Singapore's Maritime Services and Port Development: A Survey

Abstract

This survey examines Singapore's maritime services and port development initiatives, emphasizing their role in positioning the city-state as a leading logistics hub and maritime cluster. The analysis is structured across eight sections, exploring the interconnectedness of maritime services, strategic policies, and innovation. Singapore's shipping industry is dissected to reveal its strengths and challenges, with a focus on innovation and technology as key drivers of competitiveness. Port development initiatives, including infrastructure improvements and capacity expansion, are highlighted for their strategic importance in maintaining Singapore's global maritime leadership. The survey also delves into the concept of a maritime cluster, underscoring Singapore's robust ecosystem that supports regional and global trade. Strategic maritime policies are evaluated for their impact on enhancing maritime services and port development, while innovation is discussed in terms of its contributions to efficiency, sustainability, and competitiveness. The conclusion synthesizes these findings, emphasizing the critical role of strategic integration in sustaining Singapore's maritime leadership. Future research directions are suggested, including the exploration of sustainable port practices, digital transformation, and the socio-economic impacts of maritime operations.

1 Introduction

1.1 Structure of the Survey

This survey comprises eight sections, each addressing a vital aspect of Singapore's maritime services and port development. The introduction underscores Singapore's status as a premier logistics hub and maritime cluster, emphasizing the influence of strategic maritime policies and innovation on global competitiveness. The subsequent section on background and definitions offers a comprehensive overview of key concepts, including maritime services, port development, and strategic maritime policy, clarifying their interrelations within Singapore's maritime ecosystem.

The third section investigates the shipping industry in Singapore, assessing its current condition, strengths, challenges, and contributions to the global maritime landscape, while also highlighting the significance of innovation and technology in sustaining competitiveness. The fourth section focuses on port development initiatives, detailing infrastructure enhancements, capacity expansions, and technological advancements that are crucial for establishing Singapore as a leading logistics hub.

The fifth section discusses the maritime cluster concept, illustrating how Singapore has cultivated a robust ecosystem that supports diverse maritime services and its pivotal role in regional and global trade. Following this, the strategic maritime policies section evaluates the policies enacted to bolster maritime services and port development, analyzing their effects on the shipping industry and the wider maritime cluster.

The penultimate section addresses maritime innovation, examining the cutting-edge practices and technologies embraced by Singapore's maritime sector, and how these innovations foster efficiency,

Figure 1: chapter structure

sustainability, and competitiveness. The conclusion synthesizes the survey's key findings, highlighting the interconnectedness of maritime services, port development, and strategic policies in reinforcing Singapore's position as a global maritime leader, while identifying avenues for future research and potential policy implications.The following sections are organized as shown in Figure 1.

2 Background and Definitions

2.1 Conceptual Framework of Maritime Cluster

The maritime cluster concept is pivotal to comprehending the dynamics of Singapore's maritime ecosystem. Defined as a geographically concentrated network of interconnected enterprises, suppliers, and institutions, this cluster promotes collaboration and innovation, essential for maintaining competitiveness in the global maritime sector [1]. Singapore's cluster is distinguished by its specialization and global connectivity, influenced by the interplay of traffic diversity and port specialization [2]. Effective communication networks, such as hybrid satellite-terrestrial systems, are vital for optimizing transmission and coverage in this context.

Operational efficiency within the cluster is assessed through a multi-dimensional framework that includes operational, financial, sustainable, and logistics performance, underscoring their interdependence [3]. This approach is crucial for sustaining Singapore's competitive advantage. The drivers of port competitiveness are framed within a conceptual model that emphasizes the need for an integrated understanding of causal relationships among various dimensions [4].

Singapore's strategic location and infrastructure benefit from the development of dry ports, enhancing connectivity and efficiency [5]. Digital innovations, such as precise ETA estimations, are critical for efficient logistics operations [6]. Despite challenges in digital adoption, overcoming these barriers is vital for advancement [7]. Port Community Information Systems (PCIS) significantly enhance information integration, boosting operational capabilities [8].

2.2 Role of Logistics as a Spatial Practice

Logistics extends beyond traditional supply chain management, serving as a calculative logic and spatial practice that impacts capitalism and warfare [9]. In Singapore's maritime services, logistics

is crucial for shaping spatial dynamics and enhancing operational efficiency, reinforcing its role as a leading logistics hub. The strategic development of port infrastructure and hinterland connectivity exemplifies logistics' spatial implications, enhancing port competitiveness while integrating sustainability [10, 4, 2, 11].

