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Smart ports and digital transformation: the future of port operations in the UAE

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Smart Ports and Digital Transformation: The Future of Port Operations in the UAE

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Abstract– **Port operations all over the world are being transformed by the fast growth of digital technologies, which include artificial intelligence (AI), the Internet of Things (IoT), blockchain, and digital twins. The United Arab Emirates (UAE) has made the development of smart ports a top priority in order to be in accordance with UAE Vision 2031 and Dubai's Smart City plan. This is because the UAE is a significant logistics and transshipment center. Nevertheless, there is a limited amount of empirical synthesis about the impact of digital transformation on the operational and strategic performance of ports in the United Arab Emirates. This conference paper on smart port development focuses on Khalifa Port and Jebel Ali Port, and the objective of the paper is to examine the digital transformation process validated through the Integrated Supply Chain Performance Measurement (ISCPM) model, which incorporates ten strategic performance attributes are Financial Health (FH), Collaboration (CL), Velocity (VC), Resilience (RE), Reliability (RL), Continuous Improvement (CI), Visibility (VS), Work People Health (WPH), Sustainability (SS), and Service Excellence (SE). This study applies a mixed-method approach; a systematic literature review was done from Web of Science and Scopus indexed publications from (2017-2025) along with a secondary quantitative benchmark of port performance indicators. The study unlocks that the ports of the United Arab Emirates have made significant progress in turnaround time for ships, operational dependability, documentation speed, sustainability, etc. with the adoption of automation, AI-driven scheduling, blockchain documentation, and digital twin systems. This conference paper offers theoretical insights and practical guidance for policymakers and port authorities seeking to enhance operational efficiency, resilience, and sustainability through digital transformation.**

Keywords: **Smart Ports, Digital Transformation, UAE Ports, Jebel Ali, Khalifa Port, ISCPM, AI, IoT, Blockchain, Maritime Logistics.**

I. INTRODUCTION

Modern digital technology is driving the global maritime sector's massive transformation. Ports are becoming data-centric, cyber-physical ecosystems from physical gates for freight. The Smart Port paradigm, which describes this industrial transformation, includes blockchain, IoT, AI, big data analytics, autonomous vehicles, and digital twins. These technologies enhance predictive planning, real-time decision-making, and operational insight. Smart ports have global benefits [4,5]. Studies in Shanghai, Singapore, and Rotterdam found that vessel turnaround time has lowered by 20–30%, sustainability KPIs have increased by 15%, and operational interruption resilience has improved [1,3, 4,9]. These discoveries have shifted the focus of port performance from cost efficiency and throughput to systemic competence, resilience, and sustainability.

As a global logistics and transshipment hub, the UAE is crucial. The government's economic diversification policy includes UAE Policy 2031 and the Dubai Smart City Strategy. The country's two largest seaports, Jebel Ali Port (DP World) and Khalifa Port (AD Ports Group), underpin both proposals. Jebel Ali Port and Khalifa Port handle most cargo traffic. Over the past decade, these ports have become some of the most advanced in the Middle East by implementing blockchain-based trade paperwork, autonomous container trucks, real-time IoT-enabled cargo tracking, and AI-powered berth scheduling systems. [9,23,31]

Despite rapid technological improvement, there is no empirical research on smart port transformation in the UAE. Mostly descriptive, this study is scattered. Most global studies focus on technical implementations, cost savings, or specific operational KPIs, but they do not integrate them within a corporate performance framework. There is little known about how digital transformation affects strategic and systemic performance goals at UAE ports [8,10]. These outcomes include stakeholder cooperation, workforce readiness, environmental sustainability, disruption resilience, and customer service excellence. Policymakers, port authorities, and industry leaders struggle to analyze return on investment, prioritize digital activities, and define evidence-based roadmaps for sustainable smart ports in the UAE without a comprehensive measuring framework. [3,13]

This study addresses this gap by proposing an integrated performance measurement approach for assessing smart port transformation in UAE ports [31]. The approach is grounded in the Integrated Supply Chain Performance

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Measurement (ISCPM) model developed and validated by [21,22]

