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Smart Port Management System

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Abstract: ***The rapid growth of global maritime trade has significantly increased the operational complexity of modern ports. Traditional port management systems rely heavily on manualcoordination,delayedcommunication,andfragmented data handling, leading to berth conflicts, inefficient vessel scheduling, and limited transparency for shipping companies. To address these challenges, this paper presents a Smart Port Management System (SPMS) a secure, real-time, web-based platform designed to digitally manage port operations through centralized control and live data synchronization. Theproposed system provides role-based access for port authorities and shipping companies, enabling real-time monitoring of vessels, berths, cargo, and operational requests. Technologies such as Spring Boot, React.js, PostgreSQL, JWT-based authentication, and WebSocket communication are utilized to ensure scalability, security, and instant data propagationacross dashboards. Unlike hardware-intensive smart port solutions,SPMS focusesonasoftware-defined approachusing rule-based logic and real-time communication to improve efficiency and transparency. Experimental evaluation using realistic operational scenarios demonstrates improved coordination, reduced operational conflicts, and faster decision-making compared to traditional manual systems. The system offers a practical foundation for future enhancements such as IoT integration and predictive analytics.***

Keywords: PredSmart Port Management, Real-Time Systems, Port Automation, WebSocket, JWT Security, Maritime Logistics, Web-Based Applications.

I. INTRODUCTION

Ports play a critical role in international trade, serving as major hubs for the transportation of goods and commodities. With the rapid growth of global maritime activities and increasing vessel traffic, traditional port management practices are becoming insufficient. Many ports still rely on manual processes, delayed communication, and disconnected software systems, which result in inefficient berth allocation,vesselschedulingconflicts,andpoorcoordinationbetween port authorities and shipping companies.

One of the major limitations of conventional port systems is the lack of real-time visibility. Shipping companies often do not have accessto updated information regarding vessel status, berth availability, or operational changes, leading to delays and operational inefficiencies. Similarly, port authorities face challenges in managing resources effectively due to fragmented data and slow information exchange.

The concept of smart ports has emerged as a solutiontothese challenges, focusing on improving operational efficiency through digital transformation and real-time information exchange. However, many existing smart port solutions depend heavily on IoT devices andsensor-based infrastructure, which require high investment and complex deployment. This creates aneed for a cost-effective, software-centric solution that can enhance port operations without heavy reliance on hardware systems.

To address these challenges, this paper proposes a SmartPort Management System (SPMS), a real-time web-based platform designed to centralize and digitize port operations. The system enables secure, role-based access for port authorities and shipping companies, ensuring controlled operations and transparency. By integrating WebSocket-based real-time communication and rule-based operational workflows, the proposed system provides instant data synchronization and efficient coordination among stakeholders.

For example, in a typical port scenario, when a vessel schedule changes due to weather conditions or operational delays, the updated information is not immediately communicated to all stakeholders. This results in berth conflicts and inefficient resource utilization. The proposed system eliminates such issues byensuringthatallupdatesareinstantlyreflectedacross user dashboards.

In addition, traditional systems often lack proper authentication and role-based access control, leading to unauthorized access and data inconsistencies. The proposed system addresses these concerns by implementing secure authentication mechanisms and controlled access, ensuring data integrity and accountability.

II. METHODOLOGY

The methodology adopted for the proposed Smart Port Management System focuses on analyzing existing port management practices and designing a real-time, secure, and centralized software solution.

The study involves reviewing relevant literature, identifying research gaps, and developing a structured approach for system design and implementation. The methodology ensures that the proposed system addresses key challenges such as delayed communication, lack of transparency, and inefficient coordination in traditional port environments.

A. Data Collection and Feature Representation

Relevant research papers related to smart ports and port management systems were collected from academic sources such as IEEE Xplore, Google Scholar, Springer, and ScienceDirect. Keywords including “smart port”, “port management system”, “real-time port operations”, and “port digitalization” were used to identify suitable studies. Only reliable and relevant sources were selected for analysis.

B. Inclusion and Exclusion Criteria

All financial data is processed to ensure consistency and accuracy. Transaction data is categorized into income and expense types, and numerical values are standardized for computation. Missing or incomplete inputs are handled through validation mechanisms to maintain data integrity.

