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RESEARCH TITLE

**"From Infrastructure Gap to Global Gateway:
Assessing Infrastructure Development Readiness of Saudi Commercial Ports
and Building a Strategic Roadmap for Vision 2030 and Beyond
— A Case Study of Jubail Commercial Port —"**

"من فجوة البنية التحتية إلى بوابة عالمية:
تقييم جاهزية تطوير البنية التحتية للموانئ التجارية السعودية
وبناء خارطة طريق استراتيجية لرؤية 2030 وما بعدها
— دراسة حالة: ميناء الجبيل التجاري —"

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1. Introduction

Saudi Arabia's Vision 2030 identifies the logistics and maritime sector as a critical pillar of economic diversification. The Kingdom aims to rank among the top 10 global logistics hubs by 2030, leveraging its strategic geographic position at the crossroads of Asia, Europe, and Africa. MAWANI (Saudi Ports Authority) oversees 9 commercial ports handling over 13 million TEUs annually, with ambitious expansion plans targeting 40 million TEUs annually across the network.

The Eastern Region ports — including King Abdulaziz Port in Dammam and Jubail Commercial Port — serve as critical gateways for the Kingdom's industrial heartland, supporting ARAMCO, SABIC, and the world's largest industrial city at Jubail. Despite this strategic importance, infrastructure readiness at these ports has not been comprehensively assessed against global competitiveness benchmarks and Vision 2030 requirements.

This research proposal presents a comprehensive investigation into the infrastructure development readiness of Saudi commercial ports, with Jubail Commercial Port serving as the primary case study. The study is uniquely positioned at the intersection of engineering expertise, port operations, and strategic management — reflecting the researcher's 360-degree career spanning electrical engineering, oil and gas, contracting, technical operations, terminal development, and senior civil project management at Saudi ports in the Eastern Region.

The research introduces the Integrated Port Infrastructure Readiness Framework (IPIRF) — an original 4-pillar model assessing Physical, Technology, Sustainable, and Strategic infrastructure readiness. The findings will provide MAWANI, the Ministry of Transportation, and industry stakeholders with actionable intelligence and a strategic roadmap to bridge existing infrastructure gaps and position Saudi commercial ports as world-class global gateways aligned with Vision 2030 and beyond.

2. Problem Statement

Saudi commercial ports face a critical inflection point: Vision 2030 demands they transform from traditional cargo-handling facilities into world-class integrated logistics hubs capable of competing with Singapore, Rotterdam, and regional rivals such as Dubai's Jebel Ali Port. However, the current state of infrastructure readiness across physical, technological, sustainability, and strategic dimensions remains largely unassessed, unquantified, and without a formal development roadmap.

Jubail Commercial Port, despite serving one of the world's most strategically important industrial zones, has received minimal academic and policy attention compared to Jeddah Islamic Port or King Abdulaziz Port. The port's infrastructure — encompassing civil structures, utilities, technology systems, and environmental compliance — faces growing pressure from increasing cargo volumes, industrial expansion, and evolving global port standards.

Without a comprehensive assessment of infrastructure readiness gaps and a strategic roadmap to address them, Saudi commercial ports risk falling behind global competitors and failing to meet the ambitious logistics targets embedded in Vision 2030 and the National Industrial Development and Logistics Program (NIDLP). The study identifies the following core problem dimensions:

- No holistic framework exists to assess Saudi port infrastructure across all four critical dimensions simultaneously.
- Jubail Commercial Port remains understudied despite its industrial and strategic significance.

- The economic impact of infrastructure gaps on port performance and Vision 2030 targets remains unquantified.
- There is no formal strategic roadmap linking infrastructure readiness to Vision 2030 logistics targets.

Key Research Gap Statement

No existing study has comprehensively assessed the multi-dimensional infrastructure readiness of Saudi commercial ports — integrating physical civil infrastructure, technology adoption, sustainability compliance, and strategic alignment with Vision 2030 — within a single unified framework. This research addresses that gap through the development of the IPIRF model and its application at Jubail Commercial Port.

3. Significance of the Study

A) Academic / Scientific Significance

- Introduces the first comprehensive Infrastructure Readiness Framework (IPIRF) specifically designed for Saudi commercial ports.
- Bridges the gap in the literature by integrating physical, technology, sustainability, and strategic dimensions in a single model.
- Provides a replicable theoretical and methodological framework applicable to port infrastructure research in the GCC and beyond.

B) Applied / Practical Significance

- Delivers actionable intelligence and a prioritized strategic roadmap directly usable by MAWANI for Jubail Commercial Port development.
- Provides evidence-based policy recommendations for the Ministry of Transportation's National Logistics Strategy.
- Develops an investment prioritization tool applicable across all nine Saudi commercial ports.
- Supports alignment with Saudi Green Initiative and Net Zero 2060 sustainability commitments.

C) Strategic / National Significance

- Directly supports the National Industrial Development and Logistics Program (NIDLP) by providing an evidence-based assessment of Jubail Commercial Port's infrastructure readiness against NIDLP's 2030 logistics hub targets.
- Contributes to the Kingdom's ambition to rank among the world's top 10 logistics hubs by 2030, by identifying the specific infrastructure investments with the highest impact on Saudi port competitiveness.
- Positions the Eastern Region — Saudi Arabia's industrial heartland — as a primary driver of the Kingdom's economic diversification by unlocking the full logistics potential of Jubail Commercial Port's strategic location serving ARAMCO, SABIC, and Jubail Industrial City.

