Response Coordination Model for Real Time Decision Making in Coastal Search and Rescue Operation Using Fuzzy Logic Technique

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Abstract:- Coastal search and rescue (SAR) operations are complex, involving dynamic and uncertain conditions that demand real-time, effective decision-making. This paper aimed to analyze response coordination for real-time decision-making in coastal SAR operations using the fuzzy logic technique. The main aims of this study were to identify the key parameters and linguistic variables critical for effective decision-making in SAR operations and finally to design a fuzzy logic model tailored to the dynamic and uncertain conditions inherent in coastal SAR operations. The proposed fuzzy logic model demonstrated improved responsiveness and adaptability to changing conditions, offering a more robust framework for decision-making in SAR operations. However, this study contributes to enhancing the efficiency and effectiveness of real time decision making in SAR operations in coastal environments, with broader implications for maritime safety.

Keywords:- *Fuzzy Logic, Real-Time Decision Making, Search and Rescue Operations, Coastal Environments, Decision Support System, Response Coordination Model, Fuzzy Model.*

I. INTRODUCTION

Risks associated with sea transportation and shipping include fire, collision, grounding, floods, shifting cargo, man overboard, and, not limited to, piracy (Barzehkar et al., 2021). Even with the implementation of new safety regulations and guidelines, maritime accidents continue to occur (Kosmas et al., 2022). Search and rescue (SAR) operations play a critical role in saving lives and minimizing casualties in emergencies and disasters worldwide (Hasan et al., 2021). Whether responding to maritime accidents, natural disasters, or humanitarian crises, SAR teams face immense challenges in coordinating efforts, allocating resources, and making timely decisions in dynamic and uncertain environments (Chitikena et al., 2023).

Search and rescue operations can occur in various environments, including urban areas, wilderness areas, and maritime environments such as oceans, lakes, and rivers (Radojević & Kresojević, 2020). In maritime SAR operations, responders often face unique challenges, including vast search areas, adverse weather conditions, limited visibility, and communication difficulties (Andreassen et al., 2020). Additionally, the rapid detection of distress signals, precise situation evaluation, effective resource deployment, and efficient response unit coordination are all necessary for SAR missions to be successful (Alsamhi et al., 2022).

Technological developments over time, especially in the domains of robotics and artificial intelligence (AI), have created new avenues for improving the efficacy and efficiency of SAR operations (Soori et al., 2023). One such technology that shows promise in this domain is fuzzy logic, a computational paradigm that enables the representation and processing of uncertain and vague information (Sarihi et al., 2023). Fuzzy logic has the potential to enhance real-time decision-making capabilities, which would increase SAR teams' adaptability and reactivity in difficult and unpredictable situations (Malyszko, 2022).

Furthermore, Technology is essential for improving SAR teams' capabilities and improving outcomes in emergency situations through effective, accurate, and timely decision-making (Zawawi et al., 2022). Moreover, over the years, advancements in communication systems, navigation technologies, remote sensing, and unmanned aerial vehicles (UAVs) have revolutionized SAR operations (Mohsan et al., 2023), enabling responders to access real-time information, coordinate efforts, and deploy resources more effectively (Damaševičius et al., 2023). In recent years, AI-powered technology, such as computer vision and machine learning, and robotics, have emerged as promising tools for enhancing situational awareness, automating decision-making processes, and enhancing the capabilities of SAR teams (Byeon et al., 2023; Mathur et al., 2022).

Furthermore, Several authors address how to change the procedure such that the ship assessment process which determines whether a ship is appropriate for a maritime search and rescue operation makes the best use of fuzzy logic (Uflaz et al., 2023). The researcher states that one of the action planning elements is choosing the most suitable ships. Additionally, the allocation of search and rescue resources is done using a multi-objective approach. (Malyszko, 2022). Likewise, the location of search and rescue boats is determined by a number of specific elements, including the number and nature of incidents handled in the region of interest, resource capacities, topography, and operational guidelines of the government. Therefore, it is no longer

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appropriate to use standard models that exclusively take political decisions into account (Malyszko, 2022).

Finally, while there is literature on fuzzy logic applications in various domains, including robotics, control systems, and decision support, there is a noticeable gap in research focusing specifically on its application in SAR operations at sea (Nasar et al., 2023). Existing studies primarily focus on traditional decision-making approaches, overlooking the potential benefits of fuzzy logic in enhancing the adaptability and strength of SAR systems deployed at sea. Furthermore, the few studies that do explore the application of fuzzy logic in SAR operations often lack a comprehensive examination of its effectiveness in real-time decision-making situations, particularly in dynamic and uncertain maritime environments (Li et al., 2024). Thus, there is a clear research gap in understanding the extent to which fuzzy logic can improve decision-making processes for SAR operations at sea.

II. LITERATURE REVIEW

In recent years, there has been growing interest in leveraging advanced technologies, such as fuzzy logic modeling, to enhance decision-making capabilities in SAR operations (Meziani et al., 2023) .

- *Fuzzy Systems*

Fuzzy inference systems (FIS) are computational structures based on the theory of fuzzy sets, if-then rules and fuzzy logic (Meziani et al., 2023). Since fuzzy systems vary in structure and purpose, different names such as fuzzy expert system, fuzzy model, fuzzy associative memory, fuzzy logic controller, fuzzy system and others are use.

- *Mamdani-Type Fuzzy Systems*

In 1975, Ebrahim Mamdani created a fuzzy system for operating a steam engine and a boiler in which the linguistic rules were tailored to the operators' human experience, making it one of the earliest fuzzy set theory-based systems (Vashishtha et al., 2023). A Mamdani-type fuzzy system varies from other fuzzy systems in its output variables (Iqbal et al., 2024).

In a Mamdani-type fuzzy system, the output variables are fuzzy and must be defuzzified using various approaches. The defuzzification operator employs a variety of ways to convert the output fuzzy variable into a crisp value (Starczewski et al., 2020). Two choices are typically employed for the T-norms and T-conorms: an algebraic product for the T-norm and max operator for the T-conorm with a max product for the composition; a min operator for the T-norm and max operator for the T-conorm and a maximin operator for the composition. Literature contains additional information about T-norms and T-conorms. Although the model can be produced in various ways using different operators and compositions, Mamdani-type fuzzy models all include fuzzy sets as output variables, necessitating defuzzification. As per (Sii et al., 2004) there are numerous techniques available for defuzzifying these aggregated output fuzzy variables. For this study, the centroid method was chosen for defuzzification, as it provides a crisp output value that represents the priority of SAR operations. This method averages the output fuzzy set into a single actionable value, facilitating the real-time decision-making process crucial to SAR operations.

A critical step in the Mamdani fuzzy system is the defuzzification process, which converts the fuzzy output into a crisp value, enabling actionable decisions in real-time search and rescue (SAR) operations.

In the Context of Fuzzy Logic, a Fuzzy Variable can be Represented as:

$$\mathrm{A} = \{x, \mu A(x) | x \epsilon X\} \tag{1}$$

Where μA(x) is the membership function of the fuzzy set A, and x is an element of the universal set X. Several defuzzification methods were considered to derive a crisp output value xˆ, including:

- *Center of Gravity Method*

$$\mathrm{x}\hat{} = x\mathrm{COG} = \frac{\int x\mu A(x)x\partial x}{\int x\mu A(x)\partial x} \tag{2}$$

This method is widely used because it provides a balanced representation of the fuzzy set, yielding the center of mass or centroid.

