Journal of Transportation and Logistics,
JTL 2025, 10 (2): 519–530

https://doi.org/10.26650/JTL.2025.1636717

Submitted 10.02.2025
Revision Requested 26.04.2025
Last Revision Received 10.05.2025
Accepted 15.05.2025
Published Online 22.10.2025

Journal of Transportation and Logistics

Resarch Article

Open Access

Application of the cloud theory and AHP methods for stowaway incidents on ships

Şükrü İlke Sezer [1]

[1] İskenderun Technical University, Barbaros Hayrettin Faculty of Shipbuilding and Maritime, Maritime Transportation Management Engineering, Hatay, Türkiye

Abstract

Stowaway incidents on board not only cause serious legal and economic problems but also threaten operational safety and the lives of stowaways. The aim of this paper is to perform a safety assessment of stowaway incidents. In this context, the main criteria and sub-criteria that cause stowaway cases are established. The importance levels of these criteria are determined by weighting. To achieve this, a cloud model-based analytical hierarchy process (AHP) approach is applied. While the AHP weights the criteria, the cloud model (CM) deals with uncertainties. This approach can also be applied to other safety assessments. In the evaluation, the port-related (2) and ship-related (1) main criteria were identified as relatively critical elements. Moreover, sub-criteria 1.3 (Regular monitoring and patrolling of onboard areas) under main criterion 1, sub-criteria 2.1 (Socioeconomic situation) under main criteria 2, and sub-criteria 3.1 (Duration of the operation) under main criterion 3 were determined as relatively critical factors. The findings of the study provide valuable insights and a roadmap for strategic planning to ship crew, shipowners, terminal authorities and safety researchers in terms of identifying priority areas for the prevention of stowaways.

Keywords Maritime transportation · stowaway · Cloud-AHP model · safety assessment

Citation: Sezer, Ş. İ. (2025). Application of the cloud theory and AHP methods for stowaway incidents on ships. *Journal of Transportation and Logistics*, *10*(2), 519-530. https://doi.org/10.26650/JTL.2025.1636717

Corresponding author: Şükrü İlke Sezer ilkesezer@gmail.com

Application of the cloud theory and AHP methods for stowaway incidents on ships

The maritime sector is one of the most important elements of global trade by transporting different types of cargo such as liquid, dry cargo, gas etc. (UNCTAD, 2024). The commercial activities in this sector are inherently reliant on ensuring safety on board. Therefore, maritime safety is of great importance for sustainable transportation. Safety at sea is not only limited to operational hazards but also includes unexpected situations that the crew may encounter. One of these hazards is the presence of stowaways. Stowaways are a serious problem that can disrupt ship operations and jeopardize ship safety and security (Aguocha, 2018). The IMO stowaway regulations and the Convention on the Facilitation of International Maritime Traffic (FAL Convention) of 1965 set out the provisions relating to stowaway incidents. According to IMO, stowaway; "a person who is secreted on a ship, or in cargo which is subsequently loaded on the ship, without the consent of the shipowner or the master or any other responsible person and who is detected on board the ship after it has departed from a port, or in the cargo while unloading it in the port of arrival, and is reported as a stowaway by the master to the appropriate authorities" (IMO, 2018). Stowaways on board ships can cause costly and complex problems as well as operational delays. They also jeopardize the cargo on board and undermine operational safety (Aguocha, 2018; IMO, 2019).

In recent years, studies on safety analysis have been widely conducted in the maritime industry. In these studies, techniques such as the Success likelihood index method (SLIM) (Erdem & Akyuz, 2021; Sezer et al., 2023), Cognitive reliability and error analysis method (CREAM) (Pei et al., 2024; Arici et al., 2024), Human error assessment and reduction technique (HEART) (de Maya et al. 2022, Islam et al., 2018), Fault tree analysis (FTA) (Sezer et al., 2024; Hocek et al., 2024), Event tree analysis (ETA) (Raiyan et al, 2017; Tunçel et al., 2021), bow tie (Temel et al., 2024; Camliyurt, et al. 2022), Failure mode, effects, and criticality analysis (FMECA) (Ceylan, 2023; Elidolu et al., 2024), Bayesian network (BN) (Kong et al, 2024; Zhang et al., 2024), Analytic hierarchy process (AHP) (Zhou et al., 2020; Wan et al., 2024) were widely used. In these studies, the authors integrated approaches such as fuzzy logic and evidential reasoning into their methodology to deal with uncertainties and vagueness. On the other hand, there are some studies in the literature on stowaways aboard ships. Aguocha (2018) investigated the difficulties caused by stowaways, how they are treated upon discovery, and the repatriation process. In their study, Kirichenko and Sabadash (2018) discussed the consequences of the carriage of stowaways on board. It also provides statistics on the dangerous sailing areas where stowaways are most likely to enter. Chen et al. (2005) evaluated the economic and social impacts of stowaways and proposed appropriate measures to deal with this problem.

According to the literature review, despite the negative consequences of stowaways on ships, it has not gained sufficient attention in the maritime sector. There is a lack of studies addressing the issue of stowaways. This paper performs a safety analysis of the stowaway incident in order to enhance the level of safety and security on board ships and to prevent the disruption of maritime transportation. The main goal of this study is to prioritize the criteria that cause the stowaway incident. To achieve this, a cloud model-based AHP approach is used. While the weight of each criterion can be determined with the AHP approach, the uncertainty and randomness in the weighting process can be reduced through the CM. From this perspective, the paper is structured as follows. This section presents the motivation for the research on stowaways on board and a brief literature review. Section 2 provides an overview of the methodologies and explores their integration. In Section 3, a safety assessment is performed for stowaway incidents on ships using cloud-based AHP. Finally, Section 4 summarizes the findings and presents the conclusions of the study.

