Handling Dangerous Goods Issues Based on Radio Frequency Identification as An Export-Import Solution

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Abstract: Global supply chain dynamics increasingly rely on efficient maritime dangerous goods management, particularly in archipelagic nations where seaborne trade constitutes the primary mode of international commerce. Maritime transportation dominates global trade with an 80% market share, positioning ports as critical infrastructure for international cargo movement. Nevertheless, handling dangerous goods remains a paramount safety challenge, necessitating rigorous compliance with the International Maritime Dangerous Goods (IMDG) Code. Contemporary operational challenges encompass insufficient regulatory frameworks, systematic non-adherence to Standard Operating Procedures (SOPs), and fraudulent documentation practices, collectively compromising maritime safety standards. This study develops an RFID-based system that enhances identification, verification, and real-time tracking of dangerous goods during export-import processes. Employing a Research and Development (R&D) methodology, this study conducted comprehensive stakeholder interviews to identify critical operational deficiencies. The investigation revealed prevalent issues including systematic misclassification of hazardous materials and insufficient transparency in cargo documentation procedures. The proposed RFID-based system aims to establish a robust framework for dangerous goods management in export-import operations, addressing existing vulnerabilities while ensuring regulatory compliance and operational safety. This technological intervention promises to revolutionize dangerous goods handling protocols, offering scalable solutions for Indonesia's maritime logistics sector.

Keywords: dangerous goods handling; Radio Frequency Identification (RFID); maritime logistics; export-import operations; IMDG Code compliance.

1. Introduction

Based on reference data, the sea area released by the Coordinating Ministry for Maritime Affairs of the Republic of Indonesia, the total sea area in Indonesia is 6,400,000 km2 or more than 77% of the total area of Indonesia, to be precise 8,300 km2, sea area which includes exclusive economic zones, territorial seas, archipelagic waters, inland waters, additional zones, and continental shelf waters [1], [2]. As Indonesians, this is a positive impact in developing the potential of the sea in Indonesia,

one of which is by utilizing it as a marine trade sector. Currently, the port is a gateway in the implementation or movement of goods, where the development of freight transportation through sea transportation has reached 80% of the market share in the world. Not only that, sea trade or commonly referred to as export and import has become an enhancer of the Indonesian economy besides MSMEs. The marine economy in Indonesia is something that can be created to generate income and employment [3], [4]. This is certainly done to achieve a good economy for Indonesia. The idea

of a world maritime axis is also a maritime approach and strategy to achieve Indonesia's Vision, which is Indonesia as a maritime country [5]. This idea is outlined in the National Maritime Policy stipulated in Presidential Regulation No. 16/2017 regarding maritime policy. Therefore, it is imperative to focus on the development of the maritime sector, and it has become an obligation and imperative for our country [6]. The important and strategic role of a port is an important thing in making a major contribution to the development of industry and trade and contributing to the development of the national economy. Maritime resources based on economic views have a comparative advantage, while their location is a competitive advantage [7]. In import and export, there are many types of goods that can be traded, one of which is dangerous & toxic goods (Dangerous Goods). Dangerous goods are substances at risk to health, safety, property or the environment [8], [9].

Quite a lot of agendas or activities are carried out in handling dangerous cargo [10]. The handling of dangerous goods is carried out under strict supervision to refer to the standard operating procedures (SOP) that have been implemented [11]. There are seven pillars of Indonesia's marine policy, two of the seven pillars state, "Marine resource management and human resource development" and "Maritime diplomacy" [12]–[14]. Therefore, Indonesia's maritime diplomacy combines various international relations sciences and theories on geopolitical dependencies related to the creation of a sea strategy that not only focuses on security, but also economic, social and environmental sustainability (Ramadhani, et al., 2025). However, currently there are still several frauds committed by handling dangerous cargo, including the handling of dangerous cargo that has not been organized, non-compliance with SOPs, human resources who do not understand their duties and authorities, and manipulation of documents for personal gain. Right on May 14, 2024, there was an incident of a class 9 (Miscellaneous) container fire, where the container contained goods such as batteries, TWS, and others. Dangerous cargo if not managed according to standards will cause

incidents and even accidents [11], [15]. Homeland security issues have become a crucial problem in line with globalization. This has an impact on companies involved in the transportation of goods, where there are limitations to gate operations that lead to delays in unloading, distribution, and delays in loading and unloading to the destination gate [16]. Based on preferences, there are three interrelated parties, namely the company, freight forwarding, and the Port Authorities (Syahbandar).

