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Domestic RoRo Ferry Safety Performance Level Monitoring Based on Risk Assessment Model Using IoT: A Literature Review and Application

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ABSTRACT: Domestic RoRo (roll-on/roll-off) ferry safety has been a growing concern for years due to its continued casualty events, which have significant consequences. However, the development of the transport mode from the perspective of safety performance is considered a slow process due to the nature of its operation and less stakeholder concern. One of the significant issues, among others, lies in monitoring the safety level of the service. This condition results in a lack of awareness in every aspect of operation and every mindset of related parties. On the other hand, the Internet of Things (IoT) development has been significantly progressive, covering nearly every aspect of the transport system. The progressive process has been followed by accessibility and affordability of the technology so that every stakeholder can utilise it to the fullest. The paper explores the possibility of IoT technology being included in improving the safety of domestic ferry operations by monitoring the overall safety performance from the perspective of its risk status. The research maps the stakeholder's position based on their function and current or future IoT system. As a risk assessment model, the F-N Curve is used as the base concept for assessing the operation's safety performance and risk state condition. The research identified the possibility of integration under the IoT scheme in dynamic risk assessment. The research also recognises the significant strengths and challenges of integrating every available IoT system, which is contributed by the system's openness.

1 INTRODUCTION

The Internet of Things (IoT) and data science significantly impact the maritime industry. IoT involves the interconnection of devices like sensors and cameras that can gather and exchange data. In contrast, data science utilises this data to make informed decisions. IoT and data science are helping the maritime industry improve safety, efficiency, and sustainability [1], [2], [3].

One of the key areas where IoT and data science are being used in the maritime industry is vessel monitoring and tracking. With sensors and cameras installed on ships, shipping companies can now collect data on the ship's location, speed, fuel consumption, and cargo. This data can then be analysed using data science techniques to identify patterns and trends, which can help to improve the ship's overall performance. For example, shipping companies can use this data to optimise their routes, reduce fuel consumption, and avoid delays.

1.1 *Role of domestic Ferry in Global and Indonesian nationwide perspective*

Ro-ro ferries are regarded as the world's most successful maritime operation due to their service reliability, carrying capacity, and operational flexibility. [4]. Stakeholders have considered ferry transport a more affordable, timely service and reliable mode of transporting passengers and goods between islands. Its capability to provide cost-effectiveness and support the operational efficiency of other transport modes has also led to using ferry transport to integrate islands and create efficient routes to reduce distance and operation time [5].

Ferry operation has been utilised worldwide. For developed countries, ferries are considered the safest transportation form. Their safety record demonstrates significant achievement. Domestic ferries have been a crucial foundation for national economic activities in developing countries. The most common ferry type used in these regions is the RoPax ferry, which typically offers space for passengers, vehicles, and cargo simultaneously. [6].

For archipelagic nations, domestic ferries are crucial for the efficient transport of many passengers. The transportation modes bridge islands and road transport networks and facilitate commercial activities, which helps maintain national unity. Technological advancements in RoRo passenger ferry operations enable these ships to function as connecting bridges. RoRo passenger ferries remain the most cost-effective transportation option compared to actual bridges. Consequently, their service must be swift, dependable, structurally sound, and punctual while ensuring adequate safety. [7].

As an archipelagic nation, Indonesia fully recognises the crucial role of maritime transport in fostering the country's development. Domestic RoPax ferries are vital as a national asset to maintain connectivity throughout the country. The current system is designed to link significant islands, serving as a transport hub for other modes of transportation. Domestic RoRo ferries facilitate inter-island connectivity and spur regional growth, aiding the national development equality program. This transport system bolsters logistics distribution and promotes economic parity by offering affordable transportation nationwide. [8].

1.2 *Safety program for domestic ferry service*

Despite its achievements, ferry operations carry significant risks. The nature of these operations means that ferry disasters can have catastrophic outcomes. Incidents such as the Herald of Free Enterprise (UK, 1989), Estonia (Baltic Sea, 1992), Dona Paz (Philippines, 1985), Al Salam Boccaccio (Red Sea, 2001), and Princess Ashika (Tonga, 2009) have heightened public concerns about the safety of domestic ferry operations in developing countries. The international maritime community has also raised alarms due to ongoing accidents involving domestic ferries despite improvements in their operations. In 2006, the International Maritime Organisation (IMO) and the international ferry operators' community, Interferry, launched a pilot project to provide technical assistance to enhance the safety of domestic ferry operations in developing countries. This project occurred in Bangladesh, a country known for its severe ferry accidents.[4], [9].

