INTERNATIONAL JOURNAL OF ACADEMIC RESEARCH IN BUSINESS & SOCIAL SCIENCES

Vol 16, Issue 11, (2026) E-ISSN: 2222-6990

# Factors Influencing Supply Chain Integration at Port Sudan: The Moderating Role of Environmental Uncertainty

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**DOI Link:** http://dx.doi.org/10.6007/IJARBSS/v16-i11/29404

***Published Date:*** 14 November 2026

**Abstract**

This study aims to explore operational and contextual factors that influence supply chain integration (SCI) within Port Sudan and how environmental uncertainty acts as a moderating influence. Four determinants i.e. port infrastructure efficiency (PIE), digitalization and technology adoption (DTA), stakeholder coordination (STC) and customs clearance efficiency (CCE) were studied in a cross-sectional survey of 118 maritime and logistics professionals. Partial least squares structural equation modeling (PLS-SEM) was performed using SmartPLS 4 and 10,000 bootstrap subsamples to analyze the data. The reflective measurement model consisted of 30 indicators which met the usual criteria for reliability and convergent validity, while the discriminant validity was qualified. The structural model explained 50.6% of the variance in SCI (adjusted $R^2$ = .465; $Q^2$predict = .189). While none of the hypothesized pathways was statistically significant at .05, stakeholder coordination proved to be the greatest predictor (β = .318, p = .058). The main effect of environmental uncertainty on SCI was significant and positive (β = .532, p < .001). The four interaction effects, though, were not significant. Analysis conditioned on the uncertainty showed that coordination among stakeholders was significant in the high uncertainty (β =.569, p =.026) but not in moderate and low uncertainty. Environmental uncertainty was positively associated with SCI, while the four operational associations were not statistically supported in the model tested. This study is unique in providing quantitative data for the supply chain from a Red Sea gateway port that has not received sufficient attention in the global supply chain literature. This translates into some practical implications such as the emphasis on shared shipment information, coordinated cargo-release processes, and infrastructure continuity to strengthen the integration process in uncertain environments.

**Keywords:** Supply Chain Integration, Environmental Uncertainty, Port Sudan, Port Community

## Introduction

Supply chain integration (SCI) integrates the information, planning and operations of the organizations involved in a shipment. The port's role has expanded with the introduction of containerization and intermodal transport from cargo handling to logistics co-ordination. Robinson (2002) saw ports as part of value-driven chains while Notteboom and Rodrigue (2005) examined their growing links with inland distribution networks. Port and terminal integration in global supply chains has also been examined by Song and Panayides (2008). Coordination between terminal operations, customs, shipping agents and inland transport is thus important in comprehending the function the port plays in the supply chain.

Port Sudan is the country's main maritime gateway for both commercial and relief cargo. The port was ranked 388 of 405 ports in the CPPI 2023 report and was not included in the subsequent CPPI annexes reviewed (World Bank & S&P Global Market Intelligence, 2024, 2026a). CPPI measures the time spent in port by vessels, not the integration of port–community actors . Therefore, it provides operational context to this study. Customs fees and delays, importation procedures and physical-access constraints in Sudan are also mentioned in humanitarian coordination records (Logistics Cluster, 2026).

The position of Port Sudan may also have an attraction for the landlocked economies of the region. A feasibility assessment of the Ethiopia–Sudan railway examined an alternative maritime outlet for Ethiopia through Port Sudan (CPCS Transcom, 2026). At the time, Chad's main maritime access route was still Douala, although a possible alternative corridor for Chad was discussed in International Finance Corporation (2023). These examples are illustrative of potential regional connectivity, not current market shares for transit. This potential requires the development of coordinated port and border procedures and reliable inland links. Location alone does not establish a functioning regional hub.

However, limited quantitative research exists on operational factors and their relationship to supply chain integration in Port Sudan. Much of the literature on ports is concentrated on large ports in Asia and Europe and there are fewer studies on Port Sudan. This research investigates the nexus between the SCI and four operational factors, namely port infrastructure efficiency (PIE), digitalization and technology adoption (DTA), stakeholder coordination (STC), and customs clearance efficiency (CCE). It also examines whether perceived environmental uncertainty (EU) moderates each relationship with SCI.

### *Regional Port Context*

The World Bank and S&P Global Market Intelligence produce CPPI to compare container-port performance using adjusted vessel time in port. A lower numerical rank indicates a better position. The CPPI score is an index value, not a duration. Table 1 uses the original 2023 overall ranks for a common-year comparison and reports the 2025 results separately. Port Sudan was not listed in the reviewed annexes for 2024 and 2025. The comparison includes the Red Sea ports of Djibouti, Jeddah and El Sokhna, along with the Omani logistics gateways of Salalah and Sohar.

