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Port Supply chain Performance Measurement: Stakeholder-Centric Decision Model

Raji Hajar[1,*]

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ABSTRACT

Grounding itself in Peter Drucker's adage "What gets measured gets managed," this study presents a novel, data-driven model for evaluating port performance at the port of Casablanca. The model adopts a survey of 112 companies operating within the port, encompassing various stakeholder groups such as shipping lines, terminal operators, etc. Univariate analysis was employed to identify the key performance indicators (KPIs) most relevant to port performance measurement. Cronbach's alpha ensured the reliability of these data, which then formed the foundation for a decision tree model constructed using the QUEST (Quick, Unbiased, Efficient Statistical Tree) method, a decision-making tool. This model offers a comprehensive understanding of performance by integrating the main stakeholder's perspectives. This data-driven approach empowers port authorities to make informed decisions that address stakeholder concerns and, ultimately, enhance overall port performance.

1. Introduction.

Ports serve as the lifeblood of global trade and the manufacturing supply chain, with over 80% of merchandise by volume and more than 70% by value traversing maritime routes [1]. High-quality, efficiently operated port infrastructure is fundamental for successful export-driven growth strategies. The Container Port Performance Index (CPPI), a robust metric tracking performance for nearly 350 global ports, reflects the ongoing post-pandemic recovery [1]. Beyond operational efficiency, ports exert a significant economic impact, generating an estimated 4.3 USD in value added to the global economy for every 1 USD flowing through them [1]. This multifaceted perspective underscores the crucial role ports play in facilitating global trade patterns. Further research is needed to explore the multifaceted dimensions of port criticality, encompassing infrastructure development, performance optimization, economic impact, and their combined influence on global trade dynamics.

To optimize the port performance network, a performance measurement model has become an essential concept for the port management decision-centric approach, particularly for addressing the complexities of a multi-stakeholder environment. Traditionally, this focused on operational and financial aspects like throughput and cost-effectiveness [2, 3, 4, 5, 6]. In the mid-2000s, the notion of effectiveness emerged, emphasizing the achievement of desired outcomes for stakeholders [7]. Thus, numerous studies have introduced conceptual frameworks and addressed evolving port trends, such as supply chain integration, Lean/agile perspectives, customer-centric practices, and value-added activities [8, 9, 10, 11]. Performance measurements have evolved beyond traditional operational and financial indicators to encompass external environmental factors and stakeholder relationships. Today, a comprehensive view of performance is essential considering the diversity of stakeholder expectations. Network performance measurement captures this multifaceted perspective, encompassing a range of dimensions that reflect the complex dynamics of modern ports. By adopting such a holistic approach, port authorities and stakeholders can gain a comprehensive understanding of their performance and identify areas for improvement, ultimately enhancing the overall port effectiveness. Port authorities increasingly rely on

[1]Professor assistant in management and logistics sciences, Laboratory of Studies and Research in Economics and Management Sciences, University Sultan Moulay Slimane, Beni Mellal Institute of Technology, University Campus M'ghila BP:591, Beni Mellal 23000, Morocco.
*Corresponding author: Raji Hajar. E-mail Address: hajar.raji@live.fr.

stakeholder management practices to establish long-term relationships with key port stakeholders [12], seeking to minimize conflicts that directly impact port performance.

This paper commences with a comprehensive review of the existing literature on port performance measurement (Section 2). This section critically examines current research trends and methodologies to establish a strong foundation for the proposed framework. Subsequently, the research methods are applied to the case of the Port of Casablanca (Section 3). This application involves identifying key stakeholders, pinpointing relevant performance indicators (KPIs), and selecting appropriate data collection methods (Section 4). Section 5 presents the results of the data analysis, followed by a discussion that explores the significance of various indicators in constructing a decision tree for evaluating and measuring the overall performance of Casablanca Port. Finally, the paper concludes by summarizing the key takeaways from the research and acknowledging the limitations of the proposed model (Section 6).

2. Port Performance Measurement: State of Art.

2.1. Port Performance Measurement: A Look at the Key Studies.

Within the realm of organizational performance, the term ”performance” encompasses a multifaceted construct often described as a ”triptych” consisting of efficiency, effectiveness, and efficacy – all united by the notion of coherence or relevance [13, 14]. In the financial dimension specifically, industrial performance was historically synonymous with efficiency before evolving to encompass the broader triptych. Dohou and Berland [15] define efficiency through practical examples: ”maximizing the quantity of products or services obtained from a given quantity of resources.” Profitability (ratio of profit to capital invested) and productivity (ratio of volume obtained to volume consumed) serve as two illustrative metrics of efficiency [15]. Efficiency is further measured by the relationship between resources deployed by stakeholders and the results obtained [16]. This metric reflects the output of equipment as well as the productivity of direct labor [17, 18, 19]. Le Moigne emphasizes the singular focus of efficiency, characterizing it as ”a monocriteria, simple and highly structured concept” [20]. Consequently, this primary facet of performance is intrinsically linked to achieving objectives [21]. Marion et al. [14] reinforce this notion, highlighting efficiency as an essential performance evaluation logic, defined as the connection between an objective and its successful achievement.

Effectiveness, in contrast to efficiency, focuses on achieving organizational goals. It is the ability of a company to translate objectives into concrete results [13, 22, 23]. Le Moigne emphasizes this by defining effectiveness as ”the evaluation of the triptych (objectives - means - results) – going back to the finalities at the very origin of the system whose performance we are seeking to evaluate” [22]. Effectiveness, therefore, is measured by the discrepancy between established objectives and the actual results achieved [13]. Similarly, Bouquin aligns effectiveness with the ability to attain predetermined objectives [23]. While efficiency emphasizes resource optimization, Swink et al. [24] argue that effectiveness necessitates ”multi-criteria” performance improvement. They suggest that ”effectiveness-based arguments suggest that Project A managers can indeed improve performance in multiple dimensions simultaneously through a significant and fundamental process change in the technology used to transform inputs into outputs”.

Performance measurement systems serve as a critical tool for organizations to assess both the effectiveness and efficiency of their actions [13]. In the context of ports, performance is often evaluated through a multi-dimensional approach, utilizing various indicator groups such as productivity, production, service quality, and utilization [25]. Fundamentally, performance measurement encompasses monitoring and analyzing past actions, ongoing activities, and their impact on future improvements [26]. Within this framework, port performance can be conceptualized as a multifaceted construct, encompassing three key dimensions: effectiveness, efficiency, and the integrative approach of the port supply chain [27].

2.1.1. Port Effectiveness.

Efficiency and effectiveness are interrelated concepts, yet their goals can diverge. Consider a scenario where a terminal operator prioritizes asset utilization, potentially leading to increased ship anchorage times to minimize downtime. While this approach might improve utilization metrics (a measure of efficiency), it could simultaneously create delays that negatively impact customer service expectations [28]. This example highlights how maximizing efficiency can come at the expense of effectiveness. Furthermore, different stakeholders within the port ecosystem may prioritize performance metrics differently. The following table provides a summary of studies investigating the impact of effectiveness on port performance measurements.