- Informs Saudi Arabia's international port partnership strategy by establishing a clear, quantified infrastructure readiness baseline that MAWANI can present to global terminal operators (DP World, PSA, Hutchison) as part of concession negotiations and investment attraction efforts.

D) Significance for Lean Operations and Process Optimization

- Introduces lean operations assessment as an integrated dimension of port infrastructure readiness evaluation — a methodological innovation that acknowledges infrastructure readiness cannot be decoupled from the operational processes and management practices that determine how effectively infrastructure capacity is utilized.
- Provides MAWANI and Jubail Commercial Port management with a process optimization roadmap that identifies quick-win operational improvements deliverable within 6–18 months, ahead of longer-term physical infrastructure investment cycles.
- Demonstrates that lean process optimization and infrastructure investment are complementary, not alternative, strategies for port competitiveness improvement — a finding with broad applicability across all nine Saudi commercial ports and GCC ports more generally.

4. Research Objectives

General Objective

To assess the infrastructure development readiness of Jubail Commercial Port across four integrated dimensions — Physical, Technology, Sustainable, and Strategic — using the Integrated Port Infrastructure Readiness Framework (IPIRF), and to develop a prioritized strategic roadmap aligned with Vision 2030.

Specific Objectives

- Develop the Integrated Port Infrastructure Readiness Framework (IPIRF) — an original 4-pillar assessment model covering Physical, Technology, Sustainable, and Strategic infrastructure dimensions for Saudi commercial ports.
- Assess the current state of infrastructure readiness at Jubail Commercial Port across all four IPIRF pillars, identifying specific gaps and deficiencies.
- Benchmark Jubail Commercial Port's infrastructure readiness against international best practices and leading global ports (Singapore, Rotterdam, Dubai).
- Quantify the economic and operational impact of identified infrastructure gaps on port performance, competitiveness, and Vision 2030 alignment.
- Develop a prioritized strategic roadmap with actionable recommendations for MAWANI, the Ministry of Transportation, and port operators to bridge identified gaps.

5. Research Questions

Primary Research Question

To what extent is Jubail Commercial Port infrastructure-ready to support Saudi Arabia's Vision 2030 logistics ambitions, and what strategic roadmap is required to bridge existing gaps across physical, technology, sustainable, and strategic dimensions?

Secondary Research Questions

- What is the current state of physical infrastructure (civil structures, facilities, and utilities) at Jubail Commercial Port, and where do the critical gaps exist?
- How mature is the technology infrastructure at Jubail Commercial Port in terms of digitalization, AI adoption, and automation readiness?
- To what degree does Jubail Commercial Port's infrastructure comply with international sustainability standards, and how aligned is it with Saudi Arabia's net-zero 2060 commitment?
- How does Jubail Commercial Port's infrastructure readiness compare to global port benchmarks and regional competitors?
- What are the prioritized investments and interventions required to transform Jubail Commercial Port into a globally competitive infrastructure-ready facility?

6. Research Hypotheses

Given the mixed-methods design, the following hypotheses guide the quantitative component of the research:

Main Hypothesis

There is a statistically significant relationship between the level of infrastructure readiness across the four IPIRF pillars and Jubail Commercial Port's overall competitiveness and Vision 2030 alignment score.

Sub-Hypotheses

- H1: Physical infrastructure deficiencies at Jubail Commercial Port have a significant negative impact on operational throughput and cargo handling efficiency.
- H2: Higher levels of technology infrastructure maturity (digitalization, AI, automation) are positively correlated with port efficiency and competitiveness scores.
- H3: Sustainability infrastructure compliance is positively associated with the port's alignment with Saudi Green Initiative targets and international green port standards.
- H4: Strategic infrastructure readiness gaps significantly impede Jubail Commercial Port's capacity to meet Vision 2030 national logistics targets.

7. Literature Review & Prior Studies

The academic literature on port infrastructure readiness spans several interconnected domains: port economics and governance, smart port digitalization, sustainable port transition, and strategic alignment with national development agendas.

7.1 Port Economics, Governance and Strategic Management

Notteboom, Pallis & Rodrigue (2022) provide the foundational textbook framework for port economics, infrastructure planning, and governance models, establishing the theoretical baseline for this research. Rodrigue (2020) further contextualizes port infrastructure within multimodal logistics and port-hinterland relations. De Langen & Heaver (2021) analyze port competitiveness and investment frameworks, while Notteboom & Haralambides (2020) examine port governance transformation in a post-COVID-19 context — directly applicable to the strategic pillar of IPIRF.

7.2 Smart Port Technology and Digitalization

Min (2022) introduces a comprehensive smart port architecture framework integrating AI, automation, and Industry 4.0 elements. Heikkilä, Saarni & Saurama (2022) provide a digitalization roadmap for container ports, while Song, Lee & Cullinane (2024) identify critical success factors for smart port development. Yao et al. (2022) examine barriers to smart port implementation — particularly relevant to the Saudi regulatory and operational context. Al-Fatlawi & Motlak (2023) offer direct insight into IoT and automation adoption in the Arabian Gulf, making their findings particularly salient to this research.

7.3 Sustainable Port Infrastructure

Sogut & Erdogan (2022) propose a holistic framework for green port transition aligned with energy and environmental sustainability — directly informing the Sustainable pillar of IPIRF. Acciaro, Renner & Teuber (2024) examine green strategies from a stakeholder management perspective relevant to MAWANI's sustainability agenda. Alamoush, Ölçer & Ballini (2022) address port decarbonization frameworks aligned with Saudi Arabia's net-zero 2060 commitment, while Deng, Lu & Chen (2025) identify the latest drivers of green port innovation.

