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A MODEL FOR ANALYZING CAPACITY OF PORTS TO ACCOMMODATE AUTONOMOUS SHIPS USING K-MEANS CLUSTER ANALYSIS: A CASE STUDY

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Abstract- Today with the evolution of the industry 4.0, and after the success of several projects and tests, autonomous ships are becoming a reality. In fact, the world's main ports are investing more and more in improving their performance and flexibility in order to facilitate the integration of autonomous ships into their logistics chain. To remain competitive, Moroccan ports for their part must be able to accommodate this type of ships in the future. To do this, a Moroccan ports performance evaluation are required. In this article, an evaluation and classification of Moroccan ports is carried out. While using a set of indicators developed to assess and classify seaports according to their performance and their capacity to accommodate autonomous ships. By using the K-MEANS unsupervised classification technique.

Keywords: Autonomous Ship (AS), Port Performance Indicators, Moroccan Seaport, Unsupervised Classification.

1. INTRODUCTION

Autonomous Ship (AS) are soon a reality, given the multitude of demonstrations and deployments in real conditions that have taken place over the past five years, even if they are limited to small vessels navigating in short distances. Furthermore, the continued increase in port traffic and the size of ships is forcing ports to increase their capacities. One solution for this increase, other than building new infrastructure, is improving the port terminal performance by following the 4.0 revolution. This revolution has put the world's largest ports in a race towards automation, in order to have a competitive advantage that allows to better serve customers. [1] mention that 75% of container terminal operators see automation as essential to remain competitive, and 65% consider it as a lever for ensuring safe operations. Over 60% of port operators believe that automation will improve control and consistency of operation, and 58% believe it will reduce overall terminal operating costs. The respondents were generally convinced of the possible profitability of the investment. About a third of them saw automation as a way to achieve up to a 50% increase in productivity, and about a fifth believed it could reduce operating costs by more than 50%. Today, digitization and automation initiatives are routinely implemented in some seaports. Indeed, [1] estimates that 1% of container terminals are fully automated, while 2% are semi-automated. In order to be competitive, Moroccan ports in turn are called upon to adapt to this industrial revolution and to assess their ability to accommodate future autonomous ships.

To properly determine the port most likely to accommodate these autonomous ships, a benchmark between the various Moroccan ports is necessary. Therefore, the rest of the article is structured as follows: In section 2, a literature review of the classification methods and the port performance indicators are presented. In Section 3, an analysis of the concept of autonomous ships and a study of how the increased automation of these vessels affects the seaport is carried out. In section 4, the data collection method and the study approach are presented. In section 5, the final list of suggested indicators thus analysis and classification of Moroccan ports are made to determine the Moroccan port most likely to accommodate the autonomous ship. In section 6, the article is concluded.

2. PORT CLASSIFICATION APPROACH AND PERFORMANCE INDICATORS RELATED WORK

2.1. Technical Efficiency Approach

Most researchers opt for an analysis of technical efficiency to evaluate port performance, using the data envelopment analysis or the stochastic frontier models, which consists in evaluating several processes having the same tasks to determine the best in terms of performance than in calculating for each process the deviations from the best. Nguyen and all [2] analyzed Vietnamese ports. They showed that the important inputs are handling and information technology and that each region requires an adapted approach. Birafane and all [3] analyzed Moroccan ports. They conclude that port size is not the only indicator of performance because large ports are not necessarily the most efficient.

While Sun and all [4] considered environmental factors when assessing the effectiveness of Chinese ports. They show that the average efficiency was low for all harbors when environmental factors were taken into account. The environmental performance of these port companies is mainly impacted by the number of berths, the geographical location, and the port assets.

In [5] and [6] Authors compared the efficiency of selected African ports using different and multiple inputs and output. The results show that larger ports are not always more efficient than smaller ports. However, Saglam and all [7] have noticed that many Dea studies use as output the cargo throughput. They conclude that berthing time difference and efficiency are important indicators for port selection and good service quality. They mainly affect the future selection decisions of port users. Seth and Feng [8] Analyzed 15 United States container ports. They conclude that container throughput is mainly affected by the changes in security policies. Whereas Lin and all [9] measured container port's efficiency and understand their resource consumption. In [10] Authors confirmed that the polyvalent port is more pertinent than the specialized one and that infrastructure characteristics are essential in the port efficiency.