Table 1: Port Effectiveness Measurement studies.

Author(s) & Year	Theme	Selected Indicators
Roll & Hayuth (1993) [28]	Pioneering efficiency research	Customer satisfaction
Tongzon & Ganesalingam (1994) [29]	Customer-centric effectiveness	Customer focus, reliability, vessel waiting time + financial (10), ship operating (6), container operating (13), internal/external (9)
Brooks & Pallis (2008) [25]	Port reform performance framework	Financial (14), ship operating (7), container operating (13), internal/external (10)
ESPO (PPRISM WP 1, 2010; WP 2, 2011) [30, 31]	Societal, environmental, economic impact	Market evolution/structure (2), socio-economic (2), environmental (4), supply chain/operational (3), governance (3)
Brooks et al (2011) [32]	User perception of efficiency	General criteria (12), SC partner criteria (13), shipping company criteria (16), freight interest criteria (9)
Brooks & Schellinck (2013) [33]	Investment guidance for improvement	General criteria (6), shipping company criteria (13), SC partner criteria (9), freight interest criteria (5)
Schellinck & Brooks (2014) [7]	Investment prioritization for improvement	General evaluation criteria (12), freight interest assessment criteria (9)

Source: Author.

2.1.2. Port Efficiency.

The United Nations Conference on Trade and Development (UNCTAD) played a pioneering role in port performance measurement by introducing indicators like berth occupancy, revenue per cargo tonne, capital expenditure per cargo tonne, turn around time, and number of gangs employed. While previous research predominantly focused on operational efficiency, proposing the implementation of an operating index, it is crucial to recognize the limitations of this singular perspective [34, 35, 36, 37]. Efficiency measures, typically focused on the operational level, rely on physical quantities, effort levels, activity scope, resource conversion efficiency, and financial viability (e.g., operating revenue profits) [35, 36, 37]. However, a comprehensive understanding of port performance necessitates the inclusion of effectiveness measures as well. Effectiveness metrics assess how effectively strategies, structures, and working environments contribute to fulfilling organizational missions and achieving established objectives. The table presented offers a summary of studies on port effectiveness measurement.

Table 2: Port Efficiency and Productivity Studies.

Authors	Subjects	Indicators
UNCTAD (2015, 2016, 2017, 2018) [34, 35, 36, 37]	Suggested performance indicators	Financial, Operational
Suykens (1983) [2]	Port productivity factors	Employment, Physical layout, Equipment
Kim & Sachish (1986) [38]	Port industry productivity	Containerization, Economies of scale, Production growth
Tongzon & Ganesalingam (1994) [29]	ASEAN port performance and efficiency	Operational, Customer-oriented
Tongzon (1995a) [39]	Port performance models and influencing factors	Cargo size (throughput), Terminal efficiency
Tongzon (1995b) [40]	Systematic approach to port performance measurement	Throughput, Ship calls, Ship size, Cargo exchange, Infrastructure, Port nature/role, Port functions
Sachish (1996) [41]	Engineering methods for port productivity	Volume, Employment, Technology, Capital, Management, Externalities
Talley (1994, 2006) [4, 42]	Economic and engineering optimization methodologies	Technical efficiency, Cost-effectiveness, Throughput, Physical capacity
De Langen (2002) [43]	Port cluster performance	Added value (direct/indirect jobs)
Sánchez et al (2003) [44]	Port efficiency and cost variables	Port efficiency factors (time, productivity, ship stay), Transport cost factor
Ducruet et al (2007) [25]	US port economic prosperity	Average salary level
Cruz et al (2013) [6]	Port performance indicators and development	Operational, Physical resources

Source: Author.

2.1.3. Integrative approach to ports (Supply Chain Approach).

Port integration within the broader Supply Chain Management (SCM) framework has garnered significant attention from both academics and industry professionals [8, 46]. Recent studies on port performance measurement have emphasized the role of port logistics as facilitators and their seamless integration into logistics chains [46]. The crucial role of ports and terminals within the logistics chain ecosystem is well-recognized, with various studies offering compelling empirical evidence to support this notion [45, 49, 50, 11]. This approach underscores the significance of ports not only as critical logistical nodes but also as providers of comprehensive transport solutions within the logistics chain [46]. Furthermore, these studies advocate for enhanced collaboration and integration between ports and other logistics players throughout the supply chain [45, 49, 50, 11]. Table 3 summarizes the main studies on Port integrative approach and its impact on port performance.

2.2. Port Performance Measurement: Perspectives and Key Indicators Selection .

Traditionally, port performance measurement has prioritized internal operational efficiency, neglecting the multifaceted nature of port operations and the diverse interests of stakeholders involved [52]. This study advocates for a stakeholder-centric approach that incorporates the perspectives of key maritime stakeholders, including port authorities, shipping lines, shippers, and local communities [53]. Integrating these viewpoints fosters a more balanced assessment of port performance by recognizing the varied priorities of each stakeholder group [52].

Table 3: Port integrative approach Studies.

Authors (date)	Theme	Selected Indicators
Carbone & Martino (2003) [45]	Customer value creation	Relationship with customers, Service provided, Information & communication technologies (ICT)
Marlow & Paixão (2003) [46]	Lean & agile port performance measurement	Multimodal processes (16), Port unloading processes (14), Ship processes (11), Road infrastructure processes (5)
Bichou & Gray (2004) [8]	Port performance framework based on logistics & SCM	Internal logistics integration, External SCM integration
Bichou (2006) [47]	Benchmarking port performance against SCM	Internal logistics integration, External SCM integration
Langen et al (2007) [48]	Categorization of port performance indicators (PPIs)	Cargo transfer product, Logistics product, Port manufacturing product
Song & Panayides (2008) [49]	Port integration and competitiveness	Technology for data sharing, Relationship with shipping lines, Value-added services, Integration of transport modes, Relationship with land transport suppliers, Channel integration practices
Panayides & Song (2009) [50]	Terminal supply chain (TESCI) integration	Information & communication systems, Value-added services, Multimodal systems & operations, Supply chain integration practices
Woo et al (2011a) [51]	Port performance framework reflecting changing environment	External (Quality of service: 5, Customers: 3, Price of service: 4), Internal (Efficient operation: 8, Safety & security: 3), Logistics (Connectivity: 2, Value-added service: 2, Port cooperation & networking)
Woo et al. (2013) [11]	Seaport integration and performance	Port supply chain orientation (organizational relationships: 4, human resources: 3, senior management support: 4), Port supply chain integration (information & communication systems: 4, long-term relationships: 3, value-added logistics services: 4, intermodal transport services: 4, supply chain integration practices: 4), Port performance (effectiveness: service quality: 5, customer focus: 3, service price: 3; efficiency: maritime & land operations: 4, freight operations: 3)

Source: Author.