7.4 Saudi Vision 2030 and Regional Maritime Strategy

Sheline & Ulrichsen (2025) provide authoritative analysis of Vision 2030 progress and institutional transformation relevant to the strategic context of this research. The World Bank's Container Port Performance Index (2025) and LPI 2.0 dataset (2025) provide the benchmarking foundation for global competitiveness assessment. UNCTAD's Review of Maritime Transport (2024) contextualizes Jubail's performance within global maritime trade trends. Notteboom, Haralambides & Cullinane (2024) analyze the Red Sea crisis — directly relevant to Arabian Gulf port strategy and the urgent need for strategic infrastructure investment.

7.5 Lean Operations and Process Optimization in Port Management

The application of lean management principles to port operations has emerged as one of the most impactful strategies for closing infrastructure performance gaps without necessitating large-scale capital investment. Lean thinking, rooted in the Toyota Production System, focuses on eliminating waste (*muda*), reducing variability (*mura*), and alleviating overburden (*muri*) across operational processes. In the port

context, this translates to the systematic elimination of non-value-adding activities such as unnecessary vessel waiting times, redundant cargo inspections, inefficient yard planning, and suboptimal gate management protocols.

Wiegman & Louw (2011) were among the early scholars to demonstrate that lean process redesign in European container terminals could reduce vessel turnaround times by 15–25% without new infrastructure. More recently, Almotairi & Lumsden (2021) applied lean principles to Gulf Cooperation Council (GCC) logistics hubs, finding that process waste accounted for up to 30% of operational delay costs in Arabian Gulf ports — a finding directly applicable to Jubail Commercial Port's operational context. Their analysis specifically highlighted idle equipment cycles, documentation redundancy, and uncoordinated shift handover protocols as primary lean improvement targets.

Value Stream Mapping (VSM) has proven particularly powerful in identifying port process bottlenecks. Sönmez & Güneröglu (2023) applied VSM methodology to Turkish container terminals, producing a replicable framework for mapping cargo dwell time reduction across stevedoring, customs clearance, and inland transport handover processes. Their findings revealed that approximately 40% of total cargo dwell time was attributable to documentation and administrative processes rather than physical handling — suggesting that process optimization investments can yield disproportionately large efficiency gains relative to their cost.

In the Saudi context, MAWANI's Ports Logistics Integration Program (PLIP) has begun incorporating lean methodologies through its Operational Excellence Initiative, launched as part of Vision 2030's National Industrial Development and Logistics Program (NIDLP). However, academic assessment of lean implementation outcomes at individual Saudi commercial ports remains limited. This research contributes to filling that void by incorporating lean operational assessment as a cross-cutting dimension within the IPIRF framework's Strategic Pillar — recognizing that infrastructure readiness cannot be decoupled from the operational processes that infrastructure serves.

Figueiredo de Oliveira & Cariou (2015) demonstrated through a multi-port efficiency study that the combination of physical infrastructure upgrades and lean process optimization delivers exponentially greater performance gains than either approach in isolation — a finding that underpins the integrated, multi-dimensional design of the IPIRF model proposed in this research. The Kaizen continuous improvement philosophy, when applied to port equipment maintenance cycles, has also been shown to extend asset life by 20–30% in comparable industrial port settings (Tan et al., 2022), with direct implications for Jubail Commercial Port's aging civil and mechanical infrastructure.

7.6 Port Infrastructure Investment Frameworks and Prioritization Models

The challenge of prioritizing infrastructure investment in commercial ports has generated a substantial body of literature, drawing from public finance theory, project appraisal methodologies, and multi-criteria decision analysis (MCDA). Tongzon & Heng (2005) established foundational work on the relationship between port privatization structures and infrastructure investment efficiency, demonstrating that hybrid governance models — combining public ownership with private operational concessions — tend to produce superior infrastructure investment outcomes compared to fully public or fully private models. This finding is directly relevant to Jubail Commercial Port, which operates under MAWANI's public authority structure with increasing private sector participation.

Ferrari, Parola & Morchio (2006) developed a multi-criteria investment prioritization framework for Mediterranean feeder ports that balances economic return, strategic positioning, and social impact — a model whose structure directly informs the Strategic Pillar of the IPIRF. More recently, Nguyen et al.

(2023) applied the Analytic Hierarchy Process (AHP) to container terminal infrastructure investment decisions in Southeast Asia, weighting criteria across throughput capacity, technology enablement, environmental compliance, and market connectivity. Their weighting methodology provides a reference point for the IPIRF scoring matrix calibration in the current research.

The World Bank's Port Reform Toolkit (2007, updated 2021) provides the most widely adopted framework for assessing port investment readiness across developing economies, emphasizing the alignment of infrastructure investment plans with national logistics strategies and sovereign credit capacity. In Saudi Arabia's case, the National Industrial Development and Logistics Program (NIDLP) effectively functions as the overarching strategic framework within which MAWANI's capital expenditure prioritization must operate — creating a direct linkage between the macroeconomic policy environment and port-level infrastructure investment decisions that this research explores in depth.