2.2. Multi-Criteria Decision-Making

To analyze port performance other authors opted for a multi-criteria analysis, which consists of explicitly evaluating several criteria [11]. There are several multi-criteria analysis methods available. Among the most used methods in seaport performance evaluation: The Analytic hierarchy process, the Evidential Reasoning, and the fuzzy technique. Wan and all [12] developed a performance hierarchical model composed of four dimensions: infrastructure, operation, development, and finance, using AHP and ER. Ramachandran and all [13] proposed a strategy performance system using a fuzzy logic analysis. They take into account different characteristics such as less competition, social character, more focus on fulfilling its mission, and achieving long-term financial results, which is the main strategic objective of the public sector. Always using fuzzy logic, Allahverdiyev [14] showed the importance of taking into account the technological criterion to strengthen the coordination between the car and its environment

Other authors have opted for the concatenation of the two methods, Ha and all [15] used analytic hierarchy process with fuzzy logic for port performance prioritizing. They applied it to analyze the Busan ports. Su and all [16] establish also a comprehensive performance system by using the Balanced Scorecard, and by selecting 31 performance measuring criteria. Then they compare three commercial ports in Taiwan through the methodologies of AHP and fuzzy set theory.

Still using the Fuzzy-AHP Diaz and all [17] proposed a classification method for container terminals. They concluded that automation characteristics are a very important criterion in the classification. Dongni and Yifei [18] classified seaports using a clustering methodology. They proved the importance of the port city, infrastructure, operation, and environmental level as a port performance criterion.

2.3. Other Approach

There are other approaches less used in the literature than the approaches already mentioned. Among these approaches, the K-means approach. Azzam and all [19] used it to analyze and process data from 3685 ports and using 25 dimensions. They have developed a new global classification model according to 13 dimensions. Othman and all [20] used a qualitative approach to redefine a new classification of Malaysia seaport, composed of primary, secondary, and tertiary ports. While a holistic approach was used by Vaggelas [21] to examine shipping lines and port users' perceptions of port performance. Then he developed a port performance tool, that offers seaport authorities the flexibility they need for personalized approaches.

There is also the exploratory factor analysis that Muangpan and all [22] used to select the sustainable port indicators and test them in Thailand seaports. They classify these KPIs into four groups, where social aspects group and economic aspects group are considered as most important ones, whereas the environment aspect group and organization management aspects group are the preferable ones. The Delphi analysis used by Chen and all [23] to analyze Chinese ports. Selected a set of green performance indicators. Finally, the bottom-up and top-down approaches used by P. Antao and all [24] for depth analysis of indicators. To identify a set of indicators belongs to Health, Safety, Security and Environmental dimension. Table 1 presents a summary of these methods with the used family of indicators. Without forgetting the criterion energy efficiency who gained prominence in recent years. Sezgin and all [25] has shown the importance of these indicators following its evolution in the Turkish airport.

3. AS CONCEPT AND REQUIREMENT

The concept of AS needs to be clarified in order to assess its impact in seaport and analyze the ability of the port to accommodate it. An AS operates autonomously or remotely from the control center on land, without a crew on board. They offer the promise of economic, ecological and social sustainability while improving safety, reducing costs by removing the human element on board ships. Shortly, these ships will sail alongside CS, and any port wishing to remain competitive in the future must be able to accommodate and integrate these autonomous ships into its logistics chain and without affecting the performance of these autonomous ships. In [26], the author explain that the ship expected to be autonomous are bulk carriers. In fact, this ship requires a little human intervention and supervision throughout the trip and they have one loading and discharging port. While, in [27] Sakhi and all, shows that the bulk carriers can be autonomous in the first position, followed by general cargo ships, container ships and finally RO-ROs without passengers on board.

