Fire Drill Performance Evaluation Model Onboard RoRo Passenger Ship

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***Abstract*— Fire accident onboard RoRo (Roll on/Roll off) passenger ferry notoriously indicates intense symptoms of human, technical and organisational issues. In some cases, the more complex the fire's origin, the more challenging the crew would handle handling, suppressing, and putting out the fire. The crew response plays a significant role in the success of firefighting onboard. The research focuses on evaluating the effectiveness of fire drill performance by developing an evaluation model based on the cognitive model and analytical network process. The model was developed to overview crew performance and consistency in conducting fire drills on board the roro passenger ship. The questionnaire is developed to obtain crew perspective and awareness of fire risks. The analytical network process (ANP) model is utilised to identify crew preference during fire drills. The result of decision-based research identified significant issues that occurred in every step of cognition. Competency and proficiency of the crew, along with continuous training and familiarisation, were the main issues in improving effectiveness in firefighting. The results of the analysis were resourceful evidence to enhance audit and supervision for the emergency preparedness system. In addition, it is also a reference for developing further training models to improve crew overall performance in firefighting.**

Keywords—Fire Drill, RoRo Passenger, Analytical Network Process.

I. INTRODUCTION

Safety is considered the main critical point in domestic RoRo passenger ferry operations. Referring to its typical operation, deficiencies and gaps in ferry operation could lead to catastrophic and severe outcomes. Therefore, proper and adequate systems were introduced, designed, and applied to avoid injury and or loss of personal life, property loss, and negative impact on marine life and its ecosystem [1], [2].

RoRo passenger vessels are acknowledged as the most suitable transportation mode for Indonesia's archipelagic conditions [3], [4]. The transport mode serves affordable fares, flexibility related to the berthing operation, and mature and affordable technology. Following its draft, RoRo can easily be manoeuvred to access inland and coastal waterways, which demand small draft vessels. On the other hand, following its operational flexibility, coastal ferries are essential in maintaining regional interconnectivity and a national economic fair distribution. [5].

However, despite development in every aspect of operation being progressively made to prevent any mishap, accidents involving this mode of transportation continue to occur [6], [7]. It has become a negative public precedence for the so-called maritime nation, particularly in Indonesia's water. In general, there is no such risk-free fire onboard a ship. Therefore, safety defences were put in place to deal with this situation.

Fire accidents onboard are frequently relevant to the KNKT data. Nearly every year, one or more domestic ropax vessels are involved in a fire [8]. In most cases, misconduct in firefighting is due to many reasons, resulting in further consequences such as the loss of the vessels and multiple fatalities for crew and passengers [9], [10], [11]. The paper attempted to identify mainly the factor of crew performance in firefighting using marine operation cognitive models. The model was developed to identify issues in every step of cognition during the development of a fire accident. The crew is considered to be a central factor in handling the fire. Therefore, it is essential to acquire the crew's perception of handling fire onboard their vessel. Crew perception of firefighting can be influenced by their training and familiarisation, fire handling knowledge, experience and understanding of the procedure. Every crew likely have their perception, which might result in various actions in battling the fire. Despite company policy on fire drills, it is also essential to understand how the crew perceives the risk of fire onboard and how to handle it efficiently.

Fire is a rapid oxidation process followed by a rapid increase in temperature and release of heated gaseous products from the material on both visible and invisible views. The tetrahedron of fire was the standard approach to understanding the essential relation of elements establishing fire. There are three main elements to start a fire, i.e., a sufficient level of oxygen, energy to ignite, and combustible material at a sufficient level related to the oxygen level. All components need an uninhibited chemical chain reaction, so the fourth element, the tetrahedron, occurs. A sufficient level of oxygen and combustible material would not be able to ignite without spark energy and the absence of oxygen and the combustible material itself. Each element needs to be sufficiently connected through a chemical reaction. Inhibiting the reaction would prevent all elements from combining and create a chain reaction. Knowing this is the key to effectively fighting and controlling the fire [12], [13], [14].

In handling fire on board, standards and procedures

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were established. IMO SOLAS Chapter II-2 on fire protection, detection, and extinction is the primary referral for ship designers and operators to establish the fire protection system. Therefore, the system involving mechanical, structural, and crew as the key parties to handling the fire onboard should be well established. The crew, particularly, needs to have sufficient knowledge of firefighting. A training set, certification, and familiarisation were provided to the crew, so they were expected to handle the fire properly when it happened. Locating the fire in time, identifying the elements, and suppressing the outbreak are the primary keys in the firefighting procedure [14]. As a differential from the SOLAS Convention, the fire safety system (FSS) code provides details for ship designers and safety analysts in developing engineering specifications for fire safety systems. The code contains detailed information on how to handle the fire fighting equipment [15].

In November 2023, the United States Coastguard (USCG) issued marine safety alerts related to firefighting preparedness due to the preliminary investigation into a fire onboard the RORO car carrier [16]. The alerts emphasised that a lack of familiarity with commercial vessels and inexperience with firefighting techniques, particularly for shipboard operation, could also put the firefighter in dangerous conditions. The alert also highlighted that the shipboard firefighting process requires more resources and specific technical capability. The shipboard fire might be considered less frequent but could have severe consequences, primarily when untrained firefighters handle it. From the case, the USCG recommended that the ship owner develop training, qualifications, and responsibilities by referring to relevant standards [16].

The data for this analysis was acquired from KNKT, the Indonesian investigation body. The report was published on the website and accessible to the public. From 2003 to 2023, the records show 49 cases involving domestic ropax ferries, and 20 were fire-type accidents. Most fire cases were categorised as serious marine casualty under IMO occurrence level standards (IMO, 1974). This case means most cases were high profile and severe, resulting in a fatality and or loss of property [8], [17].