Furthermore, user satisfaction, particularly among shipping lines and shippers, provides valuable insights into their service level expectations and informs targeted service improvements [54]. This user-centric approach allows port authorities to tailor performance measurement systems to directly address user needs, fostering a collaborative environment that benefits all stakeholders [43]. Beyond operational efficiency, a more holistic picture for policymakers necessitates evaluating the port's environmental, economic, and social impacts on the surrounding region [55]. This includes aspects like job creation, contribution to regional gross domestic product (GDP), and environmental sustainability. By employing this multifaceted approach, port authorities gain a deeper understanding of their performance beyond internal metrics. This fosters stakeholder engagement, facilitates informed decision-making, and ultimately contributes to the overall success and sustainability of port operations [52].

Table 4: Port Performance Measurement: A Multifaceted Perspective.

Perspective	Description	Key Considerations	Authors
Multistakeholder	Acknowledges diverse viewpoints of actors involved in port operations.	* Port authorities (efficiency, revenue) * Shipping lines (timeliness, cost) * Shippers (reliability, hinterland access) * Local communities (environmental impact, job creation)	M. Ha et al. 2017 [27]
User Perspective	Focuses on satisfaction of port users (shipping companies & shippers).	* Timeliness of cargo movement * Information transparency and communication * Availability of necessary facilities and equipment	G. k. Vaggelas, (2019). [56]

Source: Author.

Aligning with the multi-stakeholder performance facets outlined by Ha et al. (2021) [27]. As mentioned before, this study proposes a three-facet framework for port performance measurement: port efficiency (1), effectiveness (2), and supply chain integration (3). Traditionally, efficiency focuses on "doing things right," while effectiveness emphasizes "doing the right things" (Notteboom & Rodrigue, 2005) [28]. In this context, "doing the right things" refers to achieving desired outcomes for diverse port stakeholders with varying performance objectives. The supply chain integration facet focuses on measuring collaboration, stakeholder relationships, and the creation of "added value" for each stakeholder group. In fact, Port performance measurement necessitates considering multiple perspectives, including stakeholders and users. Furthermore, various performance dimensions need to be evaluated to enhance overall port performance, productivity, and profitability, not just for the port itself but also for its stakeholders.

Drawing on the literature, activity reports, maritime transport studies, the proposed framework utilizes indicators related to eight key areas: 1) ship operations, 2) terminal operations, 3) equipment management, 4) personnel, 5) cargo handling, 6) landside transportation, 7) management systems, and 8) other port stakeholders. Table 5 presents the classification of these dimensions and axis based on the reviewed literature and activity reports. This classification offers a comprehensive framework for port performance evaluation that goes beyond operational efficiency. By incorporating financial health, user experience, supply chain integration, and sustainability, it provides a holistic picture of port effectiveness and efficiency.

Table 5: Classification of Dimensions and Axis based on Literature and Activity Reports.

Dimensions	Axis	Reference
Operational	Output Productivity Timing	UNCTAD, 1976; De monie, 1987; Roll and Hayuth, 1993; Tongzon 1995a; 1995; Cullinane and al., 2006; Brooks, 2007; Woo el al., 2011
Support Activities	Humain Capital Organisationnel Capital Informationnel Capital	Barney, 1991; Heskett and Schlesinger, 1994; Marlow and Paixão Casaca, 2003; Kaplan and Norton 2004; Albadvi et al., 2007; Brown et al., 2011; Woo et al., 2013
Financial	Profitability Liquidity & Solvability	Su et al., 2003; Bitchou and Gray, 2004; Brooks, 2007; PWC 2010
Users Satisfaction	Accomplishment Service Cost service	Marlow and Paixão, 2003; Woo et al., 2011; Brooks and Schellinck, 2013
Terminal supply chain integration (TSCI)	Intermodal Transport Systems Value added Services Integration information/ Communication	Song and Panaides, 2008; Panayides and Song, 2009; ESPO, 2010; Woo et al., 2013
Sustainable growth	Safety and security Environment Socio-economic	De Largen, 2002; IMO, 2002; PerisMora et al., 2005; Darbra et al., 2009; ESPO 2010; Woo et al., 2011a

Source: Author.

3. Empirical Study.

3.1. Port Performance Measurement: Research Model and Methodology.

Lord Kelvin's famous quote, "what you cannot measure, does not exist," as cited by Lebas [22], underscores the critical role of measurement in port performance evaluation. This study addresses this issue by constructing a conceptual framework. Our central question drives this endeavor: **What key performance indicators (KPIs) are most critical for capturing the various facets and dimensions of port performance based on multi-stakeholder and user perspectives? How can they be integrated into decision-making tools?**

A stakeholder-centric approach was employed to create a data-driven decision tool for Casablanca Port. First, key performance indicators (KPIs) are identified through a survey administered to 112 stakeholders. The survey data were then analyzed using univariate analysis by dimension to extract the most relevant indicators. Cronbach's alpha was employed to assess the reliability and internal consistency of the data, ensuring the validity of the chosen dimension. Finally, the QUEST method is utilized to construct a decision tree, which identifies crucial decision points and leads to optimal actions for improving port performance. This data-driven decision tool offers significant benefits to the port stakeholders. First, it facilitates data-driven decision making. By quantifying performance metrics, port authorities can make informed choices regarding resource allocation, infrastructure investment, and operational strategies. Second, the tool allows performance benchmarking. A comparative analysis against industry standards or other ports allows for the identification of weaknesses and areas for improvement. Finally, the tool fosters transparency and accountability for stakeholders, including shipping companies, cargo owners, and transportation agencies.

3.2. Sample size of this Research.

In order to define the sample size that will provide a high confidence level and a low margin of error we used the Following Formula:

$$n = t_2.p\frac{(1-p)}{m^2} \quad (1)$$

Where:

n: required sample sizet: 90% confidence level (typical value of 1.645)

p: estimated prevalence of subsidiary companies of multinational corporationsm: margin of error of 4% (typical value of 0.04)

In our research framework, we estimate that approximately 7% (0.07) of companies are subsidiaries of multinational corporations. Using the typical values mentioned above, the following calculation is obtained:

n = 1.645^2 x 0.07 (1-0.07) / 0.04^2

n = 2.706025 x 0.0651 / 0.0016

n = 110.1013 ≈ 110.

Table 6: Distribution of business sectors in our sample.

Professional Category					
		Frequency	**Percentage**	**Valid Percentage**	**Cumulative Percentage**
Valid	Handlers	4	3,6	3,6	3,6
	Consignee	19	17,0	17,0	23,2
	Freight Forwarders	58	51,8	51,8	75,0
	Shipowner- consignee	27	24,1	24,1	99,1
	Others	4	3,6	3,6	100,0
	Total	112	100,0	100,0	

Source: Author.