The company will send dangerous goods by identifying and classifying dangerous goods according to the IMDG Code along with the completeness of documents prepared such as Material Safety Data Sheet (MSDS) Documents which must be included from the beginning by the company to Freight Forwarding [17]. Not only that, but the company is also required to fill out a Dangerous Goods Declaration (DGD), which is a form that must be filled out by the company or shipper of goods if the goods contain hazardous materials and this form states that the goods to be sent have been packaged, labeled, and declared in accordance with applicable regulations [18]. After the goods are received, the freight forwarding party will cross-check the documents with the physical goods, verify the suitability of the labeling and marking of dangerous goods, check the condition of the packaging whether the packaging is not damaged or has a leak, check the segregation of dangerous goods in accordance with the IMDG Code rules, pack the goods, until the goods will be given to the Syahbandar.

Unfortunately, the difficulty of the Syahbandar is the lack of transparency and conformity of documents with the goods being shipped, which is a big question mark for the Syahbandar in conducting inspections. This can add cost implications if the Syahbandar opens the packaging for physical inspection and will add costs such as labor costs for opening and repacking (extra handling charge), new packaging material costs (repacking fee), special physical inspection costs (physical inspection fee), and additional storage costs if the delay exceeds the free time (demurrage/detention),

thus causing several consequences such as delays in delivery time, potential risks to security and safety when opening dangerous goods packaging, and legal liability in the event of damage or changes in the condition of the goods. In handling dangerous cargo, workers can double-check based on the classification of each item or cargo. In the import-export process, there are several costs that are required to be carried out such as insurance claims, travel costs from one place to another, storage costs if the goods exceed the storage time, and so on, where this adds to the costs that must be incurred. No wonder companies or related parties manipulate documents just to cut costs. Ports are often used by individuals to enter illegal goods in a certain way to gain large profits, be it avoiding tax payments or avoiding long administrative processes [19]. Dangerous goods are based on the type of goods that require special handling, and all types, qualities, and materials that pose a threat to human safety [20].

On the one hand, there is a system that has long been used, but has a good impact and potential in solving some of the problems in handling dangerous cargo, namely a system called Radio Frequency Identification (RFID). In today's digital era, information technology is increasingly used for warehousing administration purposes such as barcodes, RFID, and other automated warehousing management systems that can improve efficiency and accuracy in warehousing data management [21]. Although existing regulations address the handling of dangerous goods, few studies have proposed digital verification frameworks adapted to Indonesian port operations. This study addresses that gap through an RFID-based monitoring solution.

2. Materials and Methods

This research employs Research and Development (R&D) methodology, structured in systematic phases to develop and implement an RFID-based system for dangerous goods management in export-import operations. The R&D framework encompasses:
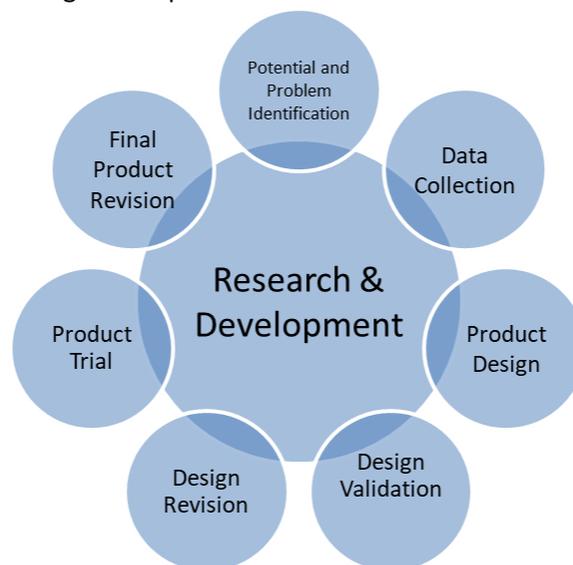