Methodology

This section introduces the theoretical background of the cloud model and the AHP methods and their integration.

Analytic hierarchy process

The Analytic Hierarchy Process (AHP) is a widely known multi-criteria decision-making (MCDM) approach developed by Saaty (1990). This method can analyze complex decision-making problems by combining qualitative and quantitative analysis. It can help users establish priority weights and support optimal decision-making (Akyuz & Celik, 2016). In the method, a hierarchical structure consisting of various alternatives and sub-criteria is formed according to the system under consideration. The relative weights of the criteria can be calculated through the method. Thus, a ranking emerges as a result of the evaluation carried out by decision-makers (Thanki et al., 2016). It ensures reliability by enabling the assessment of consistency in the evaluations provided by decision-makers. The method involves a few fundamental steps. First, the decision-making problem is analyzed and broken down into smaller components. Next, a pairwise comparison matrix is created for each criterion. Subsequently, the relative weights of the criteria were calculated. Finally, the consistency of the decision-maker's evaluations is verified (Agarwal & Ojha, 2024). AHP has been effectively used to analyze complicated issues in a variety of sectors (Moslem, 2024; Ransikarbum & Pitakaso, 2024; Kusakci et al, 2022; Darko et al, 2019).

Cloud model theory

Through the cloud model (CM), quantitative values can be derived from qualitative concepts (Liu et al, 2017). CM can reflect the uncertainty and randomness of qualitative data (Guo et al., 2020). In a Cloud Model (CM), *U* represents a theoretical quantitative domain composed of precise values, while C signifies the qualitative concept associated with *U*. If a random quantitative value *x* belongs to *U* and is interpreted as an instance of the qualitative concept C, *x* can be assigned a stable random number $\mu(x)$ to reflect its degree of association with C. This value, $\mu(x)$, lies within the range [0,1] and can be described as a function $\mu(x) : U \to [0,1]$, where $\forall\, x \in U, x \to \mu(x)$ (Li et al., 2009). A CM provides the general qualities of a qualitative idea with three number values. These are expectation (*Ex*), entropy (*En*), and hyper-entropy (*He*). As a result, a cloud may be represented as a 3-tuple $Y = (Ex, En, He)$. Ex represents the maximum potential value of the qualitative ideas. The En reflects the concept's randomness. It describes the permissible range and dispersion of a qualitative idea. He is a measure of En's uncertainty, demonstrating the uncertainty of membership degrees (Chen et al., 2022). The forward cloud generator generates cloud drops ($x_i,\ \mu_i$) using the CM's *Ex, En*, and *He* properties. The following procedures are outlined for generating a normal cloud (Li et al., 2009).

1. A random number En' is generated such that $En' \sim N(En, He^2)$. Subsequentlı, another random number x_i is generated such that $x_i \sim N(Ex, (En')^2)$.
2. Use Equation (1) to obtain the certainty degree of x_i in the universe *U*.

$$\mu_i(x) = e^{-\frac{(x_i - Ex)^2}{2(En')^2}} \tag{1}$$

3. Repeat steps 1-2 to make A cloud drop.

Model integration: Cloud model-based analytic hierarchy process

The cloud-based AHP approach is applied to calculate the weights of the criteria and sub-criteria. The detailed calculation steps are shown below.

Step 1. Establish a hierarchical structure: The main criteria and sub-criteria related to the issue under consideration are identified and hierarchically ranked. These can be obtained from the literature and expert opinions (Zhang et al., 2020).

Step 2. Construct the judgment matrix: The CM scale was developed using the typical hierarchical analysis system scale and is shown in Table 1 (Li et al., 2024; Xie et al, 2021). Accordingly, the experts compare the two criteria/sub-criteria and obtain the judgment matrix. There is a separate judgment matrix for each expert.

Table 1
CM scale table.

Relative importance	CM scale	Description
1	$C_1 = (1, 0, 0)$	i and j are important
3	$C_3 = (3, 0.33, 0.05)$	i is slightly more important than j
5	$C_5 = (5, 0.33, 0.05)$	i is significantly more important than j
7	$C_7 = (7, 0.33, 0.05)$	i is strongly more important than j
9	$C_9 = (9, 0.33, 0.05)$	i is absolutely more important than j
$\frac{1}{C_3(Ex_{ij}, En_{ij}, He_{ij})} = C\left(\frac{1}{Ex_{ij}}, \frac{En_{ij}}{Ex_{ij}^2}, \frac{He_{ij}}{Ex_{ij}^2}\right)$		

Step 3. Judgment matrix combination: The two-by-two comparison judgment matrices provided by each expert are combined using Equation (2) (Li et al., 2024; Liu et al., 2023). Thus, one combined judgment matrix is created.

$$\left\{ Ex = \frac{Ex_1w_1 + Ex_2w_2 + \ldots + Ex_Nw_N}{w_1 + w_2 + \ldots + w_N} En = \frac{w_1^2}{w_1^2 + w_2^2 \ldots + w_N^2} En_1 + \frac{w_2^2}{w_1^2 + w_2^2 \ldots + w_N^2} En_2 + \ldots \right. \\ \left\{ \frac{w_n^2}{w_1^2 + w_2^2 \ldots + w_N^2} En_N He = \frac{w_1^2}{w_1^2 + w_2^2 \ldots + w_N^2} He_1 + \frac{w_2^2}{w_1^2 + w_2^2 \ldots + w_N^2} He_2 + \ldots \frac{w_n^2}{w_1^2 + w_2^2 \ldots + w_N^2} He_N \right. \tag{2}$$

where *N* is the number of experts. The weights of the experts were calculated using the approach of Arici et al. (2020).