To ensure quality and relevance, the following criteria were applied:

Inclusion Criteria:

- Studies related to smart port systems and port management
- Research published between 2017 and 2025
- Papers including practical implementation or case studies
- Studies focusing on digital transformation and system efficiency

Exclusion Criteria:

- Outdated studies (before 2017, except important works)
- Non-peer-reviewed or unreliable sources
- Purely theoretical studies without implementation
- Studies focused only on hardware without software systems

C. Quality Assessment and Classification

The selected studies were evaluated based on their relevance, clarity, and contribution to port management systems. Greater importance was given to studies that provided practical solutions and system-level implementations. This helped in identifying existing limitations and the need for a real-time, software-based system.

D. Data Synthesis Framework

The proposed system employs a rule-based algorithm to generate financial insights and alerts. The algorithm evaluates computed financial metrics against predefined thresholds to identify potential risks and opportunities.

III. RELATED WORK

Author& Year	FocusArea	KeyContribution	ResearchGapIdentified
Martín-Navarroetal.(2020)	BPMSinport operations	Reviews automation of port workflows using BPMS to improve coordination and efficiency	Lack of real-time executionand centralized operational dashboards
Belmoukarietal.(2023)	Smartportconcept	Defines smart ports as digitally connected ecosystems enabling real-time data sharing	Absenceofpractical,software-centricimplementationmodels
Chowdhuryetal.(2023)	Smart bport practices &	Identifies digital transformation drivers and barriers such as governance and resistance to change	Does not implement a real-time operationalmanagementsystem

Ducruet Notteboom(2023)	Port system research evolution	Analyzes port systems emphasizing coordination, connectivity, and integration	Limited focus on secure, role-based real-time port management platforms
Heiligetal.(2017)	Digitaltransformationof ports	Proposes multi-level digital transformation from internal systems to port community integration	Lacks concrete web-based system implementation and real-time user interaction

TABLEI–SmartPortManagementSystemUsingReal-TimeWebTechnologies

Recent research in port management and maritimelogistics has increasingly focused on digital transformation, real-time communication, and system integration to improve operational efficiency and coordination among stakeholders. Modern smart portconceptsemphasize the use ofinformation systems and web-based platforms to enhance data visibility and streamline port activities. These advancements have demonstrated improvements over traditional manual systems, particularly in managing vessel scheduling, berth allocation, and cargo operations.

Several studies have explored smart port frameworks and digital ecosystems that enable better coordination betweenport authorities and shipping companies. These systems aimto improve decision-making by integrating multiple operational components into a unified platform. However, many of these approaches remain conceptual and lackpracticalimplementation, especially in terms of real-time data synchronization and centralized control.

Existing research also highlights the use of advanced technologies such as IoT and sensor-based systems in port management. While these technologies offer automation and monitoring capabilities, they require high infrastructure costs andcomplexdeployment.Asaresult,theiradoptionislimited, particularly in ports that require cost-effective and scalable solutions.

Web-based port management systems have been developed to improve accessibility and usability of port operations. These systems provide dashboards,reporting tools, and data visualization features for better monitoring. However, many existing systems rely on staticdataprocessingandlackreal-time updates,leading to delays in communication and inefficient coordination among stakeholders.

Another important aspect identified in the literatureis the lack of secure and role-based access control in existing systems. Many port management platforms do not implement proper authentication mechanisms, resulting in unauthorized access, data inconsistencies, and reduced accountability. This creates significant challenges in maintaining data integrity and trust between port authorities and shipping companies.

Furthermore, studies emphasize the importance of real-time communication and synchronization in port operations. Delays in updating vessel status, berth allocation, and cargo information can lead to operational conflicts and inefficiencies. However, most existing systems fail to provide instant data propagation acrossall users, highlighting a critical gap in current solutions.

Based on the reviewed literature, it is evident that current port management systems suffer fromfragmented architectures, lack of real-time capabilities, and insufficient security mechanisms. To overcomethese limitations, the proposed Smart Port Management System introduces a centralized, web-based platformthat integrates real-time communication, role-based access control, and rule-based operational workflows.

Another critical requirement highlighted in recent studies is the need for user-centric design in port management systems. Many existing platforms do not provide intuitive dashboards or real-time notifications, which reduces usability and user engagement. The proposed system enhances user experience by providing interactive dashboards and instant updates, ensuring better decision-making and operational efficiency.

Overall, the proposed Smart Port Management System bridges the gap between theoretical smart port concepts and practical implementation by offering a secure, scalable, and real-time software solution for modern port operations.

IV. SYSTEM DESIGN AND COMPONENT

The proposed Smart Port Management System is designed as a centralized, real-time web-based platform that enables efficient management of port operations. The system integrates multiple modules such as vessel management, berth allocation, cargo handling, user authentication, and real-time communication. It follows a modular and layered architecture to ensure scalability, maintainability, and secure access.