In fact, the automation of ships must be done step by step. According to [28] ships will transit from the current degree of navigation automation to fully autonomous navigation according to seven levels of automation. Dnv Gl [29] proposed a model from five levels. Imo [30] define just four degrees of autonomy. While [31] proposed a model from three levels of automation. In addition, for every level, Authors described the technological change and the new method of operation for maritime operations. All authors precise that the control level of AS should modified during navigation according to the situation. This evolution of ship automation will stimulate a flow of innovations in seaport that will radically change global shipping. These innovations can be achieved in small stages, and requires significant investments from port system stakeholders and ship owners. According to [32] Autonomous ship technologies are necessary to enable ships to operate independently, both individually and as a group. Based on this study, and using the technology readiness level, authors identified 11 future scenarios of autonomous ships.

Table 1. A Summary of some classification method and families of indicators used

Reference	Approach	Family of indicators
[11]	DEA	Logistic Chain and Operational
		Infrastructure and equipment
		Financial indicators
		Environmental Indicators
[16]	DEA Inverse	Infrastructure and equipment
		Logistic Chain and Operational
		Financial indicators
		Environmental Indicators
[14]	DEA-CCR and DEA BCC	Infrastructure and equipment
[17]	SFA	Infrastructure and equipment
		Logistic Chain and Operational
[9]	Technical efficiency TE by SFA	Infrastructure and equipment
		Communication system
		Logistic Chain and Operational
[3]	Analytic hierarchy process AHP-ER	Logistic Chain and Operational
		Infrastructure and equipment
		Financial indicators
		Automatization and new technology
[5]	AHP-fuzzy technique	Logistic Chain and Operational
		Human capital
		Financial indicators
		Communication system
		Safety and Security
		Environmental Indicators
		Human capital
		Customer indicators
		Safety and Security
		Environmental Indicators
[18]	k-means	Infrastructure and equipment
		Logistic Chain and Operational
		Communication system
[22]	Delphi technique	Environmental Indicators
[21]	Exploratory factor analysis	Environmental Indicators
		Human capital
		Infrastructure and equipment
		Safety and Security
		Financial indicators
		Environmental Indicators
[20]	Holistic approach	Logistic Chain and Operational
		Infrastructure and equipment
		Automatization and new technology
		Safety and Security
[33]	A literature review/ industry current practices	Logistic Chain and Operational
		Human capital
		Financial indicators
		Human capital
		Environmental Indicators
		Governance Indicators
[23]	Bottom-up and top-down approach	Safety and Security
		Environmental Indicators
		Logistic Chain and Operational

4. STUDY APPROACH AND MATERIALS

To classify the Moroccan ports and determine the most suitable port to accommodate autonomous ships, the following study approach presented in Figure 1 has been adopted: Step 1: Choice of indicators which allow assessing the suitability for the implementation of AS by an analysis of the literature. Also, by carrying out a set of visits to Moroccan ports and interventions with maritime experts. Step 2: determining the list of Moroccan ports to be studied and collecting data from annual statistical reports for the period 2017-2019 and dashboards from the official website of the ANP, TMSA, PORTNET, and the Ministry of Equipment, Transport. Step 3: Processing, analysis, and standardization of the data collected. Step 4: Choosing an unsupervised classification algorithm using SPSS MODELER. Step 5: Analyze and process the classification results to resolute the port most likely to accommodate AS.

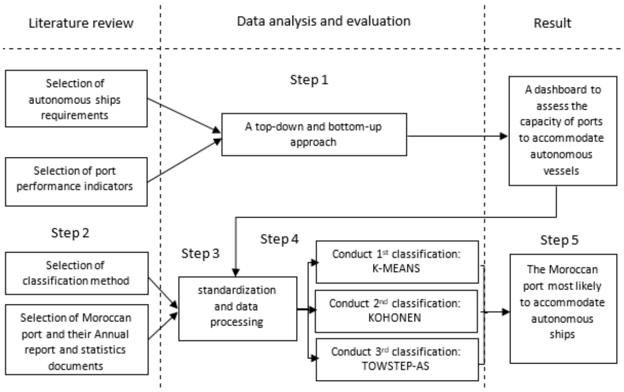

Figure 1. Diagram of the study approach

5. RESULTS AND DISCUSSION

5.1. The Performance Analysis Model

To choose the indicators to use in this study. An analysis of the literature is essential while using the top down and bottom-up approach. Indeed 441 indicators are collected through the analysis of 125 articles and by the application of a set of filters. The first filter aims to remove old articles dating back more than 5 years, which do not take into consideration the current issues. The second filter aims to eliminate the indicators which have complicated formulas and which do not have a clear definition to facilitate their integration. Then an analysis of the frequency of use of each indicator is carried out in order to select the most used indicators and group them into families.