Optimizing logistics networks ensures efficient cargo handling, reduced transit times, and minimized costs, vital for maintaining global competitiveness. Integration into maritime services supports sophisticated operations like just-in-time delivery and real-time tracking, improving efficiency and customer satisfaction. Logistics aligns maritime policies with economic objectives, leveraging Singapore's geographical and infrastructural strengths to attract international shipping lines and logistics firms. This alignment bolsters regional trade and elevates Singapore's status in global supply chains, highlighting logistics' crucial role. As shipping evolves towards integrated door-to-door services, sustainable logistics practices become increasingly important for enhancing port competitiveness and addressing diverse supply chain needs. Advances in digital technologies and information integration are transforming ports into smart hubs, enhancing operational capabilities and performance in a competitive global market [11, 2, 8, 9, 4].

In examining the complexities of Singapore's shipping industry, it is essential to consider the various elements that contribute to its success. A comprehensive understanding of this sector necessitates an exploration of its hierarchical structure, which is illustrated in Figure 2. This figure highlights the integration of maritime services and innovative practices in shipping and logistics, showcasing key areas such as technological advancements, strategic alliances, and the pivotal role of digitalization. These factors collectively enhance operational efficiency and security within the industry, underscoring the importance of a cohesive approach to maritime operations in Singapore's economic landscape.

3 Singapore's Shipping Industry

3.1 Maritime Services and Shipping Industry

The integration of maritime services with the shipping industry is crucial for global trade, enhancing operational efficiency and economic performance. Singapore exemplifies this through strategic maritime service integration, optimizing fleet deployment and bunker management to reduce costs [12]. Container shipping, vital for transporting billions of tons of cargo annually, underscores its role in global trade [13]. The industry's resilience, tested by adaptability to market demands and external shocks like the COVID-19 pandemic and the 2008-2009 financial crisis, is essential for maintaining supply chain continuity. Innovative practices, such as utilizing historical trajectory data for better vessel arrival predictions, enhance operational planning and reduce delays [6].

As illustrated in Figure 3, the key components of the maritime services and shipping industry can be categorized into integration and efficiency, strategic alliances and challenges, and innovative practices. Each of these categories highlights specific elements contributing to the industry's operational success and adaptability. Strategic alliances in container shipping strengthen maritime service connections by enabling resource sharing and collaborative strategies that optimize networks [14]. Nonetheless, challenges such as freight rate volatility and difficulties in hedging against fluctuations due to the absence of universally accepted predictive models persist [15]. The industry faces structural changes with new competitive pressures [16], and advanced unsupervised classification methods improve operational efficiency and compliance. Hybrid learning frameworks combining adaptive and batch processing enhance data handling and model training [17].

3.2 Innovative Practices in Shipping and Logistics

Innovative practices in shipping and logistics are vital for operational efficiency and competitiveness, maintaining Singapore's status as a leading maritime hub. Innovations like integrating fleet deployment with bunker management reduce costs and improve environmental performance [12]. Advancements in liner shipping fleet repositioning, using column generation and lazy constraints, enhance model efficiency and solution times [13].

Digitalization has transformed shipping operations, improving document processing with unsupervised text classification models that outperform traditional ones, even with limited training data [18]. A semi-automatic document classification approach using machine learning and user-selected