- *Medium Method (BOA)*

The medium method calculates xˆBOA is such that:-

$$\mathrm{x}\hat{} = x\mathrm{BOA} \tag{3}$$

Where $xBoA$ is such that

$$\int_{\alpha}^{xBoA} \mu A(x)\,\partial x = \int_{xBoA}^{\beta} \mu A(x) \partial x \tag{4}$$

For $\alpha = \min\{x | x \in X\}$ and $\beta = \max\{x | x \in X\}$

This method finds the point that devides the area under the membership functioninto two equal halves.

- *Average of Maxima Method*

The Average of Maxima method compute $xAoM$ by averaging the values of x that correspond to the highest membership degree

$$\mu\mathrm{x}\hat{} = xAoM = \frac{\int x_{\prime}x\partial x}{\int X_{\prime}\partial x} \tag{5}$$

Where

$$x = x' = \{x | \mu A(x) = \mu * : \ \mu * = Max\ X\left(\mu A(x)\right)\} \tag{6}$$

This method averages all points with the maximum membership grade.

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- *Min of Maxima (LOM) Method*

The min of maxima method finds the smallest x value that corresponds to the maximum membership degree.

$$\hat{x} = xLoM = \min\{x|\mu A(x) = \mu *: \mu *= \max(\mu A(x))\} \quad (7)$$

- *Max of Maxima (MOM) Method*

In the contrast, the max of maxima method takes the lagest x value that corresponds to the maximum membership degree.

$$\hat{x} = xMoM = \max\{x|\mu A(x) = \mu *: \mu *= \max(\mu A(x))\} \quad (8)$$

Existing research on the application of fuzzy logic technique for real-time decision-making in SAR operations was examined in this literature review. By identifying key concepts, methodologies, and findings from a previous research paper, this study seeks to shed light on the current state of the art and identify potential future research areas.

The review was commenced with an analysis of the fundamental principles of fuzzy logic and its applicability to decision-making in unpredictable environments, with a particular focus on the marine domain. The section then investigates into the application of the Fuzzy logic concept to the coordination of SAR operations involving numerous autonomous agents. Following this, the review was examined particular implementations of fuzzy logic technique in search and rescue (SAR) at sea. It was emphasized the difficulties, potential advantages, and consequences that arise from the integration of these technologies.

Extensive literature highlights the application of fuzzy logic in various fields requiring real time decision making, including, heartcare, automotives safety systems, and financial services. However, its application in maritime SAR operations has been limited. Study such as those by (Malyszko, 2021) have demonstrated the potential of fuzzy logic to enhance decision making under uncertainty in other emergency response scenarios, suggesting that similar benefits could be realized in maritime SAR operations. This Study was aimed to bridge this gap by specifically focusing on the integration of fuzzy logic in the operational protocols of SAR activities in Dar es Salaam.

III. MATERIAL AND METHODS

The study was carried out in the coastal waters of Dar es Salaam. These regions are known for their high incidence of maritime accidents, presenting an ideal environment for testing the efficacy of the fuzzy logic model. The study focused on operations led by the Tanzania Ports Authority, Tanzania Naval Force, and various local rescue agencies, with an emphasis on response coordination and resource allocation in real-time SAR operations.

The research employed a mixed-methods approach to ensure both depth and breadth in data collection and analysis. Qualitative data was collected via in-depth interviews with SAR personnel to gain insights into the challenges and decision-making frameworks used in real-time operations. Quantitative data, on the other hand, was gathered through structured surveys aimed at identifying key factors influencing SAR decision-making.

Primary data was collected from SAR personnel through structured questionnaires and interviews, which targeted a wide range of respondents, including SAR commanders, operators, and maritime officials. The qualitative interviews were designed to explore the experiences and perceptions of SAR personnel regarding decision-making in unpredictable environments. However, Secondary data was obtained from SAR operational reports, previous studies, and maritime accident records, offering a comparative backdrop for evaluating the fuzzy logic model.

Table 1 Research Variables and Associated Studies

Variables	Literature Source
Weather condition (wind, currant, fog and Rain)	(Malkoç & Oskar Eikenbroek ir Eric van Berkum, 2023)
Distance to Distressed Target (Based on time of Distress and speed)	(Malkoç & Oskar Eikenbroek ir Eric van Berkum, 2023)
SAR Personnel Equipment (Personal protective equipment, & personal survival equipment)	(Blitch, 1996; Malkoç & Oskar Eikenbroek ir Eric van Berkum, 2023)
Distress Type	(Su et al., 2019)

Source : Field Data (2024)

The quantitative data were analyzed using SPSS (Statistical Package for the Social Sciences) to perform descriptive statistical analysis, including frequency distributions and correlation tests. SPSS was used to establish the relationships between different variables such as weather conditions, proximity to distress sites, and the availability of resources, offering a baseline for comparison between traditional SAR methods and fuzzy logic-enhanced decision-making. Finally, the study utilized MATLAB, specifically the Mamdani Fuzzy Inference System (FIS), to develop and simulate the fuzzy logic model. Mamdani's method was chosen because it is highly interpretable and allows for human reasoning to be encoded into the decision-making process through a set of IF-THEN rules.

