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Designing of An Integrated Port Development Planning Model: Application to The Three Main Cameroonian Ports

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ABSTRACT

The Chad and the Central African Republic countries threatened to find an alternative to Cameroon's ports because of the low accessibility and inefficiency of these ports. The objective of this study in its relevance is to characterize the current hinterland of Cameroonian maritime ports, to analyze the dynamics of the flow of goods in the port hinterland of Cameroon, and to make recommendations for improving the National Port Master Plan to guarantee the increased development of Cameroonian maritime ports. The Huff model integrated into the Spatial Interaction Model (SIM) is used to geographically delimit the economic hinterland of Cameroon's seaports. The results of the study highlight two key points: (1) the significance of integrating the development of Cameroon's port hinterland into the national port planning strategy to enhance the growth of the country's maritime ports. (2) Each port in Cameroon should pay more attention to the expansion of the hinterland. This study introduces methods integrating the SIM approach for practical hinterland exploration with the Bayesian model and mutual information for analyzing hinterland needs. Additionally, it offers recommendations for a seaport development planning model. This article broadens the use of the SIM Bayesian model with mutual information, which can easily be adapted to other scenarios.

1. INTRODUCTION

1.1. Context and problem

Despite the efforts made by the Cameroonian Government a few years ago, Cameroon's seaports are encountering enormous development difficulties on the world maritime scene [1]–[5]. Chad and the Central African Republic (CAR), landlocked countries, still represent 50% of the Port Authority of Douala (PAD)'s activities, or about half of PAD's turnover [6][7]. In 2018 and 2020, these two countries threatened to find an alternative to Cameroon's ports. Given the imminent presence of new port offers, such as the construction of a dry port between Adré and Abougoulème in eastern Chad and the construction of a new Container Terminal by the company Africa Global Logistics (AGL) on the East Mole of the existing Terminal at the port of Pointe-Noire, a first worrying question that arose was what would happen to Cameroon's economic situation if Chad and the CAR were to leave Cameroon's seaports? To this concern, the question arises as to whether the National Port Master Plan of Cameroon meets the needs of the Cameroonian port hinterland.

Addressing this issue involves three primary objectives: first, to define the current hinterland of Cameroon's maritime ports, specifically Douala, Limbé, and Kribi; second, to examine the dynamics of goods flows within these port hinterlands; and third, to propose recommendations for enhancing the National Port Master Plan to support the further development of Cameroon's maritime ports. The research scope covers all ECCAS member countries, including Nigeria. The study focuses on the relations between these countries and the principal naval ports of Cameroon: the port of Douala, the port of Kribi, and the port of Limbé.

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This work is subdivided into five main parts: the introduction, the research methodology, the presentation and discussion of the results, recommendations for improving the National Port Master Plan of Cameroon, and the conclusion.

1.2. Literature review

Many researchers have made different attempts to study port hinterland demarcation methods with different objectives. Li and Tang (2014) examine a taxonomy of hinterland division methods, giving their different limitations [8]. Namely, simple division methods consider only one factor: the administrative division method, the economic division method, the graphical method, the analytical method, the circle method, the point axis method, the location potential method, and the location quotient method.

Then, the complex division methods consider several factors: the breaking point method, the power outage model method, and the gravitational model method. The administrative division law and the economic zone law can quickly determine the port's hinterland. Still, the boundaries of the indirect hinterland determined by this method are unclear. There will be many intersecting hinterlands, which cannot reflect the interaction between the port and the hinterland.

The graphical method only considers transport lines. Although transport lines play a crucial role in the relationship between the port and the hinterland, using simple drawing methods such as bisector or vertical bisector to divide the port hinterland directly is not appropriate. It completely ignores the limits of natural conditions and influences other factors such as cargo type, cargo volume, transportation cost, transportation mode, and level of regional economic development. Likewise, the analytical approach only considers cost factors and does not reflect the impact of other factors in the interaction between the port and the hinterland.

When using the circle method and point axis method to divide the hinterland of ports, there is a problem of fuzzy boundaries. In particular, the circle method will lead to severe overlaps in the hinterland of relatively dense port groups. The basic ideas of the location potential method and the location quotient method are consistent; both obtain a specific value by quantitative calculation and have a particular scientific and practical significance. However, these two methods still have some shortcomings: in the process of calculating volume, the location potential method only takes into account the size of the trading volume, and the location quotient method only takes into account the size of the cargo volume, without taking into account the influence of other factors such as the port's capacities, collection and distribution conditions, both of which are relatively one-sided.

Although the breakpoint method has enabled the practical application of the break bridge theory in the port hinterland division, the factors considered are still limited, and it is difficult to determine the fuzzy area at the boundary of the ports. Two port hinterlands. In contrast, the breakdown model division method is more complex. It introduces the electron cloud model, which is somewhat innovative, and the results obtained are more convincing than those obtained using the circle method [8]. However, combining the electron cloud model with the breakpoint theory cannot effectively fill the shortcomings of the breakpoint model, and it still cannot improve the boundary ambiguity. Furthermore, the link between the two is not very close, and the electron cloud model does not play any role; it serves as a reasonable basis.

The gravity model considers more comprehensive factors, integrating not only the port's capacities but also the role of cargo type and transport distance [8]. It presents specific feasibility but still shows shortcomings: on the one hand, with the continued development of the logistics sector, transport distance is no longer the only factor taken into account by goods owners: the cost of transport, time cost, and quality of service will affect the entire route choice; On the other hand, the conclusion drawn from the division of the gravitational model is that the port hinterland with a smaller “mass” is a regular circle that ignores the limits of natural conditions and separates the integrity of the city.

Considering the limitations of the gravity model, Jiang and Zhang used the Huff model to comprehensively assess the two modes of road and rail transportation from the three perspectives of transportation: distance, freight, and transport. Transportation time, and determine a relatively reasonable mode of transportation [8]. The Huff model has demonstrated accurate results, making it particularly famous in the port hinterland division.

They generally reviewed all these existing models and demonstrated their limitations [8]. To remedy this, they introduced an appropriate method that can comprehensively take into account the main factors affecting the division of the port hinterland and make further attempts to achieve an accurate division of each port hinterland for the future development of the port: “The hinterland plume model for port hinterland division.” It is derived from the atmospheric Gaussian plume model, an environmental model based on physical processes, confirmed by wind tunnel experiments and widely used.

A researcher demonstrate in their publication that the port hinterland can be modeled with the solution of the “port choice problem” [9]. They build a “hybrid model” combining the Mixed Integer Programming method (MILP) and the Analytic Hierarchy Process (AHP), and they use GIS technology to visualize the results.