This analysis identified 11 families: Infrastructure and equipment, finance, Chain and Operational Logistics, automation and new technology, human capital, governance, safety-security, communication system, environment, and Port city development. The second approach, the top down, allows breaking down and analyzing the concept of the autonomous ship in order to select the axes on which the indicators should focus. Therefore, a new list of well-selected 30 indicators according to our subject of study has emerged. It is made up of four families of indicators. The four families and the 30 indicators selected are presented in table 2 with a definition of each indicator and with a comparison of the importance of each indicator for conventional ships as well as for AS.

Table 2. A comparison of each indicator importance for AS and CS ((+) Important, (-) not important)

Indicators	Definition	CS	AS
Port services and infrastructure			
Geographic positioning	The situation of the port in relation to major traffic flows. The best-placed ports are those located on the very edge of major maritime traffic axes, at the ends of the main oceanic traffic currents, on the shores of busy seas, at peninsular points and on the shores of straits and inlets.	-	+
Port size	The overall area of the port	+	+
Number of cargo handling equipment	The number of loading / unloading and freight transport equipment at berth	+	+
Cargo storage facility	The number of storage equipment	+	+
Total throughput	Port throughput present the number of ships that port handles per annum	+	+
Throughput growth	Throughput growth rate per annum	+	+
Vessel call size growth	Vessel call size rate per annum	-	+
Intermodal connectivity	The number of modes of transport available in the port to move merchandise without loading or unloading cargo	+	+
Down time in port	The total stopping time of the vessel at berth	-	+
Communication System and new technologies			
Availability of communication carried	Is the ratio of the (t) values to the total time A= Up time / (up time+ Total time) (1)	+	+
Reliability of communication carrier	The probability that a communication carrier will perform the data exchange function, under stated conditions, for a stated period.	+	+
Variety of offered communication carriers	The number of communication systems available	-	+
Communication rate	Expressed Kbyte per second (Kbps)	-	+
Communication capacity	Is the Kbyte capable to transfer and is expressed in KB	-	+
Communication security	Its capacity resilience against no authorized intrusion and cyber-attack.	-	+
Communication cost	The price in $ of a Kbyte transferred	-	+
Budget allotted for new technology in %	The budget devoted, adopting new technologies in%	-	+
Response to innovativeness	The existence of a research and development service in the port or the existence of collaboration with innovative companies or schools	-	+

Government support	The port has government support or not	-	+
Automatization equipment in port	The level of equipment automation in port facilities "automatic, semi-automatic, manual"	-	+
Safety and security			
Adequate monitoring/threat awareness	The number of actions carried out in the port to predict and stop threats	+	+
Investment in protection	The budget devoted to port protection in%	-	+
Safety/security officers and facilities	The number of means / facilities used to ensure safety and security in the port	+	+
Accidents	The number of health accidents in the port per annum	-	+
Port safety policy	The existence of a port security policy	+	+
Port security incidents	The number of security accidents in the port per annum	+	+
Human qualifications			
Knowledge and skills	The number of employees with technical and IT training in%	-	+
Training and education	The number and type of training sessions carried out per annum	-	+
Employee satisfaction index	The number of satisfied employees in their job.	-	+
Employee turnover in port	The number of employees who leave an organization during a specified period, typically one year.	-	+

5.2. Moroccan Ports Selections

The Moroccan maritime sector constitutes a strategic sector thanks to its strong participation in the national GDP and the volume of jobs that it generates. It contains 13 ports open to foreigners. The study focuses on ports whose activity is containers, solid bulk, and general cargo, as these are the potential activities for autonomous vessels. Therefore, the ports subject of study is indeed those, with a total greater than or equal to one, namely port of Nador, Tangier-Med, Casablanca, Jorf-Lasfar, Safi, Agadir, Laayoune, Dakhla. The port of Kenitra is eliminated, as it is no longer active. Table 3 presents results of this analysis.