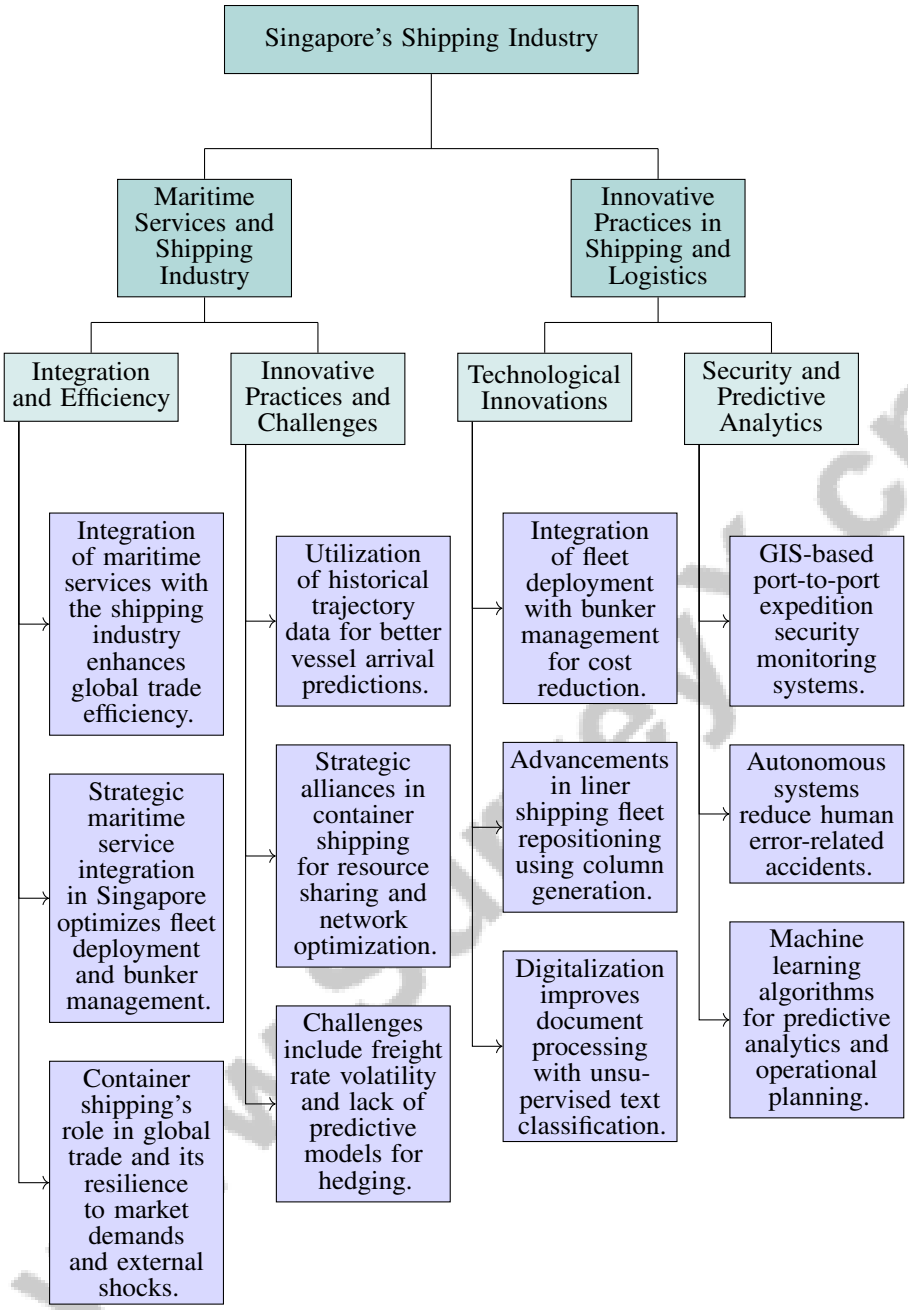

Figure 2: This figure illustrates the hierarchical structure of Singapore's shipping industry, focusing on the integration of maritime services and innovative practices in shipping and logistics. It highlights key areas such as technological advancements, strategic alliances, and the role of digitalization in enhancing operational efficiency and security within the industry.

keywords enhances efficiency [19]. Digital Green Shipping Innovation (DGSI) aligns with global efforts to reduce the shipping industry's carbon footprint, enhancing efficiency and sustainability [20].

Security innovations, such as GIS-based port-to-port expedition security monitoring systems integrating GPS tracking and digital locks, enhance cargo security during transit [21]. Autonomous systems can mitigate human error-related accidents, improving safety and efficiency [22]. However, the integration of technology introduces cybersecurity vulnerabilities, necessitating robust protective