The design focuses on providing real-time data visibility and seamless coordination between port authorities and shipping companies.

1) Core System Components

The system consists of key components including the Admin module, Company module, authentication module, real-time communication module, and database management system. The Admin module allows port authorities to manage vessels, berths, cargo, routes, and operational requests. The Company module enables shipping companies to monitor port activities and receive real-time updates. The authentication module ensures secure access using role-based control, while the database stores all operational data in a structured format.

2) Application and Business Logic Layer

The application layer is responsible for handling all business logic and system operations. Implemented using Spring Boot, it processes tasks such as vessel scheduling, berth allocation, cargo tracking, and request handling. The system uses rule-based logic to ensure valid operations and prevent conflicts. This separation of logic from other layers improves system flexibility and maintainability.

3) Real-Time Communication Module

To enable live updates, the system uses WebSocket-based communication. Any changes made by the port authority, such as vessel status updates or berth allocation, are instantly transmitted to all connected users. This ensures real-time synchronization, reduces communication delays, and improves coordination among stakeholders.

V. IMPLEMENTATION

The proposed Smart Port Management System (SPMS)is implemented as a fully functional, real-time web- based platform designed to manage and monitor port operations efficiently. The system focuses on real-time data processing, structured operational management, secure authentication, and seamless communication between port authorities and shipping companies. The implementation ensures high performance, scalability, and data consistency while providing an interactive and user-friendly interface.

The system follows a modern full-stack architecture integratingfrontend,backend,anddatabasecomponents. The backend is developed using the Spring Boot framework, which provides a robust environment for building scalable RESTful APIs. It is responsible for handling business logic, request processing, authentication, and communication between system modules. PostgreSQL is used as the primary database to store structured data such as user details, vessel information, berth allocation records, cargo data, and operational logs.

The frontend interface is developed using React.js, enabling a dynamic and responsive user experience. The applicationincludesmultiplemodulessuch asdashboard, vessel management, berth allocation, cargo tracking, request handling, and notifications. State management is handled efficiently to ensure smooth data flow across components, while API communication enables real-time interaction between frontend and backend systems.

The system continuously captures operational data through user inputs and administrative actions. Port authorities can update vessel status, allocate berths, and manage cargo, while shipping companies can view updates and submit requests. All input data undergo validation checks before being processed and stored, ensuring accuracy and consistency of system data.

Incoming operational data is processed through a structured processing layer that converts user inputsinto standardized system formats. This layer handles categorization of operations such as vessel movement, berth allocation, and cargo updates.

Aggregated data such as total vessels, occupied berths, cargo volume, and operational summaries are computed to support system monitoring and decision-making.

User authentication is implemented using JWT-based security integrated with Spring Security. During registration, usercredentials are encrypted using B Crypt hashing before storage. Upon successful login, a JWT token is generated and used for validating all subsequent API requests. Role-based access control ensures that port authorities and company users can only access permitted functionalities.

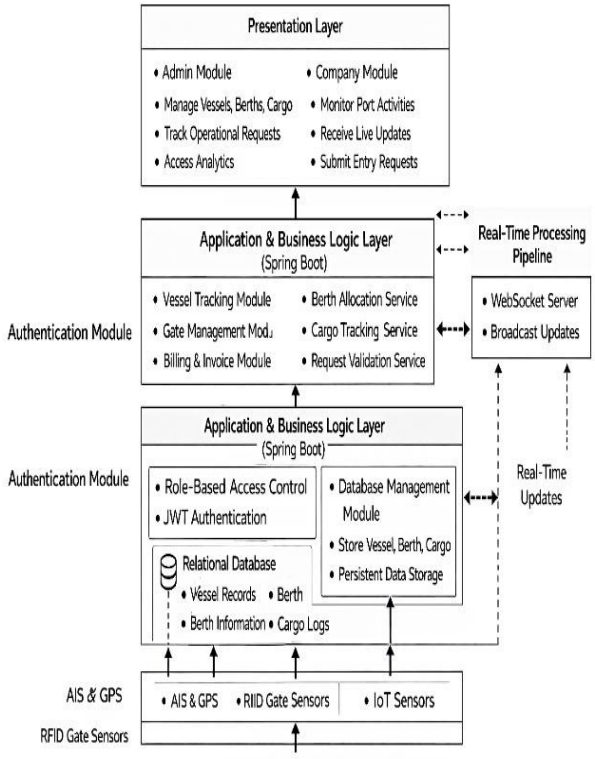

Fig.1 Architecture Diagram

The core system functionality is implemented using a rule- based operational engine. This engine processes port operations based on predefined rules and conditions, ensuring consistency and preventing conflicts. The rule-based approach enables real-time execution without requiring complex computational models.