Step 4. Weight calculation: For weighting calculation, CM rules and the traditional AHP approach are followed (Li et al., 2024; Xie et al, 2021). In this context, the product of each row element of the combined judgment matrix is computed according to Equation (3) (Xie et al, 2021; Chen et al., 2022).

$$\left\{ Ex_i = \prod_{j=1}^{n} Ex_{ij}\ En_i = \prod_{j=1}^{n} Ex_{ij} \sqrt{\sum_{j=1}^{n} \left(\frac{En_{ij}}{Ex_{ij}}\right)^2}\ He_i = \prod_{j=1}^{n} Ex_{ij} \sqrt{\sum_{j=1}^{n} \left(\frac{He_{ij}}{Ex_{ij}}\right)^2} \right. \tag{3}$$

Then, the n-th root of each element is calculated. Equation (4) is used to achieve this calculation.

$$\left\{ Ex_i' = \sqrt[n]{Ex_i}\ En_i' = \sqrt{\frac{1}{n}}.\ Ex_i^{\ \frac{1}{n}-1}.En_i\ He_i' = \sqrt{\frac{1}{n}}.\ Ex_i^{\ \frac{1}{n}-1}.He_i \right. \tag{4}$$

The parameters whose nth root is taken are summed using Equation (5) (Xie et al, 2021; Chen et al., 2022).

$$\left\{ \sum_{i=1}^{n} Ex_i' = Ex_1' + Ex_2' + \ldots + Ex_n'\ \sum_{i=1}^{n} En_i' = \sqrt{En_1' + En_2' + \ldots + En_n'}\ \sum_{i=1}^{n} He_i' = \sqrt{He_1' + He_2' + \ldots + He_n'} \right. \tag{5}$$

Finally, by applying Equations (6)-(8), normalization is performed and weights are obtained (Xie et al, 2021; Chen et al., 2022).

$$wEx_i = \frac{Ex_i'}{\sum_{i=1}^{n} Ex_i'} \tag{6}$$

$$wEn_i = \frac{Ex_i'}{\sum_{i=1}^{n} Ex_i'} \sqrt{\left(\frac{En_i'}{Ex_i'}\right)^2 + \left(\frac{\sum_{i=1}^{n} En_i'}{\sum_{i=1}^{n} Ex_i'}\right)^2} \tag{7}$$

$$wHe_i = \frac{Ex'_i}{\sum_{i=1}^{n} Ex'_i} \sqrt{\left(\frac{He'_i}{Ex'_i}\right)^2 + \left(\frac{\sum_{i=1}^{n} He'_i}{\sum_{i=1}^{n} Ex'_i}\right)^2} \tag{8}$$

Step 5. Consistency check: The consistency index (CI) is computed using Equation (9). CI < 0.1 indicates adequate consistency in the judgment matrix (Li et al., 2024).

$$CI = \frac{1}{n(n-1)} \sum_{i=1}^{n} H \frac{e_{ij}}{E} x_{ij} \tag{9}$$

Step 6. Weight value calculation: The expected value ($\tilde{s}(A)$) of any cloud *A* consisting of cloud drops can be calculated using Equation (10) (Wang et al., 2014).

$$\tilde{s}(A) = \frac{1}{X} \sum_{i=1}^{n} x_i \mu_i(x) \tag{10}$$

where *X* is the number of cloud drops. In this study, 5000 cloud drops were generated.

Safety assessment of the stowaways incident

In this section, problems related to the stowaway incident are presented and the criteria affecting the stowaway incident are analyzed using a CM-based AHP approach.

Problem statement

In addition to causing legal, financial and operational problems (IMO, 2019), stowaways affect operational safety and crew security (Aguocha, 2018). Once stowaways are detected on board, their repatriation is a very complicated process from a legal point of view (IMO, 2018). Ships finance the detention, repatriation and provision of medical care for stowaways. The presence of stowaways on board may cause the vessel to deviate from its planned route in order to comply with legal and immigration requirements, resulting in operational delays (IMO, 2018). On the other hand, unauthorized persons on board are a serious threat to the ship crew. In addition, stowaways may jeopardize the cargo and the safety of the ship as they do not know the characteristics of the cargo carried on board (Aguocha, 2018).

In this context, the IMO has adopted Resolution FAL.13 (42) to prevent the access of stowaways and to resolve the stowaway incident. The resolution specifies the measures to be taken by the port and ship parties. On the other hand, the master, the shipowner, the next port according to the voyage plan, subsequent ports, state of embarkation, state of nationality, flag state and states in transit during repatriation are the responsible stakeholders in the resolution of the stowaway cases. These stakeholders have various tasks to fulfill. Despite all this, stowaway incidents continue to occur (IMO, 2018).

Quantitative safety assessment of the stowaway incident

First, a hierarchical structure should be established for the analysis. In this study, the structure is established by utilizing expert opinions and the resolution adopted by the IMO (IMO, 2018). Accordingly, three main criteria and 11 sub-criteria are determined and listed in Table 2.

Table 2

Hierarchical structure for stowaway.

Main criteria	Sub-criteria	Definition
1. Ship-specific factors	1.1 Ship entry-exit controls	Entry-exit controls are carried out on board to prevent the presence of unauthorised persons on board. On the other hand, information can be obtained about persons on board other than ship crew. The superficiality of entry-exit controls increases the threat of stowaways.