Therefore, 240 companies were judiciously selected and interviewed for our research. To increase the response rate, several efforts were made. In fact, the number of obtained responses amounts to 117, out of which 5 companies responded in an incomplete manner. The survey was able to acquire 112 usable responses for our research.

Table 7: Results of uni-variate analysis by dimension.

Dimensions	Axes	Variables	Modality	Earnings by type in (%)
Operational	Delay	a smooth flow of maritime calls	Very important	80,4%
		Smooth road transit (average time trucks spend at terminal before container is delivered by handler)	Very important	67,0%
		Waiting time before loading a TC into a terminal	Very important	65,2%
		Waiting time before unloading a TC	Very important	66,1%
		Average processing time for a container on the import terminal	Very important	64,3%
		Average container handling time at export terminal	Very important	71,4%
		Smooth control of phytosanitary inspections	Very important	55,4%
		Residence time for containers subject to physical plant health inspections	Very important	56,3%
		Residence time for containers subject to physical veterinary inspections	Very important	58,9%
		Average time a container is parked on an export terminal	Very important	61,6%
		Import container dwell time	Very important	56,3%
		Dangerous goods import residence time	Very important	58,0%
		Deadline for payment of charges to shipping company (before goods are collected)	Very important	58,0%
		Deadline for sending ship's manifest to customs (in advance, before ship's arrival)	Very important	61,6%
		Time limit for issuing the release	Very important	59,8%
		Time between handover and release slip	Very important	59,8%
		Time between check-in and DUM creation	Very important	57,1%
		Rate of electronic customs declarations	Very important	56,3%
		Rate of goods cleared with conforming admission	Very important	51,8%
		Average clearance time	Very important	61,6%
		Time to obtain export tax receipt Automatic instantaneous	Very important	59,8%
	Productivity and output	Vertical handling productivity TEU/hour	Extremely important	53,6%
		Occupancy rate	Very important	45,5%
		Gantry breakdown rate	Extremely important	51,8%
		Dock productivity	Extremely important	73,2%
		Terminal space productivity	Extremely important	69,6%
		Equipment utilization rate	Extremely important	75,0%
		Employee productivity	Extremely important	78,6%
		Average volume processed per day	Very important	69,6 %
		Total number of container ship calls	Relatively important	53,6%
		Volume of backorders	Very important	45,5%
Financial		Operational magician	Very important	73,2%
		Labor / income	Very important	68,8%
		Capital expenditure per TEU	Very important	63,4%
		Sales figures	Very important	99,1%
		Added value	Very important	65,2%
		Overall traffic volume	Very important	66,1%
		Steering costs Towing costs Boatage costs	Relatively important	67,0%
		Port dues associated with the vessel/revenue	R. important	40,2%
		Stacking	Relatively important	49,1%
		Agency fees	Very important	56,3%
		Surestraries (ships/containers)	Extremely important	49,1%
		Handling costs	Very important	52,7%
		Berth revenue per ton of freight	Relatively important	50,9%
		Harbour dues associated with merchandise/revenue	R. important	56,3%
		Warehousing costs	Very important	40,2%
		Cost price	Very important	99,1%
		Working capital requirements	Relatively important	78,6%
		financial balance of the PA	Extremely important	73,2%
		Cost of customs procedures	Relatively important	55,4%
		Cash flow forecast	Relatively important	87,5%
Human		Training costs/salary	Very important	64,3%
		Management ratio (share of executives/total employees)	Relatively important	70,5%
		Labor costs/employee	Very important	51,8%
		Turn over percentage	Extremely important	50,0%
		Behavior and education	Relatively imp	58,0%
		Workforce fluidity and versatility	Very important	52,7%
		Women's participation rate	very important	51,8%
		service availability rate (24h/24h or less)	Extremely important	92,0%
		Number of errors/human factor	Relatively important	84,8%
		Year of experience / employee category	Very important	63,4%
Sustainable development	Environmental	Carbon footprint	Very important	55,4%
		total water consumption	Very important	58,%
		total energy consumption	Very important	56,3%
		Share of renewable energies	Very important	47,3%
		Waste volume	Very important	51,8%
		Wastewater treatment	Very important	56,3%
		Waste treatment	Very important	54,5%
		pond water pollution	very important	46,4%
		air pollution	Very important	43,8%
		Dredging discharge	Very important	48,2%
	Safety and security	Number of boating accidents	Not important	48,2%
		Number of accidents on land	Extremely important	42,9%
		Number of safety accidents	Extremely important	47,3%
		Number of bodily injury accidents	Extremely important	46,4%
		Infrastructure quality	Extremely important	50,0%
		Regulatory compliance	Extremely important	74,1%
	Socio-economic	Jobs creation	Extremely important	47,3%
		Share of GDP	Very important	48,2%
		Capital expenditure	Extremely important	42,9%
		Contribution of ports to public finances	Very important	46,4%
Supply chain approach		Integrated EDI for communication, integrated IT for data sharing.	Very important	67 %
		integrated information systems (IT) for data sharing, computerized port service systems	Very important	54,5%
		Terrestrial connectivity (intermodal)	Very important	80,4%
		Maritime connectivity and the quality of customs procedures.	Very important	67,0%
		Collaboration between chain players for chain optimization (strategic, tactical and operational concepts)	Very important	53,6%
		Trust	Very important	77,7%
		Transparency and traceability	Not important	56,7%
		Cooperation between players	**Very important**	67,1%

Source: Based on survey results.

3.3. Sample Characteristics.

A sample of 112 participants from the maritime industry identifies five business sectors: Handlers, Consignee, Freight Forwarders, Shipowner-consignee, and others. Table 6 presents the distribution of business sectors within our sample. This table revealed a diverse spread across the five sectors. Freight forwarders dominated (51.8%), followed by shipowner-consignees (24.1%) and consignees (17.0%). This distribution provides a foundation for further analysis to explore the roles and interactions of these sectors within the maritime industry.

4. Database Gathering Methodology and Analysis.

4.1. Port Key Performance Indicators and Database Alignment.

To gauge stakeholder points of view and identify the most relevant Key Performance Indicators (KPIs) for port performance measurement, a survey was administered to the same sample of 112 stakeholders introduced in the methodology section. The survey employed a Likert scale format, allowing respondents to express their level of agreement with pre-defined statements regarding potential KPIs. Recognizing the prominence of stakeholder satisfaction, the answer choices focused on a binary "yes / no" format to determine the inclusion and relative importance of each indicator.

The survey results identified 17 indicators deemed critically important and 58 considered very important by key port stakeholders for assessing overall performance. Only a small number (12) were viewed as relatively important, and a minimal number (2) were considered unimportant. These findings highlight the multifaceted nature of port performance and the diverse priorities of stakeholders. To delve deeper into stakeholder satisfaction, a "Yes/No" measurement scale was adopted to evaluate this specific performance dimension. This dimension encompasses three key areas:

- Customer Satisfaction: This area focuses on the satisfaction of port users directly interacting with port services (details can be found in Table 8).
- Port User Satisfaction: This area broadens the scope to encompass the satisfaction of all port users, potentially including shipping lines, cargo owners, and logistics providers (details can be found in Table 9).
- Value-Added Services: This area assesses stakeholder satisfaction with the range and quality of value-added services offered by the port, such as cargo consolidation, container packing, or bonded warehousing (details can be found in Table 10).