Table 1
*Regional Container Port Benchmarks*

| Port | 2023 overall rank | 2025 rank | 2025 CPPI |
|---|---|---|---|
| Port Sudan | 388 | Not listed | Not listed |
| Djibouti | 379 | 53 | 62.6 |
| Salalah | 2 | 3 | 135.9 |
| Sohar | 66 | 49 | 66.9 |
| Jeddah | 58 | 25 | 95.8 |
| El Sokhna | 122 | 115 | 17.1 |

CPPI includes arrival and berth time, covering waiting, cargo operations, and idle time; it does not isolate active unloading. Separately, Kuehne+Nagel reported approximately four days of average vessel waiting at Port Sudan for 12–18 December 2025. This dated weekly observation is not a discharge-time estimate or an annual average (World Bank & S&P Global Market Intelligence, 2026b; Kuehne+Nagel, 2025).

*Research Objectives*

This study aims to:

RO1: Examine the association between port infrastructure efficiency and supply chain integration at Port Sudan.

RO2: Examine the association between digitalization and technology adoption and supply chain integration at Port Sudan.

RO3: Examine the association between stakeholder coordination and supply chain integration at Port Sudan.

RO4: Examine the association between customs clearance efficiency and supply chain integration at Port Sudan.

RO5: Determine whether environmental uncertainty moderates the relationship between port infrastructure efficiency and supply chain integration.

RO6: Determine whether environmental uncertainty moderates the relationship between digitalization and technology adoption and supply chain integration.

RO7: Determine whether environmental uncertainty moderates the relationship between stakeholder coordination and supply chain integration.

RO8: Determine whether environmental uncertainty moderates the relationship between customs clearance efficiency and supply chain integration.

*Research Questions*

This study seeks to answer the following research questions:

RQ1: Is port infrastructure efficiency associated with supply chain integration at Port Sudan?

RQ2: Is digitalization and technology adoption associated with supply chain integration at Port Sudan?

RQ3: Is stakeholder coordination associated with supply chain integration at Port Sudan?

RQ4: Is customs clearance efficiency associated with supply chain integration at Port Sudan?

RQ5: Does environmental uncertainty moderate the relationship between port infrastructure efficiency and supply chain integration?

RQ6: Does environmental uncertainty moderate the relationship between digitalization and technology adoption and supply chain integration?
RQ7: Does environmental uncertainty moderate the relationship between stakeholder coordination and supply chain integration?
RQ8: Does environmental uncertainty moderate the relationship between customs clearance efficiency and supply chain integration?

**Literature Review**

*Theoretical Background*

It has been developed from a maritime supply chain perspective and two organizational the ories. These each describe various parts of the proposed relationships. The survey assesses the specified associations, and not the theories in general.

*Port Supply Chain and Regionalization Perspective*

Robinson (2002) considers ports as parts of chains of activities that add value for cargo owners. While Notteboom and Rodrigue (2005) talk about the port–inland freight links, Song and Panayides (2008) concentrate on integration in global supply chains. In this context, PIE is in support of real transport of goods, CCE in support of cargo release and DTA and STC in support of information exchange and coordinated decision. This is a way to understand why handling shipments can be disjointed and inefficient while individual facilities are efficient. It offers a maritime perspective on H1–H4, and not a statistical test of regionalisation.

*Organizational Information Processing Theory*

Galbraith (1974) shows that the information needed for coordination increases with task uncertainty. Information systems and collaborative problem solving can handle interdependent tasks. DTA may provide timely information about shipments in port supply chains, while STC may support shared decisions across organizational boundaries. These mechanisms motivate H2 and H3 and explain why the need for integration may change with the EU. In this study the information processing capacity was not measured individually, so this explanation is theoretical.

*Contingency Theory*

Contingency theory connects organizational effectiveness with the match of organizational arrangements and the conditions they operate in (Donaldson, 2001). A supply chain practice may behave differently in stable and uncertain conditions. The study therefore tests if EU changes the PIE–SCI, DTA–SCI, STC–SCI and CCE–SCI relations. However, previous research has indicated that these relationships may vary across different dimensions of uncertainty (Fynes et al., 2004). The unsupported interactions do not falsify the theory; they indicate that the proposed contingencies were not established in this sample.

*Supply Chain Integration*

The SCI is about coordinating information, planning and operations between the organisations involved in a shipment. This is not only about the efficiency of a single terminal or department, but also about relationships with customers, suppliers and other logistics partners. Marin-Garcia et al. (2013) discuss the measurement of integration, and Song and

Panayides (2008) place port and terminal activities within wider supply chains. This study assesses the perceptions of integration of the respondents in the setting of Port Sudan.

*Port Infrastructure Efficiency and Supply Chain Integration*

PIE reflects the perceived adequacy of berths, equipment, yards, internal transport and hinterland links. These facilities allow the physical movement of goods, but congestion can occur at various interdependent stages (Eddrgash, 2022). Infrastructure can thus support integration even where the organizations dealing with cargo are not linked.

H1: PIE is positively associated with SCI.

*Digitalization and Technology Adoption and Supply Chain Integration*

DTA covers cargo tracking, electronic data interchange, computerised services and use of information technology for supply chain objectives. Evidence from Egyptian ports links such capabilities to port supply chain integration (Hussein, 2021), and information technology has been found to affect integration through mediating mechanisms such as enterprise-system success (Alimohamadian & Abdi, 2014).