Main criteria	Sub-criteria	Definition
	1.2 Locking the doors of restricted areas	The restricted areas indicated in the ship's security plan are the highest potential hiding places for stowaways. Locking restricted areas plays an important role in preventing unauthorised access to these areas by stowaways.
	1.3 Regular monitoring and patrolling of onboard areas	One of the duties of the personnel during the port watch is to monitor and patrol at regular intervals. Thanks to this application, it may be possible to detect unauthorised persons on board. In addition, the execution of this duty may create a deterrent for potential stowaways and reduce attempts.
	1.4 Training and awareness of ship crew	Training and awareness of the ship's crew ensure that the relevant safety procedures are fully implemented and that they are ready for potential threats.
	1.5 Pre-departure stowaway search	A comprehensive search of a ship before it leaves port is an important procedure for the detection of stowaways. Superficial or skipped searches can result in stowaways remaining on board undetected.
2. Port-specific factors	2.1 Socioeconomic situation	The threat of stowaways is very high in port states where socioeconomic situations such as unemployment, poverty and civil unrest are experienced. People in these regions aim to reach developed countries through illegal means. For this purpose, they can board commercial ships secretly.
	2.2 Enhanced port security measures	The effectiveness of security protocols in the port of call can deter illegal entry into the port area and make it more difficult for stowaways to reach the ships.
	2.3 Port area size and physical limitations	Some ports are large in area and contain complex physical structures. In such large and dispersed ports, security measures may not be implemented consistently and effectively. Under these conditions, the threat of stowaways may increase.
3. Operation-specific factors	3.1 Duration of the operation	A long duration of the operation may lead to a relaxation of security measures on board and/or an increased likelihood of stowaways making and executing plans.
	3.2 Type of cargo	Some types of cargo may create void spaces suitable for the concealment of stowaways. Such void spaces are difficult to access.
	3.3 Freeboard level	Freeboard, which is the distance between the waterline and the deck, is a factor affecting the climbing of the ship from outside. Ships with low freeboard are easier to access.

Expert judgements are needed to evaluate the hierarchical structure. Five experts participated in this study (Iskenderun Technical University Scientific Research and Publication Ethics Committee, 2025/03-1, 30.01.2025). The weights of the experts are determined according to the scoring criteria (Arici et al., 2020) and are 0.219, 0.156, 0.234, 0.156, and 0.234, respectively. The experts carried out the evaluation process according to Table 1. Accordingly, judgment matrices based on pairwise comparison were obtained from the experts. Four judgment matrices, including three sub-criteria and one main criterion, are determined by each expert. As an example, Table 3 shows the judgment matrices of the experts regarding the sub-criteria under the main criteria 1.

Table 3

Judgement matrices for the sub-criteria under the main criteria 1.

E1	1.1	1.2	1.3	1.4	1.5
1.1	(1,0,0)	(1/3,0.33/9,0.05/9)	(1/5,0.33/25,0.05/25)	(3,0.33,0.05)	(1/5,0.33/25,0.05/25)
1.2	(3,0.33,0.05)	(1,0,0)	(1/3,0.33/9,0.05/9)	(5,0.33,0.05)	(1/3,0.33/9,0.05/9)
1.3	(5,0.33,0.05)	(3,0.33,0.05)	(1,0,0)	(7,0.33,0.05)	(3,0.33,0.05)
1.4	(1/3,0.33/9,0.05/9)	(1/5,0.33/25,0.05/25)	(1/7,0.33/49,0.05/49)	(1,0,0)	(1/5,0.33/25,0.05/25)
1.5	(5,0.33,0.05)	(3,0.33,0.05)	(1/3,0.33/9,0.05/9)	(5,0.33,0.05)	(1,0,0)
E2	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**

1.1	(1,0,0)	(3,0.33,0.05)	(1/3,0.33/9,0.05/9)	(5,0.33,0.05)	(1/5,0.33/25,0.05/25)
1.2	(1/3,0.33/9,0.05/9)	(1,0,0)	(1/3,0.33/9,0.05/9)	(7,0.33,0.05)	(3,0.33,0.05)
1.3	(3,0.33,0.05)	(3,0.33,0.05)	(1,0,0)	(5,0.33,0.05)	(3,0.33,0.05)
1.4	(1/5,0.33/25,0.05/25)	(1/7,0.33/49,0.05/49)	(1/5,0.33/25,0.05/25)	(1,0,0)	(1/5,0.33/25,0.05/25)
1.5	(5,0.33,0.05)	(1/3,0.33/9,0.05/9)	(1/3,0.33/9,0.05/9)	(5,0.33,0.05)	(1,0,0)
E3	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**
1.1	(1,0,0)	(3,0.33,0.05)	(1/5,0.33/25,0.05/25)	(7,0.33,0.05)	(3,0.33,0.05)
1.2	(1/3,0.33/9,0.05/9)	(1,0,0)	(1/3,0.33/9,0.05/9)	(5,0.33,0.05)	(1/3,0.33/9,0.05/9)
1.3	(5,0.33,0.05)	(3,0.33,0.05)	(1,0,0)	(7,0.33,0.05)	(1/3,0.33/9,0.05/9)
1.4	(1/7,0.33/49,0.05/49)	(1/5,0.33/25,0.05/25)	(1/7,0.33/49,0.05/49)	(1,0,0)	(1/5,0.33/25,0.05/25)
1.5	(1/3,0.33/9,0.05/9)	(3,0.33,0.05)	(3,0.33,0.05)	(5,0.33,0.05)	(1,0,0)
E4	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**
1.1	(1,0,0)	(5,0.33,0.05)	(1/3,0.33/9,0.05/9)	(5,0.33,0.05)	(1,0,0)
1.2	(1/5,0.33/25,0.05/25)	(1,0,0)	(1/3,0.33/9,0.05/9)	(3,0.33,0.05)	(1/3,0.33/9,0.05/9)
1.3	(3,0.33,0.05)	(3,0.33,0.05)	(1,0,0)	(3,0.33,0.05)	(1,0,0)
1.4	(1/5,0.33/25,0.05/25)	(1/3,0.33/9,0.05/9)	(1/3,0.33/9,0.05/9)	(1,0,0)	(1/3,0.33/9,0.05/9)
1.5	(1,0,0)	(3,0.33,0.05)	(1,0,0)	(3,0.33,0.05)	(1,0,0)
E5	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**
1.1	(1,0,0)	(5,0.33,0.05)	(1/3,0.33/9,0.05/9)	(3,0.33,0.05)	(1,0,0)
1.2	(1/5,0.33/25,0.05/25)	(1,0,0)	(1/5,0.33/25,0.05/25)	(3,0.33,0.05)	(1/3,0.33/9,0.05/9)
1.3	(3,0.33,0.05)	(5,0.33,0.05)	(1,0,0)	(5,0.33,0.05)	(1,0,0)
1.4	(1/3,0.33/9,0.05/9)	(1/3,0.33/9,0.05/9)	(1/5,0.33/25,0.05/25)	(1,0,0)	(1/5,0.33/25,0.05/25)
1.5	(1,0,0)	(3,0.33,0.05)	(1,0,0)	(5,0.33,0.05)	(1,0,0)