Key findings from investigations into ferry-related incidents have been shared with all stakeholders in ferry operations to raise safety awareness and serve as a reference for enhancing shipboard safety. Despite these efforts, catastrophic accidents persist, as demonstrated by the Sewol incident in South Korea in early 2014. Even with safety improvements driven by technological advancements, public interest, and human involvement, there is always the potential for errors that could result in a disastrous accident. In other words, certain latent factors may be overlooked, eventually accumulating and leading to a single catastrophic event. [6], [10], [11].

Indonesia has developed an extensive safety program to enhance the safety of the domestic ferry service. The focus of development not only focuses on vessel quality but also on considering upstream factors such as implementing the safety management system, reviewing, and developing regulations to answer ongoing safety issues, and extending regulatory oversight in even smaller populations. Regarding vessel standards, the government had appointed BKI as the recognised organisation to conduct the statutory survey and certification of the domestic ferry [12].

2 INTERNET OF THINGS TECHNOLOGY: AFFORDABILITY AND ACCESSIBILITY ISSUE

2.1 *Concept of IoT*

While instances of interconnected electronic devices can be traced back to the early 19th century, notably with the invention of the telegraph that transmitted coded signals over distances, the inception of the Internet of Things (IoT) can be pinpointed to the late 1960s [13], [14], [15], [16]. During this period, a notable group of researchers initiated efforts to establish connections between computers and systems. One significant example of their efforts was ARPANET, a network created by the Advanced Research Projects Agency (ARPA) of the US Defense Department, which acted as a precursor to the modern Internet. In the late 1970s, there was a growing interest among businesses, governments, and consumers in interconnecting personal computers (PCs) and other machines. By the 1980s, local area networks (LANs) emerged as an effective and widely adopted means of real-time communication and document sharing among groups of P.C.s. [17], [18], [19].

In the mid-1990s, the Internet expanded its capabilities on a global scale, prompting researchers and technologists to investigate improved connections between humans and machines. In 1997, Kevin Ashton, a British technologist and co-founder of the Auto-ID Center at MIT, initiated the exploration of a technological framework known as radio-frequency identification (RFID) [13]. In 1999, Kevin Ashton introduced the "Internet of Things" concept, envisioning a system where physical devices could communicate through microchips and wireless signals. Subsequently, technological advancements, including smartphones, cloud computing, enhanced processing power, and improved software algorithms, laid the foundation for a more robust framework for collecting, storing, processing, and sharing data. Simultaneously, sophisticated sensors emerged, capable of measuring various conditions such as motion, temperature, moisture levels, wind direction, sound, light, images, vibrations, and geolocation. These developments enabled real-time communication with both digital devices and physical objects. The widespread adoption of mobile devices and pervasive wireless connectivity further facilitated the nearly ubiquitous connection of people and things. Consequently, intelligent traffic networks, connected storage tanks, and industrial robotics systems became standard practices. [16].

In general, IoT is developed by adopting layers of architecture. Some scholars mentioned three layers of architecture: the application layer, network layer, and perception/sensing layer. In comparison, five layers of architecture were also introduced to provide more details on filling the gaps between the application layer and the perception layer. These include the business layer and middleware layer [20].

The number of different aspects characterises the IoT, so it would function perfectly and meet its needs [20]. Srinadh (2021) described that IoT requires interaction with other mediums or platforms (interconnectivity). The IoT needs to be safe to use and capable of handling the threat without compromising the operation (safety), adapt to different and dynamic conditions (heterogeneity), capable of conducting large-scale computations (enormous scale), be aware and adapt to dynamic change, connect with a relevant network, and be accessible by general users.

2.2 *Relevant proven technology and ongoing IoT research in the aspect of transportation system*

The Internet of Things (IoT) is a system where physical objects are linked together in a network that allows them to gather and exchange data through the Internet. These objects are typically embedded with sensors, actuators, and other technology that enable them to collect and transmit information, facilitating their ability to interact with their surroundings and execute tasks autonomously without human involvement. [16], [21]. The main objective of the IoT is to establish a smooth and intelligent network where devices work together and exchange data to improve efficiency, productivity, and convenience in different areas of our everyday lives [16]. IoT applications can be found in diverse fields, including home automation, healthcare, agriculture, industrial processes, transportation, and other aspects of life.