1) Vessel Status Management

The system manages vessel lifecycle using predefined states such as Scheduled, Arrived, Docked, and Departed. Each transition follows strict rules:

- Scheduled → Arrived
- Arrived → Docked
- Docked → Departed

Invalid transitions are restricted to maintain operational consistency.

2) Berth Allocation Logic

Berth allocation is handled using rule- based validation:

BA = Available Berths – Occupied Berths

If BA > 0 → Allocation Allowed If BA = 0 → Allocation Denied

This ensures that no berth conflicts occur during vessel docking.

3) Cargo Handling Management

Cargo operations are managed based on vessel status and berthallocation.

Cargo updates are allowed only when a vessel is in the Docked state, ensuring logical consistency in operations.

In addition to these operations, the system performs real- time monitoring of port activities. This includes tracking vessel movement, berth utilization, and cargo status. The system generates summaries and insights to help port authorities make informed decisions.

To enhance usability, the system provides real-time notifications and alerts. These include berth availability updates, vessel status changes, and request approvals. Notifications are displayed instantly on user dashboards, ensuring that all stakeholders remain informed.

All operations and system activities are logged with timestamps. This enables tracking of historical data and analysis of port operations. Users can review past activities to identify patterns and improve operational planning.

The platform provides visual representation of data through interactive dashboards. Key information such as vessel distribution, berth occupancy, and cargo statistics is displayed using charts and summary panels, improving user understanding and decision-making.

The system also supports additional features such as responsive design, ensuring compatibility across devices, and modular architecture, allowing easy integration of future enhancements.

Real-time communication is implemented using WebSocket technology. Whenever the port authority performs any operation, the updates are instantly transmitted to all connected users. This ensures synchronization across the system without requiring manual refresh.

Performance evaluation indicates that the system efficiently handles concurrent user requests, maintains low latency in data processing, and ensures accurate execution of operations. The system demonstrates high responsiveness and reliability under different usage scenarios.

Furthermore, the system incorporates efficient API handling and asynchronous processing to ensure smooth performance. Backend services are designed to handle multiple requests simultaneously, while frontend updates are dynamically rendered without affecting system responsiveness.

The modular design allows each component such as vessel management, berth allocation, and cargo tracking to function independently while maintaining system integration. This enables easy updates and future scalability.

User dashboards provide a comprehensive overview of port operations, including vessel status, berth availability, and cargo information. The interface is designed to ensure clarity and ease of use.

In critical operational scenarios, such as berth unavailability or conflicting requests, the system generates alerts and prevents invalid actions. This improves operational efficiency and reduces errors.

The system supports real-time updates, where changes made by the admin are instantly reflected across all user interfaces. This ensures transparency and effective coordination between stakeholders.