The combined judgment matrices are obtained using the cloud judgment matrices of the experts and Equation (2). Table 4 shows the combined judgment matrix calculated through the comparison matrices in Table 3. Equations (3)-(8) are then applied to calculate the weights of the main criteria and sub-criteria. In this context, Table 5 shows the weights for the cloud model. Finally, the weight score of each main criterion and sub-criteria can be calculated using Equation (10) and is given in Table 5. The consistency test was performed according to Equation (9) and yielded satisfactory results.

Table 4

Final judgment matrix for the sub-criteria under the main criteria 1.

	1.1	**1.2**	**1.3**	**1.4**	**1.5**
1.1	(1,0,0)	(3.1979,0.2620,0.0333)	(0.2729,0.0250,0.0038)	(4.5625,0.3300,0.0500)	(1.1688,0.0924,0.0140)
1.2	(0.8646,0.0956,0.0145)	(1,0,0)	(0.3021,0.0304,0.0046)	(4.5313,0.3300,0.0500)	(0.7500,0.0713,0.0108)
1.3	(3.9063,0.3300,0.0500)	(3.4688,0.3300,0.0500)	(1,0,0)	(5.5938,0.3300,0.0500)	(1.5938,0.1252,0.0190)
1.4	(0.2470,0.0232,0.0035)	(0.2432,0.0215,0.0018)	(0.1949,0.0128,0.0019)	(1,0,0)	(0.2208,0.0160,0.0025)
1.5	(2.3438,0.1252,0.0190)	(2.5833,0.2953,0.0415)	(1.2188,0.1006,0.0152)	(4.6875,0.3300,0.0500)	(1,0,0)

Table 5

Numerical expression of the CM weights.

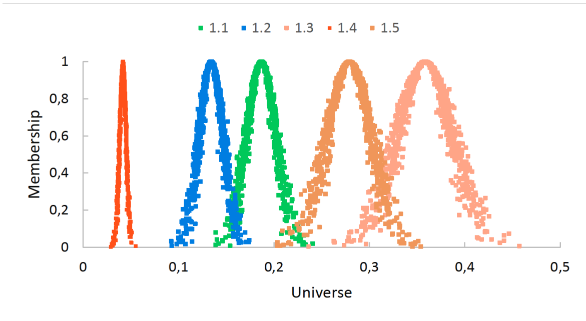
Main criteria			**Sub-criteria**		
No	**CM**	**Weight score**	**No**	**CM**	**Weight score**
1	(0.4261,0.0317,0.0048)	0.297	1.1	(0.1868,0.0153,0.0022)	0.132

Main criteria			Sub-criteria		
No	**CM**	**Weight score**	**No**	**CM**	**Weight score**
			1.2	(0.1341,0.0126,0.0019)	0.095
			1.3	(0.3583,0.0291,0.0044)	0.253
			1.4	(0.0417,0.0034,0.0005)	0.029
			1.5	(0.2770,0.0233,0.0034)	0.196
			2.1	(0.6811,0.0492,0.0075)	0.482
2	(0.5075,0.0388,0.0059)	0.358	2.2	(0.1901,0.0155,0.0023)	0.133
			2.3	(0.1288,0.0076,0.0011)	0.091
			3.1	(0.6665,0.0527,0.0080)	0.472
3	(0.0665,0.0040,0.0006)	0.047	3.2	(0.2563,0.0232,0.0035)	0.181
			3.3	(0.0772,0.0057,0.0009)	0.055

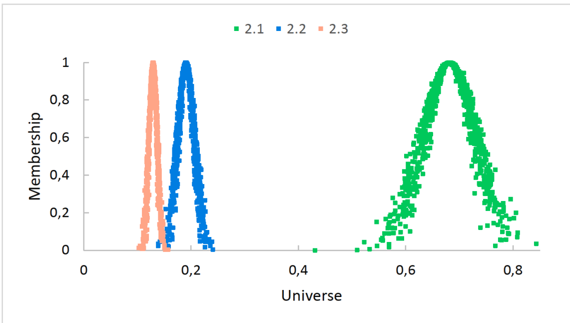
On the other hand, the calculated results are shown in Figure 1 for the sub-criteria and Figure 2 for the main criteria through the expression of images.

Figure 1

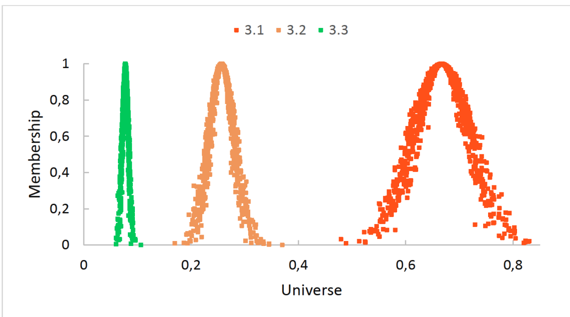
Weight cloud diagrams of sub-criteria.