From the investigation data, the fire origins were divided into three locations, i.e., accommodation spaces, car deck, and machinery spaces. As indicated in Figure 1, more fire was started from the car deck of the ropax. In addition, the car deck fire also resulted in more significant consequences than other fire origins.

The investigation conducted by KNKT identified the following findings as contributors to the marine occurrence under domestic ferry operations. The ineffective training and familiarisation factor was critical, followed by a mismatch between training and the actual situation [2], [18]. The investigation also found that there was no emergency response procedure available onboard, and the procedure was even available but not updated and not adequate to be implemented and comprehended by the crew. Under technical factors, firefighting equipment and lifesaving appliances were unavailable or malfunctioned [10].

Following the above-described background, the research attempts to identify the scope of the firefighting process from the crew's perspective. The research utilises multi-criteria decision-making (MCDM) tools to apprehend the crew's perception of handling fire. The research selects the analytic network process (ANP) as an MCDM tool for its comprehensive approach to including relevant factors in decision-making. The result of the analysis is compared qualitatively to the applied procedure in firefighting. The research findings help understand the crew preferences, which can be used as a reference for improving the procedure quality and evaluating crew performance in fire drills.

A. Past research on crew performance in fire drill

Previous research on fire drill performance monitoring has been conducted to review the effectiveness of the current drill program as set up by the management. The

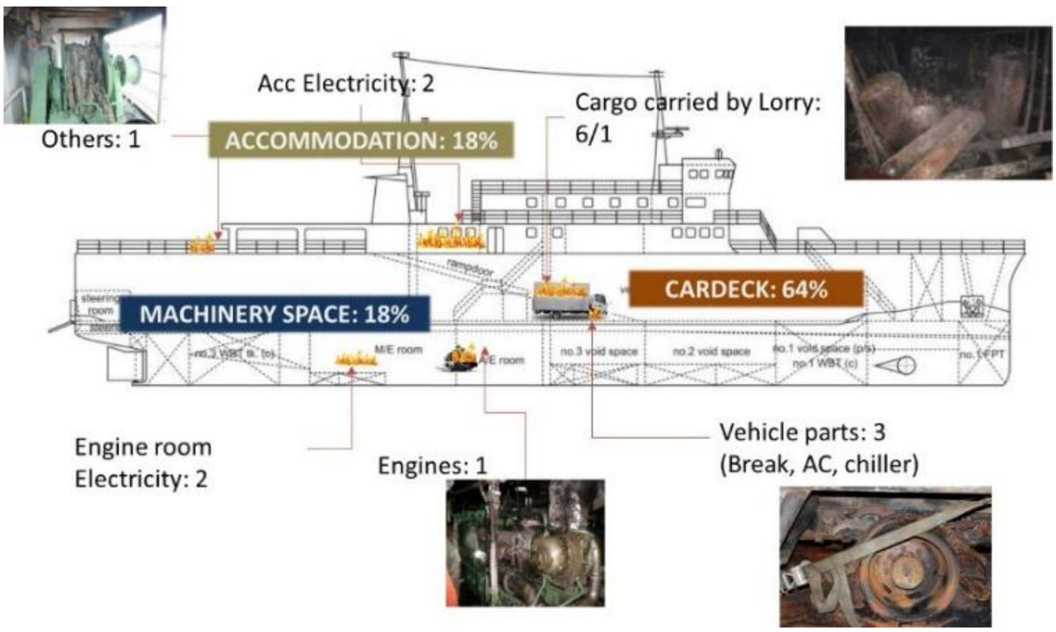

Figure 1. Cluster of fire-origin-based investigations carried out 2007 – 2023. Reproduce from KNKT database 2007 – 2023.

research on past fire cases found some findings that indicated crew proficiency issues. Lack of knowledge of fire characteristics resulted in the wrong or ineffective firefighting action. Issues in the identification and analysis of the situation indicate this. Also, findings on the emergency response taken indicate a lack of proficiency in handling the situation after the main event. This factor might have raised a question about how the crew education, assessment and training procedure development were conducted. Wu et al. (2014) proposed an evaluation model for fire drills from the perspective of port state control. The paper points out that the effectiveness of evaluation, preparation stage performance level, and recovery of fire drills are crucial to understanding their effectiveness [11].

Many studies have contributed to developing an evaluation model for fire drill performance onboard ships. Celik (2020) identified factors influencing ship emergency preparedness, including insufficient practice and training, missing crew and supervisor, and incorrect placement of firefighting equipment [19]. Sim (2019) proposed a standard firefighting drill scenario, considering crew assembly time, arrival time to the fire scene, and the time to wear firefighting gear [20]. Wu (2014) emphasised the importance of evaluating the effectiveness of fire drills for emergency and Port State Control inspections and introduced a System Engineering Theory-based evaluation method. Larsson (2002) conducted model scale tests to investigate fire development on a Ro-Ro ferry vehicle deck, focusing on the impact of ventilation and sprinklers [21]. These studies provide a foundation for developing a comprehensive evaluation model for fire drill performance onboard ships.