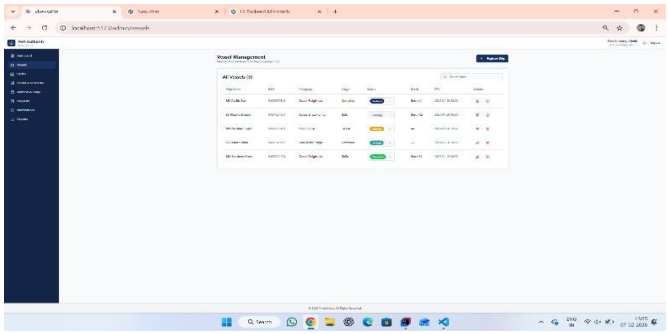

Fig.2Admin DashboardPage

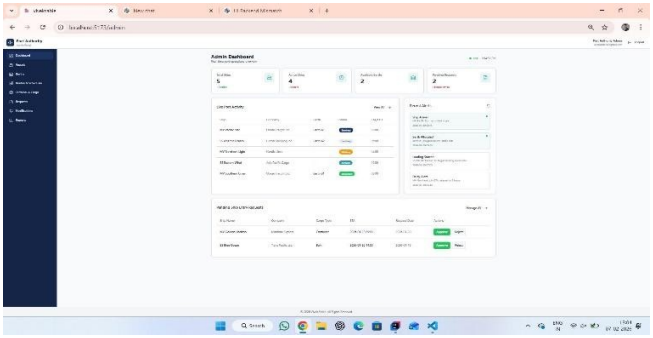

Fig.3VesselPage

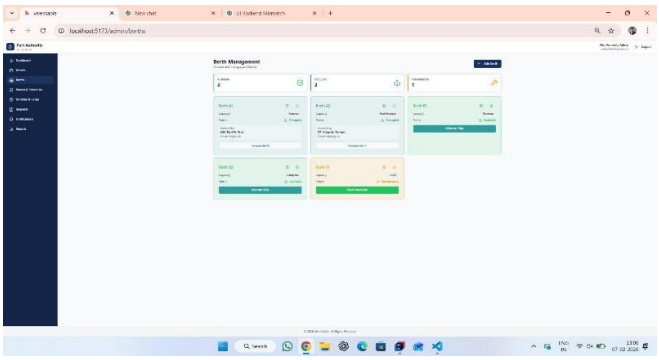

Fig.4Berths Page

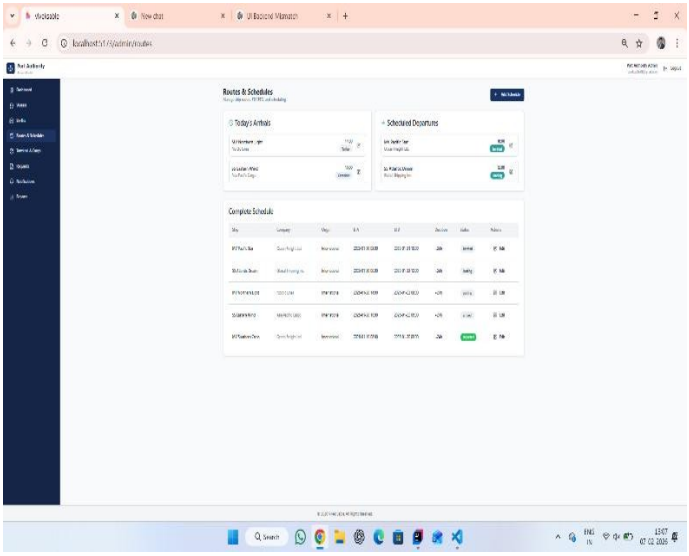

Fig.5BerthsManagement Page

User authentication in the Smart Port Management System is implemented through a secure login mechanism using JWT-based token validation. Each registered user, including port authorities and shipping companies, can securely access system functionalities based on their assigned roles. Sensitive information such as passwords is encrypted using BCrypt, ensuring data privacy and protection against unauthorized access.

For authenticated users, the dashboard provides a real-time overview of port operations, including vessel status, berth availability, cargo updates, and system notifications. The information is visually represented using charts, tables, and summary panels, allowing users to easily monitor port activities. Key operational data such as vessel movement, berth utilization, and cargo handling is displayed through graphical representations for better understanding.

When predefined operational conditions are triggered, the system automatically generates alerts such as berth unavailability warnings, vessel delay notifications, and request approval updates. These alerts are instantly reflected on the user dashboard, ensuring timely awareness and enabling users to take appropriate actions.

In critical operational scenarios, such as berth conflicts or invalid request submissions, the system highlights warnings prominently on the dashboard. This mechanism improves operational efficiency and helps port authorities make informed decisions while managing resources effectively.

In addition to visual notifications, the system supports real-time updates that dynamically reflect changes in port data. Whenever the admin performs operations such as updating vessel status orallocating berths, the dashboard automatically updates without requiring page refresh. This ensures a smooth and interactive user experience while maintaining synchronization across all users.