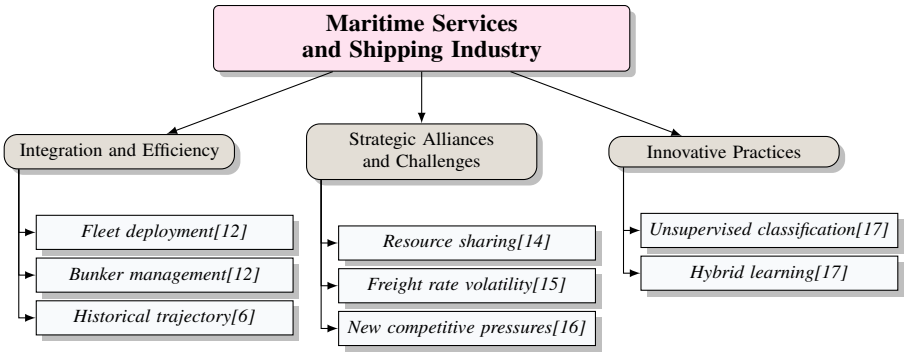

Figure 3: This figure illustrates the key components of the maritime services and shipping industry, focusing on integration and efficiency, strategic alliances and challenges, and innovative practices. Each category highlights specific elements contributing to the industry's operational success and adaptability.

measures [23]. Machine learning algorithms analyzing historical delay data enhance predictive analytics, improving operational planning and minimizing delays [24]. A simplified neural network model requiring only operational data for ship performance predictions highlights potential advancements [25].

Challenges include technical barriers like the lack of standards and data sharing, stakeholder issues such as trust and business model alignment, and the need for a coherent digitalization strategy among port actors [10]. Despite these, advancements in intelligent shipping technologies continue to enhance operational efficiencies and reduce environmental impacts [26]. The adoption of digitalization, security enhancements, and predictive analytics is crucial for sustaining efficiency and competitiveness in the global maritime industry. These innovations bolster Singapore's maritime capabilities while advancing global initiatives for sustainable and secure maritime operations, particularly through digital green shipping technologies and strategic planning focused on environmental sustainability in shipping logistics [10, 11, 20, 23, 7].

4 Port Development Initiatives

4.1 Infrastructure Improvements and Capacity Expansion

Singapore's port development initiatives are pivotal for maintaining its status as a leading global maritime hub, focusing on infrastructure enhancements and capacity expansion to boost operational efficiency and support future growth. Incorporating advanced technologies like GPS tracking and digital locking systems exemplifies innovative approaches to securing cargo and streamlining port operations. These systems enhance cargo monitoring and security through GPS and RFID-enabled digital locks, ensuring efficient handling [21].

Figure 4 illustrates the key components of Singapore's port development initiatives, highlighting infrastructure enhancements, capacity expansion, and operational efficiency improvements, with references to supporting research. The development of hybrid satellite-terrestrial maritime communication networks (MCNs) is a testament to Singapore's commitment to upgrading port infrastructure. This research aims to improve transmission efficiency and network coverage, providing maritime-specific services crucial for modern port operations [27]. These advancements facilitate real-time data exchange, optimizing coordination and management of port activities to increase throughput and reduce turnaround times.

Capacity expansion is a key element of Singapore's port strategy, addressing the growing demands of global trade. Enhancements to port facilities and logistics networks emphasize the importance of aligning corporate strategies with innovation efforts, highlighting the necessity of stakeholder collaboration to achieve shared objectives [7].

The integration of machine learning algorithms in delay prediction models represents a significant advancement in port operations. By analyzing historical shipping data, these models accurately predict

container vessel delays, improving scheduling and resource allocation. This predictive capability enhances operational efficiency, reduces congestion, and elevates service levels for shipping lines and logistics providers [24].

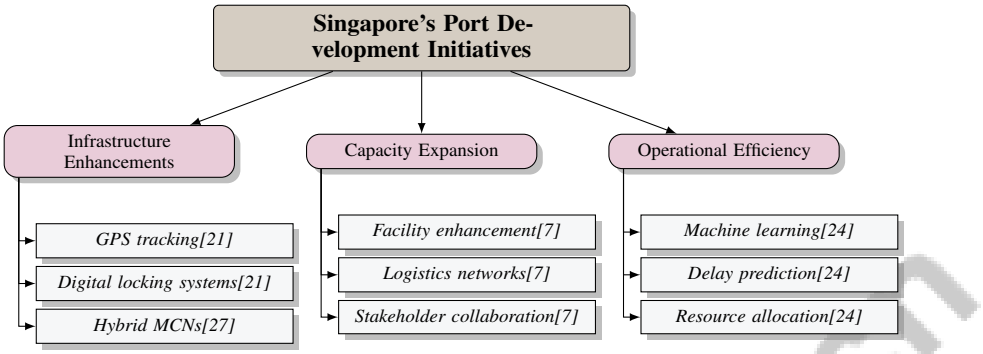

Figure 4: This figure illustrates the key components of Singapore's port development initiatives, highlighting infrastructure enhancements, capacity expansion, and operational efficiency improvements, with references to supporting research.