H2: DTA is positively associated with SCI.

*Stakeholder Coordination and Supply Chain Integration*

STC is about sharing information, problem solving together, relationships and the co-ordination of organizations that deal with cargo, both within and between them. In Mombasa, Njuguna et al. (2025) found that coordination, transportation management systems and clearance efficiency had significant positive effects on the performance of shipping companies, while Al Azzani et al. (2024) found that internal and information integration had positive effects on the operational performance of Omani container ports. Both studies use performance rather than SCI as the outcome but provide the motivation for the expectation that connected processes support integration.

H3: STC is positively associated with SCI.

*Customs Clearance Efficiency and Supply Chain Integration*

CCE is all about time, inspections, costs, predictability and the paperwork to clear cargo. Clearance is one of the steps in a process that also involves delivery orders, terminal payments, examination, and gate release. Hence, faster clearance should enable integration to the extent that it connects with the adjacent steps (Njuguna et al., 2025).

H4: CCE is positively associated with SCI.

*Environmental Uncertainty as a Moderator*

EU is defined here as respondents' perception of changing and unpredictable demand and technology-related competition. Uncertainty may encourage joint planning and information exchange, but it may also disrupt routines or exceed organisations' capacity to respond, so its moderating role cannot be assumed in a single direction. Empirical findings support this caution. Ganbold and Matsui (2017) found that uncertainty–integration relationships varied by uncertainty and integration dimension, Fynes et al. (2004) reported that some forms of uncertainty moderated supply chain relationship quality–performance links while others did not, and Hieu et al. (2024) reported positive moderation by uncertainty in Vietnamese firms. The four interactions are therefore tested as open empirical questions.

H5: EU moderates the relationship between PIE and SCI.

H6: EU moderates the relationship between DTA and SCI.
H7: EU moderates the relationship between STC and SCI.
H8: EU moderates the relationship between CCE and SCI.

*Research Framework*

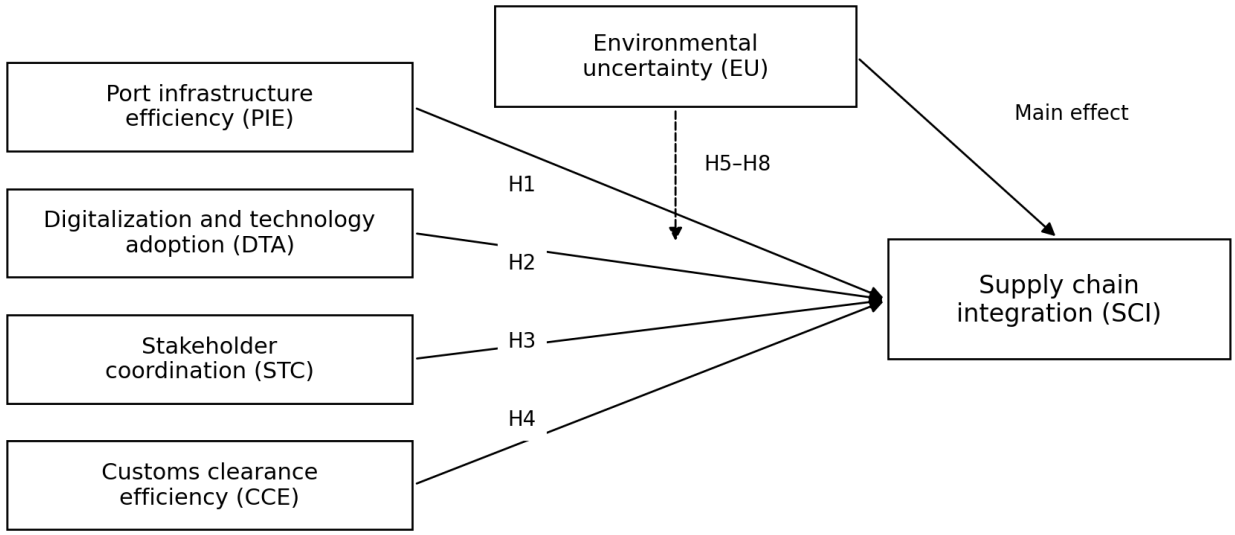



Figure 1 Research framework. Dashed arrow denotes moderation of the four operational paths.

**Methodology**

*Overall Design Target Population Sampling and Sample Size*

The present study was a cross-sectional survey, quantitative type. The target population included professionals directly involved in the maritime and logistics operations at Port Sudan, such as representatives of shipping lines, port officials, licensed clearing agents, port operations officers, logistics and supply chain officers and inland transport operators. Respondents with relevant knowledge of integration and operating conditions were selected using non-probability purposive sampling (Saunders et al., 2019). The questionnaire was administered online in English with Arabic translation. Participation was voluntary and responses were anonymous.