B. Cognitive model on fire fighting performance based on Simple Cognition model

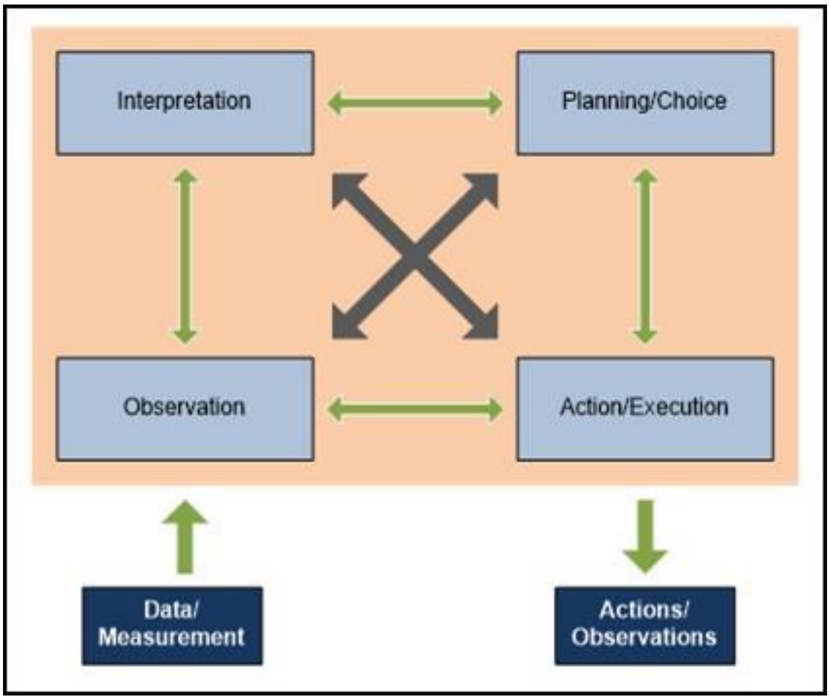

Figure 2. Hollnagel's simple cognitive model

Hollnagel (1993) introduced a simple cognition module to express the human cognitive process. According to Hollnagel, as shown in Figure 2, human performance generally follows four main steps: observation, interpretation, planning/selection of action, and executing the action selected [22, p. 199].

Within the perception step, the cognition model observes issues that possibly occurred. During this step, the model evaluates the crew's perception of fire hazards from different sources because of its accuracy, availability, and accessibility of information. There are three possible options to present crew perception of fire hazards onboard.

In the detection stage, transmitting information is the main factor in deciding the main objective of the process. The primary reference for the detection process involves transferring information from the previous step. In general, during the detection stage, the evaluation mechanism of the information involves reception and concludes with information transmission.

The analysis stage is considered the central process in cognition. It varies relevant to the overall process results, either sufficiently predicting the threat or even escalating the risk in a fire situation. The process of analysis requires information reception, decision-making, and setting up planning. Other than crew onboard or external sources, the crew could take the information analysis. The information transmitted from the previous step becomes the main factor for the failure or success of this stage, as well as the involved subject's capability.

Select action is the concluded activity during the process of cognition. The cognition model separates the operation based on the risk of different nature of the occurrence. The decision-making stage divides cognition into different sub-stages: communication process, timing and sequence, and quality and selection. This process analysed the overall cognitive process results under the action selection step.

C. Analytic Network Process (ANP)

The Analytic Network Process (ANP) is a comprehensive decision-making framework that is particularly valuable for analysing societal, governmental, and corporate decisions [23], [24]. It enables decision-makers to consider all relevant factors and criteria, both tangible and intangible, to make well-informed choices. ANP facilitates incorporating interactions and feedback within groups of elements (inner dependence) and between these groups (outer dependence). This feedback mechanism effectively captures the intricate dynamics of human society, especially when dealing with risks and uncertainties [23], [25].

Developed by Thomas L. Saaty, the ANP allows users to input judgments and measurements to determine ratio scale priorities, guiding allocating resources among factors and groups of factors in the decision-making process. The well-known Analytic Hierarchy Process (AHP) is a specific instance of ANP, as both methods derive ratio scale priorities by comparing elements based on a shared property or criterion. While many decision problems are best addressed using ANP, comparing the results obtained through ANP with those from AHP or other decision-making approaches is advisable. This comparison should consider factors such as the time required to obtain results, the effort involved in making judgments, and the relevance and accuracy of the outcomes [26]. Application of ANP covers broad sectors, including industrial [27], community science and public administration [28] [29] [30], academic research [31] and customer perspective research [32].

ANP models consist of two components: a control hierarchy or network of objectives and criteria overseeing interactions in the studied system and multiple sub-networks representing influences among the elements and clusters related to each control criterion. The ANP has found applications in various domains, including marketing, healthcare, politics, social issues, forecasting, and prediction. Notably, its predictive accuracy is remarkable, as demonstrated in economic trend analysis, sports outcomes, and other situations where the eventual results are known.

The ANP analysis comprises seven steps, including:

1. Setting goals and assessment criteria

   The model is developed, and the problem is listed. The decision maker must state the problem clearly and decompose it.

2. To conduct a pairwise comparison for each alternative based on every criterion.

   A matrix is used to show pairwise comparisons. The equation below is used to extract a local priority vector. This formula will determine the relative importance of clusters/elements.

$$A = \lambda_{max} \times \omega \qquad (1)$$

3. Develop unweighted supermatrix

   The local priority vectors from Step 2 are used to shape a supermatrix, grouped and then placed in a suitable place in the supermatrix. This position is based on the influence flows obtained from two different situations: a cluster to another and a loop from a cluster to itself. A supermatrix is shown in equation 2.

$$\begin{array}{ccc} & & \begin{array}{ccc} & c_1 & \\ e_{11} & e_{12} & e_{1\,m1}\end{array} \\ W = \begin{array}{c} c_1 \\ \vdots \\ c_k \\ \vdots \\ c_n \end{array} & \begin{array}{c} e_{11}\\ e_{12}\\ \vdots \\ e_{1\,m1}\\ \vdots\\ e_{k1}\\ e_{k2}\\ \vdots\\ e_{k\,mk}\\ \vdots\\ e_{n1}\\ e_{n2}\\ \vdots\\ e_{n\,mn}\end{array} & \begin{bmatrix} w_{11} & \cdots & w_{1k} & \cdots & w_{1n} \\ \vdots & & \vdots & & \vdots \\ w_{k1} & \cdots & w_{kk} & \cdots & w_{kn} \\ \vdots & & \vdots & & \vdots \\ w_{n1} & \cdots & w_{nk} & \cdots & w_{nn}\end{bmatrix} \end{array} \qquad (2)$$