The ISCPM framework fuses the logic of the Balanced Scorecard (BSC) and the Supply Chain Operations Reference (SCOR) model and incorporates ten interlinked performance attributes: Financial Health (FH): economic performance, cost, profit, and budget variance. Collaboration (CL): quality of internal/external stakeholder relationships Velocity (VC) encompasses factors such as responsiveness, cycle time, lead time, and time-to-market. Resilience (RE) is the ability to anticipate, absorb, and recover from disruptions. Reliability (RL) is accuracy, predictability, and consistency of operations. Continuous Improvement (CI) is a culture of Lean, Kaizen, TPM, and innovation. Visibility (VS), traceability, and transparency across the supply chain. Work People Health (WPH) workforce safety, skills, engagement, and governance. Sustainability (SS) is environmental and social responsibility performance. Service Excellence (SE) customer service quality, satisfaction, and innovation. 21,22]

These attributes are categorized across three supply chain domains Supplier Relationship Management (SRM, input), Internal Supply Chain Management (ISCM, process), and Customer Relationship Management (CRM, output) and assessed at strategic, planning, and operational levels. By embedding these ten attributes, this study offers a multi-dimensional lens to assess smart port performance, moving beyond conventional metrics (throughput, cost) to incorporate human capital, resilience, collaboration, and sustainability outcomes. [21,22]

The study aims to (I) Map the current status of smart port digital transformation at Jebel Ali and Khalifa Port, (II) Identify key digital enablers (AI, IoT, blockchain, digital twins) and barriers (integration issues, skill gaps, cybersecurity), (III) Evaluate how smart port initiatives are influencing the ten ISCPM performance attributes and (IV) Propose a Smart Port 4.0 conceptual framework for guiding sustainable digital transformation in UAE ports. [31]

And based on the aims, the research questions are (I) What digital technologies have been implemented in UAE ports, and how are they integrated into port operations? (II) How do these technologies impact the ten ISCPM performance attributes (FH, CL, VC, RE, RL, CI, VS, WPH, SS, SE)? (III) What are the key enablers and barriers affecting the digital transformation of UAE ports? (IV) How can UAE ports leverage the ISCPM framework to achieve long-term smart port maturity and global competitiveness? [3, 21,22]

II. LITERATURE REVIEW

Smart Ports, which digitalize ports, are revolutionizing global marine supply chains. Smart ports utilize AI, IoT, blockchain, DT, and automation to improve visibility, predictive planning, and real-time decision-making. This differs from typical ports. Smart ports like Singapore, Rotterdam, and Shanghai are used worldwide. These ports may reduce vessel turnaround time by 30%, schedule reliability, and carbon emissions by 15%. These advances demonstrate that digitization may boost efficiency, resilience, and sustainability. These reforms have not increased empirical research in non-Western societies, notably the UAE. Jebel Ali Port (DP World) and Khalifa Port (AD Ports Group) are regional leaders; however, there is little research linking their digital efforts to performance. [1,4,5]

International ports use several smart technologies, according to recent research. AI-driven scheduling, self-driving guided vehicles, and predictive maintenance enhance VC, RL, and FH. Blockchain tools like TradeLens PCS systems simplify global supply chain collaboration and visibility. Governance and interoperability remain issues. [19,23] Digital twins simplify predictive modeling for port operations planning, improving resilience (RE) and visibility. Meanwhile, green technology like smart grids and powered equipment cuts carbon emissions and promotes a circular economy. However, most global research is dispersed and mainly focuses on operational KPIs like throughput and dwell time, not strategic areas like workforce readiness (WPH), continuous improvement (CI), or customer service quality. The constrained scope underlines the need for robust performance frameworks. [5,19]

The UAE has invested much in port digitization to promote UAE Vision 2031 and Dubai Smart City. The UAE aims to be a global logistics powerhouse. AI to design berths, blockchain to preserve data via Trade Lens, and robots to transport containers were first used in Jebel Ali. Khalifa Port uses self-driving trucks, the blockchain-based Silsal platform via Maqta Gateway, and IoT yard monitoring. These initiatives improved speed, reliability, visibility, and sustainability. From 2016 to 2024, ship turnaround time dropped 28–31%, and more than 90% of individuals utilized paperless paperwork. Still, issues persist. Disjointed Port Community System integration, analytical and cybersecurity skills gaps, and cyber resilience issues plague UAE ports, according to research. Operational KPIs show progress, but organizational traits like cooperation (CL), resilience (RE), and workforce preparedness (WPH) are still behind top ports worldwide. [10,18,23,31]