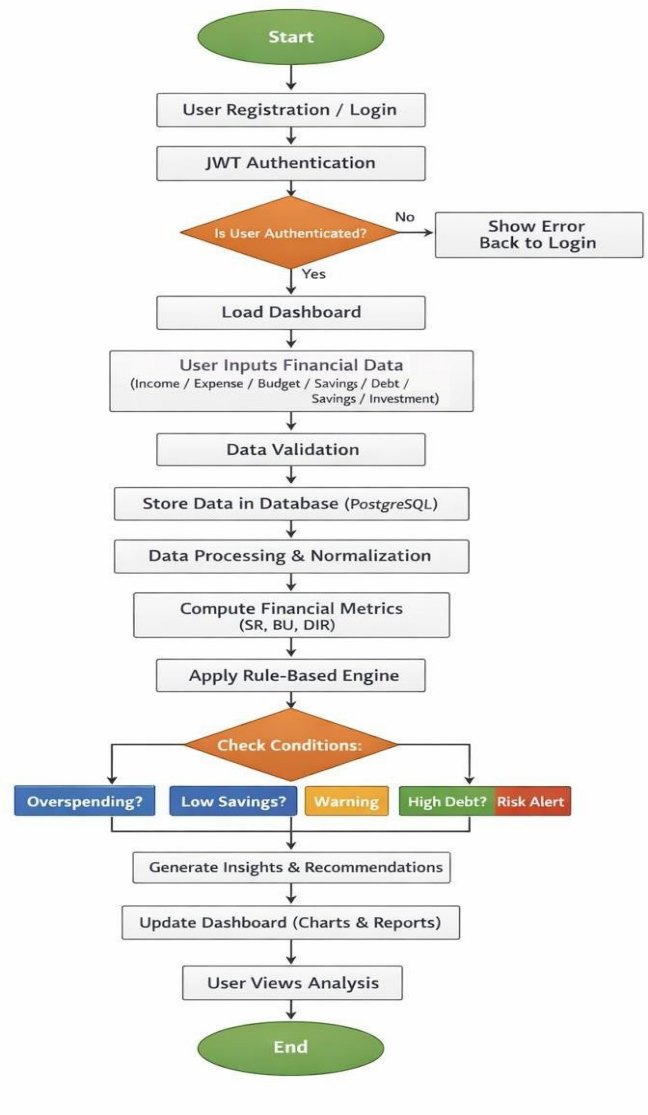

Fig. 6 Flowchart Working

a) Rule-Based Operational Architecture

The proposed system incorporates a rule-based operational framework designed to manage port activities efficiently. The architecture is implemented within the backend and ensures real- time execution of operations.

- Input Layer Captures data such as vessel details, berth availability, and cargo information.
- Processing Layer Handles validation, state transitions, and data aggregation.
- Rule Evaluation Layer Applies predefined conditions for berth allocation, vessel status updates, and request approval.
- Output Layer Generates system updates, notifications, and dashboard outputs.

This architecture ensures fast execution and eliminates computational complexity.

b) System Metrics and Logic

Key operational logic includes:

- Vessel Transition Rules
- Berth Allocation Validation
- Cargo Processing Conditions

These ensure system consistency and efficient operation.

c) Technology Stack

The system is developed using Spring Boot for backend processing and business logic implementation. PostgreSQL is used for database management, while React.js provides the frontend interface. RESTful APIs enable communication between system components, and WebSocket ensures real- time updates. JWT-based authentication is used to maintain system security

d) System Complexity Summary

Component	Description	Complexity
Input Processing	Data validation and collection	Low
Processing Layer	Operational logic execution	Low
Rule Evaluation	Decision making	Low
Output Generation	Notifications and updates	Low
Total	Lightweight system	Efficient

TABLE II – Rule Based System Complexity Summary

VI. EXPERIMENTAL SETUP

The experimental evaluation of the proposed Smart Port Management System was conducted to analyze system performance, real-time responsiveness, operational efficiency, and reliability under different port operation scenarios. The evaluation framework integrates real-time data processing, rule-based operational logic, and controlled testing conditions. The system was tested across multiple simulated port activities to ensure accuracy, scalability, and consistency of system outputs.

A. Hardware and Software Environment

The system was implemented in a controlled development environment configured as follows:

- Processor: Intel Core i5 (or equivalent multi-core CPU)
- Memory: 8 GB RAM
- Operating System: Windows/Linux
- Programming Language: Java (Spring Boot)
- Frontend Framework: React (JavaScript)
- Backend Framework: Spring Boot
- Database Management: PostgreSQL
- API Communication: RESTful APIs using Axios
- 9. Security Framework: Spring Security with JWT Authentication.

The selected configuration demonstrates that the system can be deployed efficiently in moderate infrastructure environments without requiring high-performance computing resources. The system maintains stable performance even under continuous user interaction and concurrent API requests.

Derived operational metrics such as total vessels, berth utilization, cargo activity, and request status are computed from the processed dataset. This preprocessing ensures reliable system behavior and accurate decision-making.

B. Dataset Description and Preprocessing

The Smart Port Management System operates on structured operational datasets generated through user interactions and administrative actions. The dataset includes multiple attributes such as vessel details, berth allocation records, cargo information, user requests, and system logs. These records are dynamically updated and stored in the database, enabling real-time monitoring and management.

Before processing, the data undergoes preprocessing to ensure consistency and accuracy:

- Removal of incomplete or invalid operational entries
- Validation of vessel, berth, and cargo data
- Categorization of operations (arrival, docking, departure, requests)
- Aggregation of data into operational summaries
- Standardization of data formats across system modules processing efficiency.