➢ *Methodological Flow Chart*

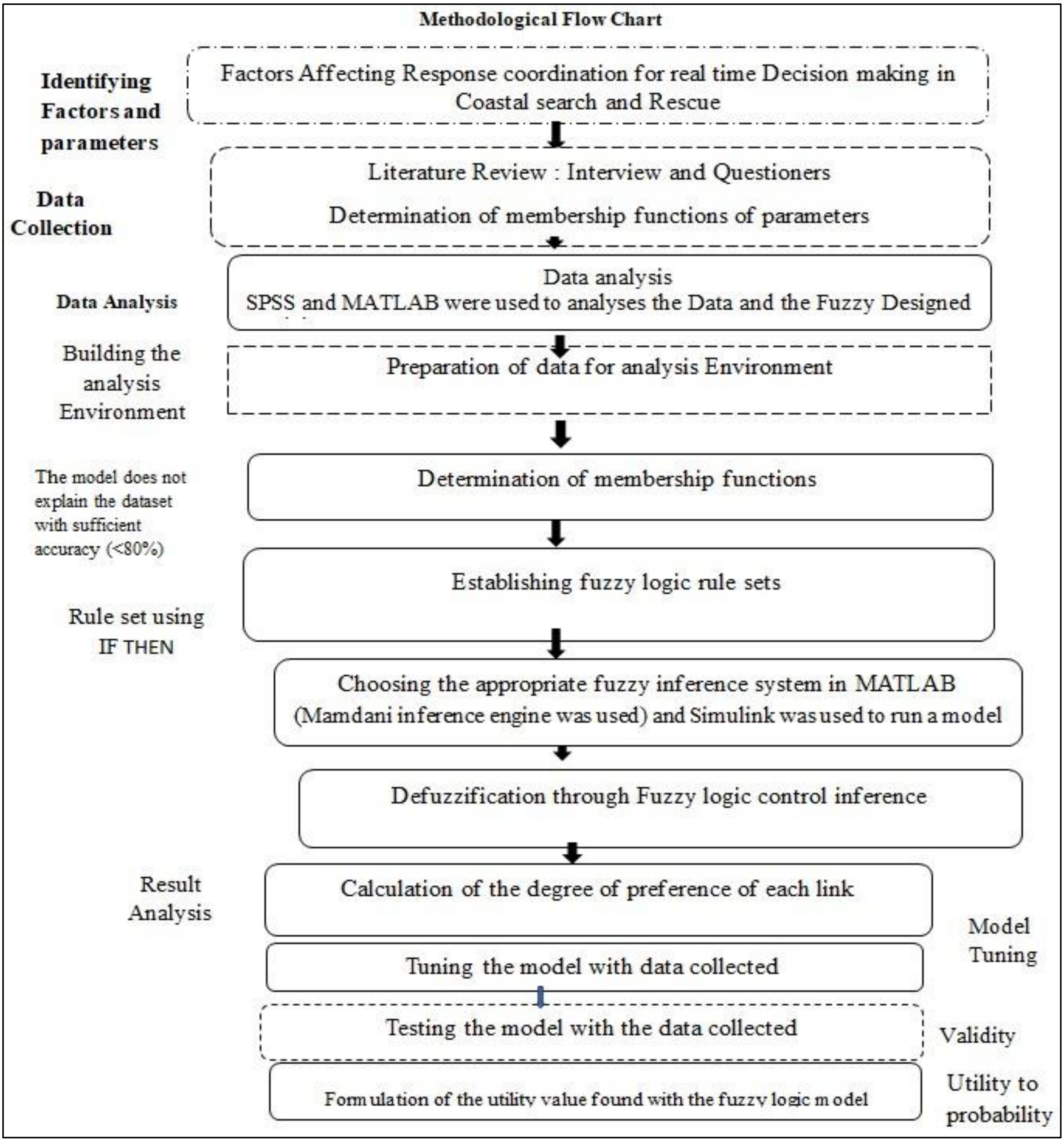

Fig 1 Model Methodological Framework
Source : Field Data (2024)

IV. RESULTS

➢ *Variable to Consider in Response Coordination for Search and Rescue Operation.*

After data collectin and analysis, in this study identified several key factors that are essential for effective decision making in Roperations, particularly in the context of the Indian ocean at Dar es salaam. These factors were gathered through interviews with SAR personnel. Reseacher were using this factor as the variable in designing a model for real time decision making in coastal search and rescue operation. This factors includes Weather conditions, SAR resource available, Distress type, severity of Distress and Distance from the distressed target.

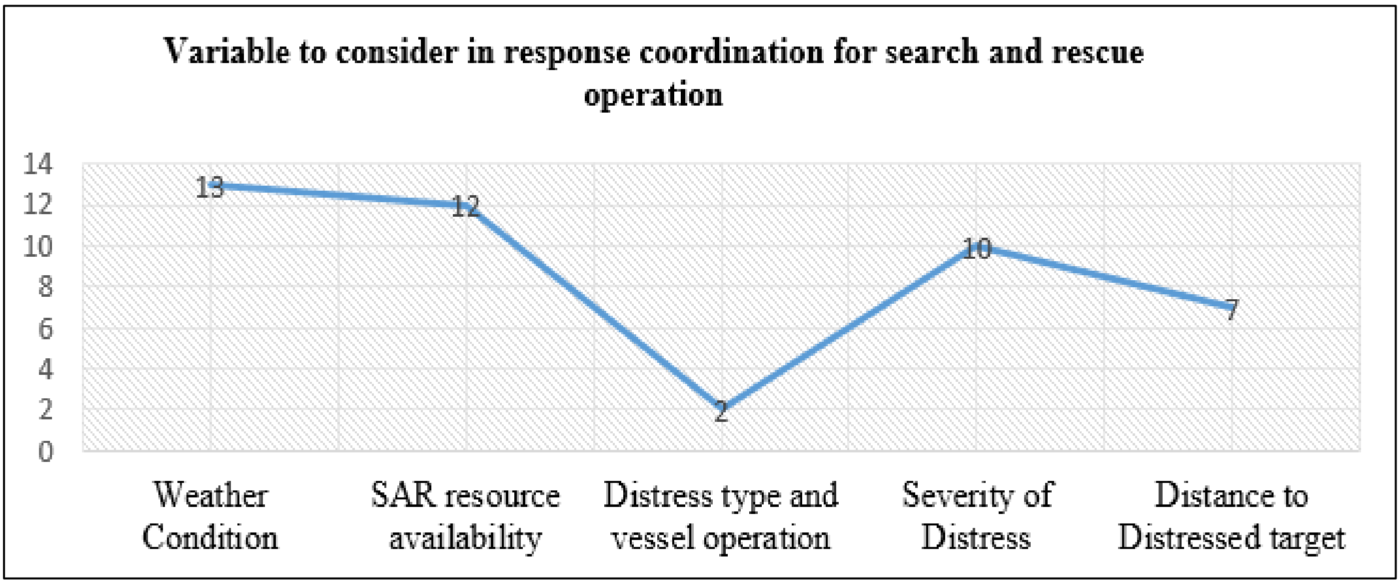

Fig 2 Variable to Consider in Response Coordination for Search and Rescue Operation
Source : Field Data (2024)

In order to investigate the frequency with which weather variables (such as wind speed and visibility) are taken into account when making decisions for SAR operations, data was gathered from 44 respondents for the first specified objective where by the interview and questioner were used to investigate these parameters.

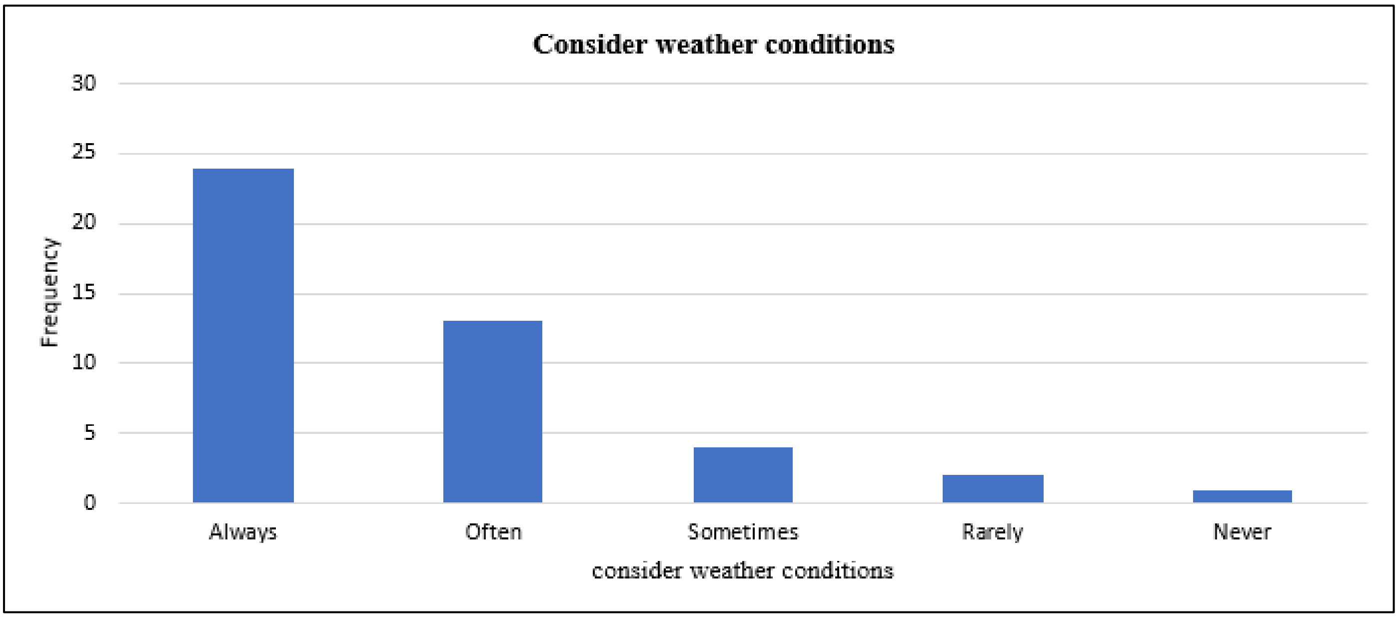

Fig 3 Weather Conditions

According to (Zhou et al., 2020), the coordination and implementation of coastal search and rescue (SAR) operations are significantly influenced by meteorological conditions. Because coastal areas are dynamic, SAR teams must constantly watch the weather and adjust their tactics to keep their operations safe and effective. SAR personnel may find it challenging to locate victims or manoeuvre safely when there is severe visibility reduction due to fog, snow, or rain. Poor visibility can cause response times to be delayed, as SAR units may need to wait for conditions to improve before beginning their search (Fjørtoft & Berg, 2020),.