   As shown in equation 2, in the supermatrix, Ck represents the cluster (k=1,2, 3…, n), and each cluster (k) possesses mk elements. These elements are shown as ek1, ek2, ek3…., ekmk. When elements have no influence, zero entries are used in the related position in the matrix. Consider a three-level network structure shown in Figure 4 as an example with goal, criterion, and alternatives. The supermatrix for this problem can be shown as the equation.

$$W = \begin{bmatrix} 0 & 0 & 0 \\ W_{21} & W_{22} & 0 \\ 0 & W_{32} & I \end{bmatrix} \qquad (3)$$

   Raise the former matrix to exponential powers. Different values are suggested for this purpose (k, 2k+1, etc). The following equation can be used to bring all elements of the weighted supermatrix, noting that the operations continue until all elements of the supermatrix are identical.

$$\lim_{k \to \infty} W^k \qquad (4)$$

   Then, all elements' final priorities are gained by normalising the cluster of the final matrix obtained. Furthermore, where the number of elements is relatively few, they can be estimated using matrix operations.

4. Determine the final weight of the alternatives to select the best alternative based on the criteria given.

   The best alternative was selected based on the normalised supermatrix. Priority weights indicate this, and the alternatives with higher scores are considered the best choices. Point to note that when supermatrix is considered an interrelated cluster, priorities are taken by conducting additional analysis.

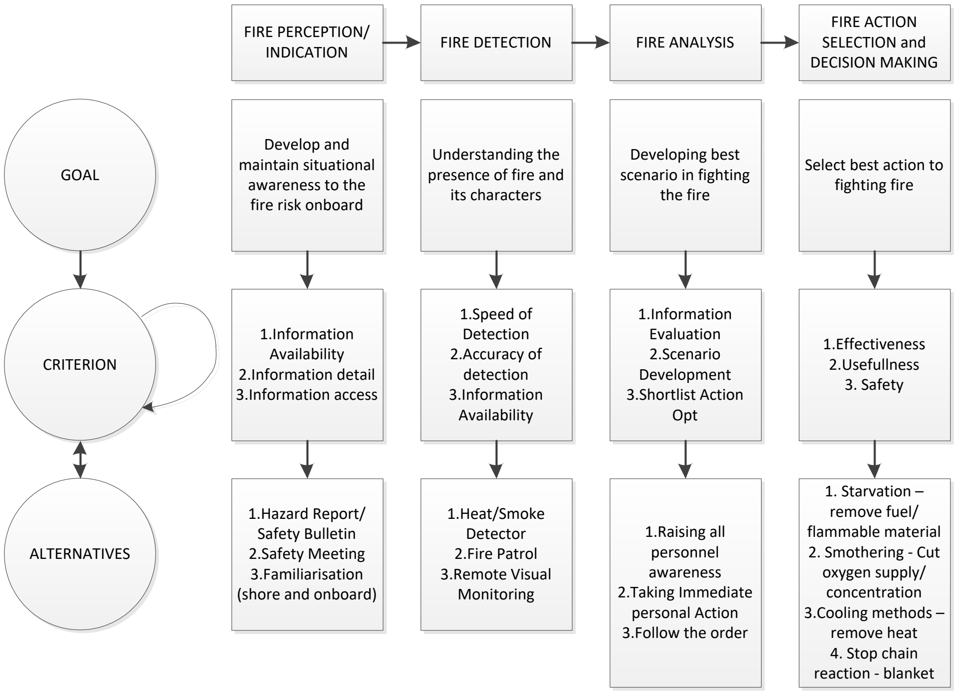

Figure 3. Cognitive model for fire drill in views of ANP model

II. Method

For this research, the scope of analysis is limited to the crew performance in handling fire onboard the RoRo passenger vessel, regardless of its size and modes of service. The research also gave access to acquired crew perceptions from a reputable RoRo company operating in domestic service in Indonesia. The selected company is the largest private ferry company in Indonesia. The company operates 48 RORO passenger ferries in various sizes, and their service covers significant islands in the country. For operating such large fleets, the company employs 1000 crew members and another 500 personnel for shore support activities. The company also possesses safety management certification from the flag state and applies safety management systems for every aspect of ship operation.

In brief, the flow of research includes:

1. Develop the pairwise model (Figure 3)

   The chart below presents the pairwise model from the perspective of ANP models. The chart's heading is provided on the left side, indicating the generic concept of ANP. The objective in each cognition stage is described, followed by a list of alternatives correlated with the criterion.

2. Review the current procedure for the fire drill.

   The company safety management system issued relevant procedures and checklists for fire drills onboard. The prescriptive procedure explained in tabulated form contains the responsibility of each crew member based on rank (DLU, 2023).

   The procedure within the company SMS states that all crew members must ring an alarm in sequential order when a fire is found and reported to the master. The master orders the safety officer to lead the firefighting team. All officers are required to perform their tasks based on each responsibility. The selection of proper fire fighting equipment is provided in detail within the procedure. Observation of the weather conditions is an additional task within the list when a fire breaks out in an open deck.

   The crew must remove all dangerous material that might escalate the fire rate. When a fire breaks out inside a confined space, the fixed fire extinguisher is operated before sending the fire team. The same procedure is applied when deemed ineffective, like handling fire in an open space. The crew might handle the fire directly for small fires and report to the master or relevant officer. The master must be extra cautious during firefighting and apply securing measures. In addition, the master should prepare to abandon the ship whenever required. The procedure of abandonment should be complied with for this purpose. The master must also report to the company headquarters and declare an emergency to the nearby vessels or relevant authorities for the safety of passengers and the ship. All activity must be recorded within the logbook (DLU, 2010).

