

# DIGITAL TRANSFORMATION IN PORTS AND SUSTAINABLE PERFORMANCE OUTCOMES: THE MODERATING EFFECT OF CUSTOMS MODERNIZATION

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## Original research

## ABSTRACT

*This study explores the importance of Smart Port Practices (SPP) in relation to improving Port Sustainable Performance (PSP) and in particular the moderating effect of institutional modernization, as is the case with Pakistan Customs Modernization (PCM). The study adopts a quantitative, cross-sectional design and uses survey data on the groups of port authorities, terminal operators, logistics companies, and customs officials working in one of the largest seaports of Pakistan, Karachi Port and Port Qasim. The results of the analysis are obtained with the help of Structural Equation Modeling (SEM), the results prove that the adoption of SPP, including smart automation, data analytics, integration of the Internet of Things (IoT), and the utilization of digital platforms, is significantly positively associated with the concept of multi-dimensional port sustainability, as the metrics of economic, operational, and environmental indicators. Institutional theory helps to develop a detailed mechanism of external regulatory systems, industry practices, and institutional fit to influence the implementation and success of digital transformation efforts in the port sector and the role in the development of relations between technological adoption and sustainable performance results, played by customs modernization. The research provides unique empirical data in a developing economy setting, which shows that modernization of the technological port and modernization of the institutional regulations are not coextensive processes but rather complementary. Modernization increases the effects of SPP on sustainable performance by minimizing administrative delays, and increasing the transparency of the procedures and the visibility of the supply chain. The study provides practical information to port managers and policymakers, proposing a comprehensive and integrated approach to the operation of the port using technology to link operational and regulatory aspects and attain competitive and sustainable port ecosystems.*



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## 1. INTRODUCTION

The seaports have become important in the international trade and a factor in the national economic growth, especially in the developing economies whereby most of

the external trade must be carried out by sea. Karachi Port, Port Qasim, and Gwadar Port are some of the ports that play an important role in the imports and exports of Pakistan, linking them to the world supply chains. However, the volume of trade, the increase in container

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traffic, and the growth of competition between ports in the region have created high stress on the port infrastructure of Pakistan to enhance its efficiency and quality of services. The manual documentation, the presence of information systems in parts, and the length of administrative processes are common in the traditional port operations in most developing countries, such as Pakistan, which can cause delays in the handling of cargos and in customs clearance. These are operational inefficiencies that lower the performance of logistics and raise transaction costs of international trade (Notteboom et al., 2021; Grainger, 2011). To manage these challenges, the digital transformation has become a strategic tool to enhance the operations in ports and enhance connectivity in the supply chain. With the implementation of innovative technologies, including the internet of things, big data analytics, blockchain, and automated terminal systems, ports will be able to achieve improved cargo tracking, enhance vessel scheduling, and provide real-time information exchange between stakeholders. The digitalization has the potential to save on a lot of delay in operations, enhance transparency, and optimize usage of resources in port ecosystems. Empirical research indicates that digitally ready port systems do not only increase the productivity of the operational process but also help to maintain environmental sustainability due to an improved assessment of the emissions, energy consumption, and logistics operations (Heilig & Voß, 2017; Molavi et al., 2020; Acciaro et al., 2014). Although there are some possible gains of digital transformation, the success of these technologies can be significantly determined by the regulatory and institutional framework of port operation. Customs authorities are one of the most powerful institutional forces in port ecosystems since they affect cross-border commerce and control the clearance process of cargo. In most of the developing nations, the traditional customs processes are still bureaucratic and paper-based, which forms bottlenecks to the productivity gains created by the digital port technologies. Governments and international organizations have realized this difficulty and thus have focused on modernization of their customs systems by means of electronic documentation, automated risk management, and integrated digital clearance platforms to make trade easier and minimize administrative delays (Grainger, 2011). Some projects (like the Pakistan Single Window system and the current process of digitalization of customs in Pakistan Customs) are also intended to bring the Pakistani context into the realm of the modernized system of facilitating the trade and enhancing the communication between the regulatory bodies and port operators. When modernization of customs is in tandem with digital transformation in ports, it would be able to speed up the clearance process of cargo, increase transparency, and integrate the supply chain. Despite that, there is little empirical work that has studied the impact of modernization of customs on the connection between digital transformation and

sustainable performance results in Pakistani ports. This interaction needs to be understood by the policymakers and port authorities interested in improving the effectiveness of operations and environmental and long-term competitiveness in the maritime sector of the country.

The proposed study attempts to fill this gap by focusing on the direct association between smart port practices and sustainable port performance, where it is theorized that Pakistan customs modernization is a moderating variable. This study explores the intersection of the Institutional Theory in light of the viewpoint that competitive advantage is a result of valuable and scarce internal resources (Barney, 1991) and the viewpoint that external regulatory frameworks constrain and enable (Scott, 1995).

Karachi Port, Port Qasim, and Gwadar Port are major maritime gateways in Pakistan that have been experiencing chronic problems such as cargo delays, a lack of technological integration, and difficult administrative processes that delay the passage of goods. Despite the opportunities offered by technological advancement to modernize the port operation and enhance the sustainability outcomes, their use is always limited by institutional and regulatory challenges, especially in the customs administration. Although Pakistan Customs has continued to implement various reforms to transform trade facilitation systems in the country, no empirical studies have analyzed how institutional changes relate to the effectiveness of technological change in enhancing sustainable performance in ports. This disconnect is what indicates that the issue of regulatory modernization is necessary to influence the results of technological projects in port ecosystems of developing economies.

This study will be beneficial to the existing literature in the field of maritime logistics and port management, as it investigates the impact of technological developments on sustainable operations in port settings and in emerging economies in particular. In reference to the Pakistan context, where key maritime gateways like Karachi Port, Port Qasim, and Gwadar Port contribute immensely to international trade, it is of much relevance to know what factors contribute to operational effectiveness and sustainability. Raising the importance of modernization efforts of Pakistan Customs, the present study gives some valuable insights into the possibility of enhancing the efficacy of technological undertakings in the port systems due to the regulation changes. The results present practical implications to the policymakers and port authorities interested in enhancing trade facilitation, minimizing delays in operation, and increasing the environmental and economic efficiency of maritime logistics, as well as filling an important knowledge gap in the literature regarding the relationship between technological change and institutional reform of the port operation (Notteboom et al., 2021; Heilig & Vouss, 2017; Grainger, 2011).