The table shows that the majority of port stakeholders agree that customer satisfaction is a key performance factor. (99.1%) of respondents stressed the importance of the satisfaction rate, showing that stakeholders' practices are always aimed at satisfying their customers' expectations. Focusing on the second category of port user satisfaction, we need to know which indices have a direct impact on the satisfaction of the port's main stakeholders.

Table 8: Results of the uni-variate analysis of the customer satisfaction axis.

Indicators	Measurement mode	Workforce (f)	Results by modality in (%)
Satisfaction rate	**No**	**1**	0.9%
	Yes	**111**	99.1%
Loyalty rate	**No**	**109**	97.3%
	Yes	**3**	2.7%
Number of complaints (customer)	**No**	**51**	45.6%
	Yes	**60**	53.6%
Market share	**No**	**35**	31.25%
	Yes	**77**	68,75%
Number of surveys per year (customer)	**No**	**87**	77,7 %
	Yes	**25**	22.3%
Litigation rate	**No**	**73**	65.17%
	Yes	**25**	34.3%
Processing time for customer complaints	**No**	**69**	61.6%
	Yes	**43**	38.39%
		112	100%

Source: Based on survey results.

Table 9: Results of uni-variate analysis of port user satisfaction axis.

Indicators	Measurement mode	Workforce (f)	Results by modality in (%)
Overall service reliability and flexibility	No	**50**	44.6 %
	Yes	**62**	55.35%
Responsiveness to special requests	No	**110**	97.3%
	Yes	**2**	2.7%
Accuracy of documents and information	No	**50**	45.6%
	Yes	**62**	53.6%
Meeting deadlines	No	**46**	31.25%
	Yes	**66**	68,75%
Impact of cargo damage	No	**53**	47.3%
	Yes	**59**	52.7%
Impact of service delays	No	**53**	47.3%
	Yes	**59**	52.7%
Accessibility of port premises for pickup and delivery (door congestion)	No	**53**	47.3%
	Yes	**59**	52.7%
		112	100%

Source: Based on survey results.

In fact, we observe that meeting deadlines is of prime importance to 66% of respondents, which means that the port is following the logic of Benjamin Franklin 1748 in Advice to a Young Tradesman "Remember that time is money". It's a notion adopted by all port stakeholders. Citing the following example, a ship's delay on the quayside increases demurrage, which in turn delays all subsequent cargo transit activities.1 In second place was the accuracy of documents and information (62%). What also attracts attention in principle are the last three indices, which represent the same level of importance (52.7%). The port players most interested in these indices are freight forwarders, who represent (51.73%) of our target population. This is the category that is most concerned with merchandise.

The third category underscores the significance of value-added services (VAS) in port performance measurement. This necessitates the identification of a pertinent indicator to capture the contribution of VAS within our research framework.

Table 10: Results of the uni-variate analysis of the value-added axis.

Indicators	Measurement mode	Workforce (f)	Results by modality in (%)
Facilities to add value to cargo,	Yes	**110**	98.2%
	No	**2**	1.8%
Adapting service to customers	Yes	**108**	96.4%
	No	**4**	3.6%
Ability to provide various value-added services	Yes	**85**	75,9%
	No	**27**	24,1%
Personalized customer services	Yes	**33**	70,5%
	No	**79**	29,5%
		112	100%

Source: Based on survey results.

These results show that the creation of value-added services is a key element in the integration of ports into the supply chain [7]. Indeed, port stakeholders are aware of the importance of diversifying their services in order to create added value and increase port performance. The following table represents the different services offered by our target population.

Table 11 illustrates the distribution of the primary dimensions and axes of our model, showcasing the essential elements of your performance measurement framework. It categorizes performance into six main dimensions such as operational, Financial, and more, with the possibility of further subdivision, for instance, Sustainable Development. Although the extensive number of metrics (107) implies the potential for streamlining, the overall structure lays a robust foundation. The subsequent steps entail defining specific metrics, assigning importance weights, and establishing data collection methods. Enhancing this framework will yield valuable insights into your organization's performance across these crucial areas.

Table 11: Distribution of the main dimensions and axes of our model.

Dimensions	Axis	Number of Indicators
Operational	Deadline	21
	Productivity and output	10
Financial		20
Human		10
Sustainable development	Green performance	10
	Socio-economic	4
	Safety and security	5
Stakeholder satisfaction	Customer satisfaction	7
	Satisfaction of port users	8
	Value-added service	4
Supply Chain Integration		8
Total dimensions: 6	Total Key Performance Indicators : 107	

Source: Interviews results.

Table 12 presents a classification of dimensions based on stakeholders' perspectives, categorizing performance into six key dimensions including Operational and Financial aspects. This comprehensive framework provides a clear structure for understanding the factors influencing the performance of the Port of Casablanca. The classification facilitates discussions about stakeholder priorities, allowing for a deeper exploration of the relative importance of each dimension. By engaging with stakeholders, we can tailor a performance measurement model to the specific needs of the port, maximizing its overall contribution to performance. This approach ensures that the dimensions considered most crucial by stakeholders, such as Operational Efficiency and Financial Performance, receive appropriate emphasis, while also accommodating varying views on the importance of dimensions like Sustainable Development.

Table 12: Dimensions Classification based on stakeholder's perspectives.

Dimensions	Operational	Financial	Human	Sustainable development	SC Integration	Port User Satisfaction
Workforce	90	59	56	80	78	89
Percentage	80.4%	52.7%	50%	71.4%	69.6%	79.5%
Ranking	(1)	(5)	(6)	(3)	(4)	(2)

Source: Compilation based on survey results.

4.2. Database Reliability test.

To evaluate and examine the five primary dimensions (operational, financial, human, sustainable development, and integration Supply Chain) and their key indicators, we have opted to employ multiple component analysis (MCA) along with reliability testing based on Cronbach's alpha. This decision is supported by the fact that the bidimensional solution accounts for 86% of the variance, demonstrating significant connections between the dimensions and the indicators. In Table 13, a reliability test is conducted to gauge the reliability and consistency of our measurements.

Table 13: Reliability test.

Summary of models

		Explained variance		
Dimension	Alpha of Cronbach	Total (eigenvalue)	Inertia	Percentage of explained variance
1	,989	45,831	,521	52,080
2	,978	29,885	,340	33,960
Total		75,715	,860	86,040
Average	,985[a]	37,858	,430	43,020

a. The average Cronbach's Alpha value is based on the average eigenvalue.

Source: Quantitative Study /SPSS.20.