3. Collect crew perception on fire drills using direct questionnaires developed based on a cognitive model.

A direct polling model acquires crew perception of the fire drill performance. This polling model relies mainly on the crew's perception of the information provided in the questionnaire. The polling form is designed with sufficient information about the fire drill and its supplementary details. In addition, the crew is provided with the options for every pairwise comparison. The questionnaire design includes the respondent's background, the experience of handling fire onboard, and assessment for each cognitive stage.

4. Analyse the crew perception using the analytical network process (ANP).

   The following alternatives and criteria are developed based on the relevant references in fire drills such as SOLAS, fire fighting best practices and NFPA.

   For the cognition stage of perception, the main objective is for the crew to develop and maintain situational awareness relevant to the fire risk onboard. For this factor, three alternatives can be references for the crew, i.e., from a hazard reporting program, regular safety meetings and familiarisation onboard. Those three alternatives are based on three criteria: information availability, information detail and access to the information.

   During the detection stage, the crew must understand how to detect fire based on the signs and nature of the fire. For this reason, three tools can be used to cover heat/smoke detectors: fire patrol and remote visual monitoring, typically done through a closed-circuit television (CCTV) system. The alternatives given should be viewed from the speed of detection, accuracy, and availability of information that the crew can access.

   Under the cognition stage of analysis, the crew must analyse the situation based on their perception and detection of the fire presence, thus developing a scenario to fight the fire. To view this condition, the crew presented three alternatives of the analysis model, i.e., raising all personnel awareness, taking immediate personal action, or waiting for the order. All those alternatives are based on three criteria: the information evaluation model, scenario development and shortlisting action options.

   The last part of the cognitive model is decision-making or taking action. The respondent has four alternatives to handling the fire regardless of the situation. The options cover starvation techniques, smothering, cooling, and stopping chain reactions. The respondent must select the preferred action based on their perception and experience.

   The respondent must express their opinion on the alternatives based on each stage of cognition. In addition, the respondent also asked to put value for their interest discretely as formulated by the ANP. The following table describes the fundamental scale as prescribed by Saaty to guide the respondent in selecting and valuing the comparison selection for the ANP analysis model.

TABLE 1. SUGGESTED SCALE FOR INTENSITY OF IMPORTANCE

Intensity of importance	Explanation	Definition
1	Two activities contribute equally to the objective	Equal importance
3	Experience and judgement slightly favour one over another	Moderate importance
5	Experience and judgement Strongly favour one over another	Strong Importance
7	Activity is strongly favoured, and its dominance is demonstrated in practice.	Very Strong Importance
9	The highest possible order for one factor's importance over another is considered.	Absolute Importance
2, 4, 6, 8	Compromising between the above priorities	Intermediate Values

   The research uses super-decision software to support a robust and effective analysis process. All the connections between goals, criteria and alternatives are arranged according to the software guidelines.

5. Review the result and compare it with the relevant applied procedure in the fire drill.

   The crew response is compared to the prescribed guidance of the fire drill procedure. A set of questionnaires was developed using Google Forms, which contains information and questions. The range of questions is extracted from the cognitive model in **Figure 3**.

III. RESULTS AND DISCUSSION

A. *Survey Result*

Two hundred thirty-four participants from 34 vessels responded to the survey (Figure 2). This response covers about 25 per cent of the total crew from the shipping company. Therefore, information acquired from the survey was considered sufficient to provide the crew's perspective on handling the fire onboard RoRo.

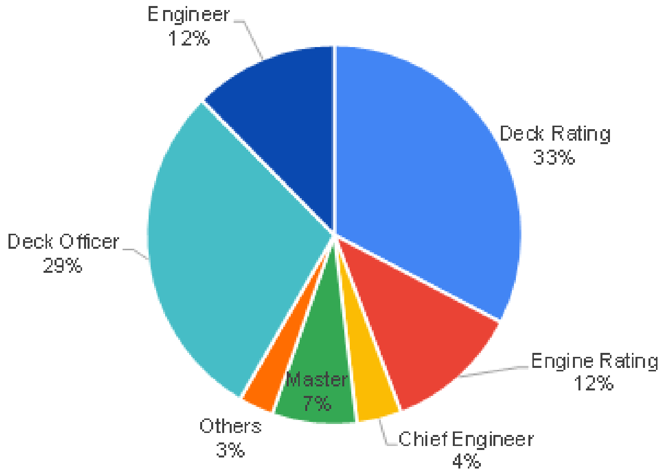

Figure 4. The proportion of respondents is based on their ranks.

TABLE 2. SUMMARY OF THE RESPONDENTS' OPINIONS FOR THE PERCEPTION/INDICATION (P) STAGE

Stage	Pairwise Comparison		Criteria: PC1 Info Availability				Criteria: PC2 Info Detail				Criteria: PC3 Info Acces			
			Respondent Proportion		Modes Value		Respondent Proportion		Modes Value		Respondent Proportion		Modes Value	
P	PA1	PA2	61	173	9	9	79	155	9	9	132	102	9	9
	PA1	PA3	37	197	9	9	66	168	9	9	83	151	9	9
	PA3	PA2	118	116	9	9	112	122	9	9	120	113	9	9

TABLE 3. SUMMARY OF THE RESPONDENT'S OPINION FOR DETECTION (D) STAGE CRITERION

Stage	Pairwise Comparison		Criteria: DC1 Speed				Criteria: DC2 Accuracy				Criteria: DC3 Info Availability			
			Respondent Proportion		Modes Value		Respondent Proportion		Modes Value		Respondent Proportion		Modes Value	
D	DA3	DA1	55	179	9	9	59	175	9	9	135	99	9	9
	DA2	DA1	134	100	9	9	116	118	9	9	99	135	9	9
	DA2	DA3	188	46	9	9	191	43	9	9	174	60	9	9