Figure 1 R&D (Research & Development) method

Based on Figure 1, it is known that the RnD method focuses on the development of a product. so that in this study it is determined to be carried out in 5 phases, namely:

a. Phase 1: Preliminary Study and Needs Analysis
   1) Comprehensive literature review on

dangerous goods handling protocols and RFID applications in maritime logistics
2) Stakeholder mapping and in-depth interviews with port authorities, freight forwarders, customs officials, and shipping lines
3) Identification of operational gaps and

regulatory compliance challenges in current dangerous goods management systems

4) Analysis of existing documentation processes and technological infrastructure

b. Phase 2: System Design and Development

1) Conceptual modeling of RFID-based dangerous goods tracking system

2) Technical specification development for RFID tags, readers, and integrated software platforms

3) Database architecture design for real-time data capture and monitoring

4) User interface prototyping for various stakeholder requirements

c. Phase 3: Prototype Development

1) Integration of RFID hardware components with software applications

2) Development of automated classification algorithms based on IMDG Code parameters

3) Implementation of real-time tracking and alert mechanisms

4) Creation of digital documentation workflows to ensure transparency

d. Phase 4: Testing and Validation

1) Laboratory testing of RFID tag performance under various environmental conditions

2) Pilot implementation at selected port facilities

3) System validation through simulation of actual dangerous goods handling scenarios

4) Performance evaluation against predetermined efficiency metrics

e. Phase 5: System Refinement and Implementation

1) Iterative improvements based on testing feedback

2) Scalability assessment for broader implementation

3) Development of Standard Operating Procedures (SOPs) for system utilization

4) Training module creation for end-users

The research methodology emphasizes iterative development cycles, ensuring continuous improvement of the RFID system to address real-world operational challenges. Data collection involves both quantitative metrics (processing time, error rates, compliance scores) and qualitative assessments (user satisfaction, operational feasibility) to comprehensively evaluate system effectiveness.

This R&D approach enables systematic progression from problem identification to solution implementation, ensuring the developed RFID system effectively addresses dangerous goods handling challenges while maintaining compliance with international maritime safety regulations.

3. Results

This research developed a conceptual design of RFID-based technology for monitoring dangerous goods handling in export-import operations. The R&D approach produced the following design outcomes:

3.1 System Architecture Design

The proposed RFID architecture system consists of three integrated layers (Table 1):

Table 1. RFID System Architecture Components

Layer	Components	Fuctions
Hardware Layer	RFID tags, Fixed readers, Handheld readers	Data capture and transmission
Network Layer	Wireless network, Gateway servers	Data communication
Application Layer	Database, Web interface, Mobile app	Data processing and visualization

3.2 Functional Design Specifications

The system design incorporates the following functional modules:

1. Identification Module
   a) Unique tag assignment for each dangerous goods container
   b) Automatic IMDG Code classification reading
   c) Multi-tag simultaneous reading capability
2. Tracking Module
   a) Real-time location monitoring
   b) Movement history recording
   c) Geofencing alerts for restricted areas

3. Verification Module
   a) Cross-reference with IMDG database
   b) Document-to-physical matching
   c) Compliance status reporting
4. Alert Module
   a) Classification mismatch notifications
   b) Unauthorized movement alerts
   c) Emergency response triggers

3.3 System Workflow Design

The proposed operational workflow follows these steps:

Figure 2 RFID System Operational Workflow [22], [23]

3.4 Integration Framework

The design includes integration points with existing port systems (Table 2):

Table 2. System Integration Design [10], [11]

External System	Integration Method	Data Exchange
Customs Database	Web services	Declaration documents
IMDG Code Database	Direct query	Classification codes (Annex)
Emergency Response	Push notifications	Alert messages

3.5 User Interface Design

Three interface designs were developed:

a. Control Center Dashboard
   1) Real-time facility map with tag locations
   2) Alert management panel
   3) Statistical reporting tools
b. Mobile Application
   1) Handheld reader integration
   2) Inspection checklists
   3) Offline capability
c. Web Portal
   1) Administrative functions
   2) Report generation
   3) System configuration

3.6. Prototype Validation Method

Validation of the RFID-based dangerous goods monitoring system prototype incorporated structured feedback from industry practitioners and academic experts. A comprehensive validation framework was implemented through a mixed methods approach:

- Expert Panel Evaluation: A panel of 3 maritime logistics experts (1 from industry and two from academia) conducted a systematic assessment of the prototype using a standardized evaluation matrix. Each expert evaluated the system based on predefined criteria including compliance with the IMDG Code, operational feasibility, intuitiveness of

the user interface, and potential integration with existing port systems.