(a) Ship-specific factors



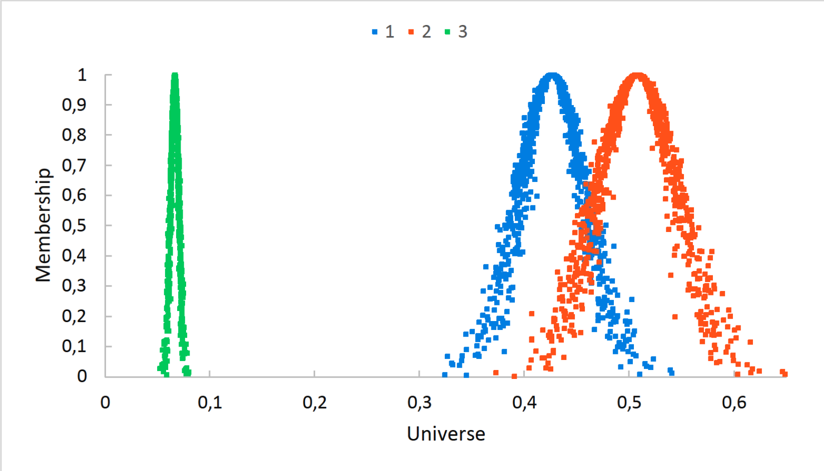
(b) Port-specific factors



(c) Operation-specific factors

Figure 2

Weight cloud diagrams of main criteria.



Findings and extended discussions

Because of the cloud-based AHP analysis, the weight clouds and weight scores of the main criteria and sub-criteria were calculated. According to Figure 1(a) and Table 5, where the ship-specific factors are evaluated, it can be seen that the weights of 1.3 (Regular monitoring and patrolling of onboard areas), 1.5 (Pre-departure stowaway search) and 1.1 (Ship entry-exit controls) are relatively high. In contrast, the weights of 1.2 (Locking the doors of restricted areas) and 1.4 (Training and awareness of ship crew) were relatively low. Moreover, Figure 1(b) and Table 5 illustrate that 2.1 (Socioeconomic situation) of the port-specific factors has a relatively high weight, while 2.2 (Enhanced port security measures) and 2.3 (Port area size and physical limitations) have a relatively low weight. Finally, Figure 1(c) and Table 5 indicate that sub-criteria 3.1 (Duration of the operation) related to operations has a relatively high weight. Sub-criteria 3.2 (Type of cargo) and 3.3 (Draft level) have relatively low weight. Among the main criteria, the relative weight of port-related factors (2) and ship-related factors (1) is high, while the relative weight of operation-related factors (3) is low.

Regular monitoring and patrolling of onboard areas on board (1.3) is a critical sub-criteria in detecting and preventing stowaways. These practices both reduce security vulnerabilities and make it more difficult for stowaways to enter or hide on board. Routine monitoring of areas that may be overlooked, such as cargo areas, accommodation and engine room, ensures that potential risks that may occur in these areas are recognized at an early stage. On the other hand, the use of advanced technologies for monitoring and patrolling processes can create a deterrent effect on stowaways. A pre-departure stowaway search (1.2) involves a systematic and thorough inspection of the vessel before it sails. Pre-departure searches include a detailed examination of different areas of the ship. In particular, cargo holds, containers, engine room, storerooms, and other rarely used areas are places where stowaways may prefer to hide. Performing these controls in a systematic manner is very effective in preventing stowaway incidents. Pre-departure stowaway search is not only limited to the detection of stowaways; it also increases the safety of ship operations.

The socioeconomic situation of a port (2.1) has a significant impact on the frequency and nature of stowaway incidents. The economic conditions, employment opportunities, social infrastructure and political stability of the region where the port is located may be among the main factors that trigger stowaway incidents. The duration of the operation (3.1) may have indirect effects on stowaway incidents. The long duration of a ship's operation in a port can determine the opportunities and methods by which stowaways enter the ship. Control measures may be weakened by distracting personnel, especially during operations such as loading, discharging, or maintenance. Stowaways can observe the routines of the ship's crew and identify vulnerabilities when the duration of the operation is long. This facilitates infiltration attempts. On the other hand, when the operation time is short, ship operations may need to be completed quickly. This haste may lead to protocols not being fully implemented. Stowaways may take advantage of the confusion that may occur during intensive and fast operations to try to enter the ship.

In addition, analysis of data from previous years indicates that most stowaways originated from African countries. While Nigeria and the United Republic of Tanzania remain the primary sources, there was a notable rise in the number of Syrian and Albanian stowaways during the 2017 policy year (IMO, 2019). Extra attention should be paid to stowaways in these ports of call.

Conclusion

The purpose of this paper is to identify the critical criteria for preventing stowaway incidents on board ships and to analyze the importance of these criteria. The stowaway issue has not received the attention it deserves in the maritime industry. However, stowaways can lead to legal problems, financial losses, reduced operational safety, as well as endangering their own lives. This situation reveals that stowaway incidents should be handled more systematically. In this context, the cloud model-based AHP approach is used to perform a safety assessment of this important issue. This method can be applied to prioritize the hazards encountered in the maritime industry. On the other hand, the results obtained show that it is an effective tool. In particular, the method provides a powerful framework for managing uncertainties and subjectivity in decision-making processes. Although the approach used in the study has been applied in some studies in the maritime literature, it is quite limited. This paper presents another example of this approach and adds theoretical enrichment to the field by contributing to safety assessment processes involving uncertainty.