Answers were reviewed for completeness and patterns of response. We excluded those who gave incomplete answers and those who selected the same option for all measurement items. The screening resulted in 118 responses with no missing measurement or demographic data. The unit of analysis was not the port or terminal but the individual professional. Respondents with direct knowledge of port and logistics operations were identified through a purposive sampling technique.

Prior to data collection, an a priori power analysis was performed using linear multiple regression, fixed model, $R^2$ deviation from zero in G*Power (Faul et al., 2009). The model included 9 predictors: 4 operational determinants, EU and 4 interactions. With f2 =.15, alpha =.05, and target power =.80, the minimum required sample size was 114 (Cohen, 1988). This

requirement was exceeded by the final sample of 118. At N = 118, power was approximately.82 for the assumed medium effect size.

For the joint test of nine predictors, a sensitivity analysis for N = 118, α =.05, power = .80 suggested a detectable effect of approximately f 2 = .143. The detectable effect for a test of four interaction terms in the nine-predictor model was about f 2 = .106 for an increase in R 2 . These calculations are for joint tests and do not give adequate power for each individual path or interaction. Small moderation effects may not be detected, so non-significant interactions do not demonstrate the absence of moderation.

*Instrumentation*

The online questionnaire included questions that were relevant to the port context in the form of 5-point agreement scales and demographic questions. The questionnaire was in English with an Arabic translation. In the original model, there were 32 indicators, which comprised 7 indicators for SCI, 5 indicators for PIE, 4 indicators for DTA, 6 indicators for STC, 5 indicators for CCE, and 5 indicators for EU. The items included in the SCI were adapted from Marin-Garcia et al. (2013). The PIE items were modified from Eddrgash (2022). The items for DTA were modified from Hussein (2021). Items for CCE were adapted from Njuguna et al. (2025). Items for STC were adapted from Njuguna et al., (2025), Hussein (2021), and Marin-Garcia et al., (2013). To adapt the items to EU, selected dimensions of demand and technology of the environmental uncertainty instrument reported by Üstündağ and Ungan, 2020 (Table 1) were changed for the port service. Not all seven items of the instrument are included in the five items shortened version.

Following measurement-model assessment, SCI3 and EU4 were removed, leaving 30 indicators: six for SCI and four for EU (with other item counts remaining the same). These are post hoc deletions which decrease coverage of the construct. EU has 3 demand items, 1 is competition with technology. Not a measure of war, political instability or security - not interpreted as such.

*Data Collection and Data Analysis*

The model was estimated in SmartPLS 4. Reflective measurement quality was assessed through indicator loadings, Cronbach's alpha, rho_A, rho_C, and average variance extracted (AVE), and discriminant validity through the Fornell–Larcker criterion and the heterotrait–monotrait ratio (HTMT; Henseler et al., 2015). Interaction terms were constructed with the two-stage approach. Significance was assessed with 10,000 bootstrap subsamples, two-tailed tests at α = .05, and percentile 95% confidence intervals. Collinearity was examined through variance inflation factors (VIF), explanatory power through $R^2$ and $f^2$, predictive relevance through PLSpredict (10 folds, 10 repetitions), and model fit through SRMR. Common method bias was screened with Harman's single-factor test.

**Results**

*Demographic Information of Respondents*

Respondents were logistics and supply chain officers (28.0%), port operations staff (24.6%), shipping-line representatives (19.5%), clearing agents (13.6%), port-authority officers (10.2%), and inland transport operators (4.2%). Most were male (80.5%) and held a bachelor's

degree (71.2%); the largest age group was 26–35 years (36.4%), and the largest experience group had 4–6 years of experience (28.0%).

*Reliability*

Table 2 presents the aggregate reliability and convergent-validity estimates for the refined reflective model. Cronbach's alpha, rho_A, and rho_C all exceeded .70.

Table 2
*Reliability and Convergent Validity*

| Construct | Cronbach alpha | rho_A | rho_C | AVE |
|---|---|---|---|---|
| CCE | 0.822 | 0.836 | 0.874 | 0.583 |
| DTA | 0.854 | 0.861 | 0.901 | 0.695 |
| EU | 0.736 | 0.737 | 0.835 | 0.558 |
| PIE | 0.856 | 0.922 | 0.890 | 0.620 |
| SCI | 0.823 | 0.830 | 0.871 | 0.531 |
| STC | 0.816 | 0.820 | 0.868 | 0.525 |

Note. N = 118. AVE = average variance extracted. Construct abbreviations follow the research framework.

*Convergent Validity*

100% of the AVE ratings were above .50. Retained indicator loadings were between .557 and .875. CCE3 (.642), PIE4 (.619), SCI5 (.658), and STC5 (.557) were below .70; EU2 (.707765) and SCI2 (.706443) were marginally below .708. These indicators were kept as a content support while group indicators were met. The thresholds for aggregates are not "pass/fail" criteria; passing the thresholds do not indicate complete construct or content validity.