More recently, the Huff model was used for its application in the context of the analysis of port competitiveness in the Gulf of Guinea port group [10]. Traditionally, a traditional theory for examining the port-hinterland relationship has been the spatial interaction model (SIM), which is represented by the gravity model and the Huff model [10]. More and more research is including the domestic transportation network in the spatial interaction model as geographic information systems (GIS) advance [10]. These methods show the high availability of GIS technology in investigating port-hinterland linkages and fully account for the inequality of the inland connection in the spatial interaction model.

These situations, however, are found in East Asia or Europe, which have excellent transit systems. However, low-income areas with inadequate transportation infrastructure development cannot benefit from the network analysis method based on the vector model, which has been widely used to study accessibility [10]. They combined the raster and vector models to examine the effects of intermodal corridors on the development of the Gulf of Guinea port group's hinterland, taking into account the benefits of the raster model in this particular context.

The Huff model's theoretical and practical effectiveness has made it one of the most widely used methods in research [10]. But it simply simulates shippers' discrete port selection. In general, using this approach directly to examine hinterland competitiveness is challenging. However, the situation in Africa differs significantly from that in Europe and Asia. One of the world's least developed regions, Sub-Saharan Africa, is home to the Cameroon ports scenario we are examining [10]. This distinctive feature poses two difficulties for our study. First, it is challenging to identify the hinterland using measured traffic flow because of the absence of Origines/Destinations data and performance indicators. Second, it is difficult to use a network model to examine hinterland accessibility due to the inadequate local inland transit infrastructure. In their paper, [10] suggested a two-step approach. Initially, the GIS raster model was used to facilitate the development of the Huff model. Second, "penetrative power" was applied to studying hinterland competitiveness. Using this approach, they defined the Gulf of Guinea port group's hinterland rivalry and distinguished between the individual ports' contestable and captive hinterlands. These studies allowed for the extension of the Huff model's use in addition to clarifying the current state of hinterland competition in the Gulf of Guinea port group.

Due to the complex interactions between various cargoes and a wide range of contributing factors, port traffic analysis is challenging [11]. Due to challenges in identifying the primary cargo, figuring out exogenous and endogenous variables, and their intricate causal linkages with cargoes, demand analysis may produce an unclear result [11]. According to [11], who remark on these variables in their article, port traffic and macroeconomic variables should be related because economic development is a significant driver of marine trade [12].

They emphasize that the flow of goods is increasingly linked to population, trade, global economic activity, fuel and energy prices, competitive position, and market share, the national logistics system and the supply chain, technological developments, and government policies. In their discussion, they testify that Fankel (1987) emphasized that in-depth knowledge of the hinterland is fundamental before analyzing port traffic. They noted that the analysis of goods flows should begin with characterizing the hinterland, which revolves around the port studied [13]. Based on this discussion, there are many factors to consider when analyzing port traffic. However, considering every variable is neither required nor feasible (because of the small amount of data) [11]. High false dimensionality and multi-collinearity can cause many issues when there are a lot of exogenous inputs.

While [14] criticized JICA for utilizing improper factors in their study, JICA employed population and GDP variables in 1994 to assess and forecast container port traffic using a regression model [11]. They remark that they forecasted port traffic using several macroeconomic variables but did not explain why they chose those variables.

Managing uncertainty and the abstraction of the concept of information is a key idea in information theory. They recommend a methodology called the analysis of mutual information as a solution to the challenge of determining and defending the factors that account for port traffic [11]. They show that forecast models become more reliable when mutual information is applied because it considers model uncertainties. The mutual information technique finds crucial variables that should be included in Bayesian models, improving the accuracy of model findings.

Port traffic has previously been predicted using a variety of time series models. The moving average is a straightforward time series model that forecasts future values using patterns in historical internal data [15][16]. However, this model was critiqued for inadequate simplification for (long-term) port traffic forecasting since it assumes a static environment devoid of information from external factors. Regression models are used to predict container traffic [17].

The authors used the occasion to restate the necessity of stationary regressive variables. They also point out that in the context of port traffic forecasting, if a non-stationary time series exhibits a random walk, the model's ability to incorporate the impact of a transient macroeconomic shock is constrained [14], and/or the shock does not fade with the time series [16].

It has been argued that a vector error correction model with no theoretical foundation is purely mathematical [15]. For multivariate forecasting models where macroeconomic variables are defined by stationary time series [15] and have a real long-term relationship with port throughput [16], vector error correction and its alternative error correction are appropriate [17]. If the observed data has a seasonal trend and the seasonal component has a multiplicative or additive trend, port traffic can be predicted using a time series decomposition model [18].

Forecasts of medium- to long-term port traffic are best suited for this model. Owing to the drawbacks of time series models, recent research has turned to software computing models such as fuzzy logic, genetic algorithms [19], artificial neural networks [14], transfer prediction models [15], artificial bee colonies [20], and ant colony algorithms [15]. Because of their unpredictable nature and nonlinear properties, these models simulate complicated processes that are impossible to describe mathematically [21].

These models hypothesize the relationship between port traffic and one or more independent factors. Non-stationary data can be handled by an artificial neural network [22]. Because the artificial neural network successfully captures the intricate correlations (both linear and nonlinear) between macroeconomic variables and port throughput, this method outperforms standard methods in predicting [14][23]. However, to produce accurate and trustworthy results, artificial neural network models need significant input data during the training and learning phase [23]. Models frequently have too many variables because of their intricacy and black-box nature [22]. Expert judgment is the primary determinant of qualitative approaches [12].

Rating scales, analog, Delphi, leading indicators, diffusion, performance appraisal review approaches, surveys, interviews, direct observation, and written documentation are some of the strategies used in these procedures [15]. Qualitative models are employed when data is sparse, ambiguous, or unavailable. However, these models' outcomes are subjective and susceptible to (cognitive) bias because they are based on expert opinion, knowledge, and experience [17]. A single model is frequently insufficient and can result in faulty forecasts because of the diversity of the numerous impacting elements [15].

Combining two or more models to synthesize their knowledge, hybrid (or joint) models leverage each model to improve forecast accuracy and produce more stable outcomes [16]. When it's unclear whether the model will make the most accurate forecast, hybrid models can be helpful [18]. However, caution was made that when using hybrid models, it is essential to choose each model carefully as each has a unique influence and raises the uncertainty of the outcome. Conversely, hybrid models may become more complex, redundant, and computationally demanding when numerous models are used [15].