4.2 Smart Ports and Autonomous Shipping

The development of smart ports and autonomous shipping technologies marks significant progress in the maritime sector, enhancing operational efficiency and sustainability. Smart ports are characterized by technological integration and operational effectiveness, with frameworks evaluating their maturity based on these traits [28]. The digital transformation of ports follows maturity models that emphasize real-time data integration and operational enhancement.

Intelligent shipping frameworks further categorize smart ports by prioritizing integrated logistics and automated services, optimizing operations and service delivery [26]. The use of digital twins in port operations enables real-time simulation and optimization, improving decision-making and operational effectiveness [29].

Autonomous shipping technologies represent a transformative aspect of modern maritime operations, applicable across diverse sectors such as short-sea, Arctic, and conventional shipping [30]. However, the deployment of autonomous vessels presents regulatory challenges that must be addressed to ensure safe and efficient operations [22].

Benchmark datasets, like the OASIs dataset, encapsulate various maritime conditions and provide metrics such as the Integrated Figure of Calculation Performance (IFCP) to support the development and assessment of autonomous systems [31].

Advancing smart ports and autonomous shipping technologies is crucial for fostering a more efficient, sustainable, and competitive maritime industry. These innovations significantly enhance port operations by integrating advanced information and communication technologies (ICT), streamlining processes, and facilitating the transformation of maritime logistics through increased digitalization and automation. This evolution enables ports to align more closely with supply chain management strategies, optimize resource utilization, and adopt new business models, ultimately leading to heightened productivity, cost savings, and a more sustainable approach to maritime operations [10, 22, 7, 8].

5 Maritime Cluster and Logistics Hub

5.1 Hinterland Connectivity and Operational Efficiency

Hinterland connectivity is essential for enhancing operational efficiency within the maritime cluster, ensuring seamless goods transit between ports and inland areas. It plays a pivotal role in smart port development, directly influencing performance metrics and operational capabilities [10]. Aligning hinterland logistics with port operations facilitates efficient and cost-effective goods distribution.

Key drivers of hinterland connectivity include inland transportation networks, shipping service linkages, and port infrastructure [4]. These elements collectively streamline supply chain operations, minimize transit times, and improve cargo delivery reliability. The use of Big Data analytics enhances operational efficiency, safety, and environmental protection within the maritime cluster, supporting informed decision-making and resource allocation [32].

The interconnected systems in the maritime cluster, such as onboard technologies and port infrastructure, underscore the need for strong hinterland connectivity. Vulnerabilities in these systems can lead to cascading failures, highlighting the importance of comprehensive cybersecurity measures to maintain operational integrity [23]. Challenges like weather conditions and port congestion complicate delay predictions, necessitating an integrated approach using intelligent shipping components to strengthen regulatory frameworks and operational oversight [26, 24].

Research frameworks that focus on the formation, management, and optimization of strategic alliances are crucial for improving hinterland connectivity [14]. These alliances promote stakeholder collaboration, resource sharing, and the development of integrated logistics networks, enhancing connectivity and operational efficiency. The implementation of smart port technologies, even in smaller ports, demonstrates potential improvements in connectivity, as evidenced in comparative analyses of ports like Gdynia and Rotterdam [28].

As depicted in Figure 5, this figure illustrates the hierarchical structure of factors influencing hinterland connectivity and operational efficiency in the maritime cluster, categorized into key drivers, technological enhancements, and strategic alliances. This visual representation further elucidates how these elements interact to bolster the overall performance of maritime operations.

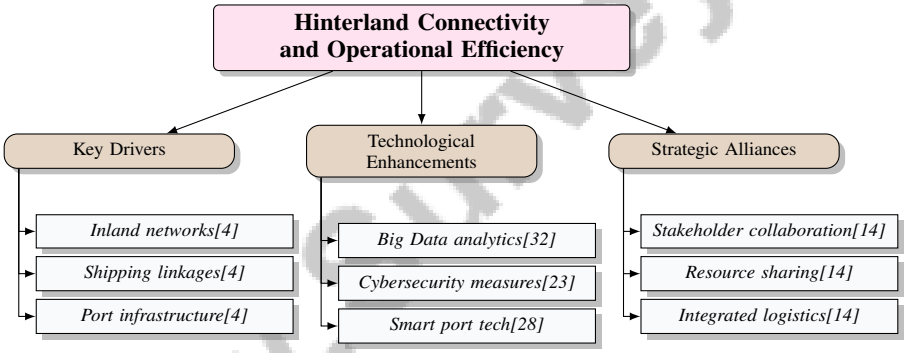

Figure 5: This figure illustrates the hierarchical structure of factors influencing hinterland connectivity and operational efficiency in the maritime cluster, categorized into key drivers, technological enhancements, and strategic alliances.