**Table 1.** Current Issues Affecting Pakistan Ports (2025–2026)

Issue Category	Statistic / Indicator	Reported Data	Source
Port Underutilization	Combined vessel handling at Karachi & Port Qasim	3,600 vessels annually	(Business Recorder)
Decline in Gwadar Traffic	Vessels handled by Gwadar Port	28 (2022) vs 61 (2018)	(Business Recorder)
Container Backlog	Imported containers awaiting onward transport	25,000 containers	(The Express Tribune)
Export Delays	Export containers not reaching port due to strike	15,000 containers	(The Express Tribune)
Port Congestion Causes	Afghan transit cargo pressure	Reported as significant congestion factor	(The Express Tribune)
Infrastructure Bottlenecks	Crumbling road infrastructure impacting cargo movement	Reported widespread transport delays	(inp.net.pk)
Logistics Deficiencies	Lack of road & rail connectivity affecting Gwadar operations	Identified by stakeholders	(The Express Tribune)
Operational Delays	Slow unloading of cargo (sugar, cement, clinker)	Causing export delays, vessel backlog	(Arab News PK)
Customs Inefficiency	Red tape & procedural delays causing congestion	Reported as ongoing problem	(The News International)

## 2. LITERATURE REVIEW

### 2.1 Impact of smart port practices on port sustainable performance

The current literature demonstrates the existence of a positive causal relationship between the adoption of Smart Port Practices (SPP) and increased Port Sustainable Performance (PSP) in its economic, operational, and environmental aspects. The academic studies suggest that Internet of Things (IoT), AI-based data analytics, and automated terminal operations are the technologies that can directly lead to improved economic performance due to their ability to maximize the use of assets and minimize the turnaround time (Belmoukari et al., 2023; Bottasso et al., 2018; Molavi et al., 2020; Iris & Lam, 2019; Lam & Van de Voorde, 2012) (Table 1). Smart ports have become an emerging trend in the literature as a revolutionary solution that incorporates the use of sophisticated digital solutions to enhance efficiency and sustainability in maritime logistics. A systematic review by (Dağistan et al., 2024; Munim, et al., 2020; Parola et al., 2017) points out the concept of smart port practices that include digital transformation to ensure efficiency, the use of energy-efficient technologies, collaboration with stakeholders, and governance frameworks, which aim at balancing economic, environmental, and social aspects of port performance, but still gaps exist in the fulfillment of the objectives (Dağistan et al., 2024; Puig et al., 2017). In the same manner, detailed studies of smart port developments indicate that information and communication technologies (ICT) and automation and real-time data exchange make ports achieve efficiency in operations (delay reduction) as well as decision-making that leads to sustainability delivery (Hawari et al., 2025; European Transport Research Review, 2023). Research on particular technological solutions like digital twins

also demonstrates the ability of these technologies to increase operational efficiency and assist in environmental protection and sustainability purposes at large due to improved monitoring and predictive opportunities (Homayouni et al., 2025). The studies of energy management systems in the framework of smart ports also testify to the quantifiable decrease in energy usage and emissions, which forms the basis of the dimension of environmental impact of smart practices (Yang et al., 2025). In realistic port settings, the application-oriented research demonstrates a positive relationship between the use of smart standards and operational performance and competitive capacity in container terminals, which implies that smarter digital practices can lead to better sustainable performance results (Davarzani et al., 2016). In practical terms, such digital tools improve efficiency, safety, and reliability by means of real-time monitoring and predictive maintenance, recorded in large port complexes (Dinwoodie et al., 2012; Farahat et al., 2025; Gancheva 2024; Notteboom et al., 2021). Importantly, a considerable amount of literature demonstrates the positive environmental impact of SPP, such as considerable energy consumption and greenhouse gas emissions reduction due to optimized equipment placement and integrated energy management systems (Acciaro et al., 2014; Heikkilä et al., 2022; Woo et al., 2018). The vast majority of the empirical evidence is provided by the developed economies with well-developed regulatory ecosystems, which does not leave a sufficient amount of knowledge about how such a relationship operates within the institutional and infrastructural framework characteristic of emerging economies such as Pakistan, where supporting environments can mediate technological efficacy (Qasim, 2019; Bourdon et al., 2020) (Table 2).

**HI:** *Smart Port Practices have a positive effect on Port Sustainable Performance.*

**Table 2.** Current Issues Affecting Pakistan Ports

Issue Category	Indicator / Statistic	Reported Data	Source
Port Charges vs Regional Competitors	Karachi Port dues for 50,000 GRT ship	USD 18,900 – highest among 6 regional ports	(Profit by Pakistan Today)
	Port Qasim & Gwadar port dues	USD 15,000 each	(Profit by Pakistan Today)
	Jebel Ali Port (UAE) dues comparison	USD 3,406	(Profit by Pakistan Today)
Container Throughput (Karachi)	Container throughput FY24-25	2.65 million TEUs	(content.ballastmarkets.com)
	Capacity utilization at Karachi	62% of 4.25M TEU capacity	(content.ballastmarkets.com)
Cargo Volume Statistics (All Ports)	Karachi Port total cargo FY25	54 million tons	(Arab News)
	Port Qasim total cargo FY25	33.8 million tons	(pakalumni.com)
	Gwadar Port cargo FY25	0.5 million tons	(pakalumni.com)
Utilization Ratios (FY25)	Port Qasim utilization	37.9% of capacity	(fpcci.org.pk)
	Gwadar utilization	0.36% of capacity	(fpcci.org.pk)
Customs & Clearance Delays	Average vessel dwell time at Karachi Port	5 days (target)	(Arab News)
	Planned reduction in dwell time	-70% proposed (from 7 days → 2 days)	(pid.gov.pk)
Operational Inefficiencies	Sugar off-loading capacity at Port Qasim	4,500 MT/day (not fully utilized)	(The Express Tribune)
Port Congestion Trends	Cargo tracking problems causing congestion	3–4 days for trucks to enter port area	(The News International)
Connectivity Bottlenecks	Lack of dedicated Cargo Express Way (KPT)	Freight movement limited to 6–7 hrs/day	(The News International)
Profitability / Economic Performance	Maritime port sector profit in 2025	USD 360 million	(Arab News)
Industry Observations	Stakeholders report “critical” port congestion	Congestion rated as severe	(inp.net.pk)

## 2.2) Role of Pakistan customs modernization between smart port practices on port sustainable performance

An emergent literature is exploring how institutional modernization, such as customs reform, can facilitate the effective adoption and effect of Smart Port Practices (SPP) on sustainable performance. The modernization of customs has been found to play a paramount role in defining the success of smart practices in ports and, ultimately, sustainable port performance, especially in enhancing the efficiency of trade, transparency, and security. Although the positive impacts of digital customs systems, including automated single windows, risk-based inspections, and electronic data interchange on the facilitation of trade and efficiency of clearance are well-documented (Duval & Utoktham, 2014; Grainger, 2019), their role as an essential intervening variable in the SPP-PSP relationship is under researched. It has been shown that ports operate in a complicated ecological system and that technological improvements to terminal processes could be canceled because of bureaucratic obstacles at the regulatory boundary (Notteboom et al., 2021). Therefore, researchers state that institutional alignment, or the coordination of digital operations between port operators and governmental bodies, is a condition of achieving the maximum opportunities of SPP (Rodrigue & Notteboom, 2022). Existing research examining trade enabling in Pakistan has shown that automation by these digital customs systems has helped in improving the turnaround and transparency in big seaports, but that big

challenges still remain in terms of coordination, infrastructure, and consistent digital uptake across land and dry port points of entry (Bukhari & Zaidi, 2025). The IoT is a system of physically located objects that have in-built sensors, programs, and connectivity to enable the gathering, sharing, and evaluation of data required in making decisions with the least amount of human involvement. Empirical research, including the one by (Bourdon et al., 2020) about the Web-Based One Customs (WeBOC) system in Pakistan, has shown that such modernization has a beneficial effect in shortening dwell time and lowering the cost of documentation, which in turn increases the operational and economic aspects of sustainability (Hussain et al., 2025). In addition, the supply chain can be made more visible through modernized customs processes that allow the flow of the data to be smooth and that can support advanced SPP, such as predictive logistics and just-in-time operations, thus eliminating idle times and related emissions (Acciaro et al., 2014; Lun et al., 2016). Earlier, quantitative research modeling and testing customs modernization as a moderating factor enhancing the relationship between technological port investments and overall sustainable performance is scarce, especially in the developing world, where institutional restructuring is in progress and whose interactions have the most significant consequences (Qasim, 2019). The results are consistent with the existing literature in customs reforms, where researchers suggest that digital modernization

such as real-time data exchange, risk management tools, and the use of single-window platforms enhances the interface between customs and port activities, leading to a better operational throughput and sustainability performance, achieved through a reduction in the cost of transactions, fewer delays, and increased compliance

(Smart and Sustainable Ports, 2023; UNCTAD, 2025) (Table 3).