*Discriminant Validity*

Tables 3 and 4 report Fornell–Larcker and HTMT results. Fornell–Larcker was not fully satisfied: the DTA–STC correlation (.730) exceeded the square root of STC's AVE (.725). All 15 HTMT point estimates were below .90, although DTA–CCE (.861837) and DTA–STC (.881561) exceeded .85. EU–SCI was .740789, with a percentile 95% bootstrap interval of [.412917, 1.013890], which included 1. DTA–STC's interval [.747014, .999744] excluded 1 only narrowly, and DTA–CCE's interval [.742033, .973596] excluded 1 while extending above .90. Discriminant validity was therefore not uniformly supported by the reported inference (Henseler et al., 2015).

Excluding 1 from an interval is different from demonstrating that HTMT is below .90. The current results use two-tailed bootstrapping and percentile 95% intervals; they are not presented as a one-tailed, bias-corrected threshold test. Several interval upper bounds exceed .90. Cutoff-based and interval-based evidence are therefore reported separately, and no complementary .90 threshold test is claimed (Franke & Sarstedt, 2019).

Table 3
*Fornell–Larcker Criterion*

| Construct | CCE | DTA | EU | PIE | SCI | STC |
|---|---|---|---|---|---|---|
| CCE | 0.764 | | | | | |
| DTA | 0.727 | 0.834 | | | | |
| EU | -0.031 | 0.042 | 0.747 | | | |
| PIE | 0.653 | 0.623 | -0.123 | 0.787 | | |
| SCI | 0.231 | 0.307 | 0.586 | 0.151 | 0.728 | |
| STC | 0.656 | 0.730 | 0.233 | 0.656 | 0.438 | 0.725 |

Note. Diagonal values are square roots of AVE; off-diagonal values are construct correlations.

Table 4
*Heterotrait–Monotrait Ratios*

| Construct | CCE | DTA | EU | PIE | SCI | STC |
|---|---|---|---|---|---|---|
| CCE | | | | | | |
| DTA | 0.862 | | | | | |
| EU | 0.138 | 0.118 | | | | |
| PIE | 0.838 | 0.775 | 0.177 | | | |
| SCI | 0.264 | 0.364 | 0.741 | 0.170 | | |
| STC | 0.799 | 0.882 | 0.319 | 0.828 | 0.514 | |

Note. HTMT point estimates are below .90; this does not override the EU–SCI confidence-interval concern.

A diagnostic review of the 30 indicators that were retained revealed that each of these indicators loaded highest (and in some cases highest absolute) onto its assigned construct as compared to the other five original constructs. Interactions scores were not analyzed as items on the questionnaire. For example, SCI2 loaded .706443 on SCI and .486226 on EU, whereas EU2 loaded .707765 on EU and .443166 on SCI. There were no clear cross load reversals to warrant reassignment or deletion on this basis found in any of the indicators. This diagnostic is not validating the validity of the HTMT as the criteria measure separation differently.

In addition, integration practices were separated from demand uncertainty and technology uncertainty, and digital tools from coordination practices and clearance procedures in content review. The information sharing process offers a reasonable link between DTA and STC, and digital documentation offers a link between DTA and CCE. The overlap was spread out across indicators not on one indicator only. After this diagnostic review, no more indicators were deleted and the 30-item model was kept, with the original specification kept

unchanged to be compared to the model and caution taken in interpreting the findings in the structures.

*Structural Model Assessment and Collinearity*

VIF values were 2.471 for PIE, 2.938 for DTA, 3.384 for STC, 2.625 for CCE, and 1.569 for EU. Interaction VIFs were 4.182 for EU × PIE, 5.276 for EU × DTA, 8.422 for EU × STC, and 6.225 for EU × CCE. Three interaction VIFs exceeded 5, indicating collinearity concerns that limit the precision of their estimates.

SCI $R^2$ was .506 (adjusted $R^2$ = .465). The construct-level $Q^2$predict was .189; the SCI5 was negative (−.046). In the absence of errors in the prediction of the benchmark, the superiority of the prediction relative to a linear model is not established. SRMR was .091 (saturated) and .092 (estimated), above .08 but below the less conservative .10 reference. Model fit therefore warrants qualification (SmartPLS, n.d.).

Harman's unrotated test attributed 31.8% of the variance across the 32 original indicators to the first component. This is lower than the usual 50% screening reference but does not rule out common method bias.

*Hypothesis Testing*

None of H1–H8 was supported in two-tailed tests at .05 (Table 5 and Figure 2). Each direct and interaction confidence interval included zero. STC had the largest operational coefficient (β = .318, p = .058; 95% CI [−.009, .646]). EU had a significant positive main effect (β = .532, t = 4.334, p < .001; 95% CI [.279, .752]; $f^2$ = .365), which does not establish moderation. In a model with interactions, the operational coefficients are conditional associations at the moderator's reference level.