Additionally, even with the advancements in forecasting techniques, port authorities still face difficulties in accurately interpreting the results and effectively communicating them to stakeholders about the selection and use of appropriate forecasting techniques. Time horizon might further influence the forecasting method, and port authorities should deal with uncertainties, including opportunities and vulnerabilities, in strategic planning [15].

In light of this, a methodology for handling uncertainty in the port planning process aims to manage vulnerabilities and take advantage of opportunities at various port plan time horizons offered by [15]. They point out that the time horizon can influence the forecasting approach and the degree of uncertainty.

There has always been epistemic uncertainty in port traffic forecasting models because of the lack of knowledge about model components and complicated, partially understood causal relationships. Many macroeconomic variables frequently include little data, the modeling technique used, the assumptions made, and the required simplifications [15]. The unavoidable epistemic uncertainty must be taken into account in order to improve the dependability of forecast findings. Ship emissions, shipping accidents [15], the resilience of deep-water port infrastructure [19], ship emissions [15], port variable classification, and enhanced forecast accuracy are just a few of the areas in which the Bayesian method has been applied in the literature.

Research on hinterland spatial rivalry in Europe and East Asia is generally growing, but little attention has been paid to the situation in central Africa. More realistic methods are required to portray the imprisoned and contestable hinterland of the Cameroonian ports due to the dearth of fundamental data and the intricacy of the rivalry. Additionally, the Bayesian approach has been applied in the literature in a variety of domains, such as ship emissions, shipping mishaps, inland waterway port resilience, deep-water port infrastructure resilience, and port variable classification [24]–[27]. However, there aren't many scientific publications or commerce flow forecasting organizations that use a Bayesian approach to predict port throughput.

1.3. Value of research

In addition to what was said in the paragraph above, the contribution of this article is multiple. Firstly, given the rarity of similar studies in Africa, this research aids local stakeholders in making informed decisions regarding port development and planning for both ports and their hinterlands. Secondly, this article proposes practical methods combining, on the one hand, the SIM with the power of penetration in the search for the hinterland. Thirdly, this paper's theoretical contribution is the development of a robust port throughput forecasting model that takes into account epistemic uncertainties, such as model uncertainties (variable selection, assumptions, and procedures) and parameter uncertainties (quantity and quality of data used). The model is based on the influencing macroeconomic variables. Additionally, the paper's managerial contribution consists of developing a trustworthy framework for port throughput forecasting that can assist Cameroonian port authorities in rationalizing their investment choices based on future demand, preserving their ports' competitive edge, and expanding their market share.

2. METHOD

2.1. Characterization of the port hinterland of Cameroon.

The characterization method will consist of delimiting the geographical extent of the port hinterland of Cameroon, identifying the economic activities generating port traffic in Cameroon, and highlighting the state of connectivity of Cameroonian seaports [28]–[31].

To geographically delimit the port hinterland of Cameroon, the technique utilized by [10] in their investigation of the competitiveness of the Gulf of Guinea port group is the Spatial Interaction Model (SIM), which is based on the Huff model and penetration power [32][33]. In his research, [10] have established that this model is predicated on two fundamental assumptions: (1) Shippers' subjective willingness is the basis for the hinterland capture scope. (2) Shippers always select the cost path or route (i.e., the path with the lowest cumulative cost) as the transportation route between a particular origin and destination because they are logical individuals and base their port selection judgments on the utility of cargo transportation options. These presumptions allow for the following formulation of the model:

$$P_{ij} = \frac{A_j^{\gamma} D_{ij}^{-\lambda}}{\sum_{j \in J} A_j^{\gamma} D_{ij}^{-\lambda}} \tag{1}$$

Where i,j ($i \in I, j \in J$) = location point of the hinterland and the port ;
P_{ij} = The probability that shippers or loaders are located at the location I will choose port j for the transportation of goods. That is, the competitiveness of Port J at location i;
A_j = Attractiveness of the port j;
D_{ij} = Transport accessibility between location i and port j ;
λ = Parameter measuring the sensitivity of senders to accessibility D_{ij} ;
γ = The parameter measuring the sensitivity of senders to attractiveness A_j.

It should be mentioned that the variable. P_{ij} Represents both the competitiveness of the port at location j and the likelihood that shippers from location i will select port j. The accessibility (D_{ij}), which will be thoroughly explained in the following section, is calculated using the raster model in order to increase the precision of spatial analysis [34][35].

The resolution process corresponds to the following three steps:

Step 1: Calculation of port attractiveness
Port attractiveness is determined by a scheme expressed in traffic [36]–[38]. That is, in the case of our research, the annual port container traffic is considered the leading indicator reflecting port attractiveness.

Step 2: Port-Hinterland accessibility calculation
The accessibility between the port and the hinterland is measured using the generalized distance depending on shipping time [39]–[41]. The raster GIS model is used to determine the cumulative time between any inland location and the port, and the procedure is dependent primarily on geospatial data of hierarchical road networks [42]–[45]. In particular, it can be broken down into three smaller steps:
(1) Geospatial data import and processing
Significant ports (point), administrative divisions (polygon), and hierarchical road networks (polyline) are among the geographical data needed for this approach. After being imported into ArcGIS, all spatial data will be projected and clipped to the designated range.
(2) The research region will be rasterized and assigned into mass square cells using ArcGIS's conversion tool. These cells are allocated based on the relevant transportation conditions using the reclassification tool, and the precise guidelines are expressed in the equation that follows:

$$t_{cell} = \frac{d_{cell}}{v_{cell}} \tag{2}$$

Where t_{cell} =the dispatch time of trucks passing through the cell unit;
d_{cell} =The size of the cell;
v_{cell} = The speed of trucks in different cells is assigned according to the broad categories defined in Step 1.

(3) Calculation of Port-Hinterland Accessibility
The cost raster database calculates hinterland accessibility (i.e., cumulative shipping time) between any inland point and the port. ArcGIS's Cost Distance tool is used for this procedure.
Step 3: Solution for the Spatial Interaction Model
To determine the competitiveness of any port at any location, the hinterland accessibility and port attractiveness determined in step 2 are entered into formula (1). Python scripting and the ArcGIS Raster Calculator can be used for this operation.
The Cameroon port group's competition hierarchy is divided using penetration power:

$$Z_{ij} = \frac{(P_i)_{max} - P_{ij}}{(P_i)_{max}} \tag{3}$$

Where $(P_i)_{max}$ = the maximum value of hinterland competitiveness of all ports at location i;
Z_{ij} = The relative difference in competitiveness between port j and the maximum location i
if Zij > f, port J is regarded as more competitive in location I and competes in the hinterland.