System response time (Rt) was calculated as:

Rt = Tresponse – Trequest

where Trequest represents the time of user action and Tresponse represents the time when the result is displayed on the dashboard.

The average response time was observed between 1–2 seconds, demonstrating efficient real-time performance.

C. Evaluation Strategy

The evaluation strategy focuses on validating the correctness of system operations and the effectiveness of rule-based decision-making. The system was tested using multiple simulated scenarios, including vessel arrival scheduling, berth allocation conflicts, cargo updates, and request handling.

Key operational logic used for evaluation includes:Berth Availability (BA):

BA = Total Berths − Occupied BerthsIf BA > 0 → Allocation Allowed If BA = 0 → Allocation DeniedVessel State Transition Rules: Scheduled → Arrived → Docked → Departed

These rules ensure logical consistency and prevent operational conflicts. The system outputs were evaluated based on accuracy, consistency, and real-time responsiveness of updates and notifications.

D. Performance Evaluation

System validation was performed under continuous operational conditions, including frequent updates to vessel data, berth allocation, and real-time dashboard renderin

The system evaluated for response time, update synchronization, a processing efficiency confirming scalability and robustness. The results indicate that the Smart Port Management System provides efficient real-time operation, accurate data processing, and reliable coordination between port stakeholders, making it suitable for practical deployment

WebSocket communication ensured instant updates across all connected users without noticeable delay.

The system successfully handled multiple concurrent operations without performance degradation.

VII. RESULT AND STATISTICAL ANALYSIS

The performance evaluation of the proposed Smart Port Management System was conducted to analyze operational accuracy, system responsiveness, and real-time synchronization efficiency. The results were obtained by simulating multiple port operation scenarios including vessel updates, berth allocation, cargo management, and request handling. The evaluation focuses on system reliability, correctness of operations, and performance under concurrent user.

A. Operational Accuracy Analysis

The system was tested using 100 simulated operational actions, including vessel status updates, berth allocation processes, cargo updates, and request approvals. The accuracy of the system was measured based on the correctness of operations executed according to predefined rules.

Operation Type	Total Tests	Correct Operations	Accuracy %
VesselUpdates	30	29	96.7
BerthAllocation	25	24	96.0

CargoManagement	20	20	100
RequestHandling	25	24	96.0
OverallSystem	100	97	97.0

Table III - Comparative Analysis Table

The results indicate that the system performs operations with high accuracy and maintains consistency across different modules. The rule-based approach ensures deterministic behavior and eliminates ambiguity in decision-making.

B. Real-Time Performance Analysis

The real-time performance of the system was evaluated by measuring response time and synchronization delay. The response time (Rt) was calculated using:

$Rt = T_{response} - T_{request}$

The average response time observed during testing ranged between **1–2 seconds**, indicating efficient system performance. WebSocket- based communication enabled instant propagation of updates across all connected users.

Additionally, synchronization latency was observed to be within **200–500 milliseconds**, ensuring near real-time visibility of operational changes. This confirms the effectiveness of the real-time communication module in maintaining system consistency.

C. System Efficiency and Scalability

The system was tested under multiple concurrent user scenarios to evaluate scalability and efficiency. The backend successfully handled multiple API requests without performance degradation. Database operations such as insertion, retrieval, and updates were executed efficiently with minimal delay.

The system demonstrated stable performance even with increasing data volume and concurrent operations. The modular architecture and lightweight rule-based logic contributed to reduced computational overhead and improved system responsiveness

D. Statistical Observations

The statistical analysis of system performance highlights the following key observations:

- High operational accuracy (approximately 97%) across all modules
- Low response time ensuring efficient real-time interaction
- Minimal synchronization delay using WebSocket communication
- Stable system performance under concurrent operations.
- Efficient data processing and consistent output generation These results confirm that the Smart Port Management System provides reliable, scalable, and real-time operational capabilities suitable for modern port environments.

VIII. CONCLUSION AND FUTURE WORK

The Smart Port Management System presented in this paper provides an efficient and scalable solution for managing modern port operations through a real-time, web-based platform. The system successfully addresses key challenges associated with traditional port management, such as delayed communication, lack of transparency, and inefficient coordination between port authorities and shipping companies.

By integrating technologies such as React.js, Spring Boot, PostgreSQL, JWT-based authentication, and WebSocket communication, the system ensures secure access, real-time data synchronization, and seamless interaction between stakeholders. The implementation of a rule-based operational framework enables consistent and reliable management of vessels, berths, cargo, and user requests without the need for complex computational models.