Table 5
*Path Coefficients Test of Hypotheses*

| Relationship | β | t | p | $f^2$ | Decision |
|---|---|---|---|---|---|
| H1: PIE → SCI | -0.053 | 0.397 | 0.691 | 0.0023 | Not supported |
| H2: DTA → SCI | 0.140 | 1.012 | 0.312 | 0.0135 | Not supported |
| H3: STC → SCI | 0.318 | 1.893 | 0.058 | 0.0606 | Not supported |
| H4: CCE → SCI | 0.008 | 0.063 | 0.950 | 0.0001 | Not supported |
| Main effect: EU → SCI | 0.532 | 4.334 | <.001 | 0.3652 | Significant |
| H5: EU x PIE → SCI | -0.202 | 1.184 | 0.236 | 0.0250 | Not supported |
| H6: EU x DTA → SCI | -0.093 | 0.557 | 0.578 | 0.0068 | Not supported |
| H7: EU x STC → SCI | 0.250 | 1.715 | 0.086 | 0.0418 | Not supported |
| H8: EU x CCE → SCI | -0.182 | 1.174 | 0.240 | 0.0161 | Not supported |

Note. N = 118; 10,000 bootstrap subsamples; two-tailed α = .05. Decisions use unrounded estimates.

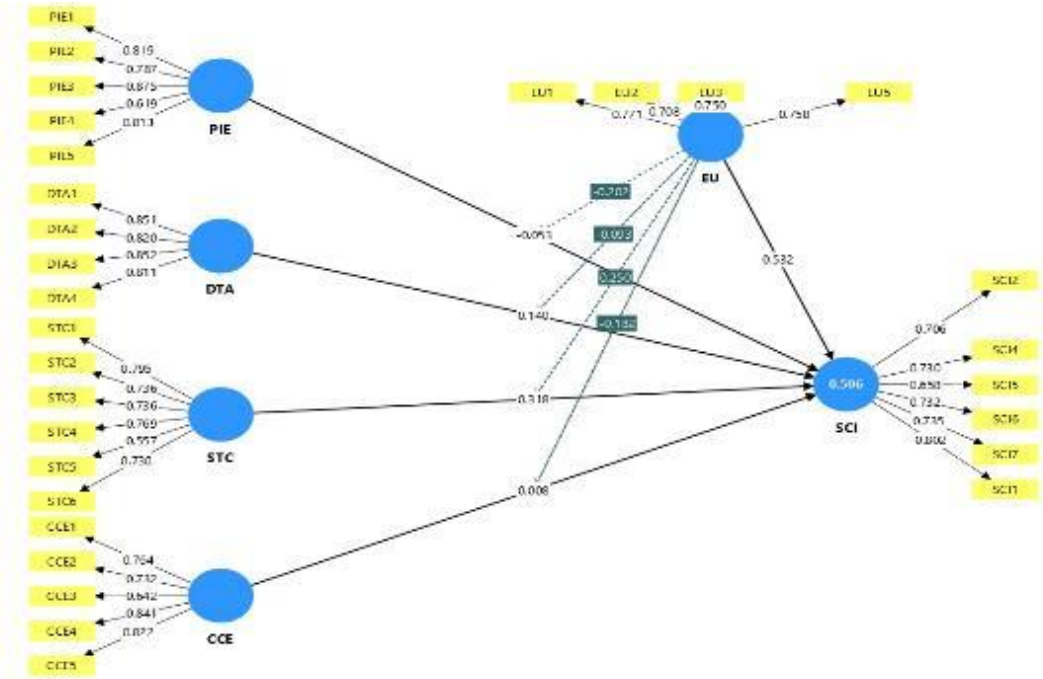



Figure 2. Path Coefficients

*Moderator Testing*

The four interaction terms were examined to assess EU's moderating role. None was significant: EU × PIE (β = −.202, p = .236), EU × DTA (β = −.093, p = .578), EU × STC (β = .250, p = .086), and EU × CCE (β = −.182, p = .240). Thus, H5–H8 were not supported at the .05 level. EU's significant main association with SCI does not establish a moderating effect.

Conditional associations were also examined at low (−1 SD), mean, and high (+1 SD) EU. The respective estimates were .149, −.053, and −.254 for PIE; .233, .140, and .047 for DTA; .068, .318, and .569 for STC; and .190, .008, and −.174 for CCE. Only the STC slope at high EU was significant (p = .026; 95% CI [.011, .998]). This significant conditional slope does not establish that slopes differ across EU levels, because the EU × STC interaction remained nonsignificant (p = .086).

**Discussion**

The model explained about half of the variance in SCI, but none of the four hypothesized relationships between operational and SCI variables, or any of the hypothesized EU interactions, were significant at .05. The largest individual effect-size estimate was for EU, but this does not allocate a portion of the overall $R^2$ to EU. The results are based on a self-reported cross-sectional model that is not meant to be an indicator of the effectiveness of operational improvements.

