addressing unknown issues, security concerns, and risks related to MASSs. Safety and security emerged as top priorities for researchers and practitioners in this field.
- Legal gaps and the lack of a suitable legal infrastructure were identified as significant barriers to the widespread adoption of autonomous ships. Lawyers, in particular, emphasized the need to address these issues.
- The most critical issues among threats are related to the unknown, security, and risk, accounting for 12.7% in terms of priority.
- The least significant factor group is weaknesses, encompassing human, software, technological weaknesses, and lack of experience. Software and technological weaknesses are rated the lowest at 4.9%.
- The highest priority group among the suggested development strategies for MASSs is the weakness-threat group, with a priority value of 37.1%. The strengths-opportunities group follows closely with a priority value of 29.9%.
- Weaknesses-Threats and Strengths-Opportunities development strategies collectively dominate with a total rate of 67%.

Based on the results obtained, the third stage of the SWOT Analysis, which is strategy evaluation, is outlined as follows. The data obtained from this research clearly indicate that experts in the field of MASSs prioritize taking precautions against potential threats and further developing existing strengths. These findings emphasize the importance of addressing unknown factors, security, and risk as primary threats in the development of MASSs. Strategies aimed at mitigating weaknesses and capitalizing on strengths, especially in response to threats and opportunities, play a significant role in shaping the future of autonomous ship technology. While there are numerous SWOT analysis studies on autonomous ships in the literature, this research has made a valuable contribution by providing a structured decision-making framework that quantifies the importance of each factor. This approach helps guide future research and development efforts in the autonomous ship industry, filling a crucial gap in the existing body of knowledge.

In this study, the research questions related to the competitiveness of autonomous ships compared to manned ships were effectively addressed through SWOT analysis. The opinions of experts in the field of autonomous ships were invaluable in providing insights into the strengths, weaknesses, opportunities, and threats of this technology. However, it's worth noting that the experts consulted in this study represent a specific range of expertise. To achieve a more comprehensive evaluation, future research could aim to gather opinions from a broader spectrum of experts, covering various domains related to autonomous ships. By doing so, a more holistic perspective on the strengths, weaknesses, opportunities, and threats of autonomous ships could be obtained, leading to more informed decision-making and further advancements in the field.

Overall, this study has made a significant contribution to various sectors related to autonomous ships, including shipbuilders, researchers, rule-making authorities, sailors, and lawyers. It offers valuable guidance on which factors and strategies should be prioritized in the context of autonomous ships, both presently and in the future.

AUTHORSHIP CONTRIBUTION STATEMENT

Hasan UĞURLU: Conceptualization, Methodology, Validation, Formal Analysis, Resources, Writing - Original Draft, Writing-Review and Editing, Data Curation, Software, Visualization.

CONFLICT OF INTERESTS

The author declares that for this article they have no actual, potential or perceived conflict of interests.

ETHICS COMMITTEE PERMISSION

Author declares that this study was conducted in accordance with Ethics Committee of Social Sciences, Science and Engineering Sciences Research. The study received ethics committee approval from Giresun University with file number 2023/09.

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Appendix I

Table A1. Reference studies to identify SWOT factors

Author(s), Year	**Article Name**	**Related Factor(s)**
(Burmeister and Bruhn, 2015)	Designing an autonomous collision avoidance controller respecting COLREG.	S6, O1, O4, O8
(Laurinen, 2016)	Remote and autonomous ships: The next steps.	W2, W4, W1, T6, O3
(Kaminski, 2016)	Who's to blame when no one is manning the ship.	O1, O3, O4, T1, T4, T6, S2, S8
(Jessee *et al.*, 2017)	A gaze-based operator instrumentation approach for the command of multiple autonomous vehicles.	W5
(Porathe, 2017)	Is COLREG enough? Interaction between manned and unmanned ships.	T5, S6
(Wróbel *et al.*, 2017)	Towards the assessment of potential impact of unmanned vessels on maritime transportation safety.	S1, W1, T8
(Zhou *et al.*, 2018)	Collision risk identification of autonomous ships based on the synergy ship domain.	S5
(Jin *et al.*, 2018)	Key technologies and intelligence evolution of maritime UV.	O2, O6, O7, W2, S7
(NYK, 2019)	NYK conducts world's first maritime autonomous surface ships trial.	W3
(Li and Fung, 2019)	Maritime autonomous surface ships (MASS): implementation and legal issues.	S1, T2, T6, T7, T8, O1, O4, O7, W4
(Veal *et al.*, 2019)	The legal status and operation of unmanned maritime vehicles.	T1, T3, T4, T8, O6
(Dallolio *et al.*, 2019)	Long-endurance green energy autonomous surface vehicle control architecture.	S2, S4, S6, S8, O1, O6
(Pedrozo, 2019)	US employment of marine unmanned vehicles in the South China Sea.	S1, O4, O5, O6, O7, S2
(Ringbom, 2019)	Regulating autonomous ships-concepts challenges and precedents.	O7, O8, T4, T8, W1, S3, S4, S5, S6, S8
(Evensen, 2020)	Safety and security of autonomous vessels Based on the Yara Birkeland Project.	W2, T6, T8, O3, O5, S1
(Ramos *et al.*, 2020)	Human-system concurrent task analysis for maritime autonomous surface ship operation and safety.	T8, W3
(Wu *et al.*, 2020)	Combined effects of acoustic, thermal, and illumination on human perception and performance: A review.	S2
(Utne *et al.*, 2020)	Towards supervisory risk control of autonomous ships	S1, S3, S4, S5, S7, O1, O4, W1
(Zanella, 2020)	The Environmental Impacts of the "Maritime Autonomous Surface Ships".	O1, O4, T4, T6, T8, S1, W1
(Dittmann *et al.*, 2021)	Autonomous surface vessel with remote human on the loop: System design for STCW compliance.	O2, O8, S1, S4, W1, T3
(Munim and Haralambides, 2022)	Advances in maritime autonomous surface ships (MASS) in merchant shipping.	T2, T7, O2, O7
(Issa *et al.*, 2022)	Maritime Autonomous Surface Ships Problems and Challenges Facing the Regulatory Process.	O2, O7, O8, T3, T4, T6, W2, S1
(Cui *et al.*, 2022)	Reduced-and Full-order Concurrent Learning Extended State Observers for Fully Adaptive	S7