The updated Huff model was thought to include the parameters γ and λ [46]. Flowerdew & Aitkin (1982) estimated the situation using an origin-constrained SIM (or constrained production model). The identification of activities generating port traffic in Cameroon and the connectivity of Cameroonian maritime ports with their hinterlands will be done using a documentary analysis [47][48].

Identifying projects and development strategies planned for each Cameroonian port is also necessary; this makes it possible to illustrate the actions planned in the SDPN to appreciate their relevance**.** This involves identifying the projects and development strategies planned by the Cameroon National Port Master Plan (SDPN) for the development of Cameroonian maritime ports [49][50]. Analysis of the SDPN is therefore necessary to achieve this identification.

2.2. Analysis of goods flows in the national port hinterland and tourist flows in Cameroon

The analysis of flows (of goods or tourism) will be done using two integrated mathematical models: mutual information and the Bayesian model.

2.2.1. Mutual information

Mutual information is crucial in information theory to handle uncertainties and information abstraction [51][52]. By measuring the quantity of information contained in one variable via another, it assesses the degree of correlation between variables and then ascertains their dependence on one another [53][54]. Information generally refers to how easily unknown outcomes may be predicted using one probability distribution compared to another. The mutual information gives a unique measure of dependence between the two variables, which is also related to the Kullback–Leibler concept of entropy and divergence [55][56]. This model allows for an objective selection of macroeconomic variables, quantifying the relationship between macroeconomic variables (explanatory variables) and port traffic (dependent variable), then determines which macroeconomic factors are important to use as Bayesian model inputs [57][58]. When two random variables (X, Y) have marginal probability distributions μ x (x) and μ y (y), the mutual information calculates the difference between the joint probability distribution m(x, y) and the distribution linked to the case of complete independence using the Kullback-Leibler measure. (i.e. $\mu_x(x)\mu_y(y)$) and is expressed as follows:

$$I(X, Y) = \iint \mu(x,y) \log \frac{\mu(x,y)}{\mu_x(x)\mu_y(y)} \, dxdy \tag{4}$$

Furthermore, mutual information quantifies how informative a random variable (X) is with possible outcomes (x_i), each with probability $p(x)$, could be:

$$H(X) = -\int p(x)\log_2 p(x) \, dx \tag{5}$$

The base 2 logarithm corresponds to the unit of information measured in "bits". Thus, mutual information can be obtained by:

$$\begin{aligned} I(X, Y) &= H(X) + H(Y) - H(X, Y) \\ &= H(X) - H(X|Y) \\ &= H(Y) - H(Y|X) \end{aligned} \tag{6}$$

Where H(X) and H(Y) are the entropy of the random variables X and Y, respectively, H (X, Y) is their ordinary entropy, and H (X|Y) and H (Y|X) are their conditional entropy and calculated as follows:

$$H(X|Y) = - \iint \mu(x,y) \log \mu(x|y)\, dxdy \tag{7}$$

Where the joint probability distribution is denoted by μ(x,y), the degree of uncertainty that remains in X after Y is understood is known as the conditional entropy H(X│Y). Hence, the I (X, Y) is understood from these equations as reducing the random variable X's uncertainty through knowledge of another random variable Y.

2.2.2 The Bayesian model

An effective strategy that synthesizes prior information with accessible data is the Bayesian statistical method, which mixes knowledge about parameters [59]. A posterior probability density in the Bayesian approach is proportional to the likelihood function over the data times the prior probability density [60]–[62]. The inference in traditional methods, like maximum likelihood, is dependent solely on the data and is based on the probability of the coefficients [63]–[66].

The outcomes of mutual information significantly improve the model's accuracy and the forecast findings' dependability [67]–[70]. Therefore, it takes into account the model's uncertainties, (2) it employs a probabilistic method to quantify the uncertainty of the parameters linked to the significant macroeconomic variables by presenting their posterior distributions, (3) the Bayesian model can be modified as new data becomes available, and (4) it can handle uncertain information that is characterized by limited and scarce data [71]–[74].

To use the Bayesian method, the prediction models can be linearized by a simple expression of the form:

$$\mathrm{Log} y_i = C_0 + C_1 x_1 + C_2 x_2 + C_3 x_3 + C_4 x_4 + \cdots + C_n x_n \tag{8}$$

When the annual port throughput is the dependent variable (yi), the macroeconomic factors are the independent variables (x_i), and Bayesian regression can be used to estimate the coefficients C_0-C_n. In other words, a linear regression model can determine the relationship between a dependent variable (yi) and the explanatory factors (xi).

Assume that$y_i = (y_i, \ldots, y_n)$ is a vector of historical data that contains n observations. One way to express the matrix of explanatory variables (X) is as:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1k} \\ \vdots & \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nk} \end{bmatrix} \tag{9}$$

Assuming a conditional normal distribution of the dependent variable (yi), given the explanatory variables (X), the mean of the normal distribution has a linear function as:

$$E(y_i|\theta, X) = \theta_1 x_{i1} + \cdots + \theta_k x_{ik} \tag{10}$$

Where θ = (θ1, …, θk) is a vector of unknown parameters. In other words, the dependent variable follows a normal distribution, $y_i \sim N(X\theta, \sigma^2 I)$ with a mean of Xθ and a variance of $\sigma^2 I$, where I is the n × n identity matrix.

In Bayesian statistics, the posterior distribution describes updated information about the unknown parameter (θ) and can be obtained by multiplying a prior distribution by a likelihood function as follows:

$$p(\theta|y) \propto p(\theta) p(y|\theta) \tag{11}$$

Where $p(\theta)$ is the prior distribution and $p(y \mid \theta)$ is the likelihood function, a probability distribution that expresses the information contained in the historical data.

In this study, the logarithm of the port throughput is assumed to follow a normal distribution curve such that (Eskafi et al., 2021):

$$P\ (y|\sigma^2, \theta, X) = \prod_{i=1}^{N} \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(y_i - (X\theta)_i)^2}{2\sigma^2}\right) \tag{12}$$

Where N is the number of available historical observations, y is the vector of the logarithm of the port throughput data, $(X\theta)_i$ is the i-th element of the vector $X\theta$ representing the mean value of the prediction model, and σ is the standard deviation.