Table 14 displays the discrimination measures utilized in the analysis, revealing promising results for two models, likely referred to as Dimension 1 and Dimension 2. The internal consistency, as indicated by Cronbach's Alpha, for both models is excellent, with values very close to 1 (0.989 for Dimension 1

Table 14: Measures of discrimination .

Dimension	Axe	Measures of discrimination	Dimension 1	Dimension 2
Operational	Timing	[Fluidity of reception of maritime stopovers]	,421	,123
		[Duration of passage of a truck]	,488	,251
		[Waiting time before loading a TC in a terminal]	,082	,280
		[Waiting time before unloading a TC]	,110	,301
		[Average processing time of a container at importation]	,465	,199
		[Duration between the removal order and the exit order]	,321	,139
		[Average processing time of a container at exportation]	,047	,031
		[Fluidity of phytosanitary inspection controls]	,528	,461
		[Stay time of containers subject to physical phytosanitary inspections]	,528	,363
		[Stay time of containers subject to physical veterinary inspections]	,526	,468
		[Deadline for sending the ship's manifest to Customs (in advance, before the arrival of the ship)]	,759	,315
		[Deadline for payment of fees to the shipping company (in advance, before the arrival of the ship)]	,824	,403
		[Average parking time of a container at export terminal]	,844	,512
		[Stay time of containers at import]	,531	,253
		[Duration of stay of dangerous goods at import]	,110	,278
		[Rate of customs-cleared goods with compliant admission]	,797	,394
		[Average customs clearance time]	,790	,345
		[Deadline for obtaining the tax certificate for automatic export]	,828	,529
		[Rate of dematerialization of customs declarations]	,475	,214
		[Delivery time for the release]	,828	,475
		[Time for release and goods exit]	,806	,459
		[Time between check-in and creation of the DUM]	,347	,199
	Productivity and output	[Vertical handling productivity (EVP/hours)]	,164	,095
		[Workstation occupancy rate]	,830	,255
		[Gantry crane breakdown rate]	,855	,331
		[Dock productivity]	,905	,446
		[Terminal space productivity]	,540	,395
		[Equipment utilization rate]	,866	,316
		[Volume of outstanding goods]	,767	,380
		[Average volume processed per day]	,462	,344
		[Total number of container ship calls per month]	,076	,298
		[Employee productivity]	,900	,553
Financial		[Operational Margin]	,322	,199
		[Value added]	,810	,589
		[Shipping fees associated with ships/Revenue]	,210	,260
		[Shipping fees associated with goods/Revenue]	,199	,228
		[Capital expenditure per TEU]	,338	,309
		[Revenue from berth occupancy per ton of freight]	,040	,244
		[Workforce/Revenue]	,346	,395
		[Pilotage, towing, and mooring costs]	,717	,252
		[Warehousing costs]	,349	,282
		[Agency fees]	,113	,235
		[Stacking]	,217	,337
		[Freight handling fees]	,281	,250
		[Demurrage (Ships/containers)]	,332	,213
		[Customs procedure charges]	,001	,002
		[Turnover]	,715	,095
		[Cost price]	,711	,069
		[Working capital requirement]	,058	,163
		[Cash flow forecasts]	,007	,032
		[Financial balance of the Port Authority]	,020	,009
Human		[Staffing ratio (proportion of senior executives/total employees)]	,500	,355
		[Turnover rate]	,923	,497
		[Behavior and education]	,509	,698
		[Cost of Labor /employee]	,934	,592
		[Cost of Training /salaries]	,843	,469
		[Women's participation rate]	,637	,400
		[Number of errors/human factor]	,079	,400
		[Flexibility and versatility of the workforce]	,076	,074
		[Years of experience/employee categories]	,173	,001
		[Service availability rate (24/7 or less)]	,008	,002
Sustainable Development	Safety /security	[Number of bodily incidents]	,921	,616
		[Number of nautical incidents]	,501	,665
		[Number of land incidents]	,374	,306
		[Number of safety incidents]	,890	,606
		[Quality of port infrastructure]	,426	,111
		[Compliance with regulations]	,607	,302
	Environmental	[Carbon footprint]	,790	,644
		[Energy consumption]	,911	,649
		[Water consumption]	,910	,635
		[Share of renewable energies]	,872	,536
		[Wastewater treatment]	,915	,620
		[Waste volume]	,898	,569
		[Waste treatment]	,912	,669
		[Air quality]	,799	,695
		[Water quality in basins]	,918	,684
		[Dredging discharge]	,917	,682
	Socio-Economic	[Employment]	,794	,543
		[Share in GDP]	,557	,347
		[Montant des investissements Amount of investments]	,478	,342
		[Contribution of ports to public finances]	,482	,316
Integration Supply Chain		[Integrated IT for data sharing]	,592	,237
		[Collaboration between chain Stakeholders for chain optimization (strategic, tactical, and operational concept)]	,590	,167
		[Transparency and traceability]	,017	,095
		Maritime connectivity]	,794	,543
		[Land connectivity]	,557	,347
		[EDI (Electronic Data Interchange)]	,482	,316
		[Cooperation between Stakeholders]	,082	,016
		[Trust]	,384	,176
		Total assets	45,831	29,885
		Percentage of explained variance	52,080	33,960
		a. Additional variable		

Source: Quantitative Study /SPSS.20.

and 0.978 for Dimension 2). Furthermore, the combined explained variance for both models is notably high at 86.04%, effectively capturing a substantial amount of information within the data. Dimension 1 accounts for a slightly larger portion of the variance at 52.08% compared to Dimension 2 at 33.96%. The reported "Total" inertia, representing the total variance in the data, is significantly explained by both models. Additionally, the average Cronbach's Alpha of 0.985 reflects the high internal consistency observed across both models.

Based on the table provided, the data analysis indicates the presence of two robust models, namely Dimension 1 and Dimension 2, which collectively account for over 86% of the data's variability. This suggests that both models effectively encompass crucial aspects of port performance. Dimension 1 primarily centers on the operational facets of the port, encompassing factors that directly influence efficiency, such as customs clearance time, employee productivity, and revenue derived from berth occupancy. Strong indicators for these factors imply that the model adeptly captures the operational strengths and weaknesses of the port. On the other hand, Dimension 2 encompasses other concepts, including financials, human resources, and sustainability, delving into areas such as cost per employee, safety incidents, and energy consumption. Additionally, the table illustrates a distinct dimension specifically dedicated to Integration Supply Chain factors. This dimension likely emphasizes the port's interactions and collaborations with other stakeholders in the supply chain to enhance cargo movement. The Supply Chain integration dimension underscores the pivotal role of cooperation, information sharing, and efficient data exchange between the port and its partners in optimizing cargo movement and overall port performance.