- Functional Testing: The prototype underwent functional testing in a simulated port environment at Jakarta State University. Testing included:
    a) Assessment of RFID tag reading accuracy in multiple devices.
    b) Database synchronization performance and clear data reading.
    c) Alert system response time and alert notification pop-up.
    d) Ability to read multiple tags simultaneously and ease of access.

4. Discussion

The conceptual design of an RFID-based system for dangerous goods handling presented in this research addresses critical operational challenges in maritime logistics while aligning with Indonesia's maritime axis vision. This section analyzes the implications of the proposed system architecture and its potential contributions to enhancing operational efficiency, regulatory compliance, and safety standards in dangerous goods management.

4.1. System Effectiveness in Addressing Export-Import Challenges

The proposed RFID system architecture directly addresses the identified operational gaps in dangerous goods handling procedures at Indonesian ports. The three-layer design integrating hardware components, network infrastructure, and application interfaces creates a comprehensive framework that enables real-time tracking, verification, and monitoring capabilities currently absent in conventional dangerous goods management protocols. This aligns with findings by Cahyadi (2009) who highlighted RFID's potential for enhancing administrative systems in Indonesian port operations.

The functional modules of the system—identification, tracking, verification, and alert mechanisms—collectively transform dangerous goods handling from a primarily document-based process to a digitally-integrated operation. This transformation is particularly significant in the context of Indonesia's archipelagic geography, where maritime transportation constitutes over 80% of international trade activities. As noted by Priadi (2022) in Maritime Technology and Society, the optimization of smart technologies is essential for improving sustainable maritime transportation across Indonesia's vast maritime territory.

4.2 Technological Innovation and Regulatory Compliance

The integration of RFID technology with existing IMDG Code frameworks represents a significant advancement in regulatory compliance management. Current operational challenges identified in maritime dangerous goods handling, particularly documentation manipulation and misclassification of hazardous materials, can be substantially mitigated through the proposed system's automated verification mechanisms. This finding corresponds with global maritime safety trends toward technology-enhanced compliance monitoring as documented in recent maritime logistics literature.

The system's capability to automatically cross-reference physical goods with digital documentation creates a transparency layer that effectively addresses the verification difficulties experienced by port authorities (Syahbandar). This transparency mechanism potentially eliminates the need for costly and time-consuming physical inspections while simultaneously enhancing compliance with international dangerous goods regulations. The real-time monitoring capabilities further enable proactive risk management rather than reactive responses to safety incidents, a paradigm shift in dangerous goods handling protocols.

4.3 Economic and Operational Implications

From an economic perspective, the RFID-based system offers potential cost efficiencies despite initial implementation investments. The system addresses multiple cost factors currently affecting dangerous goods handling in Indonesian ports:

1. Reduction in extra handling charges through minimizing the need for

physical inspection
2. Decrease in documentation verification time, reducing operational delays
3. Prevention of demurrage costs through expedited processing
4. Mitigation of potential safety incident costs through enhanced monitoring

These economic benefits align with Indonesia's broader maritime policy objectives of enhancing competitiveness and efficiency in maritime logistics. As Morra and Ghalidza (2020) observe, maritime resources present both comparative and competitive advantages for Indonesia's economic development, and technological innovations like RFID implementation can amplify these advantages.

4.4 Security Enhancement and Fraud Prevention

The proposed system offers significant potential for addressing security vulnerabilities in dangerous goods handling. The automatic identification and verification capabilities directly target the documented issue of document manipulation for tax avoidance or administrative shortcutting [19]. By creating immutable digital records of dangerous goods movements and characteristics, the system reduces opportunities for fraudulent practices while enhancing overall port security.

The geofencing and alert modules further strengthens security protocols by enabling automated monitoring of dangerous goods movements within port facilities. This capability aligns with findings regarding the importance of developing transportation infrastructure to ensure sustainable development, where security considerations form a central component of sustainability frameworks.