Lam & Notteboom (2014) examined how port infrastructure investment decisions interact with hinterland connectivity planning — finding that berth deepening and yard expansion projects that are not accompanied by corresponding inland road and rail investments yield only marginal throughput increases due to landside congestion. This systems-thinking approach to infrastructure investment prioritization is embedded in the IPIRF's Strategic Pillar, which explicitly assesses multimodal connectivity as a readiness dimension rather than treating port infrastructure in isolation.

7.7 Benchmarking and Port Competitiveness: Global Best Practices

Port benchmarking as an academic discipline has evolved substantially over the past two decades, progressing from simple throughput-based comparisons to multi-dimensional competitiveness indices that capture operational efficiency, infrastructure quality, service reliability, connectivity, and sustainability performance. The World Bank's Container Port Performance Index (CPPI), first published in 2021 and now in its fourth annual edition (2025), has become the most authoritative global benchmarking reference, ranking over 400 ports across vessel time in port, crane productivity, and service reliability metrics.

Singapore's PSA International consistently ranks among the world's top three port operators across all CPPI dimensions, with the Port of Singapore achieving average vessel turnaround times of under 10 hours for container vessels — a benchmark that most Arabian Gulf ports, including those in Saudi Arabia, currently exceed by 40–60% (World Bank CPPI, 2025). Rotterdam's Maasvlakte II terminal, featuring fully automated quay cranes, automated guided vehicles (AGVs), and a deep-water berth capacity of 23 meters, represents the European benchmark for physical infrastructure readiness. Jebel Ali Port (DP World), as the regional benchmark most directly relevant to Saudi ports, has achieved a throughput of over 14 million TEUs annually with a productivity rate of 28–35 crane moves per hour — significantly above the estimated performance at Jubail Commercial Port.

Cullinane & Wang (2006) pioneered the application of Data Envelopment Analysis (DEA) to port efficiency benchmarking, establishing a methodological approach that has since been widely replicated and refined. The DEA methodology enables relative efficiency measurement across ports of varying scales without imposing a fixed production function — making it particularly suitable for benchmarking Jubail Commercial Port against peers of different sizes and contexts. This research applies DEA efficiency modeling as part of its quantitative analysis, following the enhanced DEA-Tobit approach validated by Yen et al. (2023) for smart port environments.

The Liner Shipping Connectivity Index (LSCI), published annually by UNCTAD, provides a complementary benchmarking lens by measuring the degree to which a country's ports are integrated into global liner

shipping networks — capturing frequency of service, vessel size deployed, number of carriers calling, and number of direct connections to other ports. Saudi Arabia's LSCI score has improved notably between 2020 and 2024 following MAWANI's port development investments, yet remains significantly below the UAE, which benefits from Jebel Ali's ultra-hub status. Closing this connectivity gap is identified in this research as a key strategic infrastructure readiness dimension.

7.8 GCC and Arabian Gulf Port Development: Regional Literature Review

The GCC maritime sector has received growing academic attention since 2015, driven by the simultaneous launch of diversification agendas across the region — including Saudi Arabia's Vision 2030, the UAE's Centennial 2071, Qatar's National Vision 2030, and Kuwait's New Kuwait 2035. These overlapping strategic frameworks have created a competitive regional port development environment in which infrastructure investment decisions carry both economic and geopolitical dimensions.

Alharbi & Hosseini (2019) conducted a comparative analysis of Saudi and UAE port competitiveness, finding that the UAE's first-mover advantage in port automation, free zone development, and multimodal connectivity had created a 10–15 year lead over Saudi ports in attracting transshipment cargo — a lead that Vision 2030's logistics agenda explicitly targets to close. Their study identified technology infrastructure as the primary differentiating factor, with physical berth capacity and sustainability compliance emerging as secondary dimensions — a ranking that partially informs the weighting structure within the IPIRF model.

Baindur & Macário (2022) examined the role of port special economic zones (SEZs) in accelerating infrastructure development in the Middle East and North Africa (MENA) region, with particular attention to the King Abdullah Economic City (KAEC) Seaport and its integrated industrial zone model. Their analysis demonstrates that co-locating port infrastructure with industrial production clusters — as is the case at Jubail Commercial Port serving the Jubail Industrial City — creates compounding network effects that amplify the economic returns to infrastructure investment. This finding directly supports the strategic rationale for prioritizing Jubail Commercial Port infrastructure development within MAWANI's broader portfolio.

Nour (2023) provides a critical analysis of Saudi Arabia's logistics sector reform trajectory under NIDLP, documenting the institutional restructuring of MAWANI, the establishment of the Saudi Logistics Academy, and the rationalization of port concession agreements to attract international terminal operators. His assessment identifies infrastructure readiness gaps — particularly in technology adoption and sustainability compliance — as the primary constraints limiting the pace of reform implementation, directly validating the central research question of this study. Similarly, Elentably & Karami (2022) examined Eastern Region port performance specifically, documenting capacity constraints at King Abdulaziz Port in Dammam and the resultant cargo diversion pressures that have increased traffic at Jubail Commercial Port beyond originally planned volumes.

7.9 Supply Chain Resilience, Disruption Management, and Port Infrastructure

The COVID-19 pandemic exposed critical vulnerabilities in global maritime supply chains, triggering a fundamental reappraisal of port infrastructure resilience requirements. The unprecedented congestion at major container ports in 2021–2022 — resulting from simultaneous demand surges, vessel scheduling disruptions, and equipment imbalances — demonstrated that infrastructure capacity alone is insufficient without operational flexibility, redundancy mechanisms, and digital coordination capabilities (Notteboom, Pallis & Rodrigue, 2021; Basulo-Ribeiro, Pimentel & Teixeira, 2024).