Reliability Test and Analysis of the Dimension "User Satisfaction of the Port"

The study demonstrates the presence of two robust models: Dimension 1 exhibits strong internal consistency (0.923) and accounts for a substantial portion of the data (43.3% explained variance), whereas Dimension 2 also demonstrates satisfactory internal consistency (0.702) but could potentially be enhanced through further refinement. This suggests that the items within each dimension likely gauge the same underlying concept. Consequently, Table 15 presents the results of the reliability analysis, offering insights into the extent to which our measures yield consistent and effective outcomes.

Table 15: Reliability test.

Summary of models

Dimension	Alpha of Cronbach	Explained variance		
		Total (eigenvalue)	Inertia	Percentage of explained variance
1	,923	7,797	,433	43,316
2	,702	2,970	,165	16,499
Total		10,767	,598	59,815
Average	,862[a]	5,383	,299	29,907

a. The average Cronbach's Alpha value is based on the average eigenvalue.

Source: Quantitative Study /SPSS.20.

According to the data presented in Table 16, which assesses discrimination, we observe that the analysis uncovers favorable aspects of port performance strategies. The capacity to provide a wide array of value-added services emerges as a crucial distinguishing factor, with the potential to enhance customer satisfaction significantly. Moreover, the prompt resolution of complaints appears to exert a noteworthy positive influence. While this analysis yields valuable insights into port performance, certain constraints warrant further investigation. Conventional customer satisfaction metrics such as satisfaction rate and loyalty exhibit a weak correlation with overall performance, indicating that they may not be the most effective indicators. Furthermore, the considerable emphasis placed on "personalized services" is constrained by insufficient data, potentially impeding a comprehensive understanding of its actual impact.

Table 16: Measures of discrimination.

	Measures of discrimination	Dimension 1	Dimension 2
1	VA: Installations to add value to shipments	,061	,643
2	VA: Customizing the service to clients	,069	,555
3	VA: Ability to provide different value-added services	,580	,231
4	VA: Personalized services to clients	,696	,005
5	FC: Satisfaction rate	,556	,099
6	FC: Number of complaints	,556	,099
7	FC: Loyalty rate	,000	,065
8	FC: Market share	,742	,022
9	FC: Litigation rate	,031	,404
10	FC: Investigations	,079	,182
11	FC: Complaint processing time	,031	,404
12	SU: Overall service reliability and flexibility	,000	,109
13	SU: Responsiveness to special requests	,000	,109
14	SU: Accuracy of documents and information	,884	,000
15	SU: Adherence to deadlines	,872	,002
16	SU: Impact of cargo damages	,880	,013
17	SU: Impact of service delays	,880	,013
18	SU: Accessibility of port facilities for pickup and delivery (gate congestion)	,880	,013
19	category prof[a]	,961	,964
	Total assets	7,797	2,970
	Percentage of explained variance	43,316	16,499

a. Additional variable

Source: Quantitative Study /SPSS.20.

Table 16 illustrates the discrimination measure, indicating positive aspects of port performance. The analysis presents a comprehensive framework for measuring the performance of the Port of Casablanca, encompassing six dimensions: Financial, Operational, Human Resources, Sustainable Development, Stakeholder Satisfaction, and Supply Chain Integration. Each dimension includes specific indicators for measurement, supported by references to relevant academic studies and industry reports to ensure a solid foundation in established practices. It is important to note that some indicators rely on qualitative studies in cases where quantitative data may be unavailable. Furthermore, the framework demonstrates a clear emphasis on stakeholder satisfaction, with dedicated sections for customer satisfaction and the satisfaction of port users, underscoring the significance of user experience in assessing the port's performance.

5. Results and Discussion.

5.1. Validation of the Decision Support Tool.

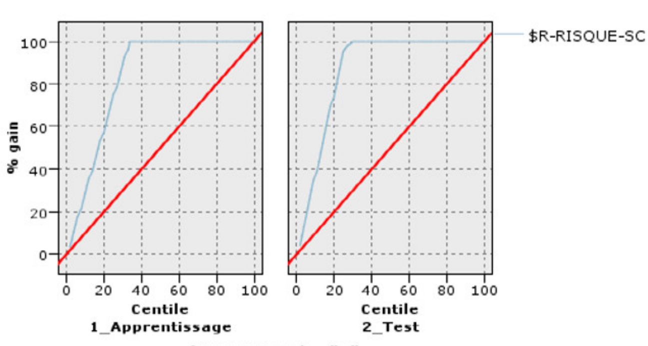
This study proposes a novel decision support tool for port performance evaluation, drawing inspiration from the QUEST method [57], QUEST is a decision tree algorithm particularly adept at explaining a qualitative variable using multiple qualitative variables with a large number of modalities. Its effectiveness is further enhanced by its utilization of well-established statistical formulations [58], making it especially suitable for situations involving large datasets.

The primary objective of the decision support tool is to create distinct classes or groups of port performance based on the identified KPIs. Additionally, the tool aims to generate ranking rules that facilitate targeted improvements in the port's supply chain orientation for each performance class. By leveraging the QUEST method's strengths and tailoring it to the context of port performance evaluation, this decision support tool empowers port authorities with valuable insights for optimizing their operations and enhancing supply chain integration.

Testing the Reliability of the Model based on the Gain Curve and the Confusion Matrix

The analysis is based on the Gain curve, which depicts how it is used to assess model reliability. This representation facilitates the comparison between the "test" and "learning" parts depicted in the figure below. The Gain curve allows us to verify whether the model achieves similar performance for both sets. This evaluation will be further complemented by a confusion matrix to assess model performance. For instance, if the QUEST decision tree demonstrates that over 90% of the independent variables (dimensions of port performance) are correctly classified for the learning set, it would suggest that the model generalizes well to the test set. As evident from Figure 2, the Gain curve indicates comparable performance for both partitions. However, a confusion matrix is necessary to definitively confirm this observation.

Figure 1: Representation of the Gain curve.



Source: Compilation based on survey results.

Table 17 presents the confusion matrix, which indicates strong performance of the QUEST decision tree model. For the learning set, 100% of the port performance dimensions were correctly classified, demonstrating perfect accuracy. The test set performance remains high, with 98% of the dimensions correctly assigned and only 1.15% misclassified.

Table 17: Representation of the confusion matrix.

Résultats du champ de sortie RISQUE-SC
Comparaison de $R-RISQUE-SC avec RISQUE-SC

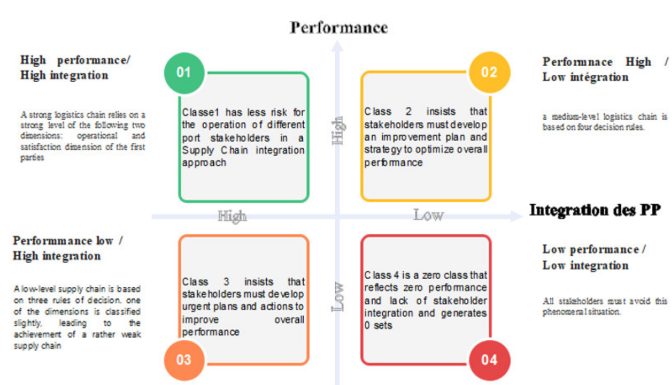
{0}	1_Apprentissage		2_Test	
Correct	83	100%	86	98,85%
Incorrect	0	0%	1	1,15%
Total	83		87	

Source: Compilation based on survey results.