On the other hand, we assume an uninformative prior for the unknown parameters, i.e., $P(\theta, \sigma^2 | X) \propto \sigma^2$. Thus, the joint posterior distribution of θ and σ^2 is given by:

$$P\ (\theta, \sigma^2 | y, X) \propto P\ (\theta, \sigma^2 | X) p(y|\sigma^2, y,\ X) \ \propto\ \sigma^2 \prod_{i=1}^{n} N(y_i | (X\theta)_i, \sigma^2\ ) \tag{13}$$

Equation 10 determines the posterior distribution of the unknown parameters θ. Consequently, the port throughput is simulated using Bayesian posterior inference from the posterior macroeconomic variables.

Documentary analysis will also be the primary tool for analyzing the location of port development projects to hinterland zones. In particular, the analysis of the National Planning and Sustainable Development Plan for the Territory of Cameroon (SNADDT).

The subject of a documentary analysis is also the assessment of the capacity of projects to meet the needs of the hinterland in terms of transport and logistics.

The comparison of existing and planned port infrastructure with hinterland needs in terms of ship types and handling aims to assess the port capacity needs generated in the hinterland. This evaluation will follow an analysis using mutual information and the Bayesian model, as presented in section 3.2.

3. RESULTS AND DISCUSSION

3.1. Characterization of the port hinterland of Cameroon

Considering the difficulty in obtaining the necessary data for implementing the port hinterland delimitation method, the study stipulates that ports whose hinterland competitiveness is greater than 80% of the maximum value will participate in hinterland competition (i.e., f = 0.2).

3.1.1 Geographical delimitation of the port hinterland of Cameroon

The spatial interaction model (SIM) application is based on the Huff model, and the penetration power shows the result obtained in the following figure. Locations, where only one port competes, are defined as the captive hinterland, while locations, where two or more ports compete, are defined as the contestable hinterland (see Fig. 2).

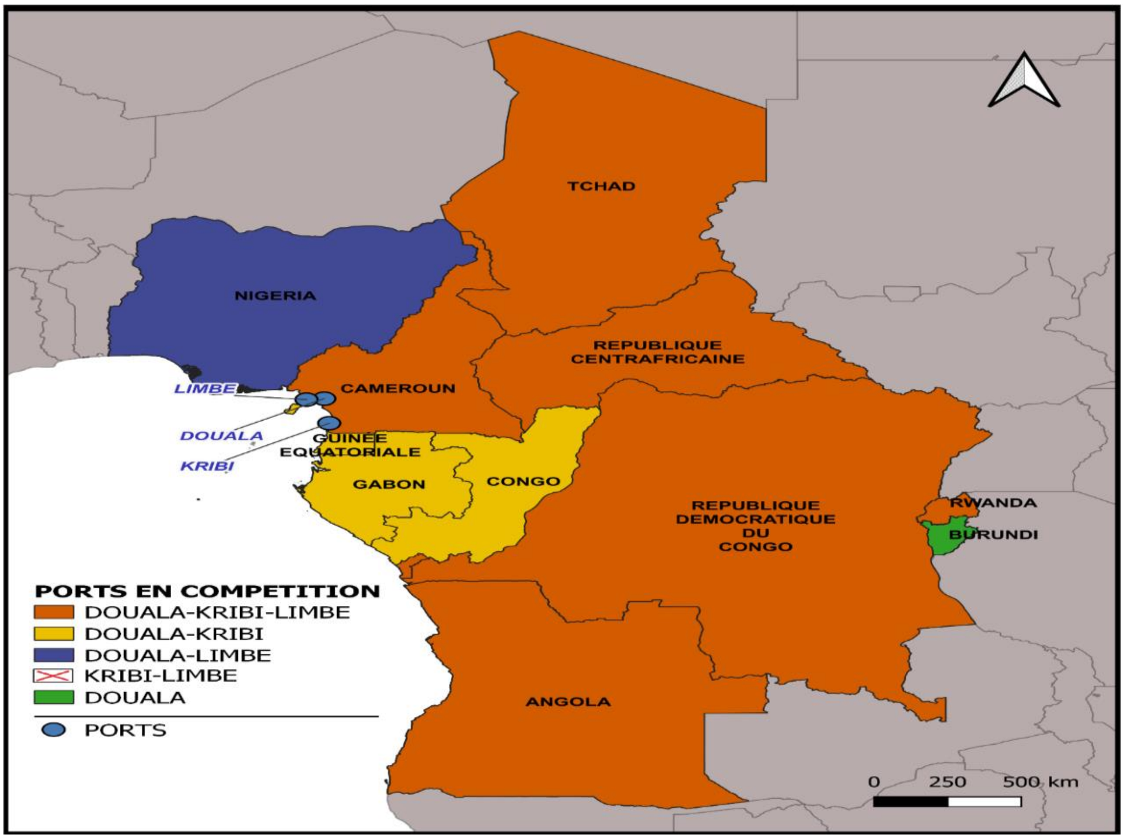

Figure 1. Hierarchical distribution of hinterland competition in the port group of Cameroon
Source: Study,2024

The results of our study show that Cameroonian ports face intense competition from their hinterlands. The contestable hinterland generally holds sway, and competitiveness levels among nations are uneven. On the one hand, landlocked nations like Chad and the Central African Republic face intense rivalry in their hinterlands. The contestable hinterland and the captive hinterland have quite different geographical forms. The port's contestable hinterland exhibits a funnel effect, meaning its spatial reach gradually extends to the far inland (Figure 1). But the hinterland that the ports control is getting smaller inland. While Kribi and Limbé ports have very little captive hinterland, Douala port has a sizable captive hinterland. This conclusion suggests that the relative geographical conditions in the Cameroonian port group significantly impact the port's development. Furthermore, the funnel effect indicates that the growth of the port hinterland greatly depends on the remote interior. The construction of inland transshipment hubs (such as dry ports and inland ports) and intermodal corridors (such as railroads and inland waterways) will assist ports in gaining the hinterland share in multi-port competitive nations.

3.1.2. Identification of economic activities generating port traffic in Cameroon and connectivity

The results obtained previously and the documentary analysis shows that the economic port hinterland of Cameroon includes Cameroon, Chad, CAR, Equatorial Guinea, Gabon, Congo-Brazzaville, and Nigeria. The main activities of the port hinterland of Cameroon include forestry, mining and hydrocarbon exploitation, agriculture, manufacturing industry, and tourism, as well as the importation of goods and equipment, construction materials, food and beverages, and other miscellaneous products. The connectivity of Cameroonian maritime ports is a crucial challenge to overcome for their development.

The insufficiency of data on the port of Kribi for implementing the models presented in Chapter 2 of the methodology and the inaccessibility of data on the port of Limbé forced the study to focus its attention on the port of Douala only.