➢ *Vessel Characteristics*

In this investigation interview were used to study this variable. The Figure below summarises the responses of 44 participants. The majority of respondents acknowledged that vessel characteristics have a substantial impact on decision-making during SAR operations, according to the report. According to (Queralta et al., 2020), the response coordination and real-time decision-making process in search and rescue (SAR) operations are greatly impacted by vessel parameters, including size, type, speed, and manoeuvrability.

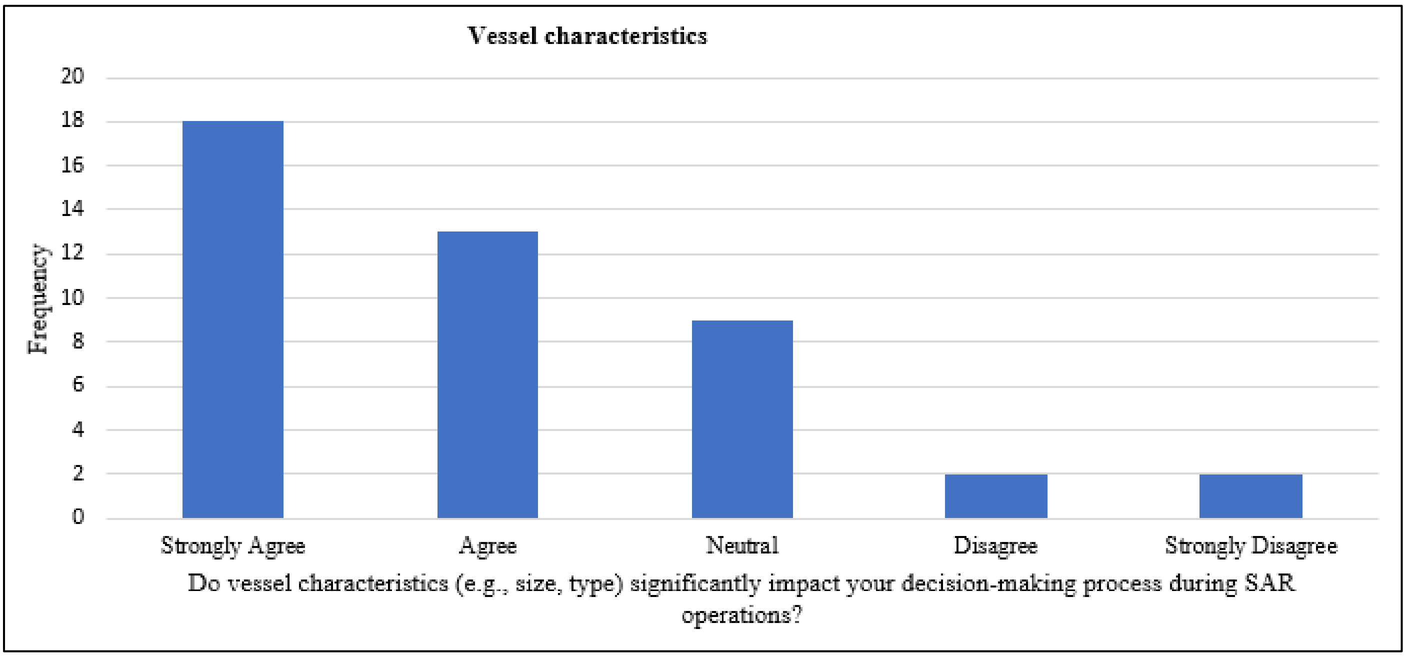

Fig 4 Vessel Characteristics
Source: Field Data (2024)

The size of a vessel determines its stability in rough seas, the number of survivors it can accommodate, and the type of equipment it can carry. Larger vessels offer more space and stability but may have limitations in shallow waters or tight spaces. Additionally, the type of vessel, including its design and purpose (e.g., rescue boat, patrol boat, or helicopter), influences its capability for various SAR scenarios. Specialised vessels outfitted with innovative technology, medical facilities, or diving equipment can considerably improve the success of rescue operations. However, vessel's speed and manoeuvrability determine how soon it can reach the emergency area and navigate through difficult conditions. High-speed vessels can travel long distances quickly, which is essential for time-sensitive rescues. Finally, Real-time decision-making entails determining the appropriate type of vessel based on the circumstances of the situation. Specialised vessels may be prioritised for operations that need specific skills, such as medical evacuations or deep-sea rescues.

- *Distance of the SAR Boat to the Distressed Vessel*

According to the data, most responders take the Distance into account when making decisions about SAR missions. this indicates that a sizable majority (73.8%) regularly takes distance proximity to distressed vessel into account, highlighting the crucial role that Distance to distressed vessel play in search and rescue operations.

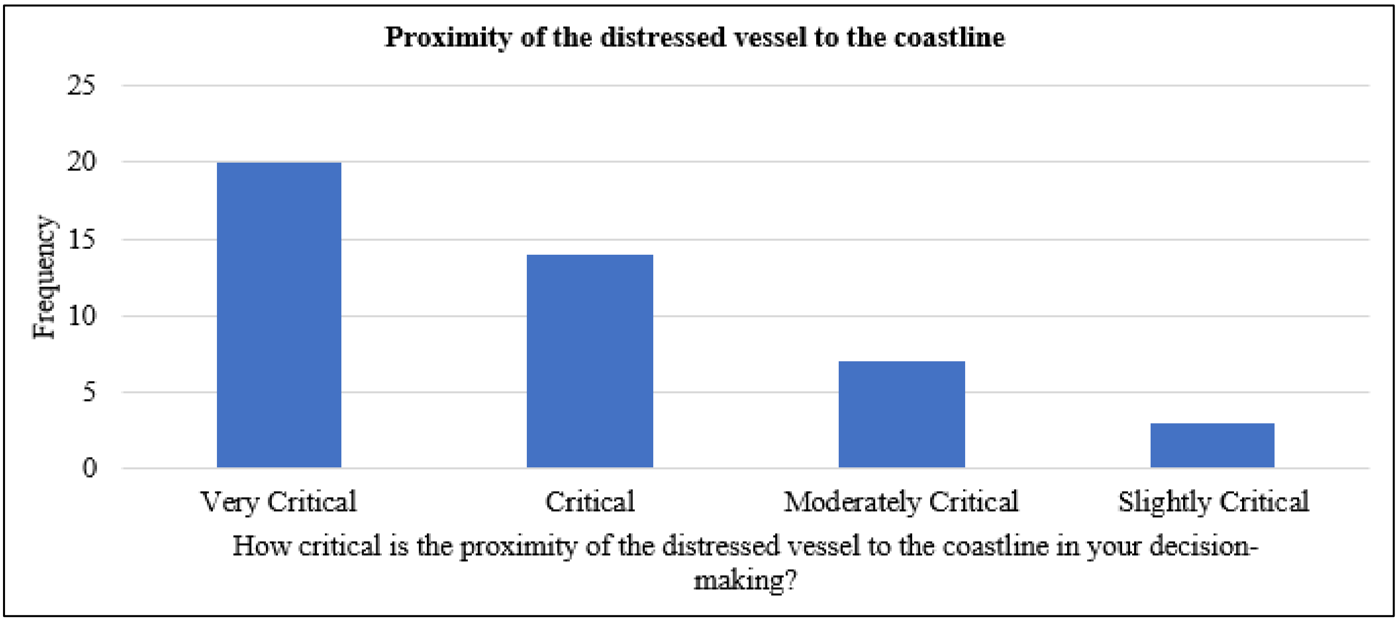

Fig 5 Proximity of the Distressed Vessel.
Source: Field Data (2024)

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According to Storvik, (2020), the closer a vessel is to the coast; the faster rescue workers can get there. This can have a substantial influence on the outcome of the rescue attempt, especially in time-critical scenarios. This indicate that distance is one of the factors that the rescue team consider before acknowledge the message of SAR missions. Additionally, proximity to the coastline affects the type and number of resources required.