*H2: Pakistan Customs Modernization (PCM) positively moderates the relationship between Smart Port Practices (SPP) and Port Sustainable Performance (PSP).*

**Table 3.** Aggregate Summary of Decline: Key Figures (2025–2026)

Metric / Issue	Numeric Value / Condition	Source
Port Qasim cargo drop	-1.6% annual decline	(The Express Tribune)
Number of NHA infrastructure projects	Reduced to 105 from 123	(The Express Tribune)
Increase in customs inspections/day	50–100 more containers	(Pkrevenue.com)
Average customs exam delay	5–6 days	(Pkrevenue.com)
Truck movement delay near ports	4–6× longer travel time	(inp.net.pk)
Port congestion described as	“Critical” by logistics groups	(inp.net.pk)
Planned increase in capacity (Karachi)	+250,000 TEUs → +33%	(adportsgroup.com)
Dredging funding utilization	20% by 2025	(Freyt Consol)
Target for import/export diversion to Gwadar	60% (not achieved)	(The Express Tribune)
Connectivity gap at Gwadar	No rail/oil pipeline	(The Express Tribune)

### 2.3 Effect of Pakistan customs modernization on port sustainable performance

The academic literature on the issue of trade facilitation highlights the important but complex impact of modernization of customs on the performance of ports. The studies by (Grainger, 2019) and (Duval & Utoktham, 2014) demonstrate a strong theoretical and empirical connection between simplified customs practices in the form of automation, one-window systems, and risk management and enhanced trade efficiency, which is one of the fundamental economic indicators of port sustainability. This is supported by certain studies in the developing environment; in particular, (Bourdon et al., 2020) discovered that the Web-Based One Customs (WeBOC) program in Pakistan directly lowered clearance durations and costs, making its seaports more economically viable. In addition to the direct economic benefits, modernized customs procedures help to make operations more sustainable by enhancing predictability in supply chains and minimizing administrative-caused congestions (Rodrigue & Notteboom, 2022). There is also a growing amount of evidence pointing to an indirect yet critical connection between the environment and efficient customs clearance through minimizing the delays spent on documentation, efficient customs

clearance is able to reduce the time spent by trucks and vessels idling at port borders, which is subsequently proven to reduce carbon emissions, which in turn contributes to the achievement of environmental performance objectives (Acciaro et al., 2014; Lun, 2016). But there is a major limitation that is found in the literature. The majority of studies, such as the ones by Pakistan Customs (2021) in its annual reports, consider it an independent variable that influences trade or operation measures in isolation. It is highly lacking in studies that formally examine its combined impact on the tripartite construct of sustainable port performance in terms of both simultaneously quantifying its impact on the economic, operational, and environmental performance of the port and, specifically, the interaction of this institutional impact with other contemporary technological developments within the port itself (Table. 4). This gap is of particular relevance to such countries as Pakistan, where the holistic contribution of institutional reforms is a key concept of coordinated policy planning (Qasim, 2019).

*H3: Pakistan Customs Modernization has a positively impact on Port Sustainable Performance.*

**Table 4.** Current Issues & Performance Figures

Issue Category	Indicator / Statistic	Numeric Value	Source
Under-utilization Losses	Estimated annual economic loss due to under-utilized ports & trade malpractices	Rs5 trillion (USD 18bn)	(Profit by Pakistan Today)
Karachi Port Capacity Utilization	Utilization of 125 MT capacity	47% utilization	(Profit by Pakistan Today)
Port Qasim Capacity Utilization	Utilization of 89 MT capacity	37.9% utilization	(fpcci.org.pk)
Gwadar Port Capacity Utilization	Utilization of 11 MT designed capacity	0.36% utilization	(fpcci.org.pk)
Cargo Throughput (Karachi Port)	Annual cargo handled	54 million tonnes (2025)	(Arab News PK)
Average Vessel Dwell Time (Before Reform)	Avg time to turnaround vessel	7 days (baseline)	(LinkedIn)

Target Container Dwell Time (Post-Reform)	Proposed clearance time	2 days (-70%)	(pid.gov.pk)
Profit (Maritime Sector)	Total profits recorded (2025)	Rs100 billion (USD 360m)	(Business Recorder)
Container Handling (latest available)	Karachi TEU handling (industry data)	1.5 million TEUs/year	(seadex.ai)
Cargo Handling Trend	Port Qasim cargo dip (2025)	-1.6% drop	(The Express Tribune)
Sugar Cargo Off-loading Capacity	Daily capacity not fully utilized	4,500 MT/day	(The Express Tribune)
Customs Coordination Savings	Overtime reduced (KPT)	Rs70 million/month saved	(Business Recorder)
Port Land Recovered	Land reclaimed (KPT + PQA)	158 acres (Rs110bn value)	(Business Recorder)
Infrastructure Projects Slashed	National Highway Authority projects reduced	From 123 → 105	(The Express Tribune)

### 2.4 Institutional theory

The connection between the Smart Port Practices and Port Sustainable Performance can be highly justified by institutional theory. Institutional theory assumes that practices are adopted by organizations not only because they make organizations more efficient but also because they get them legitimized, meet regulations, and are in tandem with industry practices (DiMaggio & Powell, 1983). In this respect, the ports introduce smart measures like IoT-based cargo monitoring, blockchain records, and mechanization to improve the operational and environmental performance but also to address the regulatory pressure and imitate the successful ports worldwide. Pakistan Customs Modernization (PCM) has

a decisive moderating influence in offering digitalized and simplified regulatory environments, which strengthen coercive and normative forces, which motivate ports to implement and maintain smart forms of actions effectively. (Javed et al., 2025) analyses that inclusive leadership impacts numerous organizational outcomes. As a result, a convergence between SPP and PCM enhances the performance of ports' sustainability in terms of performance, which explains the use of institutional forces that compel the use of innovative and sustainable operation strategies in the Pakistani port industry

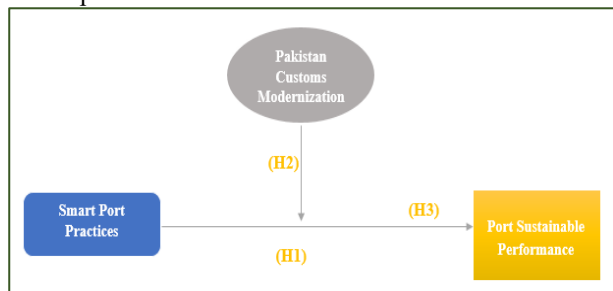
**Table 5.** Variables Description and Role in the Research Model

Variables Name	Description	Role in Model
<b>Smart Port Practices</b>	Implementation of advanced port technologies and processes such as IoT-based cargo tracking, blockchain documentation, automated operations, and real-time monitoring to enhance efficiency and sustainability.	Independent Variable
<b>Port Sustainable Performance</b>	Organizational outcomes reflecting sustainable operations, including economic efficiency, environmental protection, and social responsibility in port activities.	Dependent Variable
<b>Pakistan Customs Modernization</b>	Digitized and automated customs processes, regulatory reforms, and streamlined procedures that facilitate faster clearance, compliance, and transparency in port operations.	Moderating Variable

## 3. METHODOLOGY

### 3.1 Research design

This study adopts a quantitative and explanatory method of empirically questioning and the propositional interdependence of the constructs defined in the research.