3.2. Identification of projects and development strategy planned by the SDPN for the port of Douala

The development projects planned for the port of Douala by the National Port Master Plan are:

- Deepening of the port access channel to -8.5 m;
- Ancillary projects: which concern the improvement of land access to the port of Douala for sections of the roads coming from Edéa and Limbé in the peripheral districts of the city.

Given the increasing trend in merchandise traffic at the port of Douala, only the development strategy planned for the port of Douala, which is based on the high traffic hypothesis of the National Port Master Plan, is presented. Table 1 illustrates the forecast development of the port of Douala based on the high traffic hypothesis, according to the National Port Master Plan.

Tabel 1. Forecast development of the port of Douala based on the high traffic hypothesis.

	2012	**2015**	**2020**	**2025**	**2030**	**2035**
Conventionnel	3 à 12	3 à 12	3 à 12	3 à 11	3 à 11	1 à 11
Hydrocarbures	H1	H1	H1	H1	H1, H2	H1, H2
Clinker et Gypse	52	52	51,52	51,52	51,52	51,52
Blé	13	13	13	12,13	12,13	12,13
Alumine et Rentrants	1					
Divers Vracs	1.51	1.51	1	1.2	1,2	53,54
Conteneurs	14,15,16	14,15,16	14,15,16	14,15,16	14,15,16	14,15,16,17
Nombre de Postes nécessaires	14	12	13	16	20	23
Nombre de Postes	19	19	19	19	22	23

Source: National Port Master Plan – Report 3 – Page 15.

3.3. Analysis of goods flows in the port hinterland of Douala and tourist flows in Cameroon

Based on the results obtained from the characterization of the national port hinterland, the study classifies the identified products into large product families to facilitate the analysis of goods flows: hydrocarbons, food and beverage products, metal products/ construction materials, chemicals and pharmaceuticals, ores and raw materials, manufactured products, aluminum, wood, agricultural products, industrial products, food and beverage products, and finally other products. Notably, this classification corresponds to the national classification of products generating port traffic in Cameroon.

Regarding people, tourism is identified with international tourist arrivals in Cameroon. Figures 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, and 13 below illustrate the flow dynamics until 2030 of the different product families in the hinterland of the port of Douala.

Figure 2 shows an increasing trend in the volume of hydrocarbons since 2007. This growth becomes rapid in 2025, an increase of approximately 198% compared to 2022. Hydrocarbon trade is growing in the port hinterland from Douala. Figure 3, on the other hand, shows a decreasing trend in the volume of metal products and construction materials. A decrease of approximately 92% is observed in 2030 compared to 2020. The volume of chemical and pharmaceutical products has followed a constant upward trend since 2020 (see Figure 4). Figure 5 shows an upward trend in mining products and raw materials volume. However, this volume stabilized from 2022 until 2030. Figure 6 shows a sharp fall in the volume of manufactured products in 2014, 2016, and 2020. These falls are due to political instability and the COVID-19 pandemic in 2020. However, since 2021, an upward trend has been observed despite its slowdown. Figure 7 shows a decreasing trend in timber traffic in the hinterland until 2030. This decrease is due to the various logging reforms implemented by the hinterland countries. After its sharp fall in 2020, aluminum traffic has grown very slowly until 2030 (Figure 8).

As for agricultural products (figure 9), their volume follows a decreasing trend due to the decrease in Cameroon's GDP and the Gabon consumer price index. Figure 10 shows an upward trend in industrial products since 2018. Figure 11 shows that the evolution curve of other products has a constant trend, depending on the effectiveness of the Cameroonian government (Gov EFF CAM). The volume of food and beverage products has followed a constantly increasing trend since 2007 (Figure 12). This is due to the high consumption levels of the Cameroonian and Gabonese populations. The number of tourist arrivals has declined since 2019 (Figure 13). This is primarily due to Cameroon's crude mortality rate and level of political stability. This decrease is observed until 2030. This shows that Cameroon is increasingly becoming a less attractive country for tourism on an international scale compared to previous years. The government is increasingly abandoning its objective of reaching 3,500,000 tourists annually by 2035. The National Port Master Plan of Cameroon does not provide for the development of infrastructure or services in the ports of Cameroon. Cameroonian ports should, therefore, also focus on promoting maritime tourism in international markets and establishing adequate infrastructure and services at ports.

Market-increased unpredictability necessitates greater adaptability in port operations, infrastructure, and services. Decision-makers and port planners can benefit from this range of port throughput estimates with confidence intervals to give flexibility and a buffer in port capacity planning to meet fluctuating and uncertain future demand. The causal relationship between the growing hinterland macroeconomics and the increase in containerized throughput is supported. Larger vessels must be used to take advantage of economies of scale in response to this rise, which will affect the containerized throughput of the ports of Cameroon. The port authority can ascertain the ultimate necessary capacities and facilities to meet future demand with the aid of the noncontainerized throughput's diminishing and stabilizing range. The port authority may also think about phasing new developments in response to shifting market conditions and demand. This short-term forecast's findings help with port logistics, terminal and hinterland connection capacity, resource allocation, and operational decisions (i.e., port capacity utilization, cargo handling, and facilities expansion plan). The following are the benefits of the suggested approach over current forecasting techniques: (1) It determines the influencing macroeconomic variables as input to the model after quantifying the relationship between macroeconomic variables and port throughput. This significantly improves the model's accuracy and the forecast findings' dependability. Thus, it takes into account model uncertainties, (2) it quantifies the associated parameter uncertainty of the influencing macroeconomic variables by providing their posterior distributions using a probabilistic approach, (3) it allows for updating the Bayesian model when additional data becomes available, and (4) it can handle uncertain information that is characterized by data scarcity and limitation.

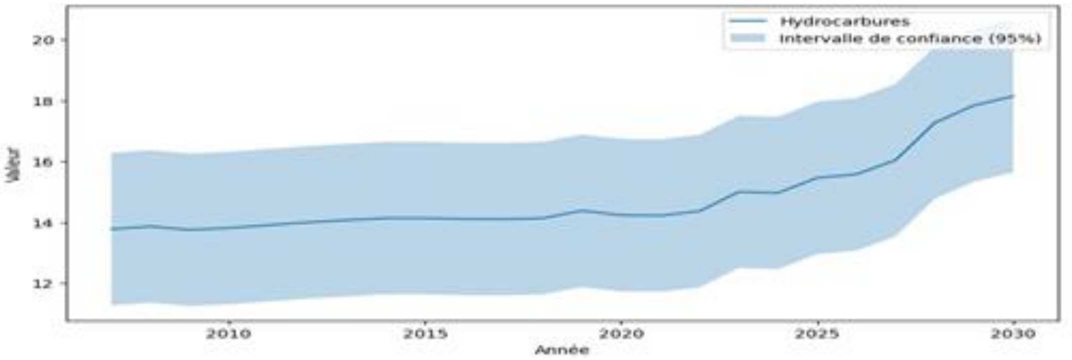

Figure 2. Evolutionary trend of hydrocarbons at the port of Douala.