➢ *Distress Type*

The response coordination and real-time decision-making process in search and rescue (SAR) operations are greatly impacted by vessel parameters, including Fire, collision, Grounding, Flooding, shifting of cargo, man overboard, Piracy, Engine Failure, Capsizing, Sinking, Medical Emergency, Severe Weather, Lost of communication, Navigation Hazard, Structure Damage, Fuel shortage, Unmanned Vessel, Terrorism, Pollution Incident and Mechanical Failure.

According to (Caulfield et al., 2023) the extent and severity of the distress impact the urgency and type of response required. Ensuring the safety of the SAR team is paramount, especially in case like fire, piracy and severe weather. Additionally, the availability of necessary equipment and resources such as firefighting gear, medical supplies and towing capability is one of the factors to consider based on the type of distress. However, Weather, sea state and visibility can significantly impact the feasibility and safety of the SAR operation. In certain scenarios, like piracy or terrorism coordination with security forces and other agencies is crucial and will require time and lead for delay in search and rescue operation, Finally, Effective communication with the distressed vessel and accurate navigation are essential for successful SAR operations. By considering these factors, SAR teams can make informed, real-time decisions to effectively respond to various types of marine distress and enhance the chances of a successful rescue operation.

➢ *Response Coordination Model*

In this study, the SAR fuzzy logic model was designed using MATLAB's Fuzzy Inference System (FIS) toolbox using Mamdani minimum-maximum inference engine based on linguistic variables and membership functions (MathWorks, 2016). This system was using IF-THEN rules formulated using expert knowledge and domain-specific heuristics to make decisions in SAR operations.

Table 2 Input and Output Variables used in the Model Design in Fuzzy Control

Input Variables	Output Variable
Proximity Distance to Distressed vessel	Urgency level (Low, Medium and High)
Distress Severity	
Environmental Visibility	
Resource Availability	

Source: Research Data, 2024

The input and output variables that were considered in fuzzy model was Weather condition, Distance to Distressed Target, Severity of distress and Resource availability according to interview made from the experts. The numerical input and output variables were transformed in fuzzy variables then were described using linguistic terms, which was used to describe all the possible fuzzy inputs. The output also was categorized based on the number of variables obtained from the questioner to characterize all the possible fuzzy output. Additionally, the fuzzy model was trained using the triangular membership function for both the input and output parameters. The choice of the number of membership functions and their initial values were based on the knowledge of the system and experimental conditions.

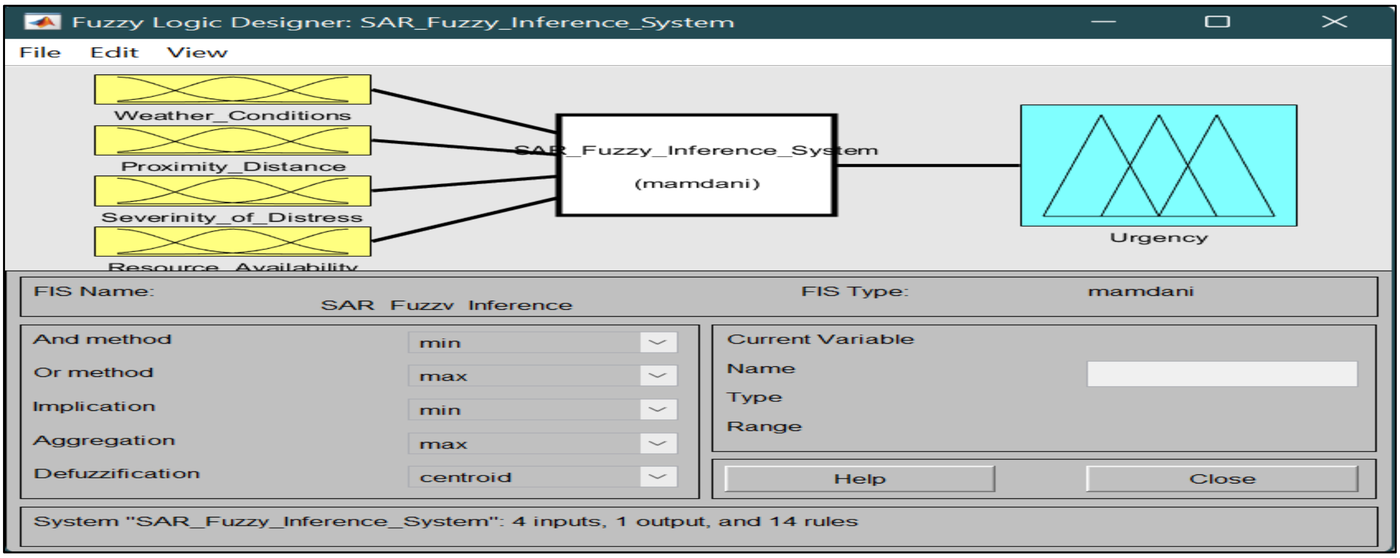

Fig 6 Input and Output Variables and Parameter in the Fuzzy Logic Designer
Source: Research (2024)

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The developed fuzzy model was relied on number of fuzzy roles generated by the rule editor to describe all relationships between the input and output variables. Moreover, the knowledge and experience of SAR operators and Experts from Dar es salaam Search and rescue were adopted to develop rules, Construct Rule Base and Formulate a set of fuzzy if-then rules. The fuzzy logic system employed a set of IF-THEN rules to model the decision-making process. Examples of rules included:

- IF the weather is Good AND proximity is Near AND resources are High, THEN the urgency level is High.
- IF the weather is Bad AND proximity is Far AND resources are Low, THEN the Urgency level is Low.
- IF the vessel is Large AND proximity is Medium, THEN the response priority is Medium.

These rules allowed the system to infer appropriate rescue actions under various SAR conditions.