Refer to the critical components of the IoT include:

- Devices/Things: These are the physical objects or devices embedded with sensors, actuators, and other technologies to collect and transmit data.
- Connectivity: IoT relies on various communication technologies such as Wi-Fi, Bluetooth, Zigbee, cellular networks, and more to facilitate data transfer between devices.
- Data Processing: Collected data is processed and analysed to derive meaningful insights, often done locally on the device or in the cloud.
- Cloud Computing: Cloud platforms are commonly used to store and process large volumes of data generated by IoT devices. Cloud computing allows for scalable and efficient data storage and analysis.
- Applications: IoT applications leverage the data generated by connected devices to provide valuable services and functionalities, improving efficiency and decision-making processes.
- Security: Given the interconnected nature of IoT devices, security is a critical concern. Data privacy and protection are essential to prevent unauthorised access and potential misuse.

Numerous research studies on IoT utilisation have been conducted and followed by promising technological developments. The research explores reputable journal index sources to acquire information on the latest developments of IoT in transportation systems. Following findings in the journal database, IoT research has grown exponentially in the past 13 years.

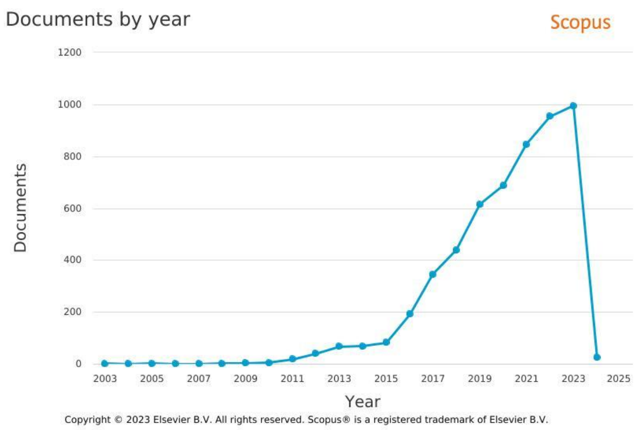

Figure 1. IoT research subject development. Data extracted and reconfigured from Scopus metadata source 2023.

Using bibliometric review, the keywords related to IoT and its connection with other research focuses found strong relationships between IoT and other research subjects.

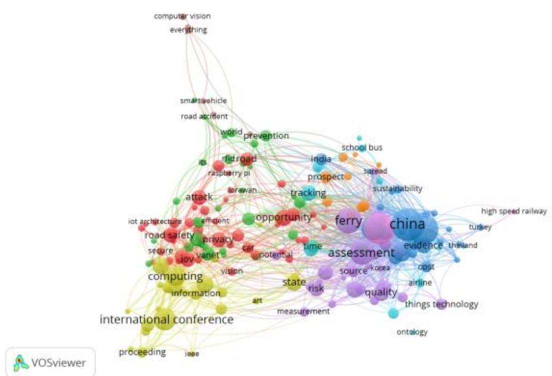

Figure 2. vos viewer results from SCOPUS metadata using IoT, transportation, safety, and ferry keywords.

The research explored and reviewed over 30 journal papers on the IoT and related subject matters with transportation safety. Additional journals have also been reviewed to support IoT as a safety performance monitoring model. The following tables summarise and categorise the literature review into several specific research topics.

Table 1. Recaps the literature review from different focus groups and research topics

Topic of research	Focus of research	Reference
IoT with transport service safety, effectiveness, and efficiency	Integration of IoT to improve the quality of transportation service. Some research proposes that IoT should be used to overview system health by allocating sensor modules to monitor the machinery system and other installed equipment.	[1], [22], [18], [17], [23], [24], [25], [14], [26], [27], [28], [29], [30] , [2], [30], [15], [31], [32], [33]
IoT security system	The IoT security guard is the primary concern in preventing and mitigating any threat to the system.	[21], [13], [34], [35],
IoT with the transport safety system	Specific research focuses on utilising the IoT to monitor safety systems such as tourism, vehicle health, and inland waterway transport.	[36], [37], [38], [39], [40], [41],
IoT with machine learning and artificial intelligence for future transport development	The coming expansion of machine learning and artificial intelligence aims to enhance and expand the quality of service in transportation.	[42], [43], [44], [45], [46]