5.2 Stages of Connectivity and Collaboration

The stages of connectivity and collaboration within the maritime cluster are crucial for boosting operational efficiency and fostering innovation. These stages facilitate digital technology integration and align stakeholder interests, enhancing port competitiveness and supply chain responsiveness [4, 7]. They involve strategic alliance formation, advanced technology integration, and the development of regulatory frameworks for seamless operations.

Strategic alliances enhance connectivity by enabling stakeholders to share resources, optimize logistics networks, and improve service offerings. Future research should examine the impact of these alliances on container shipping operations, alliance negotiation processes, and technology integration in alliance management [14].

Emerging technologies like autonomous shipping and Big Data analytics further strengthen connectivity and collaboration. However, research gaps exist concerning the ethical implications of autonomous shipping and its long-term impact on maritime employment [22]. Realizing Big Data's full potential in maritime transport requires regulatory frameworks, enhanced data processing technologies, and increased stakeholder collaboration [32].

Cybersecurity is a critical component of connectivity and collaboration, necessitating the integration of cybersecurity guidelines with emerging technologies and continuous evaluation of their effectiveness in real-world scenarios. This integration is vital for safeguarding maritime operations and ensuring the maritime cluster's resilience against cyber threats [33].

The stages of connectivity and collaboration are characterized by strategic alliances, technological integration, and robust regulatory frameworks. Strategic planning for sustainability, innovative technological advancements, and proactive resource mobilization collectively enhance operational efficiency, foster innovation, and strengthen resilience within the global maritime industry, addressing challenges related to energy transition and sustainable practices in international shipping [1, 11].

6 Strategic Maritime Policies

6.1 Strategic Importance and Global Competitiveness

Benchmark	Size	Domain	Task Format	Metric
OASIs[31]	80,000	Maritime Object Segmentation	Semantic Segmentation	IFCP, IoU
UCSID[16]	1,000,000	Shipping Economics	Data Analysis	Freight Rate, Shipping Quantity
SPB[25]	1,000,000	Ship Performance	Speed-Power Prediction	MAE, MAPE

Table 1: This table presents a comprehensive overview of key benchmarks in the maritime sector, detailing their respective sizes, domains, task formats, and performance metrics. The benchmarks include OASIs for maritime object segmentation, UCSID for shipping economics, and SPB for ship performance, each contributing to advancements in data analysis and prediction accuracy within their specific domains.

Singapore's strategic maritime policies are pivotal in maintaining its global competitiveness by enhancing operational efficiency, fostering innovation, and ensuring resilience against global challenges. These policies facilitate strategic alliances within the shipping industry, optimizing operations and competitiveness through resource sharing and collaborative strategies [14]. The Mission-oriented Innovation Systems (MIS) approach significantly contributes to integrating innovative solutions, enhancing governance structures, and facilitating novel technologies' development and diffusion [34]. This approach addresses challenges such as high development costs, stringent compliance regulations, and a risk-averse mindset that can impede innovation and new entrants [35].

As illustrated in Figure 6, Singapore's maritime policies emphasize several key components: strategic alliances that enhance operational efficiency through resource sharing and collaboration, innovation systems that advocate for regulatory adaptations to incorporate autonomous shipping and improved data management, and sustainability practices that highlight governance, measurement challenges, and strategic planning for sustainable shipping. These elements collectively underscore the importance of a cohesive strategy in navigating the complexities of the maritime sector.

Table 1 provides a detailed comparison of significant benchmarks utilized in the maritime industry, highlighting their scope, domain focus, task formats, and evaluation metrics. Singapore's policies on autonomous shipping advocate for regulatory adaptations to incorporate autonomous vessels, presenting opportunities to enhance shipping efficiency [22, 30]. However, comprehensive regulatory frameworks are necessary for safe and efficient operations. Effective capacity management, particularly highlighted during disruptions like the COVID-19 pandemic, is prioritized to maintain continuity in global supply chains and mitigate external shocks [36].