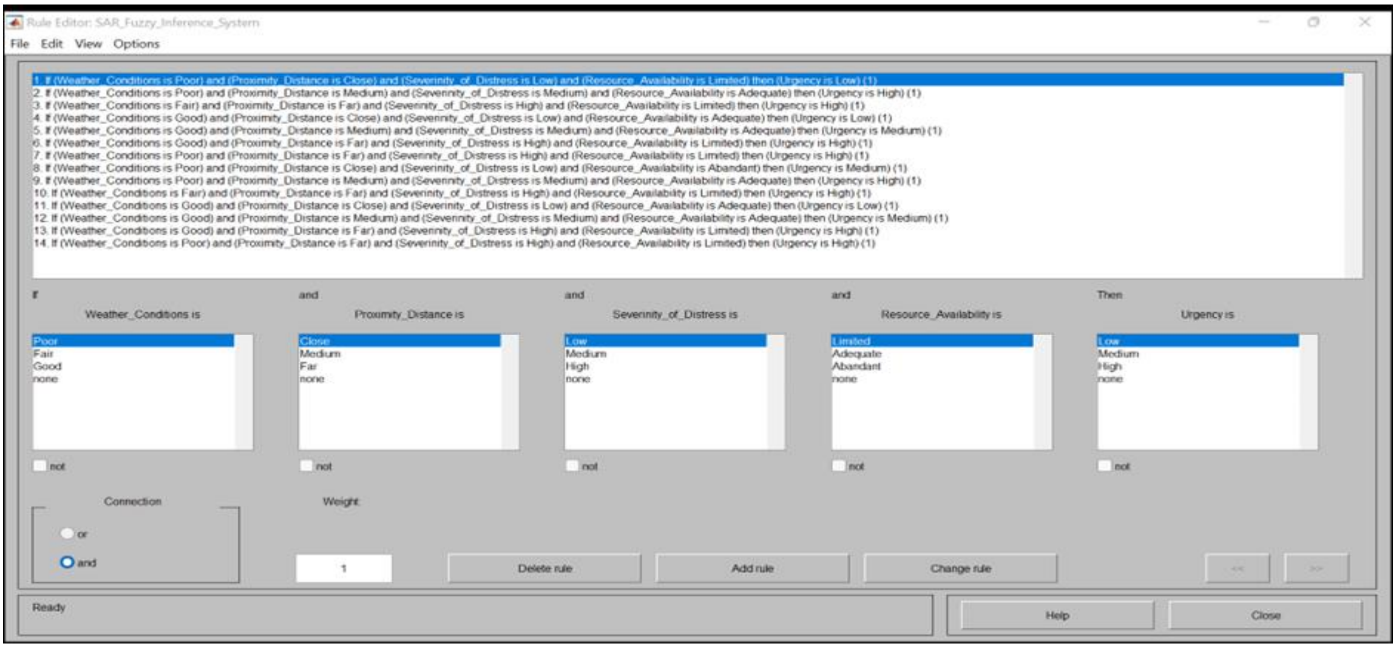

Fig 7 Fuzzy Rules Set in the Fuzzy Rule Editor.

Finally, Center of Gravity (COG) was used, which is the most popular defuzzification method for obtaining a real value (numerical) output..

For this study, the centre of gravity method was chosed for defuzzification due to its stability to provide a balanced and well representative output, considering the entire shape of the fuzzy set. This method was deal for our application in SAR operations as it ensured that decisions were made based on comprehencive assessment of the input variables. Other methods such as min of maxima and max of maxima, were considered but deemed less suitable as they focus on extremes rather than the overall distribution of the membership function. The resulting clipped membership functions of all the consequents were taken and combined into a single aggregated output.

Table 3 The Linguistic Variables for Both Inputs and Outputs were Distribute

Input Variables	**Linguistic Variables**	**Membership Functions**	**Common Type**
Distance	Close Medium Far	0 0 25 25 50 75 50 100 100	Triangular
Weather condition	Poor Fair Good	0 0 25 25 50 75 50 100 100	Triangular
Distress Severity	Low Medium High	0 0 25 25 50 75 50 100 100	Triangular
Resource Availability	Limited Adequate Abundant	0 0 25 25 50 75 50 100 100	Triangular
Output Variable			
Urgency Level	Low Medium High	0 0 25 25 50 75 50 100 100	Trapezoidal Function

Source: Field Data: (2024)

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The range of value for the corresponding Severity of distress, Weather conditions and urgency level is shown in the figure 8 The result in the figure with value ranges indicate that if Urgency level in term of probability of risk to occur and weather conditions is poor and Severity of distress is high the urgency level will be high. This indicate that the Rescue team required to take other alternative action in order to ensure safety for him/herself. Rescue operation in this rescue vessel should be avoided because of the occurrence of risk to their vessel is high. The relay of massage to nearable ship is preferable. the following key findings were observed.

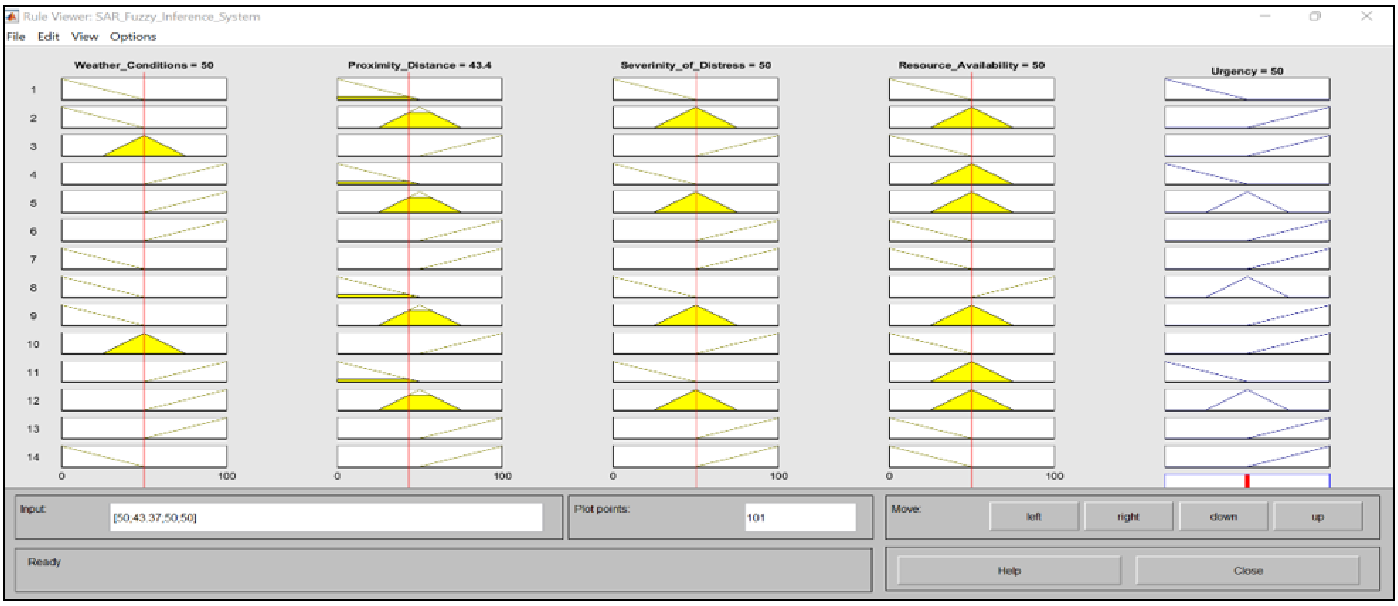

Fig 8 Fuzzy viewer Indicating how the Input Variable Control the Output

- *Simulink Model to Run and Testing a Search and Rescue Model*

After the model design accomplished, the SAR fuzzy model was simulated in the Simulink environment of the MATLAB software which is a graphical programing environment for modelling, simulating and analyzing multi domain dynamic systems. Where by the input variable are Composite and sent to the fuzzy logic controller while the output is captured in the display box. If it apparent that there is a close.