4.5 Implementation Considerations and Limitations

While the conceptual design demonstrates significant potential benefits, several implementation considerations warrant attention. The integration with existing port management systems represents a technical challenge requiring standardized data exchange protocols and system compatibility frameworks. This integration complexity is compounded by the diverse stakeholder ecosystem in maritime logistics, encompassing shipping lines, port authorities, customs officials, and freight forwarders.

Additionally, the scalability of the proposed system across Indonesia's numerous ports of varying sizes and technological capacities presents a practical implementation challenge. A phased implementation approach may be necessary, prioritizing major export-import hubs before expanding to smaller facilities.

The research design does not yet incorporate direct stakeholder feedback through interviews or surveys, which would provide valuable insights into practical implementation considerations and potential resistance points. Future research should address this limitation through comprehensive stakeholder engagement to refine the system design based on operational perspectives.

4.6 Future Research Directions

This research establishes a foundation for several promising future research directions in maritime logistics technology:
1. Development of implementation frameworks specific to the Indonesian maritime governance structure, considering the unique regulatory environment and port hierarchies
2. Investigation of integration possibilities between RFID-based dangerous goods management systems and broader maritime digitalization initiatives, including port community systems and single window platforms
3. Examination of cybersecurity implications for digitalized dangerous goods management, particularly considering the sensitive nature of dangerous goods information and potential security vulnerabilities
4. Exploration of RFID technology applications beyond dangerous goods to general cargo management in Indonesian ports, creating comprehensive visibility across maritime supply chains
5. Analysis of policy frameworks necessary to support technological innovation in dangerous goods management, including potential regulatory

adjustments to accommodate digital verification processes

Addressing these research directions would complement the current study and contribute to advancing Indonesia's position as a maritime axis through technology-enabled logistics innovation.

4.7 Contribution to Maritime Logistics Knowledge

This research makes three primary contributions to maritime logistics knowledge. First, it conceptualizes a technological solution to a persistent operational challenge in dangerous goods handling, offering a framework that can be adapted across diverse port environments. Second, it demonstrates the potential of RFID technology to simultaneously address safety, security, efficiency, and compliance concerns in maritime logistics operations. Third, it establishes linkages between technological innovation and Indonesia's broader maritime policy objectives, illustrating how specific operational improvements contribute to national strategic goals.

These contributions extend beyond the immediate context of dangerous goods handling to inform broader discussions on maritime logistics digitalization, particularly in developing maritime nations with extensive archipelagic geographies.

In conclusion, the RFID-based system for dangerous goods handling represents a promising technological intervention for enhancing export-import operations in Indonesia's maritime sector. By addressing critical operational challenges while aligning with broader maritime policy objectives, the proposed system offers a practical pathway toward improved compliance, enhanced safety, and increased operational efficiency in dangerous goods management. Future research and development efforts should focus on implementation frameworks, stakeholder engagement, and broader integration with

maritime digitalization initiatives to realize the full potential of this technological approach.

5. Conclusions

This research has developed an RFID-based system to enhance dangerous goods management in Indonesia's maritime export-import operations, addressing critical challenges such as documentation fraud, cargo misclassification, and procedural non-compliance. The study makes significant theoretical contributions by integrating RFID technology with the IMDG Code framework, creating a novel digital verification model that bridges regulatory compliance and technological innovation. This framework is particularly relevant for archipelagic nations, offering a scalable solution to improve transparency and safety in maritime logistics.

From a practical standpoint, the proposed system delivers measurable benefits, including reduced operational costs, minimized inspection delays, and proactive risk mitigation through real-time monitoring. Its modular design ensures adaptability across Indonesia's diverse port infrastructures, supporting immediate implementation while aligning with the nation's maritime axis vision. The system's automated verification capabilities also empower port authorities to enforce compliance more effectively, reducing reliance on error-prone manual processes.

Future research should explore deeper integration with broader maritime digitalization initiatives, such as Port Community Systems, as well as cybersecurity measures to protect sensitive dangerous goods data. Additionally, policy adjustments will be necessary to institutionalize digital verification processes within national and international maritime regulations. The proposed system offers a replicable framework that aligns with IMDG Code standards, supporting digital traceability and real-time risk mitigation in port logistics.

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