Table 3. Classification of Moroccan seaports according to their activities

Moroccan seaport	Traffic			
	Container	Solid bulk	General cargo	Total
Nador	1	1	1	3
Tangier Med	1	1	1	3
Casablanca	1	1	1	3
Kenitra	1	1	1	3
Mohammedia	0	0	0	0
Jorf Lasfar	0	1	1	2
Safi	0	1	1	2
Agadir	1	1	1	3
Tan-Tan	0	0	0	0
Laayoune	1	1	1	3
Dakhla	0	0	1	1

5.3. The Classification Algorithm Comparison

The K-MEANS, KOHONEN, and TOWSTEP-AS test of the SPSS modeler software are used to classify the eight Moroccan ports. Processing, homogenization, and standardization of the data are carried out in order to have a reliable classification. The simulation model is presented in Figure 2.

A comparison between these classification algorithms is made based on the quality of the silhouette. Indeed, the quality of the overall silhouette is a measure of the cohesion and the separation of the cluster "-1 to 0.2 mediocre / 0.2 to 0.5 suitable / 0.5 to 1 Good". Several tests using different cluster values were implemented. The first two-cluster test, followed by three, four, five, and six clusters. The results of K-MEANS showed that after a test with more than four clusters, the quality fall.

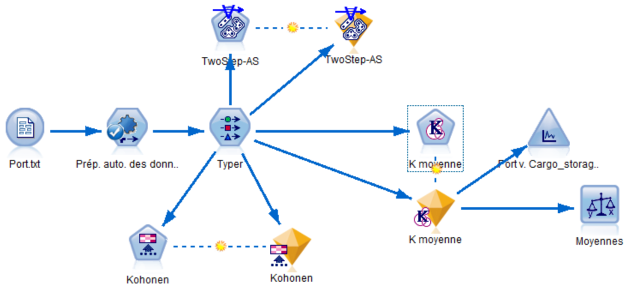

Figure 2. The simulation model

The KOHONEN allowed having six clusters with a silhouette quality of 0.8. For TOWSTEP - AS, the results show that after a test with more than 3 clusters, the quality decreases and did not add new clear clusters nor gave strong justifications for grouping. Table 4 summarizes the different algorithms used with the variation of the cluster numbers and the quality of silhouette generated. This comparison shows that the K-MEANS and KOHONEN algorithms have the best figure quality, namely 0.8. However, the K-MEANS algorithm made it possible to achieve this quality of silhouette with a minimum number of clusters 4 against 6 for KOHONEN. Therefore, the selected model is the K-MEANS with four clusters.

Table 4. A comparison of classification algorithms

Algorithms	Number of Clusters	Quality of silhouette
K-MEANS	2	0.5
	3	0.6
	4	0.8
	5	0.6
KOHONEN	6	0.8
TOWSTEP-AS	2	0.32
	3	0.31

Four different clusters were provided by the K-Means simulation Figure 2. The first cluster consists of five ports, namely the port of Nador, Safi, Agadir, Dakhla, and Laayoune. The second cluster contains Tangier Med port. The third Cluster contains Casablanca Port and the final cluster comprises the port of Jorf Lasfar.

These results are obtained after a first iteration with an error of 1.432. Despite the clearly distinguishable clusters, there are some similar factors with the same average between the four clusters. Therefore, these factors were removed to facilitate the analysis, while considering effect of these factors on port classification.

Algorithm	K-means
Inputs	21
Clusters	4

Iteration	Error
1	1.455
2	0

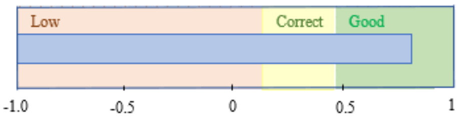

Figure 3. A summary of the model

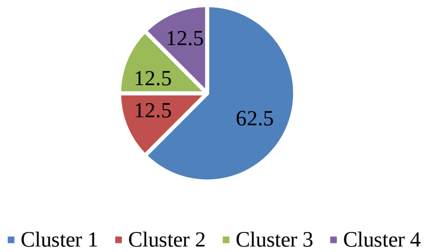

Figure 4. Clusters sizes

5.4. Cluster Taxonomy

The cluster performance classifications are related to the performance of each port within this cluster. A cluster performance table for each indicator family is established in Table 5. The first cluster contains five ports. These ports, mainly suffer from a weakness in port infrastructure: small-sized ports with limited handling and storage means. The use of new communication systems and new transport and handling technologies also remains limited. Therefore, a limited capacity to handle huge ships and especially autonomous ships that require a high technological level. However, these ports have a good level of port safety and security and invest in staff training. Therefore, the performance of these ports is low to medium.