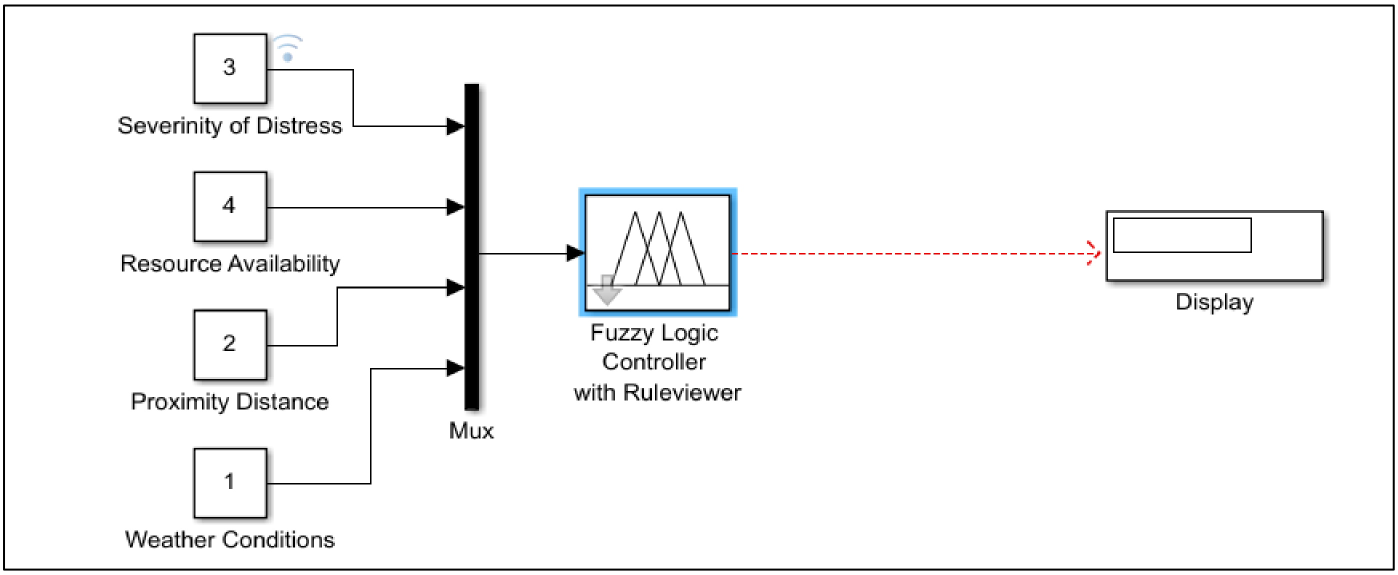

Fig 9 Simulink Model Blockto Run and Test the SAR Response Coordination Model

The model demonstrated a high level of adaptability to changing conditions, crucial for real-time SAR operations. The simulations showed that the model could adjust decision outputs in real-time, improving response efficiency. Additionally, the fuzzy logic model effectively managed uncertainty and imprecise data, which are common in coastal SAR scenarios. This led to more reliable decision-making outcomes compared to traditional methods. Moreover, the integration with Simulink provided a powerful platform for testing and validating the model in various simulated environments, highlighting its practical application in real-world SAR operations.

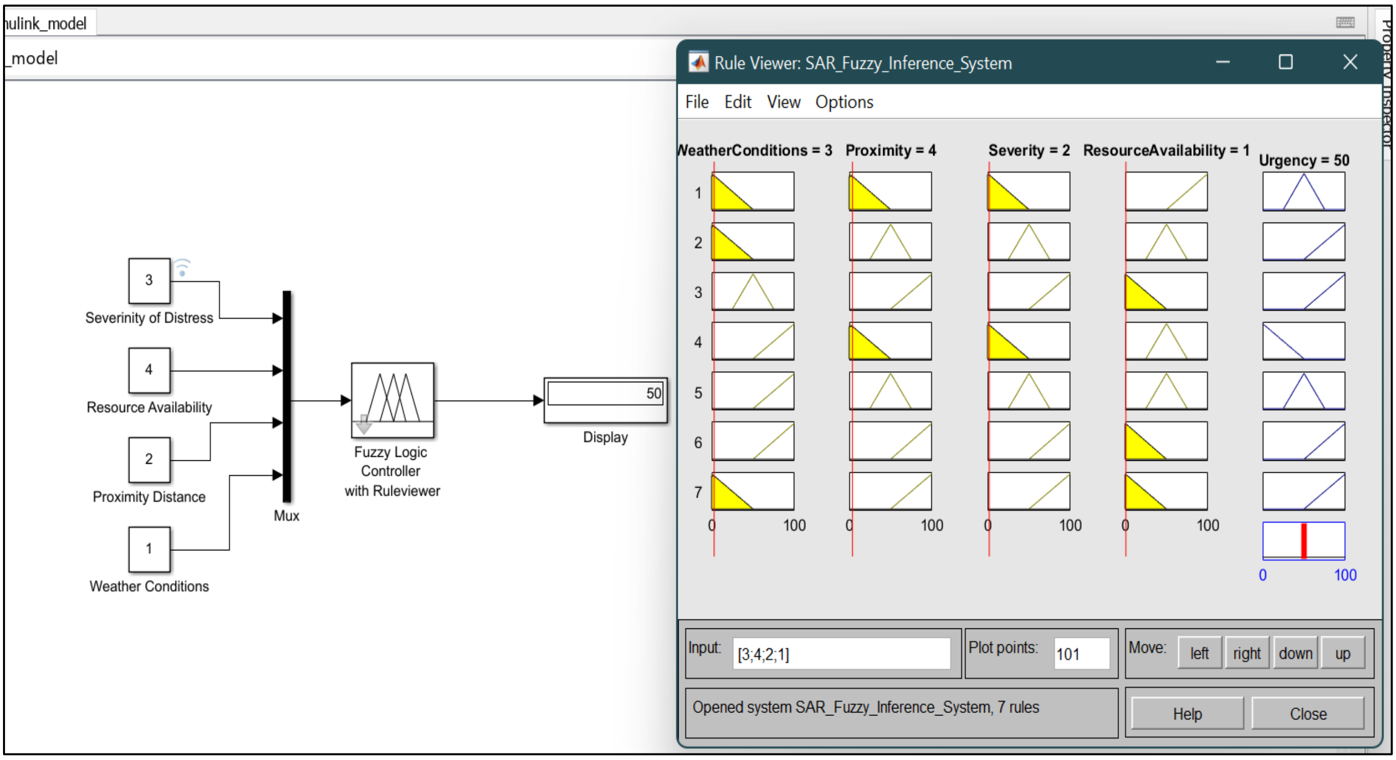

Fig 10 Simulink Model Display the SAR Response Coodination Model

Additionally, Further investigation could explore why some SAR operations have adopted fuzzy logic and others have not. Factors such as cost, ease of implementation, and perceived benefits versus limitations could be relevant. Finally, in order to increase acceptance of fuzzy logic-based decision support systems, hurdles such as training, system availability, and awareness may need to be addressed. Furthermore, establishing the efficacy of these technologies through case studies and comparative research may drive wider use.