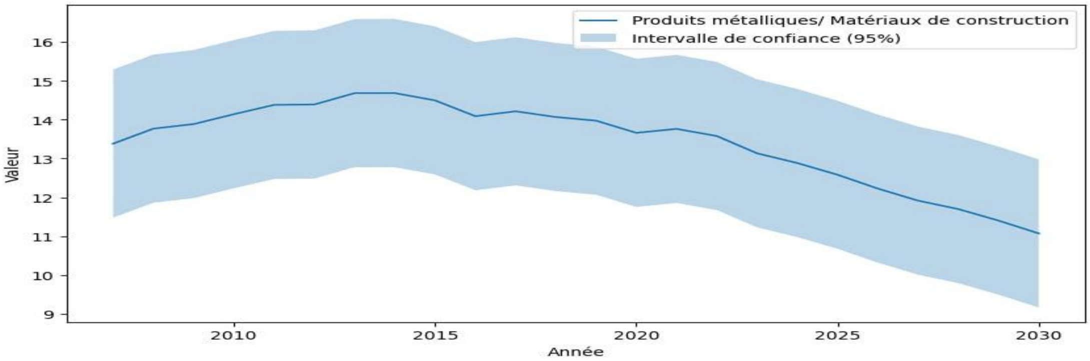

Figure 3. Evolutionary trend in the volume of construction materials at the port of Douala.

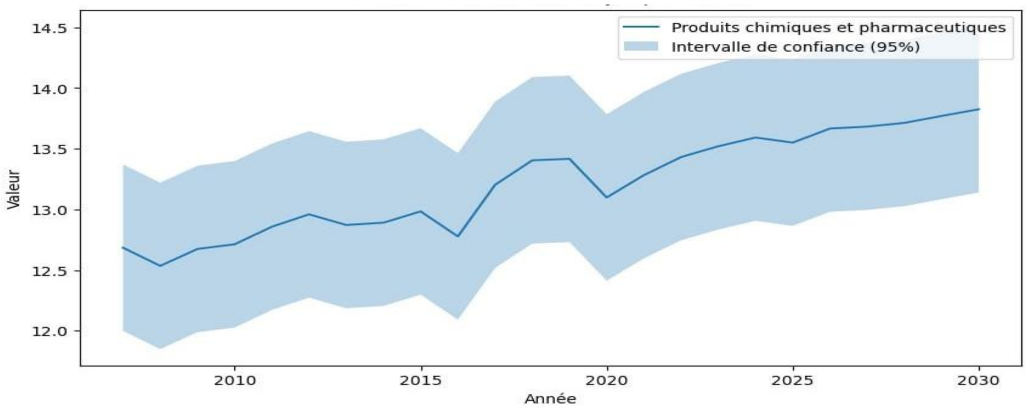

Figure 4. Evolutionary trend of chemical and pharmaceutical products at the Port of Douala.

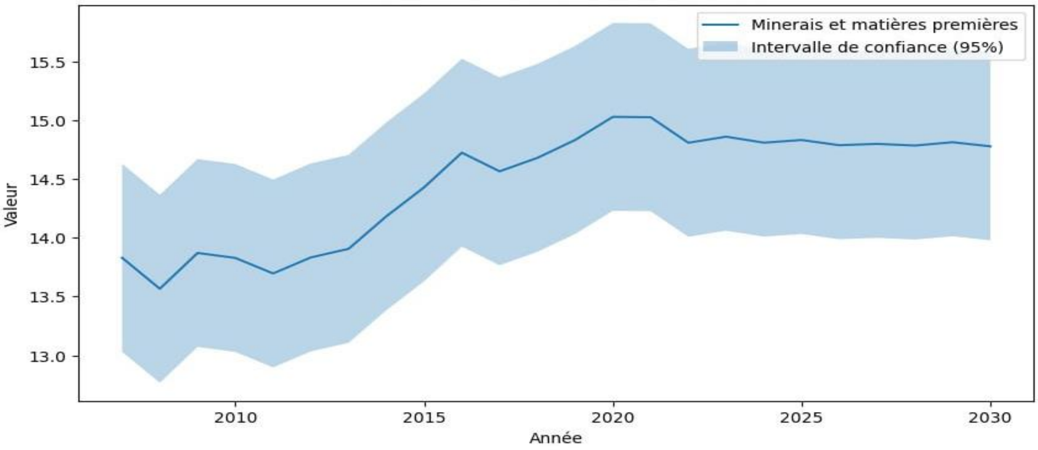

Figure 5. Evolutionary trend in mining and raw materials.

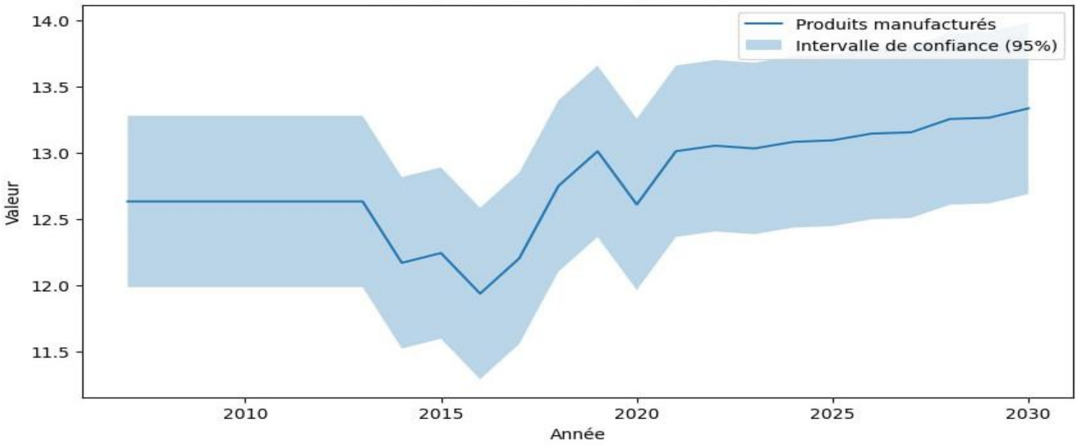

Figure 6. Evolutionary trend in the volume of manufactured products.