**Figure 1.** Proposed Research Model

This research utilized a quantitative, causal approach to analyze how smart port practices correlate with port sustainable performance and to see if Pakistan customs

modernization could be viewed as a moderator. The adopted methodology was a cross-sectional survey, which was considered to be suitable to test theoretically based causal relationships by use of perceptual data that was taken. Proposed Research Model is presented on Figure 1.

The methodology allows the researcher to determine trends of the relationship between variables without losing methodological transparency and analytical accuracy (Table 5).

### 3.2 Population and Sampling Procedure

The study population was comprised of professionals working in institutions directly involved in the field of the study, including managerial and operational cadres who had sufficient knowledge of practices that formed the subject matter of the research specially in shipping industry, port operation experts and senior executives of logistics companies. Purposive sampling approach was used to ensure data collection and done only on the

informants who met the criteria set. The respondents were obligatory because they had to possess enough experience depth to make a valuable appraisal of processes and subsequent outcomes at the organization.

### 3.3 Data collection method

Primary data was collected with a self-administered questionnaire in digital form (google form) that was excellently structured. The instrument was distributed electronically to maximize the response rates. The cooperation was voluntary, and the respondents were assured of confidentiality and anonymity, it reduced the evaluation apprehension and reduced the possibility of common-method bias. The questionnaire was critically reviewed before the deployment in terms of conceptual clarity and contextual relevance. Due to the large size of the available population, convenience sampling was used; a total of 450 questionnaires were sent out, with 350 valid responses being used for analysis.

### 3.4 Measurement of constructs

Operationalization of all study constructs was through multi-item reflective scales, which were based on the previous research (Table. 5). The lexical modifications were made minor to guarantee that the contextual relevance is retained, yet the semantics of the items remain the same. All measurement items were adopted from previously published and validated studies, and the items were measured using a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Smart Port Practices was measured using a 10-item scale from (Molavi et al., 2020; Heilig & Voß, 2017), Pakistan Customs Modernization was measured as a moderator by using a 10-item scale from (Handoyo, 2023), and Port Sustainable Performance was measured as a dependent variable by using a 12-item scale from (Lam & Li, 2019).

**Table 6.** Loadings, Composite Reliability and Average Variance Extracted

Construct	Item	Factor loading	Cronbach's $\alpha$	(CR)	AVE
Pakistan Customs Modernization	PCM1	0.647	0.908	0.924	0.552
	PCM10	0.767			
	PCM2	0.625			
	PCM3	0.599			
	PCM4	0.816			
	PCM5	0.820			
	PCM6	0.746			
	PCM7	0.759			
	PCM8	0.802			
	PCM9	0.806			
Port Sustainable Performance	PSP1	0.729	0.935	0.944	0.585
	PSP10	0.821			
	PSP11	0.787			
	PSP12	0.775			
	PSP2	0.742			
	PSP3	0.671			
	PSP4	0.801			
	PSP5	0.726			
	PSP6	0.776			
	PSP7	0.796			
	PSP8	0.802			
	PSP9	0.738			

The questionnaire also contained demographic characteristics, including age, gender, work experience, and education level. The confidentiality of respondents was protected, and their anonymity was guaranteed, as indicated by the cover letter that accompanied the questionnaire that included an explanation of the purpose of the research.

### 3.5 Data Analysis Technique

The collected data was analyzed using Smart PLS by applying reliability, validity and regression analyses and SEM to test the proposed relationships (Table. 6). PLS-SEM was selected due to the suitability of the model to predictive studies, the ability to handle non-normal data distributions, and the ability to test complex models simultaneously moderating effects (Table 7). The process was implemented in two steps: the measurement model was first evaluated and then the structural model was evaluated.

### 3.6 Measurement model assessment

Composite reliability and Cronbach alpha were used to test internal consistency reliability, and the values were found to be above the recommended values, which reflects satisfactory reliability (Table. 8). Convergent validity was created by assessing factor loadings and average variance extracted to make sure that constructs generated a significant percentage of indicator variance. The Fornell-Larcker criterion and cross-loadings were used to measure discriminant validity (Table. 9). The mean variance extracted and square root of the mean were higher than the correlations with the other constructs, which demonstrated sufficient discriminant validity.

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Construct	Item	Factor loading	Cronbach's $\alpha$	(CR)	AVE
Smart Port Practices	SSP1	0.664	0.908	0.923	0.548
	SSP10	0.780			
	SSP2	0.696			
	SSP3	0.686			
	SSP4	0.738			
	SSP5	0.733			
	SSP6	0.776			
	SSP7	0.735			
	SSP8	0.801			
	SSP9	0.778			

**Note.** Cronbach's alpha and composite reliability values above 0.70 indicate internal consistency reliability. Average variance extracted (AVE) values above 0.50 indicate adequate convergent validity (Basco et al., 2022).

**Table 7.** Discriminant Validity (HTMT Ratio)

HTMT	Pakistan Customs Modernization	Port Sustainable Performance	Smart Port Practices
Pakistan Customs Modernization			
Port Sustainable Performance	0.683		
Smart Port Practices	0.772	0.586	0

**Note.** HTMT values below 0.85 (strict criterion) or 0.90 (liberal criterion) indicate adequate discriminant validity (Yusoff et al, 2020).

**Table 8.** Discriminant Validity (Fornell - Larcker Criterion)

	Pakistan Customs Modernization	Port Sustainable Performance	Smart Port Practices
Pakistan Customs Modernization	0.743		
Port Sustainable Performance	0.635	0.765	
Smart Port Practices	0.692	0.546	0.740

**Note.** Discriminant validity is considered acceptable when the square root of the average variance extracted (AVE) for each construct is greater than its highest correlation with any other construct (Fornell & Larcker, 1981).

**Table 9.** Cross Loading

	PCM	PSP	SPP
PCM1	0.647	0.455	0.605
PCM10	0.767	0.433	0.392
PCM2	0.625	0.427	0.618
PCM3	0.599	0.400	0.669
PCM4	0.816	0.474	0.483
PCM5	0.820	0.518	0.550
PCM6	0.746	0.495	0.521
PCM7	0.759	0.502	0.453
PCM8	0.802	0.498	0.433
PCM9	0.806	0.493	0.455
PSP1	0.506	0.729	0.397
PSP10	0.518	0.821	0.493
PSP11	0.503	0.787	0.478
PSP12	0.512	0.775	0.489
PSP2	0.474	0.742	0.386
PSP3	0.319	0.671	0.327
PSP4	0.481	0.801	0.419
PSP5	0.496	0.726	0.395
PSP6	0.524	0.776	0.410
PSP7	0.458	0.796	0.361
PSP8	0.552	0.802	0.426
PSP9	0.430	0.738	0.391
SSP1	0.410	0.434	0.664
SSP10	0.565	0.415	0.780
SSP2	0.466	0.356	0.696
SSP3	0.525	0.361	0.686
SSP4	0.469	0.365	0.738