The second cluster contains the port of Tangier Med. This port is characterized by very high port infrastructures and human qualifications. It is able to manage large ships with very high quantities of goods and with a competitive dwell time. In addition, this port invests in the development of human skills. It has a good level concerning the port security and technological investments axis. Therefore, the performance of this port is high to high+.

The third cluster, which contains the port of Casablanca, had a high port performance. Indeed, this port is characterized by better port infrastructure, it is the second major port after Tangier Med and it contains a large number of handling means, which allows it to manage a large number of goods simultaneously. Thus, by a good level of the safety and security axis and human competence. However, investments in new communication, transport, and handling technologies remain poor.

The fourth cluster contains the port of JORF LASFAR. This port is characterized by a good level of port security and safety as well as human skills. However, the port infrastructure, the level of service remains to be improved. As well as investments in new communication technologies. This is why this cluster had a medium port performance.

Table 5. Cluster performance for each family of indicators

Family of indicators	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Port services and infrastructure	Low	High+	High	Medium
Communication System and new technologies	Low	High	Low	Low
Safety and security	Medium	High	High	High
Human qualifications	Medium	High+	High	High
Cluster performance	Low to medium	High to high+	High	Medium

5.5. Port Suitable for Implementation of Autonomous Ship

According to the K-MEANS classification and the analysis of the performance of each cluster, the first port is Tangier Med port, the secondly: Casablanca port, third: the Jorf Lasfar. Finally, the port of Nador, Safi, Agadir, Dakhla and Laayoune. Therefore, the Moroccan port most likely to accommodate autonomous ships in the future is the port of Tangier Med. This port had the best scores in the different families of indicators. It is characterized above all by a very important geographical position, which promotes its transshipment activity.

Therefore, future autonomous ships will want to make stopovers in this port. It is also the largest port in terms of size with significant handling equipment and with very significant national and international connectivity. This port is also characterized by their qualifying human skills, more than 40% of employees are managers with technical training. Note that it is part of a versatility policy, through the diversification of training. The port devotes more days of training to the following areas: management of port operations, port information systems, and legal management considered as important areas for seaports that wish to receive AS. These investments and their implications in terms of port safety and security as well as in terms of the implementation of new communication technology are present by significant budget allocated.

However, to accommodate autonomous ships, more effort is required on the level of two axes: communication systems and new technologies and the safety-security axis. Indeed, the port must lean towards the automation of handling and transport equipment in order to be automated such as the ports of Germany, and the Netherlands. This promotes the economic aspect by increasing the port service rate as well as the social aspect by eliminating manual and repetitive operations. More research and development are also required to improve the means of communications because the evolution of navigation and electronic communications technology has real potential for the monitoring, management, and control of ships remotely.

6. CONCLUSIONS

Before that autonomous ship begins to be fully used in commercial operations, seaports must be able to accommodate this type of vessel. This article made it possible to define a dashboard made up of 30 indicators to assess the ability of a seaport to accommodate autonomous ships. Then, this model was used to classify the eight Moroccan trading ports, using SPSS Modeler's K-MEANS classification algorithm. This classification showed that Tangier Med is the port most likely to accommodate autonomous ships while revealing the axes that require more reinforcement. The perspective of this work is the proposal of a Moroccan port model where autonomous ships represent an essential component of its logistics chain

NOMENCLATURES

1. Acronyms

AS	Autonomous ship
CS	Conventional ship
MCDM	Multi-criteria analysis decision
DEA	Data envelopment analysis
SFA	Stochastic frontier models
AHP	Analytic hierarchy process
ER	Evidential Reasoning

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