The use of the Internet of Things (IoT) in ferry transportation safety is a growing area of research. Gahalyan (2021) and Maulidi (2022) both propose IoT-based systems for monitoring various aspects of ferry operations, such as boat conditions, passenger numbers, and ship movements [36], [37]. These systems aim to improve safety by providing real-time data to ferry operators and crew. Aslam (2020) provides a broader perspective on the potential of IoT in the maritime industry, including safety enhancements and route optimisation [1]. Thakur (2017) discusses the application of IoT in road safety and traffic management, which could be adapted to ferry transportation [22]. Collectively, these studies highlight the potential of IoT in enhancing the safety of ferry transportation services. Shostak et al. (2020) explore IoT technology to ensure cargo transportation safety by applying an integrated camera module on the vehicle to record the driver's facial expressions and transmit them to the company server for further analysis [38]. Hapsari et al. adopt IoT technology to monitor real-time fuel consumption performance [47]. The fuel level is monitored by a series of installed ultrasonic sensors connecting to the microprocessor, which is transmitted to the server to identify fuel discharged and transferred. Kamolov and Park (2019) used ultrasonic sensors integrated with a microprocessor to help berthing operations [48].

Relevant to using IoT for timely monitoring a system, Shah et al. (2023) developed a dynamic Bayesian network model with the medical Internet of Things to assess resilience in healthcare engineering [49].

3 IOT INTEGRATION IS USED TO MONITOR DOMESTIC FERRY SAFETY PERFORMANCE.

Safety performance monitoring can be applied to determine the safety performance level of the ferry transport system in a dynamic and timely manner. IoT will play a significant role in integrating information from relevant stakeholders. The research identified 15 relevant stakeholders that significantly contribute to maintaining safety in domestic ferry service.

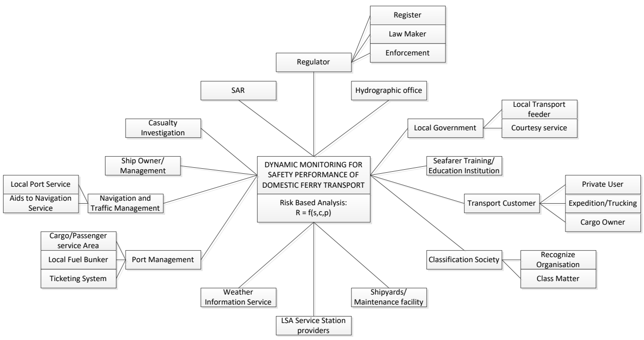

Figure 3. List of stakeholders responsible for maintaining safety in domestic ferry service.

After reviewing each stakeholder's current operation state, IoT has been developed and used to a certain extent, providing resourceful information. Each stakeholder mainly used IoT as a supporting tool to implement their task, responsibility, and accountability system.

Table 6 in the appendix presents each stakeholder's primary responsibilities and current or proposed IoT. Some stakeholders do not reasonably adopt IoT in specific applications, but a database system is developed for any purpose within their business environment transfer database data using conventional connections such as email and direct message platforms.

3.1 *Concept of Monitoring Domestic Ferry Transport Safety Performance*

Dynamic monitoring refers to the real-time monitoring system integrating relevant resources to create a comprehensive display presentation on relevant aspects of safety performance. Safety performance level presents a state of service that meets specific requirements in different levels of safety. The level should indeed be an absolute terminology and condition. However, the safety level fluctuates and is not absolute.

The research proposed that the concept of safety performance level is viewed as lowering risk level by adopting significant risk mitigation and control system action.

Risk is viewed as the combination of scenario, probability, and consequence [50].

Risk = f {s, c, p}

The logical effort to reduce risk level is to put every element of risk formulation as low as possible (ALARP). A scenario in risk conception is defined as an event that could happen within the system or entities. This event condition contributes to different sub-events in the risk cluster. Higher risk conditions could be considered critical [50], [51], [52].