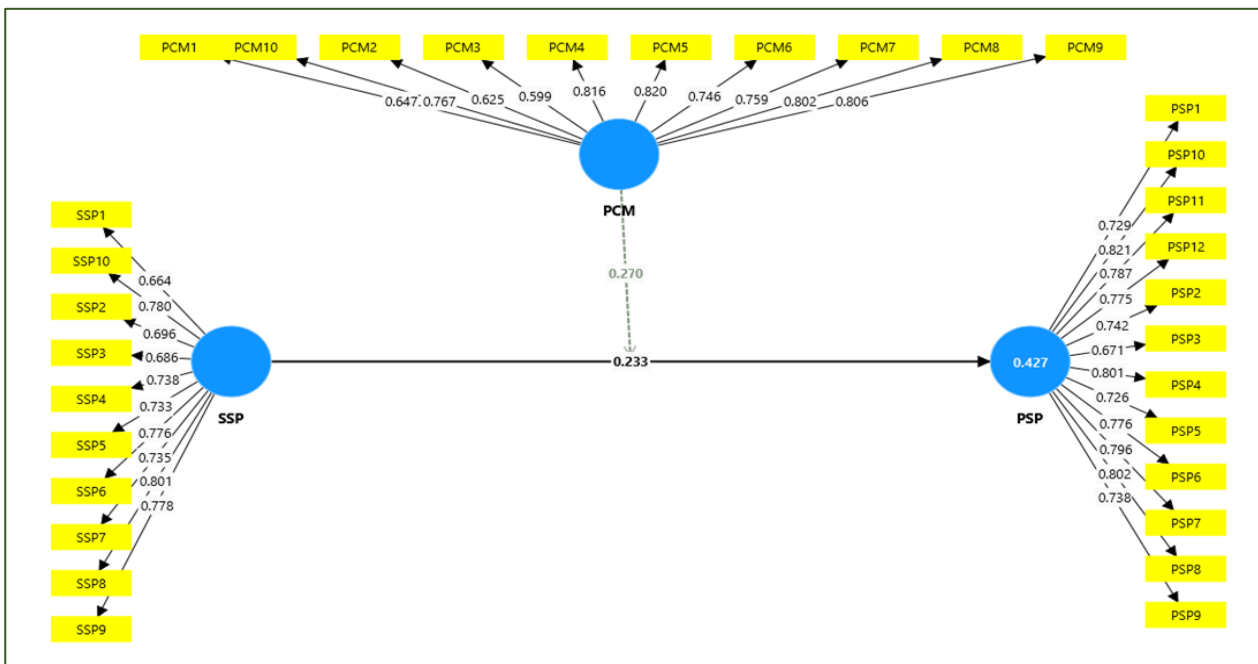
	PCM	PSP	SPP
SSP5	0.491	0.408	0.733
SSP6	0.520	0.450	0.776
SSP7	0.552	0.411	0.735
SSP8	0.557	0.392	0.801
SSP9	0.558	0.424	0.778

**Note.** Cross-loadings indicate adequate discriminant validity when each indicator loads higher on its associated construct than on all other constructs (Chin, 1998; Hair et al., 2019).

### 3.7 Structural model evaluation

The assessment of the structural model shows that the proposed relationships have acceptable explanatory power and statistical significance. The direct correlation between the independent construct and the dependent construct is positive and significant ( $\beta = 0.233$ ,  $p < 0.001$ ), and it proves that with the increase in the independent variable, the outcome of performance also improves. Moreover, there is also a positive and

significant moderating effect ( $\beta = 0.270$ ,  $p < 0.001$ ), which means that the moderating construct enhances the relationship between independent and dependent constructs (Table 10). On the whole, the findings validate the assumption that the model can bring a significant explanatory value and that the moderating mechanism can increase the impact of the independent construct upon the outcome variable (Figure 2 and Figure 3).



**Figure 2.** Measurement and structural model results with standardized estimates and explained variance ( $R^2$ ).

**Table 10.** Structural Model Path Coefficients

Hypothesis	Path	$\beta$	t-value	p-value	CI (5%-95%)	Decision
H3	PCM $\rightarrow$ PSP	0.499	7.466	0.000	0.388, 0.607	Supported
H2	PCM $\rightarrow$ SSP $\rightarrow$ PSP	0.270	2.954	0.000	0.110, 0.315	Supported
H1	SSP $\rightarrow$ PSP	0.233	3.993	0.000	0.140, 0.333	Supported

**Note.** Path coefficients ( $\beta$ ) were tested using bootstrapping with 5,000 subsamples. Paths are significant at  $p$ -value  $< 0.05$  and  $t$ -value  $> 1.65$ . **Confidence Intervals** (CI) for path coefficients ( $\beta$ ) were computed using bias-corrected bootstrapping with 5,000 subsamples. Paths were considered significant if the 95% CI did not include zero.



**Figure 3.** Structural and measurement model results obtained through PLS-SEM, showing standardized path coefficients with associated *p-values*, outer loadings, and *R*<sup>2</sup> values for endogenous constructs

#### 4. RESULTS AND DISCUSSION

PLS-SEM was applied to perform the empirical analysis to test the relationships between the constructs and assess the explanatory potential of the proposed model. The measurement assessment model initially established that the constructs were of the necessary reliability and validity. The internal consistency reliability was determined because the Cronbach's alpha and composite reliability of Pakistan Customs Modernization ( $\alpha = 0.908$ ), Port Sustainable Performance ( $\alpha = 0.935$ ) and Smart Port Practices ( $\alpha = 0.908$ ) were higher than the suggested consistency level of 0.70, which proved that the measurement scales have high reliability. The convergent validity was also established since the value of average variance extracted was more than the recommended value of 0.50; that is, investigating Pakistan Customs Modernization (AVE = 0.552), Port Sustainable Performance (AVE = 0.585), and Smart Port Practices (AVE = 0.548), one can state that the constructs explained a significant amount of variance in their indicators. The loadings of the indicators of Pakistan Customs Modernization were (0.599-0.820); the loadings of the indicators of Port Sustainable Performance were (0.671-0.821); and the loadings of the indicators of Smart Port Practices were (0.664-0.801), which also serve as evidence of the sufficient level of measurement items. Both the Fornell-Larcker and HTMT ratios were used to test the discriminant validity. The values of the HTMT scores of the constructs were found between 0.586 and 0.772, which is lower than the advised 0.85, and hence the constructs are empirically different. In the same vein, the square roots of the mean variance extracted exceeded the inter-construct correlations, and this revealed good

discriminant validity. This finding was also supported by cross-loading analysis as the indicators loaded higher on their respective constructs as compared to other constructs. After testing the measurement model, the structural model was tested to test the hypothesized relationships. The findings suggest that smart port practices do affect the port's sustainable performance positively and significantly ( $\beta = 0.233$ ,  $t = 3.993$ ,  $p = 0.000$ , CI = 0.140-0.333), which implies that the adoption of digital technologies, intelligent infrastructure, automated logistics systems, and integrated information platforms does have a positive and statistically significant impact on the sustainability performance of port operations. The implication of this discovery is that ports that embrace smart operational systems stand in a better position to improve operational efficiency, environmental impact, and service performance. It is also found that the direct relationship between the modernization of the custom and sustainable performance of the port of Pakistan is very strong and significant ( $\beta = 0.499$ ,  $t = 7.466$ ,  $p = 0.000$ , CI = 0.388-607). This finding shows that modernization mechanisms like digital clearance, automated documentation processes, and open regulatory systems considerably enhance the port performance in terms of efficiency and sustainability. Effective customs activities lead to less time wastage, efficiency of cargo handling, and trade flowing with ease, which all lead to the overall performance of ports. Moreover, the moderating analysis demonstrates that the Pakistani practices of modernization are a strong predictor of the relationship between smart port practices and port sustainable performance ( $\beta = 0.270$ ,  $t = 2.954$ ,  $p = 0.000$ , and 95% CI = 0.110-0.315). This finding indicates that the