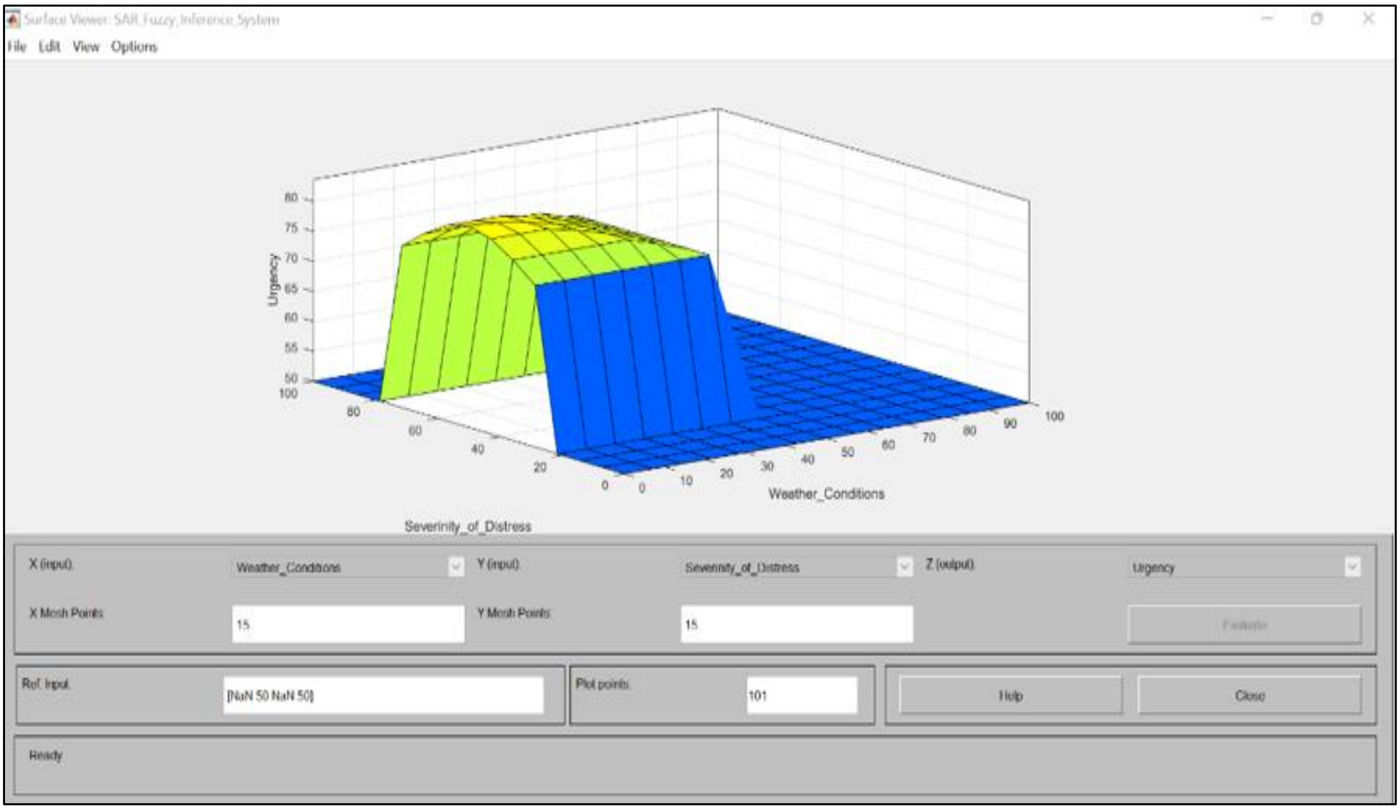

Fig 11 Severity of Distress, Weather Conditions and Urgency level in the Surface Rule Display Window

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Table 4 Model Analysis Formula

Parameter	**Description**	**Equation**
Coefficient of Determination (R^2)	Measure a degree of correlation between the experimental and predicted values	$R^2 = \frac{[\sum_{i-1}^{N}(P_1-P)(Q_1-Q)]^2}{\sum_{i-1}^{N}(P_1-P)^2(Q_1-Q)^2}$ (1)
Root mean square error	Measure the error in the same units as the variable between the experimental and predicted values	$RMSE = \sqrt{\frac{1}{N}\sum_{i-1}^{N}(P_1 - Q_1)^2}$ (2)
Mean absolute error (MAE)	Measure the average magnitude of the errors in a set of forecasts without taking into consideration their direction	$MAE = \frac{1}{N}\sum_{i-1}^{N}\lvert P_1 - Q_1\rvert$ (3)
Model efficiency (ME)	Measures the efficiency between the experimental and predicted values	$ME = 1 - \frac{\sum_{i-1}^{N}(Q_1-P_1)^2}{\sum_{i-1}^{N}(Q_1-Q)^2}$ (4)
Overall Index (OI)	Measure the performance of the mathematical models and fitting between the experimental and predicted values	$OI = \frac{1}{2}\left(1 - \left(\frac{RMSE}{Q_{max}-Q_{MIN}}\right) + ME\right)$ (5)

V. DISCUSSION

The findings of this study illustrate the significant advantages of employing fuzzy logic for decision-making in coastal search and rescue (SAR) operations, particularly when contrasted with traditional methodologies. Traditional SAR decision-making frameworks often rely on rigid, binary processes that are ill-equipped to handle the complexities and uncertainties characteristic of maritime environments. These conventional methods frequently lead to delays and suboptimal outcomes, especially under rapidly changing conditions.

The fuzzy logic model developed in this study, by contrast, proved adept at managing multiple, interrelated variables simultaneously, providing a level of flexibility that is critical in dynamic SAR contexts. The model's ability to incorporate parameters such as weather conditions, proximity to distressed vessels, and resource availability allowed for a more nuanced approach to prioritizing rescue operations. Notably, the use of fuzzy sets and inference rules enabled the system to make real-time adjustments, improving the overall responsiveness of SAR efforts.

The application of the Mamdani-type Fuzzy Inference System (FIS) and defuzzification through the Center of Gravity (COG) method provided actionable output values that were representative of the broader context in which decisions were made. This approach contrasts sharply with traditional binary models, which are often forced to make decisions based on incomplete or static data. In scenarios simulated using Simulink, the fuzzy logic model demonstrated its capability to adapt in real time, dynamically recalculating decision priorities as variables fluctuated.

However, despite these advantages, certain challenges persist. The practical deployment of fuzzy logic in real-world SAR operations necessitates access to advanced computational resources and extensive training for personnel, who must be able to interpret and act on the system's outputs. Additionally, while the simulations provided robust evidence of the model's efficacy, further field tests in live SAR scenarios are essential to fully validate its utility under the unpredictable conditions typical of maritime emergencies.

This study also highlights the potential for further development of fuzzy logic models within SAR frameworks. Refining the input parameters and enhancing the integration of real-time data streams, such as meteorological updates or vessel tracking systems, could further optimize the decision-making process. The promising results obtained suggest that the adoption of fuzzy logic systems in SAR operations could markedly improve outcomes, potentially leading to faster response times and more lives saved.

VI. CONCLUSION

This research underscores the transformative potential of fuzzy logic in refining real-time decision-making for coastal search and rescue (SAR) operations. By incorporating a diverse set of critical parameters ranging from meteorological conditions to resource availability the fuzzy logic model demonstrated superior adaptability and precision, significantly outpacing traditional SAR methodologies. Its ability to dynamically respond to the inherent uncertainties of maritime environments underscores its relevance as a robust decision-support tool.

The findings suggest that integrating such computational intelligence could drastically elevate SAR efficiency, with future studies warranted to explore its practical deployment in live operational contexts and further refine its algorithms for optimized performance. Moreover, based on the time limit and financial constraint this study focused on the coastal waters of the Indian ocean near Dar es salaam and made the design of a simple SAR fuzzy model for real time decision making for response coordination in search and rescue operation. However, Father research and development should undertake to explore the integration of fuzzy logic with existing SAR technologies, such as GPS, Automatic Identification Systems (AIS), ECDS, communication systems, Artificial Intelligence, data feed from sensor, satellite and machine learning Algorithms. This could enhance the model's predictive capabilities and lead to creation of more sophisticated decision support system that enhance the overall efficiency of SAR operations.

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