To fill the gap in measuring overall performance, this study uses the Integrated Supply Chain Performance

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Measurement (ISCPM) framework [21,22,26,27]. The ISCPM model combines the Balanced Scorecard (BSC) and Supply Chain Operations Reference (SCOR) frameworks. It has ten interrelated attributes: Financial Health (FH), Collaboration (CL), Velocity (VC), Resilience (RE), Reliability (RL), Continuous Improvement (CI), Visibility (VS), Work People Health (WPH), Sustainability (SS), and Service Excellence (SE). These traits cover three areas of the supply chain: Supplier Relationship Management (SRM), Internal Supply Chain Management (ISCM), and Customer Relationship Management (CRM). They work at strategic, planning, and operational levels. When used in the context of a smart port, ISCPM lets you look at things from many different angles by connecting digital enablers (AI, IoT, blockchain, DT) to performance outcomes across economic, human, and environmental dimensions. This study fills these gaps by comparing UAE port projects to the ten ISCPM attributes, comparing them to global leaders, and suggesting a Smart Port 4.0 framework that links digital enablers to outcomes that affect many areas. [21,22,32]

III.METHODOLOGY

The methodology employs a stringent mixed-method exploratory-descriptive design that combines a Systematic Literature Review (SLR) with secondary data benchmarking to assess the impact of smart port digital transformation on supply chain performance in the UAE. The study encompasses both global scope and local specificity by concentrating on Jebel Ali Port (DP World) and Khalifa Port (AD Ports Group). A deliberate selection of 124 Scopus/WoS-indexed publications, along with criterion-based sampling of the UAE's two operational smart ports, guarantees a focused dataset. Data were systematically gathered and evaluated in accordance with PRISMA guidelines, with thematic coding aligned to the ten ISCPM attributes substantiated in prior research [1,5,9]. We used descriptive and benchmarking analyses to look at port KPIs like turnaround times, documentation efficiency, and sustainability metrics. We also looked at digital interventions like AI, IoT, and blockchain. Double coding and triangulation from academic, industry, and policy sources helped make the data more reliable, and the ISCPM framework helped make it more valid. While constrained by dependence on secondary data and concentration on two ports, the methodology offers a solid conceptual framework for subsequent empirical validation utilizing AHP and SEM, establishing the research as a significant advancement in correlating Smart Port 4.0 initiatives with multidimensional supply chain performance outcomes. [7,2,15,29]

RESULTS / FINDINGS

Results show that UAE ports have achieved significant operational and strategic performance improvements following digital transformation, particularly in velocity, reliability, financial health, and visibility, while barriers remain in workforce readiness (WPH), resilience (RE), and full digital integration (CL, CI). [21,22,27,28]

Performance Benchmarking (KPI-Based) [9,13, 30]

KPI	Jebel Ali (2016)	Jebel Ali (2024)	% Change	Khalifa (2016)		Khalifa (2024)	% Change
Vessel turnaround time (hrs)	42	30	−28 %	48		33	−31 %
Truck turnaround time (mins)	90	65	−27 %	95		68	−28 %
Paperless documentation (%)	<20	>95	+>75%	<25		>90	+>65%
Equipment uptime (%)	85	97	+14 %	80		96	+20 %
Sustainability KPI index (0–1)	0.56	0.72	+15 %	0.51		0.70	+19 %
Reported annual CO_2 emissions (tonnes)	61,000	50,000	−18 %	66,000		52,000	−21 %

These improvements are due to AI-powered berth planning, automated cranes and trucks, blockchain-based documentation (TradeLens, Silsal), and IoT cargo tracking. UAE ports match Singapore and Rotterdam in pace and visibility. UAE lags in resilience, continuous development, and worker competency. Global ports are increasingly digital and have superior human capital plans. The UAE is the most advanced MENA nation in

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blockchain (CL, VS) and sustainable digitalization. [12,14]

AI scheduling and automation reduced turnaround time by 25–30% and improved reliability (RL) at UAE ports. Impact on sustainability: Using smart energy systems increased SS by 18-21% by reducing CO_2 emissions. VS and SE improved with real-time tracking and digital documentation. Recurring barriers: Lack of digital skills, governance, and cyber-resilience hinder RE, WPH, and CI maturity. Strategic Fit: Digital transformation is improving all 10 ISCPM qualities, proving that the framework can still quantify smart port performance. [20,24,25]

IV.DISCUSSION

The digital transformation of Jebel Ali (DP World) and Khalifa Port (AD Ports Group) has improved numerous performance areas, as shown in Section 4. This proves the ISCPM architecture is effective for smart port evaluation. AI-driven berth scheduling, automated handling, and IoT-based predictive maintenance have improved efficiency and reliability (VC, RL, FH), resulting in a drop in vessel and truck turnaround times (≈ 30%) and increased equipment uptime (> 95%). This has led to improved financial results by saving money and better asset utilization.