*H1 Port Infrastructure Efficiency and Supply Chain Integration*

The coefficient for PIE was near to zero (β = −.053, p = .691) and H1 was not confirmed. In Indonesia, Sirajuddin et al. (2019) found that the infrastructure–performance relationship is positive; however, port performance and SCI are measured differently. Hamburg Port Consulting's assignment to the South Port Container Terminal in 2021 identified long waiting times with equipment restrictions associated with poor equipment maintenance. This

comprised an emergency job to ensure the availability of the minimum equipment and standardise maintenance (Hamburg Port Consulting, n.d.). The installed capacity is by itself not a good measure of reliable service as illustrated in this account. Whilst physical capacity can be boosted by a berth or crane, its role in promoting integration may not be as great if equipment downtime does not allow for predictable handovers to yard operations, inspection, or onward transport. The project account is to be used to describe the 2021 situation only and not to show current equipment availability or provide an explanation of the estimated coefficient.

*H2 Digitalization and Technology Adoption and Supply Chain Integration*

DTA had a positive but statistically nonsignificant association with SCI (β = .140, p = .312), so H2 was not supported. The implementation of ERP and the integration of port information have been studied in the past and it can be observed that using digital tools is not enough. They are also valued based on the way organisations share and use information from the tools they create (Alimohamadian & Abdi, 2014; Jiang et al., 2023). Port Sudan was assessed by the World Bank to be one of the ports with a score lower than 2 in their digital maturity scale (World Bank, 2024), which suggests low uptake of digital tools at the time of assessment. Electronic records are sometimes employed in conjunction with paper records and manual data entry at Port Sudan. For instance, a shipping agent can check the status of a container electronically but a customs broker or transport operator has to call for confirmation of the release of the container. This system aids the shipping agent to manage its own work, but each of the other parties also has to check the data before they can begin planning the next task. This may help account for the lack of statistical significance of the positive association.

*H3 Stakeholder Coordination and Supply Chain Integration*

The coefficient for the STC was the largest with an estimated value of .318 and a p-value of .058. Since the 0 was within the confidence interval, H3 was not supported at the .05 level. This leaves open the possibility of a positive association. Njuguna et al. (2025) discovered a positive relationship between coordination and port performance in the Port of Mombasa. Seo et al. (2016) found that collaborative advantage mediated the relationship between collaboration and port performance. The two studies focused on performance, not SCI, and indicated some areas where coordination might provide value to port operations.

The World Bank's trade diagnostic of 2014 indicated that the procedures of certain agencies remained overlapping, and that the coordination of procedures between the agencies at Port Sudan was lacking in effectiveness (World Bank, 2014). The report outlines the situation at the time and demonstrates why co-ordinated procedures don't always exist between agencies when they are in the same location. A phone call or message may be enough to troubleshoot a problem that occurred with a specific shipment. It could still result in the next party not having a common set of information and understanding of what's been done, who's responsible for handing it over, or who to call if the issue comes back up.

*H4 Customs Clearance Efficiency and Supply Chain Integration*

The estimated association between CCE and SCI was very small (β = .008; p = .950) and H4 was not supported. As of June 2024, the Logistics Cluster guidance indicates that clearance/release time for humanitarian imports usually takes 10-15 working days after containers enter the inspection area. It may take some time to transport containers there

(Logistics Cluster, 2024). The estimate is thus only an approximation of the waiting time and does not account for the time between arrival and leaving the gate for commercial cargo.

In reality, customs clearance and delivery order from shipping agent, confirmation from terminal payment and gate authorisation may not have been received in a container while it is still waiting in port. Faster customs processing can save time at that stage, but the container cannot leave the terminal until the remaining release requirements are met.. This is one of the reasons that quick customs clearance does not always equate to good coordination throughout the release process.

Changes in the operating conditions at H1-H4 in Port Sudan may require other changes at the next operating stage. A more dependable crane may be able to unload the containers but the cargo could be waiting for permission. Similarly, clearance could be finalized and the terminal and transport operator may still be using different details as to the condition of the shipment. The model did not test if improvements in several operational factors need to happen simultaneously to achieve the association with SCI. The study was also based on self-reported data at only one time point from a purposive sample of 118 professionals at one port, which did not adequately distinguish some of the operational constructs. The data can therefore not conclude the degree to which the operating conditions and/or the study design were responsible for the unsupported hypotheses.

*Environmental Uncertainty*

Environmental uncertainty was positively associated with SCI in the structural model ($\beta = .532$, $p < .001$). Respondents who reported greater uncertainty about demand and technology also tended to report greater integration. One possible interpretation is that unpredictable demand creates a need for more frequent information exchange and joint planning. The survey did not establish that uncertainty prompted these responses; greater coordination could also expose respondents to changes they would otherwise not observe. Common-source reporting and uncertainty about the separation of EU and SCI in the HTMT results warrant caution. The retained EU items address demand and technology, so the association cannot be attributed directly to conflict or security disruptions.

The unconfirmed interactions are consistent with the dimension-specific uncertainty results in Fynes et al. (2004) and Ganbold and Matsui (2017) but Hieu et al. (2024) provide a contrary positive moderation result in a different model. Yusoff (2025) found that overall environmental uncertainty was not significant for supply chain performance and only supplier uncertainty moderated the relationship studied. This performance-based model allows the dimensions of uncertainty to be distinguished rather than assuming that they are all uniformly moderated.