	Anti-disturbance Surge Speed Tracking Control of ASVs.	
(Wang *et al*., 2022)	LiDAR-Only Ground Vehicle Navigation System in Park Environment.	S9
(Stateczny *et al*., 2022)	Wireless local area network technologies as communication solutions for unmanned surface vehicles.	S10

Appendix II

$$A = \begin{bmatrix} 1 & 0.424 & 0.535 & 0.57 & 0.661 & 1.302 & 0.933 & 1.672 & 1.125 & 1.365 & 0.545 & 0.683 & 0.74 & 0.812 & 0.423 \\ 2.362 & 1 & 1.077 & 1.838 & 1.201 & 1.663 & 1.431 & 2.844 & 2.229 & 2.069 & 1.863 & 0.997 & 1.143 & 1.192 & 0.601 \\ 1.864 & 0.926 & 1 & 1.349 & 1.055 & 1.528 & 1.054 & 1.33 & 1.597 & 1.712 & 1.49 & 1.061 & 1.175 & 1.353 & 0.554 \\ 1.741 & 0.541 & 0.742 & 1 & 0.845 & 1.374 & 0.974 & 1.876 & 1.633 & 1.692 & 1.39 & 0.721 & 0.867 & 1.192 & 0.489 \\ 1.513 & 0.833 & 0.948 & 1.184 & 1 & 1.713 & 1.625 & 1.016 & 0.803 & 0.856 & 0.409 & 0.674 & 0.662 & 0.73 & 0.285 \\ 0.768 & 0.601 & 0.654 & 0.728 & 0.581 & 1 & 1.19 & 0.503 & 0.533 & 0.474 & 0.308 & 0.298 & 0.385 & 0.393 & 0.186 \\ 1.072 & 0.699 & 0.949 & 1.026 & 0.611 & 0.839 & 1 & 0.585 & 0.554 & 0.643 & 0.376 & 0.376 & 0.392 & 0.505 & 0.242 \\ 0.598 & 0.352 & 0.356 & 0.533 & 0.985 & 1.99 & 1.709 & 1 & 0.791 & 0.887 & 0.345 & 0.733 & 0.981 & 1.103 & 0.505 \\ 0.909 & 0.449 & 0.626 & 0.612 & 1.246 & 1.876 & 1.804 & 1.266 & 1 & 2.825 & 0.98 & 0.896 & 0.846 & 1.162 & 0.634 \\ 0.732 & 0.483 & 0.584 & 0.591 & 1.168 & 2.112 & 1.554 & 1.051 & 0.352 & 1 & 0.55 & 0.711 & 0.668 & 1.21 & 0.478 \\ 1.832 & 0.537 & 0.671 & 0.719 & 2.443 & 3.249 & 2.656 & 2.879 & 1.02 & 1.809 & 1 & 1.735 & 1.79 & 1.816 & 0.877 \\ 1.463 & 1.003 & 0.943 & 1.412 & 1.484 & 3.361 & 2.662 & 1.365 & 1.116 & 1.407 & 0.576 & 1 & 1.895 & 2.097 & 0.58 \\ 1.351 & 0.875 & 0.851 & 1.153 & 1.51 & 2.595 & 2.551 & 1.019 & 1.201 & 1.498 & 0.559 & 0.523 & 1 & 1.396 & 0.398 \\ 1.231 & 0.839 & 0.739 & 0.839 & 1.37 & 2.543 & 1.979 & 0.907 & 0.949 & 0.826 & 0.551 & 0.473 & 0.716 & 1 & 0.866 \\ 2.365 & 1.783 & 1.804 & 2.044 & 3.512 & 5.451 & 4.137 & 1.981 & 1.431 & 2.094 & 1.141 & 1.721 & 2.492 & 1.149 & 1 \end{bmatrix}$$