5.2. QUEST Decision Tree Modeling between Generation of Rules and Performance and Integration Matrix.

Figure 3 depicts the Performance and Integration Matrix, which reveals that the QUEST decision tree model generated eight decision rules. Specifically, one rule was generated for "class 1," four rules for "class 2," and three rules for "class 3." This matrix details the characteristics of each class and the key performance indicators (KPIs) used to evaluate the performance of the Casablanca port. Furthermore, it serves as a decision-making tool, enabling stakeholders to identify corrective actions not only for performance improvement but also for supply chain integration and enhanced stakeholder connectivity.

Figure 2: Performance and Integration Matrix.



Source: Compilation based on QUEST Method Reasoning/Results.

This matrix provides a structured approach for evaluating and comparing performance and integration levels across five key dimensions: operational, financial, human resources, stakeholder satisfaction, and sustainable development. Each dimension considers key aspects and rates them based on their level of integration and performance. This comprehensive analysis allows stakeholders to identify synergies, challenges, and opportunities arising from the convergence of these dimensions, ultimately facilitating informed decision-making and strategic planning. For a port's performance to be classified as "class 1," indicating minimal risk to the functioning of stakeholders within the supply chain, the performance dimensions must adhere to the rule cartography outlined in Table 18.

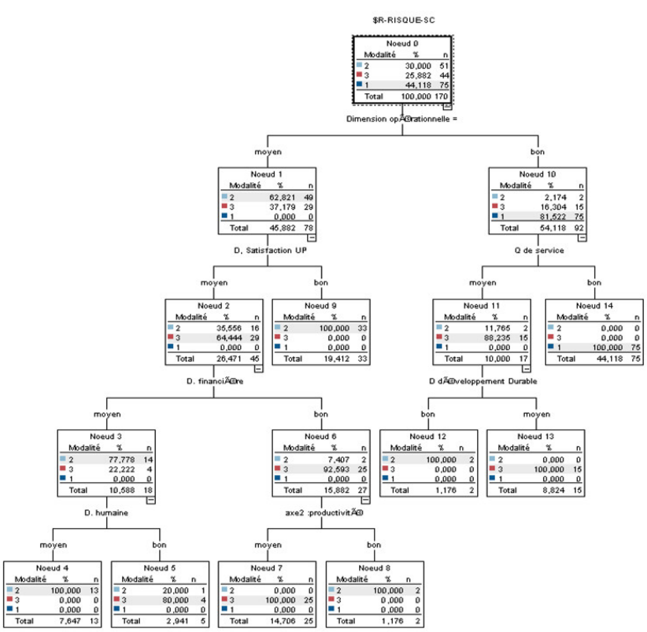
Table 18: Representation of the confusion matrix.

Performance classes	Rules
Strong SC Performance (Class 1)	a strong operational dimension and a strong user satisfaction dimension.
Average SC Performance (Class 2)	Encompasses four scenarios: A medium-to-weak operational dimension, a medium user satisfaction dimension, a medium financial dimension, and a medium human dimension. A medium-to-weak operational dimension, a medium-to-weak user satisfaction dimension, a strong financial dimension, and a strong productivity axis. A medium-to-weak operational dimension, a strong user satisfaction dimension. A strong operational dimension, a medium-to-weak user satisfaction dimension, and a strong sustainable development dimension.
Weak SC Performance (Class 3)	Encompasses three scenarios: A medium-to-weak operational dimension, a medium-to-weak user satisfaction dimension, a medium-to-weak financial dimension, and a strong human dimension. A medium-to-weak operational dimension, a medium-to-weak user satisfaction dimension, a strong financial dimension, and a medium-to-weak productivity axis. A strong operational dimension, a medium-to-weak user satisfaction dimension, and a medium-to-weak sustainable development dimension.

Default Rule: 1
the default performance class is Class 1 (Strong SC Performance).

Source: Compilation based on survey results.

Figure 3: Representation of the QUEST Decision Tree.



Source: Compilation based on survey results.

The analysis suggests that a robust supply chain hinges on a strong operational dimension (productivity, lead time, and output) and a high level of user satisfaction (including port users, customers, and value-added services). Stakeholder integration emerges as a critical pillar for optimizing port performance. However, a low score in any other dimension weakens the overall supply chain. Consequently, for a successful supply chain across all dimensions, it is imperative to continuously optimize weaker areas. As illustrated by the QUEST decision tree in Figure 3, this integrated approach demonstrably impacts port performance in its two key aspects: effectiveness and efficiency.

Conclusions.

This study proposes a novel, stakeholder-centric approach for evaluating and enhancing port performance. Establishing an effective performance measurement system is crucial not only to satisfy stakeholder demands but also to develop robust decision-making tools for navigating the complexities and uncertainties inherent in Supply chain. Our research focuses on the Port of Casablanca, Morocco, and employs a quantitative survey to identify key performance indicators (KPIs) that integrate stakeholder needs into a decision-making centric model. This model incorporates the "efficiency, effectiveness, and supply chain integration" port triptych, providing a holistic view of port performance.

Furthermore, we propose a decision support tool inspired by the QUEST method (Quick, Unbiased, Efficient Statistical Tree). This decision tree aids stakeholders in optimizing and evaluating port performance. This integrated approach offers valuable insights for port authorities in formulating global strategies, enhancing their ability to monitor and control overall performance, and fostering stakeholder satisfaction.

This novel framework equips port authorities with practical tools to understand stakeholder influence and optimize port performance. However, the model also possesses limitations:

- Rule-based thresholds: The system relies on predefined thresholds (e.g., strong, medium, weak) to classify each performance dimension. This approach may not capture the nuances of performance within each category.
- Weighting of dimensions: The relative importance of each performance dimension may vary depending on the specific port context and stakeholder priorities. The current model does not explicitly consider this variability.
- Linear relationships: The model assumes a linear relationship between the different dimensions and overall performance. In reality, the relationships may be more complex and interdependent.

Despite these limitations, the model offers a valuable foundation for port performance evaluation. Future research can refine the model by:

- Incorporating additional performance indicators to capture a wider range of port operations.
- Integrating real-time data for more dynamic and up-to-date performance assessments.
- Developing a mechanism to account for the relative importance of different dimensions based on specific port contexts.

- Exploring more sophisticated methods to capture the potentially non-linear relationships between dimensions and performance.

By addressing these limitations and incorporating future advancements, this novel framework can become an even more powerful tool for port authorities seeking to optimize operations, foster stakeholder satisfaction, and achieve long-term port competitiveness.

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