Resilience has consequently emerged as a fourth dimension alongside efficiency, sustainability, and competitiveness in the latest generation of port performance frameworks. Christopher & Peck (2004) originally defined supply chain resilience as the ability to return to original state or move to a more desirable state after disruption — a definition that translates directly to port infrastructure terms as the ability to maintain cargo throughput continuity under conditions of vessel schedule disruption, extreme weather events, cyber-attacks, or geopolitical crises. For Jubail Commercial Port, the Red Sea crisis of 2023–2024 provided a real-world stress test of Eastern Region port resilience, as shipping route diversions via the Cape of Good Hope added 10–14 days to vessel transit times and significantly altered cargo flow patterns through Arabian Gulf ports.

Pettit, Fiksel & Croxton (2010) developed the Supply Chain Resilience Assessment and Management (SCRAM) framework, which has been adapted by subsequent researchers for port-specific resilience assessment. Their identification of 14 resilience capabilities — including flexibility, visibility, adaptability, anticipation, and recovery — provides a complementary lens to the IPIRF's Strategic Pillar assessment, particularly for evaluating Jubail Commercial Port's emergency response infrastructure, backup utility systems, and crisis communication protocols. The integration of resilience dimensions into the IPIRF framework represents one of the methodological advances of this research over prior Saudi port assessment studies.

Cybersecurity resilience has emerged as a particularly critical infrastructure readiness dimension following high-profile attacks on maritime infrastructure. The 2017 NotPetya cyberattack on Maersk resulted in an estimated \$300 million loss and temporary shutdown of container operations at 76 ports globally — demonstrating that digital infrastructure vulnerabilities can be as operationally devastating as physical infrastructure failures (Hossain, 2025). The IPIRF Technology Pillar therefore incorporates cybersecurity infrastructure assessment as a core readiness dimension, recognizing that technology adoption without corresponding cybersecurity investment creates net vulnerability rather than net capability gain for port operators such as Jubail Commercial Port.

7.10 Digital Twin Technology and Future Port Infrastructure Intelligence

Digital twin technology — the creation of dynamic virtual replicas of physical assets and processes — represents one of the most transformative frontier technologies for port infrastructure management. A port digital twin integrates real-time sensor data, historical operational records, predictive analytics, and simulation modeling to enable continuous monitoring, predictive maintenance, and scenario-based planning without physical intervention. Dağıstan et al. (2025) identify digital twin capability as one of the six defining characteristics of a fully realized smart port, situating it at the convergence of the Technology and Strategic pillars within the IPIRF framework.

The Port of Rotterdam pioneered the deployment of a full-port digital twin in 2019 through a collaboration with Cisco Systems and IBM, enabling real-time monitoring of vessel traffic, water depth variations, weather conditions, and container terminal operations across a 42-kilometer port complex. This digital twin has been credited with reducing pilotage waiting times by 25%, optimizing berth allocation efficiency by 18%, and enabling predictive dredging scheduling that has saved an estimated €12 million annually in maintenance costs. The Rotterdam model has since been adapted by ports in Singapore, Hamburg, and Antwerp, establishing a new infrastructure readiness benchmark that Saudi commercial ports must aspire to meet.

For Jubail Commercial Port, the deployment of even a partial digital twin — covering berth management, crane maintenance monitoring, and yard planning optimization — would represent a transformative infrastructure readiness upgrade at relatively modest capital cost compared to physical berth construction

or terminal expansion. Hossain (2025) provides an analytical study of smart port development trajectories across Asia and the Middle East, concluding that digital twin readiness is becoming a prerequisite for attracting major international shipping lines to new port calls — creating a direct commercial incentive for MAWANI to prioritize Technology Pillar investments at Jubail Commercial Port within the Vision 2030 timeframe.

The integration of Artificial Intelligence (AI) and Machine Learning (ML) into port terminal operating systems (TOS) further extends the infrastructure intelligence landscape. AI-driven predictive analytics can optimize vessel scheduling, crane assignment, yard block allocation, and truck appointment systems simultaneously — functions that are currently managed through disconnected legacy systems at most Saudi commercial ports. Song, Lee & Cullinane (2024) identify AI-enabled TOS integration as the single highest-impact technology investment for ports seeking to close competitiveness gaps with leading global hubs, reinforcing its prominence within the IPIRF Technology Pillar assessment criteria.

7.11 Sustainability Transition Frameworks and Green Port Certification Standards

The global maritime sector accounts for approximately 2.89% of total greenhouse gas (GHG) emissions, with port operations — including cargo handling equipment, vehicle movements, vessel cold ironing, and facility energy consumption — contributing a significant share of sector emissions. The International Maritime Organization (IMO) has set a revised greenhouse gas reduction target of net-zero emissions by or around 2050, creating a regulatory imperative for ports to rapidly transition their physical and operational infrastructure toward low-carbon configurations. This transition intersects directly with Saudi Arabia's own net-zero 2060 commitment and the Saudi Green Initiative, placing the Sustainable Pillar of the IPIRF at the center of long-term infrastructure planning for Jubail Commercial Port.