In the study, three main criteria and 11 sub-criteria affecting the stowaway incident were identified. Accordingly, “2. Port-specific factors” are the most critical main criteria. On the other hand, “1.3 Regular monitoring and patrolling of onboard areas” is the most critical sub-criteria under the main criterion “1 Ship-specific factor”, while “2.1 Socioeconomic situation” is the most critical sub-factor under the main criterion “2. Port-specific factors”. “3.1 Duration of the operation” is the most critical sub-criteria under the main criterion “3 Operation-specific factors”. In line with the inferences obtained from the findings, the characteristics of the port of call play an important role in stowaway incidents. The results underline that the threat of stowaways is higher in ports with poor socio-economic status. Therefore, the ship security plan should be implemented sensitively in ports with poor socio-economic status. Since it is very critical for the ship's crew to regularly monitor and patrol the areas on board the ship, it is important that the officer of the watch follows and encourages the ship's crew in this regard. Taking additional precautions, especially as the ship's stay in port is prolonged, can reduce the hazard of stowaways.

In conclusion, the outputs of the study provide a feasible roadmap for rule-making stakeholders, ship crew, shipowners, terminal authorities and safety researchers to develop policies to reduce stowaway incidents. Important points to be considered to prevent stowaways while the ship is in port are discussed. The number of experts participating in the study is a potential limitation of the study. However, this could be addressed in future research by involving more experts or utilizing a real operational dataset. On the other hand, the generalisability of the findings can be increased by conducting case studies in different port areas. In addition to future studies, a systematic risk assessment can be performed by adapting the CM-based AHP approach to risk analysis techniques.

Ethics Committee Approval Ethics approval was obtained from the Iskenderun Technical University Scientific Research and Publication Ethics Committee, 2025/03-1, 30.01.2025
Informed Consent Informed consent was obtained from the participants.
Peer Review Externally peer-reviewed.
Conflict of Interest Author declared no conflict of interest.
Grant Support Author declared no financial support.

Author Details **Şükrü İlke Sezer (Dr.)**
[1] İskenderun Technical University, Barbaros Hayrettin Faculty of Shipbuilding and Maritime, Maritime Transportation Management Engineering, Hatay, Türkiye
0000-0002-7302-747X ilkesezer@gmail.com

References

Agarwal, A., & Ojha, R. (2024). Prioritizing implications of Industry-4.0 on the sustainable development goals: A perspective from the analytic hierarchy process in manufacturing operations. *Journal of Cleaner Production*, 444, 141189.

Aguocha, N. M. (2018). Stowaways: A threat to maritime security and the curse of shipowners (Doctoral dissertation, University of KwaZulu-Natal). https://researchspace.ukzn.ac.za/server/api/core/bitstreams/3ea9315b-d173-4a51-9489-4eedbdd82cf0/content

Akyuz, E., & Celik, M. (2016). A hybrid human error probability determination approach: The case of cargo loading operation in oil/chemical tanker ship. *Journal of Loss Prevention in the Process Industries*, 43, 424-431.

Arici, S. S., Akyuz, E., & Arslan, O. (2020). Application of fuzzy bow-tie risk analysis to maritime transportation: The case of ship collision during the STS operation. *Ocean Engineering*, 217, 107960.

Arici, S. S., Tekeli, M. M., Sezer, S. I., Akyuz, E., Arslan, O., & Aydin, M. (2024). Prediction of human error probability in helicopter to ship transfer operation under an evidential reasoning extended CREAM approach. *International Journal of Occupational Safety and Ergonomics*, 1-12.

Camliyurt, G., Choi, S. A., Kim, S. R., Guzel, A. T., & Park, Y. S. (2022). Risk Assessment for Marine Pilot Occupational Accidents using Fault Tree and Event Tree Analysis. *Journal of Navigation and Port Research, 46*(5), 400-408.

Ceylan, B. O. (2023). Shipboard compressor system risk analysis by using rule-based fuzzy FMEA for preventing major marine accidents. *Ocean Engineering,* 272, 113888.

Chen, Y. H., Chen, S. L., & Wu, C. H. (2005, October 24–26). The impact of stowaways and illegal migrants by sea: A case study in Taiwan. Proceedings of the International Association of Maritime Universities (IAMU).

Chen, Y., Xie, S., & Tian, Z. (2022). Risk assessment of buried gas pipelines based on improved cloud-variable weight theory. *Reliability Engineering & System Safety*, 221, 108374.

Darko, A., Chan, A. P. C., Ameyaw, E. E., Owusu, E. K., Pärn, E., & Edwards, D. J. (2019). Review of application of analytic hierarchy process (AHP) in construction. *International Journal of Construction Management, 19*(5), 436-452.

de Maya, B. N., Komianos, A., Wood, B., de Wolff, L., Kurt, R. E., & Turan, O. (2022). A practical application of the Hierarchical Task Analysis (HTA) and Human Error Assessment and Reduction Technique (HEART) to identify the major errors with mitigating actions taken after fire detection onboard passenger vessels. *Ocean Engineering,* 253, 111339.

Elidolu, G., Teixeira, Â. P., & Arslanoğlu, Y. (2024). A risk assessment of inhibited cargo operations in maritime transportation: a case of handling styrene monomer. *Ocean Engineering*, 312, 119049.

Erdem, P., & Akyuz, E. (2021). An interval type-2 fuzzy SLIM approach to predict human error in maritime transportation. Ocean engineering, 232, 109161.

Guo, B., Zang, W., Yang, X., Huang, X., Zhang, R., Wu, H., ... & Zhang, Y. (2020). Improved evaluation method of the soil wind erosion intensity based on the cloud–AHP model under the stress of global climate change. *Science of the Total Environment*, 746, 141271.

Hocek, H., Yazır, D., Aygün, C., & Özdemir, Ü. (2024). The effect of failure on energy efficiency in maritime vessels autopilot systems. *Ocean & Coastal Management,* 259, 107451.

IMO. (2018). Resolution Fal.13(42). Revised Guidelines on the Prevention of Access By Stowaways and the Allocation of Responsibilities to Seek the Successful Resolution of Stowaway Cases.