Addressing the inefficient management and analysis of Big Data in maritime transport, Singapore's policies aim to improve data management and prediction accuracy, contributing to cost reduction and enhanced operational efficiency [32]. Aligning ICT innovations with company strategies, particularly economic objectives, is associated with higher success rates, underscoring the importance of strategic alignment in achieving policy goals [7].

Governance, technological integration, and sustainability practices in port operations are vital components of Singapore's maritime strategy, with studies revealing varying effectiveness in these areas [2]. Achieving consistency in sustainability measurement among ports remains challenging due to the complex nature of port operations [3]. Strategic planning for sustainability in international shipping often lacks coherence, necessitating a more integrated approach to ensure effectiveness [11].

Singapore's meticulously crafted maritime policies enhance its global economic position by promoting innovation, improving operational efficiency, and bolstering resilience against international challenges. These strategies emphasize sustainability in shipping practices, the integration of advanced technologies, and proactive cybersecurity measures within shipboard operational systems [4, 2, 11, 33]. Collectively, these policies are crucial in maintaining Singapore's status as a leading maritime hub and driving continued growth in the global maritime industry.

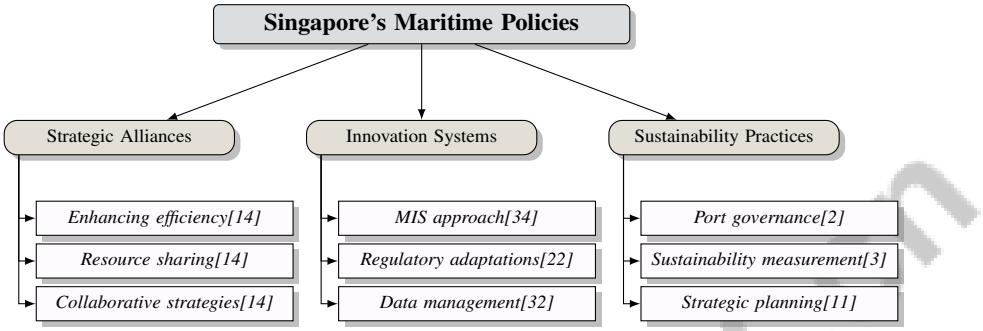

Figure 6: This figure illustrates Singapore's maritime policies, focusing on strategic alliances, innovation systems, and sustainability practices. Strategic alliances enhance operational efficiency through resource sharing and collaboration. Innovation systems emphasize the Mission-oriented Innovation Systems (MIS) approach, regulatory adaptations for autonomous shipping, and improved data management. Sustainability practices highlight governance, measurement challenges, and strategic planning for sustainable shipping.

6.2 Market Dynamics and Strategic Alliances

The maritime sector's complex market dynamics and strategic alliances are crucial for competitiveness and operational efficiency. A significant challenge is the absence of effective business models for adopting sustainable innovations, compounded by regulatory and market uncertainties [34]. These uncertainties hinder the integration of sustainable practices into maritime operations.

Strategic alliances optimize network operations and enhance service offerings, but managing these alliances involves challenges such as maintaining stability amid frequent reshuffles and navigating regulatory constraints [14]. This necessitates a robust alliance management framework adaptable to the maritime market's dynamic nature.

The adoption of Smart Port technologies complicates operations, with selecting and implementing suitable technologies in a diverse environment remaining a primary challenge [28]. This complexity is exacerbated by the need to manage cyber risks, particularly in shipboard operational technology (OT) systems. Guidelines provide actionable measures for managing these risks, focusing on practical implementation for engineers and IT/OT specialists [33].

The shipping industry faces outdated technologies and a lack of a security-first mindset during system design, leading to vulnerabilities [23]. Addressing these requires a comprehensive approach, updating legacy systems, and incorporating cybersecurity considerations into design and implementation phases.

The integration of Big Data analytics is hindered by technological limitations, competitive conditions affecting data sharing, and the need for skilled human resources [32]. Overcoming these barriers is essential for leveraging data-driven insights to enhance operational efficiency and strategic decision-making.

In terms of sustainability, gaps exist in understanding sustainability concepts, green shipping, and strategic planning methods [11]. This lack of clarity can impede the development of coherent strategies aligned with global sustainability goals.