The EcoPorts framework, developed by the European Sea Ports Organisation (ESPO), provides the most widely adopted certification standard for environmental port management in Europe and has been increasingly referenced as a benchmark by GCC port authorities. EcoPorts certification requires ports to complete an environmental self-declaration (PERS — Port Environmental Review System) covering noise management, waste management, dust emission controls, water quality protection, and energy efficiency. Alamoush, Ölçer & Ballini (2022) examine how elements of the EcoPorts framework can be adapted for Arabian Gulf port contexts where climatic conditions (extreme heat, dust, and solar radiation) create infrastructure-specific sustainability challenges absent from the original European design specifications.

Shore power (also called cold ironing) infrastructure — enabling vessels to connect to the electrical grid while at berth and shut down auxiliary engines — represents one of the highest-impact, most cost-effective sustainability infrastructure investments available to Arabian Gulf ports. Taneja, van Rhede van der Kloot & van Koningsveld (2021) document that ports with shore power infrastructure can reduce air pollutant emissions in their immediate vicinity by 70–85% per berth — a critical consideration for Jubail Commercial Port given its proximity to residential communities and environmentally sensitive coastal ecosystems in the Arabian Gulf. Investment in solar-powered shore power infrastructure at Jubail Commercial Port would simultaneously address sustainability compliance, reduce operational energy costs, and align with MAWANI's declared commitment to the Saudi Green Initiative.

Acciaro, Renner & Teuber (2024) apply stakeholder theory to green port transition, finding that the pace and completeness of sustainability infrastructure investment is significantly moderated by the alignment — or misalignment — between port authority sustainability ambitions, shipping line environmental commitments, cargo owner expectations, and regulatory enforcement capacity. In the Saudi context, MAWANI's Green Ports Initiative, launched in 2023 as a component of NIDLP's sustainability agenda,

signals institutional commitment to sustainability infrastructure investment, but the gap between policy declaration and physical implementation at individual ports such as Jubail Commercial Port remains an empirical question that this research directly addresses. Deng, Lu & Chen (2025) further document that ports which successfully integrate green innovation into their infrastructure planning processes achieve a competitive differentiation advantage that increasingly influences shipping line port selection decisions — transforming sustainability from a compliance cost to a strategic asset.

7.12 Synthesis: Positioning the IPIRF within the Literature

The foregoing literature review across twelve sub-domains — port economics and governance, smart port digitalization, sustainable port transition, Vision 2030 and regional maritime strategy, lean operations and process optimization, infrastructure investment frameworks, global benchmarking, GCC regional development, supply chain resilience, digital twin technology, sustainability certification standards, and stakeholder theory — collectively establishes the intellectual scaffolding upon which the Integrated Port Infrastructure Readiness Framework (IPIRF) is constructed.

The literature consistently reveals three overarching findings that frame this research's contribution. First, port infrastructure readiness is a genuinely multi-dimensional construct that cannot be adequately assessed through any single-pillar framework — whether focused exclusively on physical capacity, technology maturity, sustainability compliance, or strategic alignment. Second, lean operations and process optimization represent an underexplored but highly impactful lever for closing infrastructure performance gaps, particularly in emerging market port contexts where capital constraints limit the pace of physical infrastructure investment. Third, the Saudi Arabian port sector — and Jubail Commercial Port specifically — represents a significant gap in the global port research literature, with the existing body of knowledge insufficient to guide the infrastructure investment decisions required for Saudi ports to achieve Vision 2030 ambitions.

The IPIRF addresses these gaps by synthesizing insights from all twelve literature streams into a coherent, operationalizable assessment framework — one that is theoretically grounded, methodologically rigorous, and practically actionable for MAWANI, the Ministry of Transport, and port operators. Table 1 (below) presents a structured mapping of the IPIRF's four pillars against the literature streams that inform each dimension, illustrating the depth and breadth of the framework's theoretical foundations.

8. Research Gap

A systematic review of the existing literature reveals the following critical gaps that this research is designed to address:

- No holistic framework integrates physical, technology, sustainability, and strategic infrastructure readiness in a single assessment model for any Saudi commercial port.
- Jubail Commercial Port is significantly under-researched relative to its strategic and industrial importance in the Eastern Region.
- Existing studies on Saudi ports focus predominantly on operational efficiency, trade volumes, or single-dimension digitalization strategies — not comprehensive infrastructure readiness.
- No study has quantified the economic impact of infrastructure gaps at Saudi commercial ports or linked these gaps to Vision 2030 logistics targets.

- Prior research lacks the insider engineering and operational perspective necessary to assess physical infrastructure with the depth and accuracy required for policy-relevant findings.
- The role of lean operations and process optimization in bridging infrastructure readiness gaps remains entirely unaddressed in the Saudi port context, despite growing evidence of its transformative impact on port efficiency and competitiveness globally.

This Research Fills the Gap By:
Introducing the IPIRF — the first 4-pillar infrastructure readiness framework specifically designed for Saudi commercial ports.
Conducting the first comprehensive assessment of Jubail Commercial Port across physical, technology, sustainable, and strategic dimensions.
Quantifying infrastructure gap impacts and linking findings directly to Vision 2030 logistics targets.
Developing an original, replicable assessment instrument applicable to all nine Saudi commercial ports.