TABLE 4. SUMMARY OF THE RESPONDENT'S OPINION OF ALTERNATIVES FOR EACH CRITERION IN THE STAGE OF ANALYSIS (A) STAGE

Stage	Pairwise Comparison		Criteria: AC1 Evaluation				Criteria: AC2 Scenario Dev				Criteria: AC3 List of Action			
			Respondent Proportion		Modes Value		Respondent Proportion		Modes Value		Respondent Proportion		Modes Value	
A	AA1	AA2	145	89	9	9	149	85	9	9	140	94	9	9
	AA3	AA2	65	169	9	9	114	120	9	9	88	146	9	9
	AA3	AA1	33	201	9	9	85	149	9	9	79	155	9	9

TABLE 5. SUMMARY OF THE RESPONDENT'S OPINION TO ALTERNATIVES FOR EACH CRITERION IN THE STAGE OF TAKING ACTION (T) STAGE

Stage	Pairwise Comparison		Criteria: TC1 Effectiveness				Criteria: TC2 Usefulness				Criteria: TC3 Safety			
			Respondent Proportion		Modes Value		Respondent Proportion		Modes Value		Respondent Proportion		Modes Value	
T	TA2	TA1	94	140	9	9	105	129	9	9	117	117	9	9
	TA3	TA1	115	119	9	9	116	118	9	9	106	128	9	9
	TA4	TA1	135	99	9	9	103	131	9	9	111	123	9	9
	TA3	TA4	116	118	9	9	121	113	9	9	117	117	8	9
	TA2	TA3	131	103	9	9	125	109	9	9	112	122	9	8
	TA4	TA2	137	97	9	9	132	102	9	9	134	100	9	9

The following tables present each stage of polling results from the respondents. The table consists of pairwise comparison variables because of different criteria based on the ANP model design for analysis of crew performance on fire drills. Mode's value is used as the selection value in the ANP model. Mode as the value is a statistical approach to present the trend of respondent preferences [33].

TABLE 6. RESULTS OF ANP FOR EACH COGNITIVE STAGE

Stage	**Alternatives**	**Ideals**	**Normals**	**Raw**	**Consistency Value**
Perception Stage	Familiarisation	0.445	0.288	0.144	0.539
	Safety Bulletin	0.103	0.066	0.033	
	Safety Meeting	**1.000**	**0.646**	**0.323**	
Detection Stage	CCTV	0.081	0.042	0.021	0.539
	Security Patrol	0.865	0.445	0.222	
	Smoke Heat Detector	**1.000**	**0.514**	**0.257**	
Analysis Stage	Self Direct Act	0.144	0.073	0.036	0.539
	Wait for Orders	0.838	0.423	0.211	
	Warn Others	**1.000**	**0.504**	**0.252**	
Taking Action Stage	Cooling	0.305	0.152	0.076	0.539
	Smothering	0.208	0.104	0.052	
	Starvation	**1.000**	**0.498**	**0.249**	
	Stop Chain Reaction	0.494	0.246	0.123	

B. ANP Result

Table 6 presents ANP calculation results for crew preference in handling fire onboard through fire drills. The ideals indicate the crew's preference in every cognitive stage, normals and raw value. The highest number in the tables results from a weighted supermatrix based on the given value from the survey in every stage of cognition. This output presents the most preferable alternative in each stage of cognition.

Under the perception stage, most of the crew rely on the safety meeting compared to others in understanding the potential fire hazard on their vessel. The crew indicated the importance of safety meetings in developing mental models and maintaining situational awareness of the fire risk onboard. Most of the crew who selected the safety meetings stated that safety meetings are essential compared to the other two options. A practical and regular safety meeting would provide the opportunity to cover familiarisation and hazard identification. The meeting would create awareness and review the current state of operation. From this point of view, the crew would have an opportunity to be involved in the safety system by expressing their concern relevant to the subject matter.

Under the detection stage, most of the crew relied on the capability of smoke and heat detectors to acquire information on the presence of fire. The respondents expressed that the technology of sensors is reliable, mainly compared to other security patrol and remote visual monitoring options. These findings indicate strong reliability in technology rather than human operation. This factor's rationale primarily views the speed of detection and accuracy of information.

Under the analysis stage, the respondents perceived that the situation's complexity might involve determining the correct action to fight the fire. The ANP results indicated that creating overall awareness about the latest situation is more important than taking the initiative and waiting for instructions. Most respondents agreed that raising the alarm for the whole ship system would be at the top of the list for the subsequent firefighting. From the perspective of a common approach, this is considered a reasonable action since handling fire would be better in a group, involving everyone and utilising all equipment.

During the stage of action taken to put out the fire, most of the crew concurrently affirmed that starvation was the most effective and valuable firefighting method. The following preferable action to extinguish the fire is to stop the chain reaction by cutting all the fire triangles to interact with other combustion material. Both actions are considered direct attack actions compared to the other two. The firefighting team is required to access the fire scene and perform such actions to deal with the source of the fire. This high-risk operation requires a competent firefighting team supported by well-performing equipment and outfits.

TABLE 7. COMPARATIVE RESULTS BETWEEN CREW PERCEPTION AND FIREFIGHTING PROCEDURE

Cognitive Stage	**Fire fighting procedure**	**Crew Preference**
Perception	Not stated or stated otherwise	Safety Meeting
Detection	Crew required to sound the alarm and report to the master/safety officer	Smoke and heat detector
Analysis	Report to the master	Warning others
	Master orders the FF team and other ranks to conduct tasks as described in the fire drill procedure.	
	Remove all hazardous materials.	
	Observe weather situation	
	Declare emergency to Headquarters and other nearby vessel/s	
Taking action	Starvation	Starvation
	Smothering	stop chain reaction
	Cooling	cooling
	Securing and preparing for the worst scenario	smothering

C. *Compliance Evaluation Result*

The research used a qualitative comparative analysis model to observe the consistency of the crew's performance in conducting fire drills. The crew preferences are viewed based on the procedure described in the previous section. It is reasonable to view the procedure from the perspective of cognitive processes so that a fair result can be obtained. Table 7 presents comparative results from the procedure with the crew's perspective on fire drills. The company's procedure prescribes step-by-step guidance for the crew to respond to the presence of fire.