In a West African port–hinterland study, Domfeh et al. (2026) found no significant positive moderating effect of supply chain collaboration on the relationships examined. Because collaboration was the moderator and port operational performance the outcome, this is a limited maritime comparison rather than evidence about EU itself. Together, these studies show that expected interaction effects are not uniformly confirmed across contexts.

None of the four interaction terms supported moderation at the .05 level. For stakeholder coordination, the estimated slope was .068 at low EU and .569 at high EU. Although the high-EU slope was significant (p = .026), the EU × STC interaction was not (p = .086). The former tests whether the association differs from zero at one level of EU; the latter tests whether the slope changes with EU. The high interaction VIF and limited precision for individual interactions make the difference a useful question for replication rather than evidence that coordination becomes more effective as uncertainty rises. A practical implication is to examine whether shared shipment updates help actors coordinate when demand is hard to predict. The present study does not establish that these practices work better under higher uncertainty.

*Regional Comparison*

Port Sudan's low 2023 overall CPPI rank reinforces the importance of investigating operational coordination, but CPPI does not measure SCI and cannot explain the survey coefficients. The differing regional ranks and absence of a newer Port Sudan entry strengthen the case for dated operational records and comparisons within matched cargo and call-size groups, rather than treating index scores as discharge duration.

*Theoretical and Practical Implications*

From the maritime supply chain point of view, the infrastructure and clearance are part of a larger cargo flow. Information processing theory is a theory that focuses on the integration of digital systems and coordination of parts. EU interactions are motivated by contingency theory (not found in this sample). A different issue is raised by EU's primary association in relation to responding to uncertainty with information sharing. These interpretations do not constitute proof or disproof of the theories themselves, but are rather tests of specific aspects of the theories.

Practical proposals based on the field experience and literature are discussed, such as a common shipment record, customs status to shipping-agent release to terminal location to payments to examination to gate clearance, a coordination forum with clear handover responsibility and escalation procedures, and infrastructure planning including maintenance and power continuity, yards, inland evacuation. They have not been proven effective and paths that are not significant are not worth withdrawing investment from any operating area. Port authorities also need to report on a range of metrics, including separately for each vessel waiting time at the port, for each berth used, for each active discharge duration, for each period of time vessels spend in customs clearance, for each container dwell duration, and for each gate processing duration, with precise start and end events, cargo categories and reporting periods. These records would enable the comparison of other ports in a region, grouped by call-size and gateway functions.

*Limitations and Future Research Directions*

This was a purposive sample of 118 respondents from one port. The number of cases exceeds the requirement of 114 cases for the specified overall model power calculation but does not provide much power for the small individual paths and interaction terms. The calculation is based on a medium effect and is not representative. The cross sectional, self-reported design limits causal inferences and the Harman's test does not rule out method bias.

The measurement limitations include incomplete construct separation under the Fornell–Larcker criterion, several weak indicator loadings, the post hoc removal of two indicators, and an HTMT confidence interval for EU and SCI that included 1. The EU scale is more refined in terms of the components it includes for both demand and technology, and some items in the SCI relate to beliefs with regards to integration rather than practices. The higher the interaction VIF, the less precise the precision, and without a benchmark error, $Q^2$predict cannot show a better prediction.

Selected dimensions reported by Üstündağ and Ungan (2020) were used to develop the EU instrument for port demand and technology conditions. It is not directly comparable to their instrument which has seven items. The second potential source of measurement variation is the difference in respondents' interpretation of adapted bilingual items, which was not evaluated. The HTMT findings cannot be explained as conclusively as it is possible by these possibilities. Using uniform-response screening also is a limitation of sample selection, because it can filter out legitimate consistently expressed responses, and not necessarily a reflection of careless responses.

Problems with the item provenance should be reviewed in future studies, and boundaries, demand separation, technological and political/ security uncertainty, where applicable, should be explored prior to giving a revised instrument, as should expert review, bilingual cognitive testing, and a pilot. Additional multi-port samples, operational records, multiple observations, and tests of mediating processes would enhance precision and test proposed explanations.

*Theoretical and Contextual Contributions*

This study provides quantitative evidence from Port Sudan, a Red Sea gateway with limited representation in port-community SCI research. It examines infrastructure, technology, coordination, clearance, and uncertainty within one framework. Its contribution is the context-specific pattern of supported and unsupported associations and the resulting questions for future work, rather than proof that operational determinants or moderation are absent. The findings distinguish EU's positive main association from unconfirmed interactions, while reported measurement limitations define the boundaries of that interpretation.

**Conclusion**

The study examined four operational determinants of SCI at Port Sudan and EU's moderating role. None of H1–H8 was supported at .05, whereas EU had a positive main association with SCI. The results provide insufficient evidence for hypothesised operational and moderating relationships in the specified model and sample; they do not establish that infrastructure, technology, coordination, or clearance improvements are ineffective. Shared information and coordinated cargo-release procedures remain plausible practical priorities informed by the literature and field context. Larger samples, stronger construct separation, and independent operational data are needed to assess these mechanisms and replicate the conditional STC pattern.

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