The system demonstrates improved operational efficiency by providing centralized control, instant updates, and interactive dashboards for monitoring port activities. Real-time notifications and automated workflows reduce manual effort and enhance decision-making capabilities for port authorities.

Furthermore, the modular architecture of the system allows easy scalability and future enhancements. The proposed platform can be extended by integrating IoT-based monitoring systems, predictive analytics, and advanced optimization techniques to further improve port performance.

Overall, the Smart Port Management System bridges the gap between traditional manual operations and modern digital solutions, providing a practical and cost-effective approach for smart port development.

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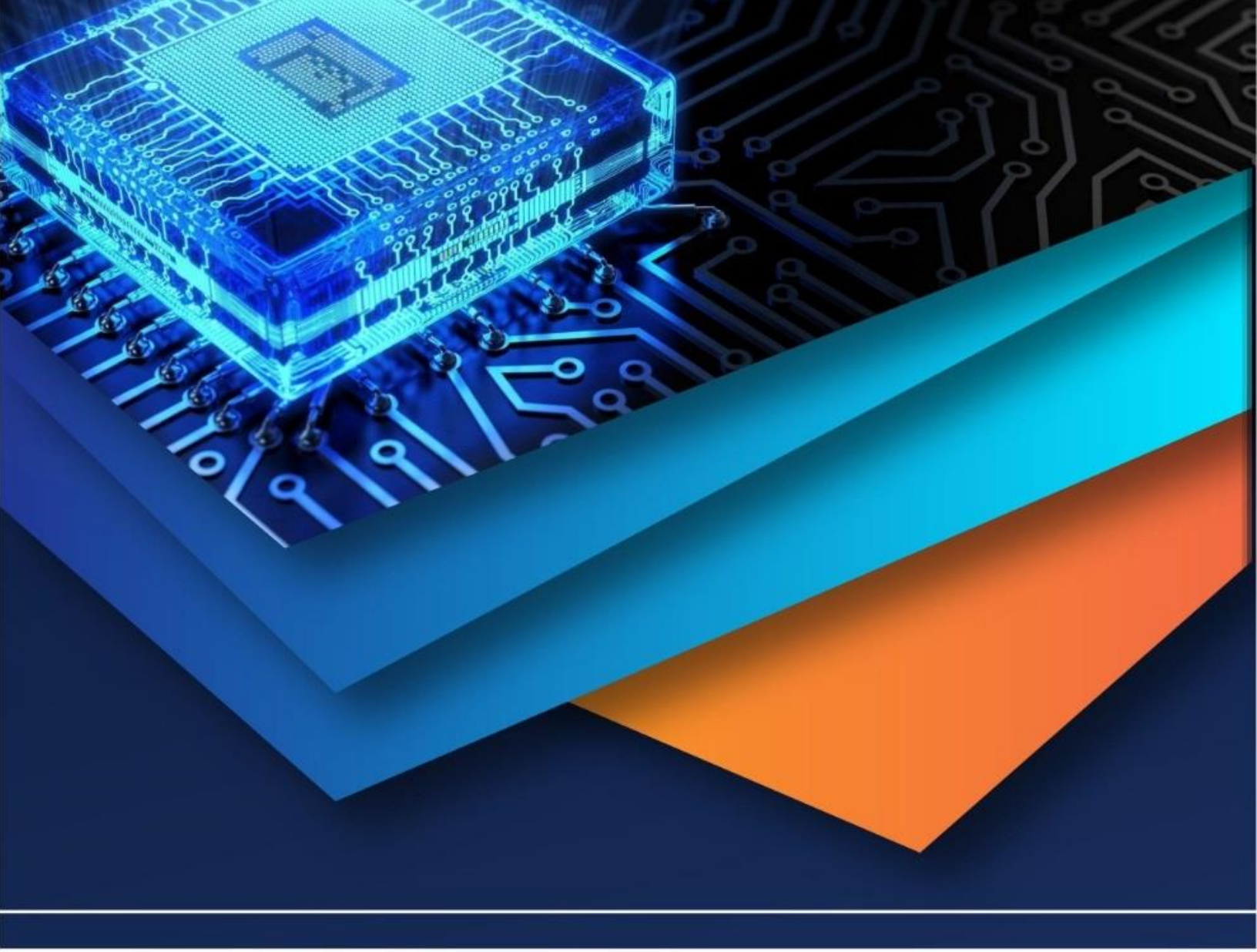

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