The comparative analysis shows that most of the crew's perception of firefighting complied with the relevant procedures. However, some areas might be improved. This area is related to the crew perception and detection stage. On the one hand, the procedure is not prescriptive in so much detail on handling the fire. This condition provides flexibility for the crew since the situation could be dynamic and require immediate and improvised action. On the other hand, the situation could also present challenges to the crew as the procedure lacks detail in dealing with different fire conditions, such as fire from an unknown substance. This condition means the crew will be challenged to handle such situations with their knowledge and experience.

D. *Limitations of The Research*

Acquiring respondents' opinions might be considered a typical and sensible solution to understanding how a population sees multiple alternatives based on specific characteristics or criteria. Since the polling was undertaken unguided, the information provided by the respondents can be varied and mostly comes from their perception of the instruction provided on the questionnaire. The lack of inconsistency value from the ANP results indicates that respondents might face difficulties viewing abundant information in the questionnaire. Therefore, the quality of respondent polling could be improved by having a direct assessment and guided polling model.

IV. CONCLUSION

Overall, the ANP method offers a powerful and flexible approach to multi-criteria decision-making that can significantly improve decision-making processes in various fields. As such, it represents an essential tool for researchers and practitioners seeking to enhance their ability to make informed and effective decisions in complex and uncertain environments.

From the model result and discussion stated in the previous section, it is ascertained that training and familiarisation are the main significant factors in preventing failure in firefighting onboard ropax. Even though the regulation forced the ropax vessel to perform scheduled and frequent ship familiarisation, safety drills, and emergency training onboard more than other types of ship, there are most probably influencing factors in how the drill was conducted. The fire drill should be simulated close to the actual situation rather than normative and just compliance practice.

The comparative results indicate that the company made a sufficient effort to implement its safety management, particularly in fire drills. The crew's perception of handling fire onboard shows they had sufficient knowledge and properly planned the operation when a fire occurred onboard their vessel. Regardless, some areas can be improved to enhance crew firefighting performance. This area is mainly under the aspect of their perception and detection process.

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REFERENCE

[1] C. T. Lawson and R. Weisbrod, "Ferry Transport: the realm of responsibility for ferry disasters in developing nations," *J. Public Transp.*, vol. 8, 2005.

[2] J.-U. S.-H. Stephan, P. Assheuer, and A. A. Hebbar, "Domestic Ferry Safety In Indonesia: HAZID/Scoping exercise to identify safety issues pertaining to passenger ships in Indonesia not engaged on international voyages," 2019.

[3] A. Nurwahyudy, "Contemporary issues in domestic ro-ro passenger ferry operation in developing countries : identification of safety issues in domestic ferry operation based on accident investigation reports on ferry involved accidents in Indonesian water," World Maritime University, Malmo, 2014. [Online]. Available: https://commons.wmu.se/all_dissertations/463/?utm_source=commons.wmu.se%2Fall_dissertations%2F463&utm_medium=PDF&utm_campaign=PDFCoverPages

[4] D. Hubdat, "Rencana Strategis Direktorat Jenderal Perhubungan Darat 2020 - 2024," Direktorat Jenderal Perhubungan Darat, Jakarta, Government report, Dec. 2020.

[5] S. Diposaptono, *Membangun Poros Maritim Dunia: dalam perspektif tata ruang laut*, 3rd ed. Jakarta: Kementerian Kelautan dan Perikanan, 2017. [Online]. Available: https://kkp.go.id/an-component/media/upload-gambar-pendukung/DitJaskel/sbdn/Membangun_Poros_Maritim.pdf

[6] I. IMO, "Philippines domestic ferry conference urges action to improve safety record," https://www.imo.org/en/MediaCentre/PressBriefings/pages/16-ferry-conf-manila.aspx#:~:text=The%20Manila%20Statement%20highlights%20that,societies%20and%20organizations%20which%20Governments. [Online]. Available: https://www.imo.org/en/MediaCentre/PressBriefings/pages/16-ferry-conf-manila.aspx#:~:text=The%20Manila%20Statement%20highlights%20that,societies%20and%20organizations%20which%20Governments

[7] I. MSC101, "Proposal for a new output to introduce a comprehensive approach to enhance domestic ferry safety," International Maritime Organisation, London, Submission MSC101/21/20, Mar. 2019.

[8] K. KNKT, "KNKT," knkt.go.id.

[9] P. Ntzeremes and K. Kirytopoulos, "Applying a stochastic-based approach for developing a quantitative risk assessment method on the fire safety of underground road tunnels," *Tunn. Undergr. Space Technol.*, vol. 81, pp. 619–631, Nov. 2018, doi: 10.1016/j.tust.2018.08.020.

[10] A. Nurwahyudy, "Fire onboard roro ferry: causation," presented at the 2019 Ferry Safety and Technology Conference, Bangkok, 2019.

[11] J. Wu, Y. Jin, and J. Fu, "Effectiveness Evaluation on Fire Drills for Emergency and PSC Inspections on Board," *TransNav Int. J. Mar. Navig. Saf. Sea Transp.*, vol. 8, no. 2, pp. 229–236, 2014, doi: 10.12716/1001.08.02.08.

[12] DNV, "Fires on RORO decks," *Det Nor. Veritas*, 2005.