Visibility and Service Excellence: Digital twins, blockchain-based documentation (TradeLens, Silsal), and IoT sensors provide real-time tracking and paperless trading, reducing paperwork time from three days to one. This has clarified matters and improved customer service, boosting confidence in UAE port services. [1,4,5]

The usage of smart grids, electric cars, and energy monitoring has reduced CO_2 emissions by 18-21%. Digitalization may assist UAE Green Port and UAE Vision 2031 achieve environmental objectives.

Collaboration and Continuous Improvement (CL, CI): Port Community Systems (PCS) and blockchain have made customs clearance quicker and more accurate, but stakeholder integration is still lacking. Many systems are still siloed, making cross-departmental choices difficult and slowing improvement. [21,22]

Resilience and Workforce Development (RE, WPH): Training programs and predictive analytics have improved these attributes, but cybersecurity preparation, digital culture, and advanced analytics skills remain lacking, making ports vulnerable to disruptions.

UAE smart port initiatives are improving all 10 ISCPM qualities, however the operational and technical dimensions (VC, RL, VS, SE) are ahead of the human and strategic dimensions. [16, 21,22]

V.CONCLUSION

Digital transformation was examined at Jebel Ali Port (DP World) and Khalifa Port (AD Ports Group) to determine its effects on operational and strategic performance. The Integrated Supply Chain Performance Measurement (ISCPM) approach [23] was used to conduct a multidimensional assessment of smart port development in the UAE to address the lack of integrated, performance-based assessments [2,4].

The ISCPM model was operationalized in this study, using ten validated performance attributes: Financial Health (FH), Collaboration (CL), Velocity (VC), Resilience (RE), Reliability (RL), Continuous Improvement (CI), Visibility (VS), Work People Health (WPH), Sustainability (SS), and Service Excellence. The findings reflect UAE ports' technological and operational improvements. Vessel and truck turnaround times have dropped 30%, equipment uptime is above 95%, and paperwork time has dropped from three days to one. Additionally, smart grids, electric automobiles, and energy monitoring enhance sustainability by reducing CO_2 emissions by 18-21% (SS). Costs fell and assets were utilized more effectively, improving financial outcomes (FH). Strategic-human qualities including resilience (RE), cooperation (CL), continuous improvement (CI), and workforce health (WPH) are underdeveloped due to cybersecurity concerns, data silos, and a shortage of qualified people. [6, 21,22]

This study moves smart port research from technology-focused KPIs to performance-oriented, theory-based paradigms. The research uses the ISCPM model to evaluate smart ports using operational, strategic, human, and sustainability factors. Its new approach is to correlate digital enablers (AI, IoT, blockchain, and digital twins) with systemic supply chain performance parameters, creating a Smart Port 4.0 conceptual framework that integrates digital efforts with performance outcomes. [14,18]

Policymakers and port authorities may use the 10 ISCPM qualities as a strategic dashboard to manage digital transformation activities, according to the report. To strengthen RE, WPH, CL, and CI, invest in interoperable data platforms, cybersecurity resilience, and workforce upskilling. Continuous improvement and sustainability in all digitalization initiatives will accelerate the UAE's transition to Smart Ports that meet Vision 2031 and Net Zero 2050 goals. While the research provides a sound conceptual foundation, its use of secondary data and

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focus on two ports limits its generalizability. For regional benchmarking, future study should use AHP-based weighting and SEM-based validation of ISCPM features, collect primary data from port stakeholders, and extend the framework to other GCC ports. A Smart Port Performance Index would measure digital change over time. [11,17]

This research concludes that digital transformation may enhance operations, economics, and sustainability if done as a performance-driven path. Using the ISCPM model as a strategic anchor, UAE ports may become Smart Port ecosystems that promote marine supply chain resilience, cooperation, and competitiveness.

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