Protectionist measures can support national fleets but often increase transport costs and market inefficiencies [37]. Balancing these measures with the need for open and competitive markets is crucial for fostering a resilient and efficient maritime industry.

7 Maritime Innovation

7.1 Digitalization and Smart Port Development

Digitalization is pivotal in transforming smart port development by significantly enhancing operational efficiency and sustainability. It drives port operations through the integration of technologies that emphasize emission control, energy efficiency, and ecological protection, as seen in Digital Green Shipping Innovation (DGSI) [20]. The strategic application of these technologies optimizes processes and enhances safety, with research underscoring their critical role in improving port efficiency and competitiveness [28, 35].

Incorporating digitalization is also crucial for advancing autonomous shipping technologies, vital to the smart port framework. This integration fosters improvements in operational efficiency and decision-making, addressing technological development, collision avoidance, autonomous systems applications, human factors, and regulatory challenges [30]. The impact of Big Data analytics further exemplifies digitalization's role in smart port development by facilitating informed decision-making and efficient operations [32]. Innovative delay prediction models using machine learning and extensive explanatory variables highlight the effectiveness of digital tools in enhancing prediction accuracy and resource allocation [24].

Future research should focus on establishing collaborative networks and refining strategic planning methodologies in maritime logistics [11]. Thus, digitalization stands as a cornerstone of smart port development, ensuring efficiency, sustainability, and competitiveness, positioning smart ports to meet modern maritime industry demands and maintain global market relevance.

7.2 Cybersecurity and Big Data Management

Cybersecurity and Big Data management are integral to maritime innovation, addressing sector complexities and vulnerabilities. The adoption of digital technologies in maritime operations necessitates robust cybersecurity measures, particularly for shipboard operational technology systems, highlighting a need for comprehensive guidelines to mitigate threats [33]. The maritime industry faces significant cybersecurity threats requiring immediate attention to ensure operational integrity and secure global supply chains [23].

Simultaneously, managing Big Data offers both challenges and opportunities. Effective Big Data analytics can enhance operational efficiency and decision-making, but the industry must overcome technological constraints, competitive data-sharing issues, and a shortage of skilled personnel to fully leverage Big Data's potential [32]. Addressing these challenges requires integrating advanced data processing technologies and fostering stakeholder collaboration. By improving data management and prediction accuracy, the maritime industry can reduce costs and improve efficiency, benefiting logistics companies and port operators and aligning with broader goals of sustainable and secure operations amid growing cyber vulnerabilities and digital innovation demands [7, 32, 23].

The convergence of cybersecurity and Big Data management is crucial for advancing maritime innovation. Implementing robust security measures and optimizing data management practices will enhance the sector's resilience, efficiency, and competitiveness in the global market.

8 Conclusion

This survey underscores the intricate relationship between maritime services, port development, and strategic policies that collectively reinforce Singapore's stature as a leading global maritime hub. The adoption of cutting-edge infrastructure, strategic hinterland connectivity, and innovative practices has significantly enhanced operational efficiency and global competitiveness. The integration of digital technologies, exemplified by smart ports and autonomous shipping, showcases Singapore's commitment to maintaining its competitive edge in the maritime industry. Furthermore, strategic maritime policies have played a pivotal role in building resilience against global disruptions, ensuring supply chain continuity, and fostering innovation.

The survey highlights the importance of cybersecurity in safeguarding maritime operations, emphasizing the need for comprehensive security measures to address vulnerabilities within the shipping industry. The adoption of Digital Green Shipping Innovation (DGSI) practices further highlights

the significance of sustainability in maritime operations, aligning with global initiatives to reduce environmental impacts.

Future research should focus on emerging trends such as nearshoring and reshoring, the digital transformation of port operations, and the environmental impacts of shipping practices in the post-COVID-19 era. Additionally, exploring sustainable port practices and examining the socio-economic effects of port operations is crucial. Investigating collaboration mechanisms among stakeholders and evaluating the performance benefits of DGSI adoption will be essential for navigating the evolving landscape of digital technologies in shipping.

Moreover, addressing weaknesses within maritime supply chains is critical, necessitating research on developing security-by-design principles and enhancing incident response capabilities. Future studies could also explore the long-term effects of cartel dissolution on market structure and competition, as well as the impacts of various regulatory frameworks on industry dynamics.

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