[13] NFPA, "Fire Extinguisher Types." Accessed: Jun. 22, 2023. [Online]. Available: https://www.nfpa.org/News-and-Research/Publications-and-media/Blogs-Landing-Page/NFPA-Today/Blog-Posts/2021/07/16/Fire-Extinguisher-Types

[14] I. IMO, "International Convention for the Safety of Life at Sea (SOLAS), 1974." International Maritime Organisation, London, 1974.

[15] IMO, "Fire Safety System (FSS) Code as amended 2014." International Maritime Organisation, Jan. 07, 2002.

[16] Safety4Sea, "USCG: Enhancing preparedness for shipboard fires," Nov. 21, 2023. [Online]. Available: https://safety4sea.com/uscg-enhancing-preparedness-for-shipboard-fires/?utm_source=newsletter&utm_medium=email&utm_campaign=SAFETY4SEA+-+daily+22%2F11%2F2023

[17] A. Nurwahyudy, "HUMAN FACTOR PERFORMANCE IN FIRE ACCIDENT ON BOARD VESSEL," presented at the SAFEMODE Symposium, Jakarta, 2022.

[18] R. Weisbrod and N. Rahman, "Improving Ferry Safety for Lake Toba and for the Republic of Indonesia as a whole," WorldBank, Jakarta, 2019.

[19] M. Celik and B. Tac, "Prediction of Emergency Preparedness Level Onboard Ships Using Discrete Event Simulation: The Case of Firefighting Drill," 2022, doi: doi: 10.7225/toms.v11.n02.008.

[20] W.-J. H. Hyosang Sim and Y.-S. Park, "A basic study on the standardisation of firefighting drill scenarios on board," *J. Int. Marit. Saf. Environ. Aff. Shipp.*, vol. 3, no. 3–4, pp. 28–35, 2019, doi 10.1080/25725084.2019.1698897.

[21] I. Larsson, H. Ingason, and M. Arvidson, "Model Scale fire test on a vehicle deck onboard a ship," Boras Sweden, Testing project SP Report 2002:05, 2002. [Online]. Available: https://www.diva-portal.org/smash/get/diva2:962221/FULLTEXT01.pdf

[22] E. Hollnagel, "MODELS OF COGNITION: PROCEDURAL PROTOTYPES AND CONTEXTUAL CONTROL," *Trav. Hum.*, vol. 56, no. 1, pp. 27–51, 1993.

[23] S. Kheybari, F. M. Rezaie, and H. Farazmand, "Analytic network process: An overview of applications," *Appl Math Comput*, vol. 367, 2020, [Online]. Available: https://api.semanticscholar.org/CorpusID:207757916

[24] I. Otay and C. Kahraman, "Analytic Network Process with Neutrosophic Sets," *Fuzzy Multi-Criteria Decis.-Mak. Using Neutrosophic Sets*, 2018, [Online]. Available: https://api.semanticscholar.org/CorpusID:126123492

[25] P. Svenson, "Social network analysis of uncertain networks," 2008. [Online]. Available: https://api.semanticscholar.org/CorpusID:16014667

[26] T. Saaty, "ANP Model for BOCR Direct Supply," Katz Graduate School of Business, Pittsburgh, Academic Research, Apr. 2005.

[27] A. W. Nugroho, R. Widhianggitasari, D. Fuani Priadi, and P. Widyo Laksono, "Penerapan Metode Analytic Network Process (ANP) untuk Mengatasi Keterlambatan Pengadaan Barang pada Bagian Umum di PT Solo Grafika Utama," *Performa Media Ilm. Tek. Ind.*, vol. 15, no. 2, 2016, doi: https://doi.org/10.20961/performa.15.2.9866.

[28] A. Febriani, "Implementasi metode analytic network process (ANP) sebagai alat bantu pengambilan keputusan pemilihan rekanan proyek." Universitas Islam Negeri Sultan Syarif Kasim, 2011. [Online]. Available: https://repository.uin-suska.ac.id/649/1/2011_2011134-.pdf

[29] P. M. Mimovic, A. Krstic, and J. Savic, "Serbia joining the European Union: An ANP model for Forecasting the accessing date," *Int J Anal Hierarchy Process*, vol. 11, no. 1, pp. 2–19, Apr. 2019, doi: 10.13033/ijahp.v11i1.616.

[30] W. A. Syafei, K. Kusnadi, and B. Surarso, "Penentuan Priorita Perbaikan Jalan Berbasis Metode Analytic Network Process Sebagai Komponen Menuju Kota Cerdas," *J SIST INF BISNIS*, vol. 6, no. 2, p. 105, Nov. 2016, doi: 10.21456/vol6iss2pp105-113.

[31] D. Nurlaila, D. Supriyadi, and A. E. Amalia, "Penerapan Metode Analytic Network Process (ANP) Untuk Pendukung Keputusan Pemilihan Tema Tugas Akhir (Studi Kasus: Program Studi S1 Informatika ST3 Telkom)," *J Inf. J Pengemb IT*, vol. 2, no. 2, pp. 63–68, Jul. 2017, doi: 10.30591/jpit.v2i2.511.

[32] A. Ujwary-Gil, A. Florek-Paszkowska, and A. Kozioł, "AHP/ANP applications in Economic Policy, Business, and Management with the T. l. saaty decision making hackathon at ICEFM 2022," *Int J Anal Hierarchy Process*, vol. 14, no. 3, Jan. 2023, doi: 10.13033/ijahp.v14i3.1071.

[33] E. Eleftheria, P. Apostolos, and V. Markos, "Statistical analysis of ship accidents and review of safety level," *Saf. Sci.*, vol. 85, pp. 282–292, Jun. 2016, doi: 10.1016/j.ssci.2016.02.001.