3.2 *Proposed modules in the decision-making network for the safe Domestic ferry operation using big data cluster*

The research proposes dynamic safety performance monitoring by adopting the risk assessment concept. A dynamic risk assessment is an ongoing safety procedure that enables workers to promptly recognise and evaluate risks and hazards in real-time, mitigate them, and proceed with work securely. These evaluations involve regular observation and analysis of work environments with elevated risks or frequent changes, requiring workers to make swift yet well-thought-out decisions [49], [53].

The research suggests the safety performance level is based on the risk rating assessment. Risk grading can be presented in a 4x4 matrix defined in the IMO formal safety assessment model [55].

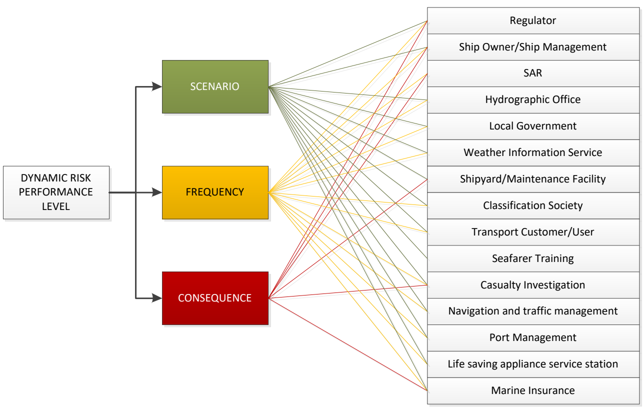

Figure 4. Cluster of potential supporting analysis from different stakeholders

The scenario of any potential mishap is extracted from the IMO FSA model but is not limited to the prescribed list. The FSA model identifies scenarios stated in the accident type: collision, contact, foundered, fire/explosion, hull damage, machinery damage, war loss, grounding, other ship accidents, other oil spills, and personal accidents.

The consequence factor is based on consequences that affect human safety and ship or property.

The frequency factor is defined according to the FSA formulation.

The FSA proposed a risk matrix, and the user suggested using a log model to calculate risk levels. Scoring is defined based on the log function as shown in the matrix below:

Table 4. The risk matrix model as suggested by the FSA.

FI	Frequency	Severity 1 Minor	 2 Significant	 3 Severe	 4 Catastrophic
7	Frequent	8	9	10	11
6		7	8	9	10
5	Reasonably probable	6	7	8	9
4		5	6	7	8
3	Remote	4	5	6	7
2		3	4	5	6
1	Extremely Remote	2	3	4	5

The matrix provides significant information on the level of the risk. Higher log numbers in the matrix present higher risk conditions, while smaller log numbers present the opposites. From this point of view, it is reasonable to propose risk criteria for higher risk, acceptable risk, and lower risk.

The dynamic conception of safety level based on the risk analysis model will continue to retrieve data from different stakeholders based on each of their functions. The data will be simultaneously retrieved, analysed, and presented to indicate the risk level from a time perspective. The scoring result will be dynamic and varied according to the simultaneous data feed from the relevant sources. The critical data would mainly rely on the events' frequency and the major event's consequences. Statistical approaches could be used to determine the probability of the event as a function of dynamic data feed from day-to-day operations.

Table 2. Consequence index as suggested by FSA model of IMO

CI	Consequence	Effect on Human Safety	Effect on Ship	S (Equivalent fatalities)
1	Minor	Single or Minor Injuries	Local Equipment damage	0.01
2	Significant	Multiple or severe injuries	Non-severe ship damage	0.1
3	Severe	Single fatality or multiple severe injuries	Severe damage	1
4	Catastrophic	Multiple fatalities	Total Loss	10

Table 3. Frequency index as suggested by FSA model of IMO.

FI	Frequency	Definition	F (per ship year)
7	Frequent	It is possible to occur once per month on one ship	10
5	Reasonably probable	It could occur once per year in a fleet of 10 ships. i.e. likely to occur a few times during the ship's life	0.1
3	Remote	It is likely to occur once per year in a fleet of 1000 ships. i.e. likely to occur in the total life of several similar ships	10^-3
1	Extremely Remote	It is likely to occur once in the lifetime (20 years) of a world fleet of 5000 ships	10^-5

4 DISCUSSION ON POSSIBLE APPLICATIONS

The IoT concept applies to overviewing safety level performance based on the risk assessment model. The risk level algorithm is developed to accommodate the live data feed from different sources of IoT, as presented in Figure 4. It is argued that the network can hinder or obstruct system connection.