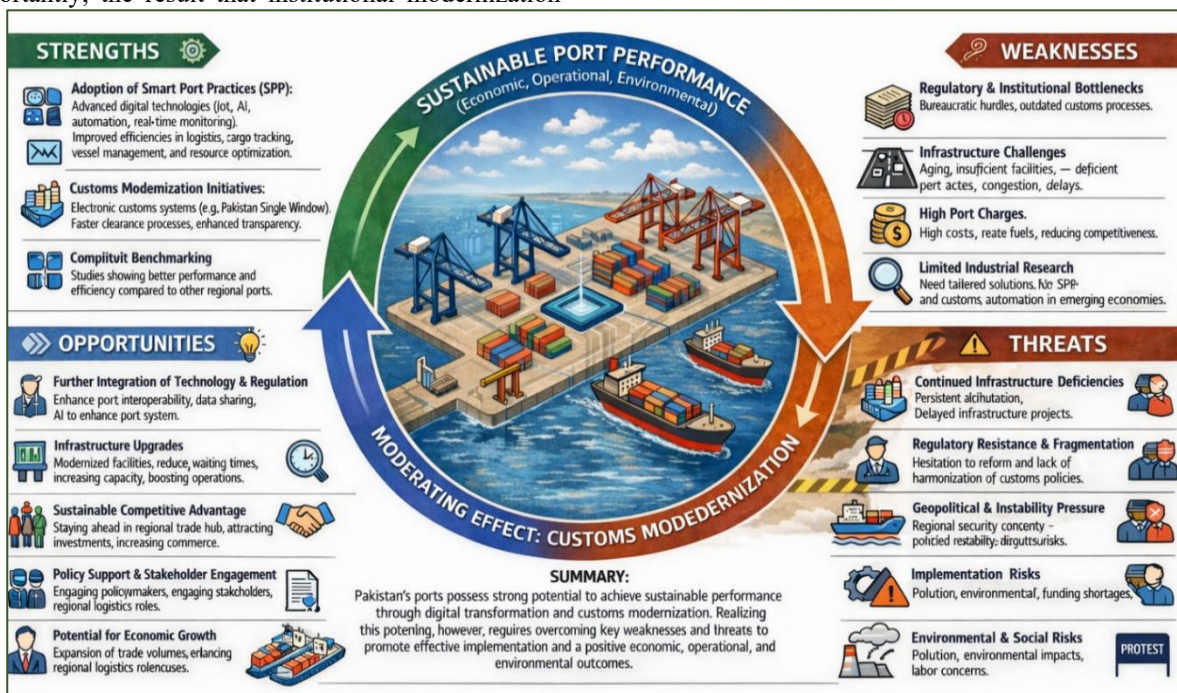
efficiency of technological implementation in ports is further strengthened with the help of the modernized customs system and institutional changes. That is, the technological changes in themselves might not provide the best results unless they are supplemented with the effective regulatory and administrative procedures. As the custom departments adopt digitalized processes and coordinated regulatory frameworks, the operational advantages of smart port systems are magnified in such a way that they improve more sustainability and performance outcomes. All in all, the results show that technological innovation and institutional modernization are both effective factors in improving the sustainability performance of ports. The findings are that ports that work in favorable regulatory environments, as well as with an advanced digital infrastructure, are better placed to meet the operational efficiency, environmental responsibility, and long-term sustainable growth in the maritime logistics industry.

This study contributes to the institutional theory because it proves the idea that regulatory mechanisms do not passively restrict the work of ports but can affect the effectiveness of technological investments. The eminent moderating impact of customs modernization empirically confirms that institutional factors such as digitized processes, clear mandates, simplified clearance, and so on, generate facilitating circumstances in which smart technologies may achieve their sustainability potential. Importantly, the result that institutional modernization

has almost twice the direct impact on sustainable performance than technological adoption only opposes technological determinism that runs through smart port literature and re-establishes theoretical dialogue on the central role of regulatory reform in building economies. The interaction effect is positive, which proves that both digital technologies and modernized regulations are complementary resources, each complementing the other and enhancing the contribution of each to the new level of understanding, rather than in the linear additive model, but with respect to the understanding of how performance is generated due to the correspondence between the technological capabilities and the institutional arrangements. Lastly, the empirical derivation of the institutional theory in the specific circumstances of Pakistan, such as its bureaucratic heritage, infrastructural limitations, and reform pathways, illustrates how the macro-institutional environments play a crucial role in defining the form of digital transformation, which opens theoretical room to contingency views that appreciate the fact that the determinants of smart ports vary qualitatively with the level of institutional maturity.

#### 4.1 SWOT analysis

Fundamentally, this SWOT analysis demonstrates a general lack of connections in the ports of Pakistan, they have sophisticated digital equipment and are bound by a poor physical and bureaucratic backbone (Figure 4).



**Figure 4.** A SWOT analysis on leveraging digital transformation and customs modernization to navigate Pakistan's ports toward a sustainable and competitive future

**Strength.** The use of smart port technologies (Blockchain, Cloud Computing, AI and IoT) and the implementation of systems like the Pakistan Single Window demonstrate that the ports possess the vision and the ability to be innovative. They have constructed a

high-tech "digital layer" that enables them to compete on paper.

**Weakness:** But this web-based veneer is stretched to breaking by endemic weaknesses. Physical bottlenecks cannot be overcome by technology only because of

bureaucratic red tape and the chronic infrastructure issues: congestion, old facilities, and poor access. A ship can be registered online within minutes, only to spend days before docking or offloading. This is where the potential of digital transformation gets stagnated.

**Opportunities:** Shifting the focus instead of adding more technology should be replaced by using available technology to solve these underlying problems. They ought to take advantage of data and automation to break the bureaucratic barriers and justify infrastructure expenditure. In this case, the important one is customs modernization. In case the customs are really modernized, they are like a powerful engine that drives the whole system. Otherwise, it is the major bottleneck.

**Threats:** External shocks, such as geopolitics, are the least significant risks, whereas internal ones (opposition to regulatory reform and inability to finance infrastructure projects) are the greatest risks. The threats have the potential to actively foil the advancement that has already taken place, leaving Pakistan with a "digital island," a technologically advanced port alone in the inefficient environment of its own.

Hence, right engine (digital technology) is in place at the ports, but the chassis (infrastructure) is falling to pieces, and the steering (regulation) is dead. The only way to succeed is by ensuring that the three are brought together in a coordinated effort to upgrade all of them in order to repair the physical and institutional issues by use of the power of digital engines.

## 5. LIMITATIONS AND FUTURE RESEARCH

The contributions of this study should be viewed within the definite methodological frames which, at the same time, shed light on the avenues of further development of scholarship. The cross-sectional design gathers perceptual data at a point in time, but digital transformation and modernization of customs is a dynamic process whose impact is felt over years, longitudinal designs should be used in the future research to monitor how SPP-PSP relationship strengthens as the technological capabilities reach maturity and the institutional reforms become more profound. The Karachi and Port Qasim geographic isolation, which may be justified by the role of these ports as the main ports of Pakistan, undermines the generalizability to highly dissimilar settings such as Gwadar Port, with its 0.36 percentage utilization of capacity and its inability to connectibility being characteristic of the same port may cause a radical change to the interaction of digitalization and customs modernization. This sole use of perceptual survey data, even after rigorous validation, is incapable of reflecting objective operational realities as seen in the

length of stay of 5-7 days and the unbelievable costs of Rs5 trillion annually of underutilization of ports; future research shall combine the perceptual survey data with archived performance measures such as actual clearance times, emission readings, and the rates of berth occupancy. Last but not least, the conceptualization of Smart Port Practices and Port Sustainable Performance as a whole should be broken down into the research of the future to understand what particular technologies, be it the IoT, blockchain, or analytics based on AI, produce the most significant sustainability dividends, and whether the modernization of customs affects the economic efficiency, environmental performance, and social performance differently, which can add to the institutional theory framework with the new prism of resource dependence or organizational learning.