IMO. (2019). Consideration and Analysis of Reports and Information on Persons Rescued at Sea and Stowaways. Facilitation Committee, 43rd session, Agenda item 13, FAL 43/13.

Islam, R., Khan, F., Abbassi, R., & Garaniya, V. (2018). Human error probability assessment during maintenance activities of marine systems. *Safety and Health at Work, 9*(1), 42-52.

Kirichenko, D., & Sabadash, Y. (2018). Stowaways on Ships: Measures for the Prevention. In Crimean Marine Science Research And Technology Conference 2018 (pp. 53-57).

Kong, D., Lin, Z., Li, W., & He, W. (2024). Development of an improved Bayesian network method for maritime accident safety assessment based on multiscale scenario analysis theory. *Reliability Engineering & System Safety*, 251, 110344.

Kusakci, S., Yilmaz, M. K., Kusakci, A. O., Sowe, S., & Nantembelele, F. A. (2022). Towards sustainable cities: A sustainability assessment study for metropolitan cities in Turkey via a hybridized IT2F-AHP and COPRAS approach. *Sustainable Cities and Society*, 78, 103655.

Li, D., Liu, C., & Gan, W. (2009). A new cognitive model: Cloud model. *International Journal of Intelligent Systems*, 24(3), 357-375.

Li, F., Zhang, L., Dong, S., Xu, L., Zhang, H., & Chen, L. (2024). Risk assessment of bolt-gasket-flange connection (BGFC) failures at hydrogen transfer stations based on improved FMEA. *International Journal of Hydrogen Energy*, 50, 700-716.

Liu, H. C., Luan, X., Li, Z., & Wu, J. (2017). Linguistic Petri nets based on cloud model theory for knowledge representation and reasoning. IEEE Transactions on Knowledge and Data Engineering, 30(4), 717-728.

Liu, J., Wang, D., Lin, Q., & Deng, M. (2023). Risk assessment based on FMEA combining DEA and cloud model: A case application in robot-assisted rehabilitation. Expert Systems with Applications, 214, 119119.

Moslem, S. (2024). A novel parsimonious spherical fuzzy analytic hierarchy process for sustainable urban transport solutions. *Engineering Applications of Artificial Intelligence*, 128, 107447.

Pei, H., Gong, H., Ding, M., Ma, Y., Wang, Z., & Xin, Q. (2024). A CREAM model optimization method based on fatigue testing experiments and machine learning techniques for maritime transportation applications. *Ocean Engineering,* 311, 118868.

Raiyan, A., Das, S., & Islam, M. R. (2017). Event tree analysis of marine accidents in Bangladesh. *Procedia Engineering,* 194, 276-283.

Ransikarbum, K., & Pitakaso, R. (2024). Multi-objective optimization design of sustainable biofuel network with integrated fuzzy analytic hierarchy process. Expert Systems with Applications, 240, 122586.

Saaty, T. L. (1990). How to make a decision: the analytic hierarchy process. *European Journal of Operational Research, 48*(1), 9-26.

Sezer, S. I., Akyuz, E., & Gardoni, P. (2023). Prediction of human error probability under Evidential Reasoning extended SLIM approach: The case of tank cleaning in chemical tanker. *Reliability Engineering & System Safety*, 238, 109414.

Sezer, S. I., Ceylan, B. O., Akyuz, E., & Gardoni, P. (2024). Improved Z-number and fault tree analysis to predict the risk of air pollution due to ship boiler operation. *Marine Pollution Bulletin*, 206, 116801.

Temel, B., Sakar, C., & Buber, M. (2024). Fuzzy bow-tie analysis for mitigating self-heating risks in maritime coal transportation. *Marine Pollution Bulletin*, 209, 117122.

Thanki, S., Govindan, K., & Thakkar, J. (2016). An investigation on lean-green implementation practices in Indian SMEs using analytical hierarchy process (AHP) approach. *Journal Of Cleaner Production*, 135, 284-298.

Tunçel, A. L., Akyuz, E., & Arslan, O. (2021). An Extended Event Tree Risk Analysis Under Fuzzy Logic Environment: The Case of Fire in Ship Engine Room. *Journal of ETA Maritime Science,* 9(3).

United Nations Conference on Trade and Development (UNCTAD)(2024). Review of Maritime Transport. Geneva: UNCTAD.

Wan, J., Baumler, R., & Dalaklis, D. (2024). Identifying key safety investments needed for arctic shipping via a fuzzy analytic hierarchy process (FAHP) approach. Journal of International Maritime Safety, Environmental Affairs, and Shipping, 8(4), 2422710.

Wang, J. Q., Peng, L., Zhang, H. Y., & Chen, X. H. (2014). Method of multi-criteria group decision-making based on cloud aggregation operators with linguistic information. Information Sciences, 274, 177-191.

Xie, S., Dong, S., Chen, Y., Peng, Y., & Li, X. (2021). A novel risk evaluation method for fire and explosion accidents in oil depots using bow-tie analysis and risk matrix analysis method based on cloud model theory. *Reliability Engineering & System Safety*, 215, 107791.

Zhang, H., Wang, T., Ding, Z., Zhang, X., & Han, L. (2020). Uncertainty analysis of impact factors of eco-environmental vulnerability based on cloud theory. Ecological Indicators, 110, 105864.

Zhang, J., Jin, M., Wan, C., Dong, Z., & Wu, X. (2024). A Bayesian network-based model for risk modeling and scenario deduction of collision accidents of inland intelligent ships. *Reliability Engineering & System Safety,* 243, 109816.

Zhou, X., Cheng, L., & Li, M. (2020). Assessing and mapping maritime transportation risk based on spatial fuzzy multi-criteria decision making: A case study in the South China sea. *Ocean Engineering*, 208, 107403.