4.1 *Dynamic risk evaluation model supported by IoT data transfer network.*

The research presents an example of integrating data used as risk evaluation in domestic roro ferry operations in Indonesia from 2007 to 2022. The research examines 84 cases involving domestic roro ferry, which resulted in a fatality. The example focuses on evaluating the event's frequency to identify the probability of causation. The societal risk analysis model, as shown by the f-N Curve, model is used to determine the dynamic level of risk. The curve is developed based on the risk integral formula as discussed by Pitblado et al. [56]:

$$RI = \sum F_i N_i^a$$

where F is the outcome frequency of occurrence that resulting in one or more fatalities, N is the number of fatalities, and a is scale aversion factors. "a" is considered one or no scale aversion for this research.

The directorate general of land transportation provides the data on ship trips, as shown in Table 5 below. In contrast, the data on casualty is extracted from the National Transportation Safety Committee, the National Agency for Search and Rescue, and the local harbour master offices.

Table 5. Domestic roro ferry casualty and production data during 2007 – 2022 [57].

Year	Fatality (N)	No events per year	Trip Year	Frekuensi per ship year (f)	Risk Rating
2007	50	2	388,964	5.14E-06	10-High Risk
2008	1	1	427,134	2.34E-06	3-Low Risk
2009	1	1	433,226	2.31E-06	3-Low Risk
2011	89	5	383,052	1.31E-05	10-High Risk
2012	8	4	482,041	8.30E-06	10-High Risk
2014	6	3	519,911	5.77E-06	10-High Risk
2016	7	3	405,050	7.41E-06	10-High Risk
2017	5	10	588,164	1.70E-05	10-High Risk
2018	42	15	558,896	2.69E-05	10-High Risk
2019	5	13	488,004	2.66E-05	10-High Risk
2021	25	20	465,542	4.30E-05	10-High Risk
2022	1	7	434,887	1.61E-05	10-High risk

The risk rating is determined according to the criteria set forth by the IMO FSA standard. The number in the Risk Rating column suggests the risk number that comes from the multiplication of severity and frequency index in the respective year. Risk Acceptance level (RAL) in this research adopts a standard from the UK HSE, which is also considered in the IMO FSA model. The UK HSE indicates RAL for passengers is 10-3 and 10-4 for the crew [58].

The chart below presents the f-N curve for domestic roro ferry service in Indonesia based on the data above.

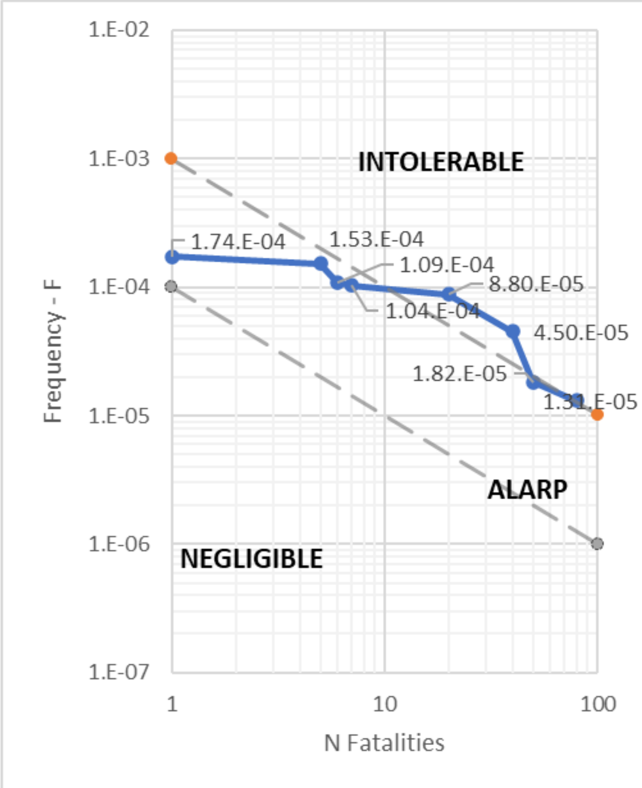

Figure 5. The F-N Curve for Domestic RoRo Ferry in Indonesia water

Figure 5 is a critical reference for understanding the current safety situation of the domestic RoRo ferry. As the graph indicates, the state of ferry operation lies within the intolerable zone. From this condition, relevant stakeholders should bring attention to the relevant authorities to take the initiative to reduce the risk status to the acceptable zone. The above data shows that high-risk conditions, such as fire and capsize events, come with distinct conditions. From this, further exploration can be done by evaluating the contributing factors. The condition above can dynamically be changed when all the inputs of risk equations contribute to it.