## 6. CONCLUSION

This paper finds that the digital transformation and institutional modernization are not only complementary forces to sustainable port performance in developing economies but in fact, interdependent forces. Experience of the leading ports in Pakistan shows that despite the fact that smart technologies considerably improve the results of sustainability, their use is also conditional on the simultaneous development of the customs administration. The fact that modernization of customs has almost two times greater direct impact when compared with technological adoption, along with the strong moderating power, essentially re-situates the digital transformation debate: ports cannot technologically get themselves out of institutional bottlenecks. Investments in IoT sensors, automated terminals, and data analytics platforms will never deliver because cargo will still be stuck in opaque clearance processes, manual documentation processes, and strained regulatory coordination. In the case of the maritime sector of Pakistan, which is incurring an estimated cost of Rs 5 trillion per year through underutilization and in which the average dwell time of vessels is persistently stuck at 5-7 days, the prescription is categorical, i.e., sustainable performance requires simultaneous development of technological capabilities along with the institutional institutions. The paper eventually concludes that, in the multifaceted web of port operations, digital systems and regulatory procedures remain complementary parts of a clockwork: neither can achieve performance in a vacuum, but jointly, they have the disruptive potential to turn new economy ports, seen as a logistical choke point, into a competitive access point to the global economy.

## References:

- Acciario, M., Vanelslander, T., Sys, C., Ferrari, C., Roumboutsos, A., Giuliano, G., Lam, J., & Kapros, S. (2014). Environmental sustainability in seaports: A framework for successful innovation. *Maritime Policy & Management*, 41(5), 480–500.

- Barney, J. (1991). Firm resources and sustained competitive advantage. *Journal of Management*, 17(1), 99–120.
- Basco, R., Hair Jr, J. F., Ringle, C. M., & Sarstedt, M. (2022). Advancing family business research through modeling nonlinear relationships: Comparing PLS-SEM and multiple regression. *Journal of Family Business Strategy*, 13(3), 100457.
- Belmoukari, B., Audy, J. F., & Forget, P. (2023). Smart port: A systematic literature review. *European Transport Research Review*, 15, Article 4.
- Bottasso, A., Conti, M., Ferrari, C., & Tei, A. (2018). Ports and regional development: A spatial analysis on a panel of European regions. *Transportation Research Part A: Policy and Practice*, 121, 27–52.
- Bourdon, M., Herghelegiu, C., & Zilic, I. (2020). The impact of customs modernization on trade: Evidence from Pakistan (Policy Research Working Paper No. 9165).
- Bukhari, S., & Zaidi, S. (2025). The impact of customs modernization on trade facilitation and port efficiency in Pakistan. *Contemporary Journal of Business and Management*, 14, 55–71.
- Chin, W. W. (1998). The partial least squares approach to structural equation modeling. In G. A. Marcoulides (Ed.), *Modern methods for business research* (pp. 295–358). Mahwah: Lawrence Erlbaum
- Dağıstan, U., Atalay, M., Aydın Ünal, D., & Aydın, S. Z. (2025). Sustainability of smart ports: A systematic literature review. *SAGE Open*, 15(3), 21582440251363339.
- Davarzani, H., Fahimnia, B., Bell, M., & Sarkis, J. (2016). Greening ports and maritime logistics: A review. *Transportation Research Part D: Transport and Environment*, 48, 473–487.
- DiMaggio, P. J., & Powell, W. W. (1983). The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields. *American Sociological Review*, 48(2), 147–160.
- Dinwoodie, J., Tuck, S., Knowles, H., Benhin, J., & Sansom, M. (2012). Sustainable development of maritime operations in ports. *Business Strategy and the Environment*, 21(2), 111–126.
- Duval, Y., & Utoktham, C. (2014). Impact of trade facilitation on trade and development: A case study of the Asia-Pacific region. United Nations Economic and Social Commission for Asia and the Pacific.
- European Transport Research Review. (2023). Digitalization and sustainability in port operations: A review. *European Transport Research Review*, 15, 1–16.
- Farahat, A., Elgazzar, R., & Salaheldin, M. (2025). Organizational and technological readiness for smart port adoption: A multi-dimensional study. *Journal of Industrial Engineering and Management*, 18(2), 45–61.
- Fornell, C. G., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of Marketing Research*, 18(1), 39–50
- Gancheva, Y. (2024). Key aspects of digital twin technology for developing sustainable smart ports. *Journal of the Union of Scientists – Varna. Maritime Sciences Series*.
- Grainger, A. (2011). Trade facilitation: A conceptual review. *Journal of World Trade*, 45(1), 39–62.
- Grainger, A. (2019). Trade facilitation: A conceptual review. *Journal of World Trade*, 55(4), 521–544.
- Hair Jr, J. F., Lds Gabriel, M., da Silva, D., & Braga Junior, S. (2019). Development and validation of attitudes measurement scales: fundamental and practical aspects. *RAUSP Management Journal*, 54(4), 490-507.
- Handoyo, S. (2023). Worldwide governance indicators: Cross country data set 2012–2022. *Data in Brief*, 51, 109814.
- Heilig, L., & Voß, S. (2017). A scientometric analysis of the maritime digitalization literature. *Hawaii International Conference on System Sciences Proceedings*, 1341–1350.
- Hawari, A., Hadiprawoto, D., Iriyanty, A., Alversia, D., & Adiyono, A. (2025). Smart port technologies: Implementation and impact on operational efficiency. *Maritime Economics & Logistics*, 27(3), 345–366.
- Heikkilä, M., Saarni, J., & Saurama, A. (2022). Innovation in smart ports: Future directions of digitalization in container ports. *Journal of Marine Science and Engineering*, 10(12), Article 1925.
- Homayouni, S. M., Pinho de Sousa, J., & Moreira Marques, C. (2025). Unlocking the potential of digital twins to achieve sustainability in seaports: the state of practice and future outlook. *WMU Journal of Maritime Affairs*, 24(1), 59-98.
- Hussain, F., Ahmed, N., & Khan, R. (2025). Digital customs reforms and their effect on port performance: Evidence from Pakistan. *Scientific Research Publishing*.
- Iris, Ç., & Lam, J. S. L. (2019). A review of energy efficiency in ports: Operational strategies, technologies and energy management systems. *Renewable and Sustainable Energy Reviews*, 112, 170–182.
- Javed, A., Ibrahim, M. Y., Ngah, A. H., Zafar, M. J., Hammad, M., Khan, A. Z., & Mir, F. (2025). Impact of inclusive leadership on project success-with mediating role of organizational commitment and top management support as moderator: A systematic literature review. *Multidisciplinary Reviews*, 8(8), 2025250-2025250.
- Lam, J. S. L., & Li, K. X. (2019). Green port marketing for sustainable growth and development. *Transport Policy*, 84, 73-81.
- Lam, J. S. L., & Van de Voorde, E. (2012). Green port strategy for sustainable growth and development. *Transport and Sustainability*, 3, 213–245.
- Lun, Y. H. V., Lai, K., & Cheng, T. C. E. (2016). *Shipping and logistics management* (2nd ed.). Springer.
- Molavi, A., Lim, G., & Race, B. (2020). A framework for building a smart port and smart port index. *International Journal of Sustainable Transportation*, 14(9), 686–700.