Appendix III

$$C = \begin{bmatrix} 0.048 & 0.037 & 0.043 & 0.037 & 0.034 & 0.04 & 0.034 & 0.079 & 0.069 & 0.064 & 0.045 & 0.054 & 0.047 & 0.047 & 0.052 \\ 0.114 & 0.088 & 0.086 & 0.118 & 0.061 & 0.051 & 0.052 & 0.134 & 0.136 & 0.098 & 0.154 & 0.079 & 0.073 & 0.07 & 0.074 \\ 0.09 & 0.082 & 0.08 & 0.086 & 0.054 & 0.047 & 0.039 & 0.062 & 0.098 & 0.081 & 0.123 & 0.084 & 0.075 & 0.079 & 0.068 \\ 0.084 & 0.048 & 0.059 & 0.064 & 0.043 & 0.042 & 0.036 & 0.088 & 0.1 & 0.08 & 0.115 & 0.057 & 0.055 & 0.07 & 0.06 \\ 0.073 & 0.073 & 0.076 & 0.076 & 0.051 & 0.053 & 0.06 & 0.048 & 0.049 & 0.04 & 0.034 & 0.053 & 0.042 & 0.043 & 0.035 \\ 0.037 & 0.053 & 0.052 & 0.047 & 0.03 & 0.031 & 0.044 & 0.024 & 0.033 & 0.022 & 0.025 & 0.024 & 0.024 & 0.023 & 0.023 \\ 0.052 & 0.062 & 0.076 & 0.066 & 0.031 & 0.026 & 0.037 & 0.027 & 0.034 & 0.03 & 0.031 & 0.03 & 0.025 & 0.03 & 0.03 \\ 0.029 & 0.031 & 0.029 & 0.034 & 0.05 & 0.061 & 0.063 & 0.047 & 0.048 & 0.042 & 0.029 & 0.058 & 0.062 & 0.064 & 0.062 \\ 0.044 & 0.04 & 0.05 & 0.039 & 0.063 & 0.058 & 0.066 & 0.059 & 0.061 & 0.134 & 0.081 & 0.071 & 0.054 & 0.068 & 0.078 \\ 0.035 & 0.043 & 0.047 & 0.038 & 0.059 & 0.065 & 0.057 & 0.049 & 0.022 & 0.047 & 0.046 & 0.056 & 0.042 & 0.071 & 0.059 \\ 0.088 & 0.047 & 0.054 & 0.046 & 0.124 & 0.1 & 0.097 & 0.135 & 0.062 & 0.085 & 0.083 & 0.138 & 0.114 & 0.106 & 0.108 \\ 0.07 & 0.088 & 0.076 & 0.091 & 0.075 & 0.103 & 0.098 & 0.064 & 0.068 & 0.066 & 0.048 & 0.079 & 0.12 & 0.123 & 0.071 \\ 0.065 & 0.077 & 0.068 & 0.074 & 0.077 & 0.08 & 0.094 & 0.048 & 0.074 & 0.071 & 0.046 & 0.041 & 0.063 & 0.082 & 0.049 \\ 0.059 & 0.074 & 0.059 & 0.054 & 0.07 & 0.078 & 0.073 & 0.043 & 0.058 & 0.039 & 0.046 & 0.038 & 0.045 & 0.058 & 0.107 \\ 0.114 & 0.157 & 0.145 & 0.131 & 0.179 & 0.167 & 0.152 & 0.093 & 0.088 & 0.099 & 0.094 & 0.137 & 0.158 & 0.067 & 0.123 \end{bmatrix}$$

Appendix IV

Table A2. Weight values of SWOT factor groups for A'WOT Analysis

SWOT Group	Factor Group	Local Weights	Global Weights
(S)	1) Strengths over humans (including factors S1 and S2).	0.171	0.049
	2) Strengths in data processing speed and analysis capability (including factors S3, S4, and S6)	0.325	0.093
	3) Strengths related to risk measurement and situational awareness ability (including factors S5 and S8)	0.269	0.077
	4) Strengths of software advantages (including factors S7, S9, and S10)	0.234	0.067
(W)	1) Weaknesses relative to the human (including factors W1 and W2)	0.429	0.054
	2) Technical and software weaknesses (including factor W3)	0.262	0.033
	3) Weaknesses due to lack of experience (including factors W4 and W5)	0.310	0.039
(O)	1) Opportunities to reduce cost (including factors O3 & O4)	0.186	0.047
	2) Opportunities related to technological and environmental factors (including factors O1, O2, and O8)	0.253	0.064
	3) Opportunities for the diversity of applications, and increased interest (including factors O6 and O7)	0.194	0.049
	4) Opportunities related to safety and security (including factor O5)	0.368	0.093
(T)	1) Threats of negative reactions and prejudice (including factors T1 and T2)	0.246	0.083
	2) Threats related to lack of legal status (including factor T4)	0.199	0.067
	3) Threats related to workforce and labor issues (including factors T3 and T7)	0.178	0.060
	4) Threats related to unknown issues, security, and risks (including factors T5, T6, and T8)	0.377	0.127