For the IoT, an algorithm can be developed by identifying the contributors behind the numbers. This effort might require extra work in sorting and classifying data from different sources, such as investigation reports, maritime court verdicts, audit results, and near-miss report analysis, but it can be quickly done by developing proper algorithms. The Figure 5 graph can be presented in an accessible platform where relevant authorities can view and assess the contributing factors.

From this example, it can be presented that the integration of the system is the key. All the necessary data must be simultaneously available and adequate in quality and quantity. The data transmitted must be verified and finalised. In addition, the data is also sufficiently available for risk dynamic analysis. This condition requires a robust and reliable network.

4.2 *Strength and opportunity*

The IoT concept applies to overviewing safety level performance based on the risk assessment model. The risk level algorithm is developed to accommodate the live data feed from different sources of IoT, as presented in Figure 4. It is argued that the connection among systems can be hindered or obstructed by the network.

The IoT technology has proved beneficial and applicable to every system. Sensory modules integrated with affordable and small microprocessors will present excellent capabilities. The technology of sensors is accessible and affordable. The sensor unit's accuracy is improving even within the most affordable unit. The critical point is the reliability of the sensor unit. The sensor unit is a frontline that senses the condition daily. The sensor unit can provide wrong data when operating outside its design conditions. This condition becomes critical since the vessel might operate in different environments.

4.3 *Challenge and weakness*

Common weaknesses in IoT are primarily focused on security issues and information accessibility. Implementing sufficient security measures is a significant issue facing the Internet of Things (IoT). Hackers have successfully infiltrated video systems, Internet-connected vehicle monitors, vessel health sensor devices, and even automobiles. Furthermore, the infiltrator has gained unauthorised access to corporate networks by exploiting vulnerabilities in unprotected IoT devices.

Srinadh (2021) identified the common vulnerabilities in the IoT, which comprise insecure web interface, insufficient authentication/authorisation, insecure network services, privacy concerns, lack of data encryptions and verification, insecure cloud interface, insecure mobile interface, insecure security configurations, insecure software/firmware, and poor physical security. Srinadh also identified weaknesses in each of the architecture layers. One significant weakness in the perception layer is malicious code injection, false data tampering, and jamming. This finding is reasonable since perception is the main gate to the system. Once the attacker gets access, this could severely threaten the system.

5 CONCLUSION REMARKS AND FUTURE STUDIES.

The utility of IoT technology has expanded in nearly every sector of transportation. Technology is becoming affordable and accessible, so the possibilities for applications are limitless. The IoT technology has been proven to improve the system's effectiveness and make it more efficient. The research has identified potential IoT integration to monitor safety performance levels based on risk assessment. Each stakeholder is currently developing system information that can be integrated into the risk assessment algorithm. The dynamic of data is a resource reference to monitor the risk level in domestic ferry transport, which can be viewed from a general perspective or per fleet or company situation. From this perspective, the monitoring model can be used as a reference for every stakeholder to mitigate the upscaling risk conditions and maintain awareness of the safety of the transport system. The stakeholder might consider actions to avoid, reduce, or transfer the risk effectively.

Despite the possible application of the model, the challenge lies mainly in the willingness of each stakeholder to open their data. Before that, not every stakeholder considered expanding their IoT system into something more accessible to other systems. This challenge needs to be overcome by the central regulator since they have more authority to enforce the policy. From this point of view, the regulator needs to present a solid will to develop the IoT environment so other institutions can follow and develop their IoT accordingly based on the characteristics provided.

This challenging situation will create additional research focus that future researchers can consider. A super IoT app that can seamlessly integrate every IoT in domestic transport services. Extensive development of the sensor unit to make it more affordable and accurate has become a critical point in developing the IoT environment.

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