9. Theoretical Framework — The IPIRF Model

The Integrated Port Infrastructure Readiness Framework (IPIRF) is the original theoretical contribution of this research. It provides a structured, comprehensive, and replicable methodology for assessing port infrastructure readiness across four interconnected pillars:

PILLAR 1: PHYSICAL INFRASTRUCTURE Civil structures, yard infrastructure, buildings & facilities, utilities systems, lighting, and maintenance infrastructure	PILLAR 2: TECHNOLOGY INFRASTRUCTURE Digitalization maturity (TOS/PCS), AI & ML, automation readiness, cybersecurity, IoT integration, and digital twin capability
PILLAR 3: SUSTAINABLE INFRASTRUCTURE Green energy adoption, carbon footprint management, environmental compliance, water conservation, LEED standards, and Saudi Green Initiative alignment	PILLAR 4: STRATEGIC INFRASTRUCTURE READINESS Vision 2030 alignment, global competitiveness benchmarking, multimodal connectivity, investment prioritization, institutional readiness, and stakeholder integration

The IPIRF draws theoretically from port economics (Notteboom et al., 2022), smart port digitalization literature (Min, 2022; Heikkilä et al., 2022), green port transition frameworks (Sogut & Erdogan, 2022), and stakeholder theory (Acciaro et al., 2024). Each pillar is assessed through a structured 1–5 readiness scoring matrix, enabling quantitative gap analysis and prioritized remediation planning.

IPIRF Pillar Detail: Key Assessment Sub-Dimensions

Pillar 1 — Physical Infrastructure assesses: (a) Berth infrastructure — quay wall structural integrity, berth depth (water depth at chart datum), bollard capacity, fender systems, and mooring infrastructure; (b)

Yard infrastructure — pavement condition and load-bearing capacity, yard lighting, drainage systems, and container block layout efficiency; (c) Buildings and facilities — gate complex capacity, administration buildings, maintenance workshops, and security infrastructure; (d) Utilities systems — power supply reliability, backup generation capacity, water supply, and communications infrastructure; and (e) Maintenance management — preventive maintenance programs, asset lifecycle management, and condition monitoring systems.

Pillar 2 — Technology Infrastructure assesses: (a) Terminal Operating System (TOS) maturity — software generation, integration capability, and automation readiness; (b) Port Community System (PCS) — digital connectivity with customs, shipping lines, freight forwarders, and inland transport; (c) Equipment technology — crane automation levels, Automated Guided Vehicle (AGV) deployment, optical character recognition (OCR) gate systems; (d) Cybersecurity infrastructure — network architecture, intrusion detection systems, incident response protocols, and compliance with IMO Maritime Cyber Risk Management guidelines (MSC-FAL.1/Circ.3); and (e) Digital twin and data analytics capability — real-time monitoring infrastructure, predictive analytics platforms, and integration with MAWANI's national port management systems.

Pillar 3 — Sustainable Infrastructure assesses: (a) Energy management — renewable energy penetration (solar PV capacity), energy efficiency of handling equipment (e.g., regenerative braking on RTG cranes), and LED lighting systems; (b) Shore power infrastructure — availability of cold ironing facilities for vessels at berth; (c) Environmental compliance — ballast water management facilities, port waste reception facilities, dust suppression systems, and stormwater management; (d) Carbon footprint monitoring — GHG emission measurement and reporting frameworks; and (e) Saudi Green Initiative alignment — formal green port certification progress, sustainability KPI reporting to MAWANI, and alignment with NEOM and Vision 2030 sustainability commitments.

Pillar 4 — Strategic Infrastructure Readiness assesses: (a) Vision 2030 alignment — formal KPI linkage between port development plans and NIDLP targets; (b) Lean operations and process optimization maturity — documented process improvement programs, waste reduction initiatives, and operational excellence frameworks; (c) Multimodal connectivity — road access infrastructure, rail connectivity status, and inland dry port integration; (d) Institutional readiness — governance structures, investment planning capacity, concession management capability, and human capital development programs; and (e) Global competitiveness benchmarking — formal benchmarking programs against Singapore, Rotterdam, and Jebel Ali across throughput productivity, service quality, and sustainability performance.

10. Research Methodology

Research Philosophy and Type

This research adopts a pragmatic philosophy using a mixed-methods approach (Research Type: Applied/Descriptive-Explanatory) — combining quantitative infrastructure assessment data with qualitative expert insights. This dual approach ensures both statistical rigor and practical relevance, producing findings that are academically credible and operationally actionable.

Qualitative Phase

- Semi-structured expert interviews with MAWANI officials, port engineers, and logistics specialists (12–15 interviews).

- Focus groups with port operators and terminal management teams.
- Case study documentation analysis (port masterplans, engineering reports, operational data).
- Site-based infrastructure assessment using the IPIRF scoring matrix.

Quantitative Phase

- Infrastructure readiness scoring matrix applied across all four IPIRF pillars.
- Gap analysis quantification and benchmarking index comparison.
- Structured questionnaire (Likert scale, 5-point) targeting port stakeholders (n = 80–110).
- Statistical analysis: Descriptive statistics, correlation analysis, regression modeling, and DEA efficiency assessment.

11. Population & Sample

The study population encompasses all infrastructure stakeholders at Jubail Commercial Port and relevant MAWANI officials across the Eastern Region.

Stakeholder Group	Sampling Approach	Method
MAWANI Officials (Eastern Region)	Purposive	Purposive
Port Engineers & Technical Managers	Purposive	Purposive
Terminal Operators & Supervisors	Random	Random
Shipping Lines & Freight Forwarders	Random	Random
Government & Regulatory Officials	Purposive	Purposive
Total Sample	80–110	Mixed

Scope: Jubail Commercial Port and Eastern Region, Kingdom of Saudi Arabia. Data collection period: Q2–Q3 2026. Study period: 2025–2027.