- Munim, Z. H., Sornn-Friese, H., & Dushenko, M. (2020). Identifying the appropriate governance model for green port management. *Journal of Cleaner Production*, 268, 122156.
- Notteboom, T., Pallis, A., & Rodrigue, J.-P. (2021). *Port economics, management and policy*. Routledge.
- Pakistan Customs, Federal Board of Revenue. (2021). *Annual report 2020–2021*.
- Parola, F., Risitano, M., Ferretti, M., & Panetti, E. (2017). The drivers of port competitiveness: A critical review. *Transport Reviews*, 37(1), 116–138.
- Puig, M., Wooldridge, C., & Darbra, R. M. (2017). Identification and selection of environmental performance indicators for sustainable port development. *Marine Pollution Bulletin*, 119(1), 5–16.
- Qasim, M. (2019). Challenges and prospects of Pakistan’s maritime trade: A case of Karachi port. *Journal of International Logistics and Trade*, 17(3), 125–137.
- Rizvi, S. F. H., & Shah, S. A. (2022). Regional disparities in the implementation of trade facilitation measures: A case of Pakistan Customs. *Journal of Economic and Administrative Sciences*, 38(2), 211–230.
- Rodrigue, J.-P., & Notteboom, T. (2022). *The geography of transport systems* (6th ed.). Routledge.
- Scott, W. R. (1995). *Institutions and organizations*. Sage.
- Smart and Sustainable Ports. (2023). Integration of digital technologies for operational and environmental efficiency in ports. *Smart Ports Review*, 2(1), 15–29.
- United Nations Trade, & Development (UNCTAD). (2025). *Trade and Development Report 2025: On the Brink: Trade, Finance and Global Uncertainty*. Stylus Publishing, LLC.
- Woo, J. K., Moon, D. S. H., & Lam, J. S. L. (2018). The impact of environmental policy on ports and the associated economic opportunities. *Transportation Research Part A: Policy and Practice*, 110, 234–242.
- Yang, Y., Hussain, H. M., Haakana, J., & Nardelli, P. (2025, October). Assessing the technical and environmental impacts of energy management systems in smart ports. In *2025 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT Europe)* (pp. 1-5). IEEE.
- Yusoff, A. S. M., Peng, F. S., Razak, F. Z. A., & Mustafa, W. A. (2020, April). Discriminant validity assessment of religious teacher acceptance: The use of HTMT criterion. In *Journal of Physics: Conference Series* (Vol. 1529, No. 4, p. 042045). IOP Publishing.

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**Questionnaire**

**Demographic Data**

Age	<input type="checkbox"/> Less than 25 <input type="checkbox"/> 26-35 <input type="checkbox"/> 36-45 <input type="checkbox"/> 46 or Above	Gender	<input type="checkbox"/> Male <input type="checkbox"/> Female
Qualification	<input type="checkbox"/> Under-Graduate <input type="checkbox"/> Graduate <input type="checkbox"/> Masters <input type="checkbox"/> Doctoral	Type of Organization	Public <input type="checkbox"/> Private <input type="checkbox"/>
Working Experience	<input type="checkbox"/> Less than 5 yrs <input type="checkbox"/> 6-10 yrs. <input type="checkbox"/> 10-20 yrs <input type="checkbox"/> 20 and above		

Please circle the score which most closely corresponds with how you see the following items: response scale is as below:

**1. Strongly disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly agree**

Smart Port Practices (Molavi et al., 2020; Heilig & Voß, 2017).						
1	Our port/terminal utilizes automated guided vehicles (AGVs) or similar automated horizontal transport.	1	2	3	4	5
2	We employ automated stacking cranes (ASCs) with remote or fully autonomous control.	1	2	3	4	5
3	Vessel and yard planning are optimized using advanced algorithms (AI/OR techniques).	1	2	3	4	5

4	Gate operations are fully automated using RFID, OCR (Optical Character Recognition), and automatic booking systems.	1	2	3	4	5
5	Equipment maintenance is predictive, based on IoT sensor data and analytics.	1	2	3	4	5
6	Real-time traffic information is provided to truckers for routing and waiting times.	1	2	3	4	5
7	Our port uses data analytics to optimize inter-modal connections (rail, barge, truck) and reduce empty trips.	1	2	3	4	5
8	We use IoT sensors for real-time monitoring of structural health (berths, cranes) and environmental conditions (wind, waves).	1	2	3	4	5
9	Emergency response is coordinated using real-time digital maps and resource tracking.	1	2	3	4	5
10	Real-time traffic information is provided to truckers for routing and waiting times.	1	2	3	4	5
<b>Pakistan Customs Modernization (Handoyo, 2023)</b>						
1	The governance structure of our port authority clearly supports and incentivizes investment in new technologies.	1	2	3	4	5
2	Decision-making processes for major technological investments are transparent and efficient.	1	2	3	4	5
3	The port's tariff and pricing structure encourages the adoption of efficiency-enhancing digital solutions (e.g., discounts for e-submissions).	1	2	3	4	5
4	The regulatory framework allows for adequate return on investment in smart port infrastructure.	1	2	3	4	5
5	Our port has a formal strategic plan that explicitly includes digital transformation and smart port objectives.	1	2	3	4	5
6	There is a dedicated budget and organizational unit responsible for implementing smart port initiatives.	1	2	3	4	5
7	There is a formal, high-level coordination committee between the Port Authority and Pakistan Customs to align modernization efforts.	1	2	3	4	5
8	Port physical layouts and processes (e.g., inspection zones) are designed in collaboration with Customs to facilitate their risk-based controls.	1	2	3	4	5
9	Joint port-customs initiatives exist to simplify and expedite the clearance process for compliant traders.	1	2	3	4	5
10	The port's service quality and reliability have measurably improved as a result of institutional reforms.	1	2	3	4	5
<b>Port Sustainable Performance (Lam &amp; Li, 2019)</b>						
1	Our port provides high operational efficiency (e.g., fast vessel turnaround).	1	2	3	4	5
2	Our port offers excellent hinterland connectivity (road, rail, barge).	1	2	3	4	5
3	Our port has sufficient capacity to handle current and future cargo volumes.	1	2	3	4	5
4	Our port offers competitive port charges and tariffs.	1	2	3	4	5
5	Our port offers incentives for green ships (e.g., port fee discounts for vessels with high environmental standards).	1	2	3	4	5
6	Our port invests in green technologies and infrastructure (e.g., solar power, electrified equipment).	1	2	3	4	5
7	Our port has effective waste management and recycling programs.	1	2	3	4	5
8	Our port actively reduces air pollution (e.g., provides onshore power, uses clean equipment).	1	2	3	4	5
9	Our port maintains good relationships with the local community.	1	2	3	4	5
10	Our port maintains transparent communication with stakeholders.	1	2	3	4	5
11	Our port contributes to local employment and economic development.	1	2	3	4	5
12	Our port ensures high standards of health and safety for workers.	1	2	3	4	5

*Digital Transformation in Ports and Sustainable Performance Outcomes: The Moderating Effect of Customs Modernization*