12. Research Instrument

A) IPIRF Infrastructure Assessment Matrix

A structured 1–5 readiness scoring matrix applied across all four pillars (Physical, Technology, Sustainable, Strategic), incorporating site inspection checklists and engineering assessment protocols. Validity tested through expert panel review (10 port infrastructure experts). Reliability confirmed through test-retest consistency checks.

B) Semi-Structured Interview Guide

12–15 open-ended questions targeting MAWANI officials and port engineers. Covers infrastructure challenges, investment priorities, Vision 2030 readiness perceptions, and strategic gap identification.

C) Structured Questionnaire (Quantitative)

- Part I: Demographic data (organization, role, experience level)
- Part II: 5-point Likert scale measuring:
 - Physical infrastructure adequacy (12 items)
 - Technology infrastructure maturity (10 items)
 - Sustainability compliance level (8 items)
 - Strategic alignment with Vision 2030 (10 items)

Validity: Content validity (expert review) + Construct validity (EFA). Reliability: Cronbach's Alpha ≥ 0.80 target.

13. Statistical Analysis Methods

- Descriptive statistics: Mean, standard deviation, frequency distributions for IPIRF pillar scores.
- Inferential analysis: Pearson correlation, multiple regression to test hypotheses.
- Gap analysis: IPIRF readiness gap quantification and weighted priority scoring.
- Benchmarking: Comparative index analysis against Singapore, Rotterdam, Jebel Ali ports.
- Data Envelopment Analysis (DEA): Port efficiency assessment (following Yen et al., 2023).
- PESTEL analysis: External environmental assessment of strategic infrastructure readiness.

Software: SPSS v26, Amos, Microsoft Excel, and IPIRF Scoring Dashboard (custom).

Qualitative Data Analysis

Qualitative data from semi-structured interviews and focus groups will be analyzed using thematic analysis (Braun & Clarke, 2006) following a six-phase protocol: familiarization with data, generating initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the final thematic report. NVivo 14 software will be used to manage and code qualitative data, enabling systematic cross-referencing of themes across participant groups. The thematic analysis will be triangulated with findings from the quantitative IPIRF scoring matrix to validate convergent conclusions and identify divergent perspectives requiring deeper investigation.

Case study documentation analysis — including port masterplans, engineering inspection reports, MAWANI annual performance reports, and regulatory compliance filings — will be subjected to content analysis to establish an objective baseline of infrastructure conditions prior to primary data collection. This documentary evidence base provides triangulation support for both interview findings and questionnaire responses, strengthening the overall validity of the research conclusions.

IPIRF Scoring Matrix: Methodology Detail

The IPIRF Scoring Matrix assigns each infrastructure sub-dimension a readiness score on a 1–5 scale, where: 1 = Critical deficiency (immediate remediation required); 2 = Significant gap (major investment needed within 1–2 years); 3 = Partial readiness (targeted improvements required within 2–3 years); 4 = Near-readiness (minor enhancements to achieve international benchmark); 5 = Full readiness (meets or exceeds global best practice benchmarks). Sub-dimension scores are aggregated using a weighted average formula to produce pillar-level readiness scores, which are then combined — using a pillar weighting scheme validated through expert panel review — to produce the overall IPIRF readiness index for Jubail

Commercial Port. The weighted scoring methodology enables sensitivity analysis to identify which infrastructure dimensions have the greatest impact on overall readiness, directly informing investment prioritization recommendations.

Ethical considerations in this research include: obtaining informed consent from all interview and survey participants; ensuring data anonymization for commercially sensitive operational information provided by port operators and government officials; securing institutional review board approval from MidOcean University prior to primary data collection; and adhering to Saudi Arabia's Personal Data Protection Law (PDPL) in all data handling procedures. All participants will be advised of their right to withdraw at any time without consequence, and all data will be stored on a password-protected institutional server accessible only to the research team.

14. Scope and Limitations of the Study

Human Scope

Study population: Infrastructure stakeholders, port officials, engineers, and logistics professionals at Jubail Commercial Port and MAWANI Eastern Region. Sample: 80–110 respondents (questionnaire, inclusive of all stakeholder categories: MAWANI officials, port engineers and technical managers, terminal operators and supervisors, shipping lines and freight forwarders, and government and regulatory officials) + 12–15 interviewees.

Geographic Scope

Jubail Commercial Port, Eastern Region, Kingdom of Saudi Arabia. Benchmarking reference ports: Singapore, Rotterdam, Jebel Ali (Dubai), King Abdulaziz Port (Dammam), Jeddah Islamic Port.

Temporal Scope

Primary data collection: Q2–Q3 2025. Secondary data: 2020–2025 (aligned with Vision 2030 progress reporting). Study period: 2024–2026.

Anticipated Limitations

- Access to classified or commercially sensitive port infrastructure data may require data anonymization.
- The single-port case study design limits direct generalizability, though the IPIRF framework is designed to be replicable.
- The rapidly evolving technology landscape may require periodic framework updates.

15. References (APA 7th Edition)

All 30 references are organized below by source type. Year cells 2022–2025 represent the most recent literature (22 of 30 sources). All peer-reviewed articles are indexed in Web of Science, Scopus, or MDPI databases.

Books

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Comoros Address: (Headquarters) Midocean university, 8764+GH9 Matelec street, BP 684 Moroni, RP 98123 Moroni, Comoros

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