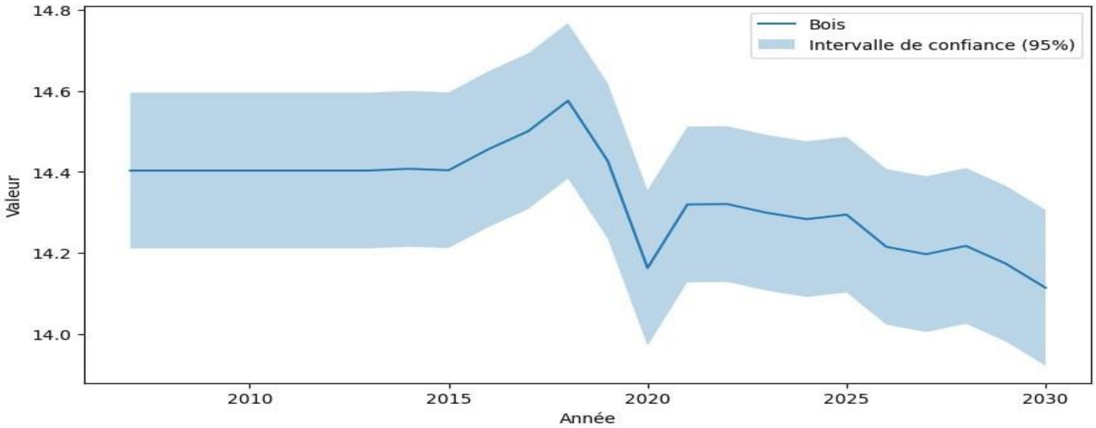

Figure 7. Evolutionary trend in wood.

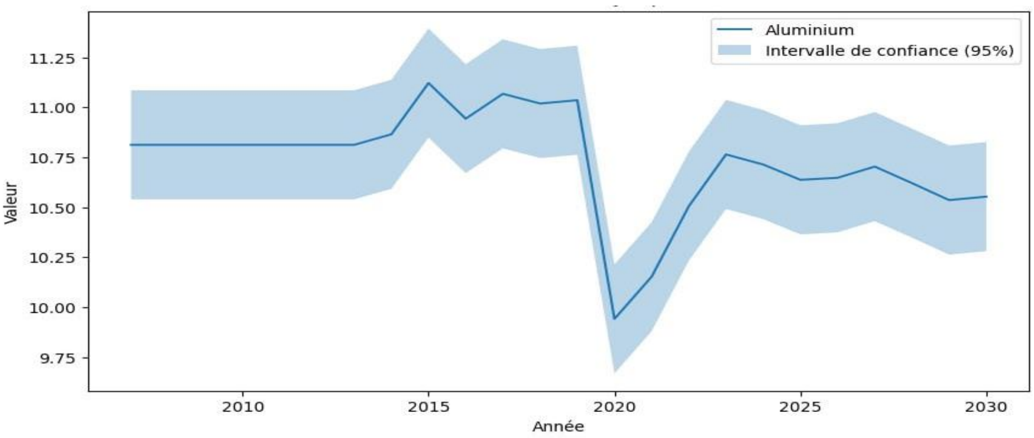

Figure 8. Evolutionary trend in aluminum trafficking

Figure 9. Evolutionary trend in the volume of agricultural products

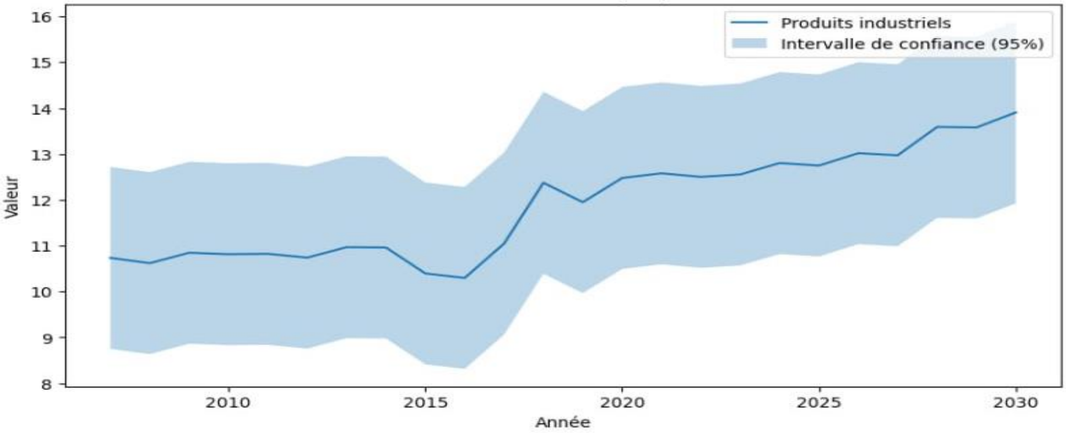

Figure 10. Evolutionary trend in the volume of industrial products.

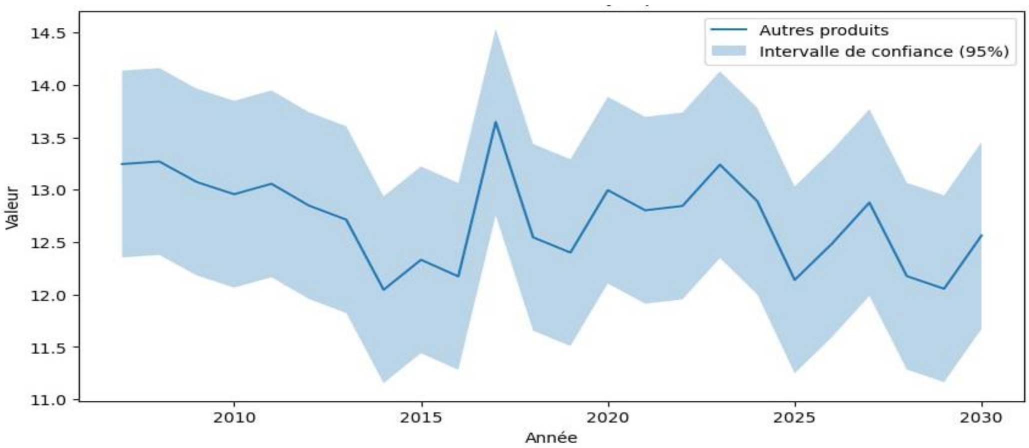

Figure 11. Evolutionary trend in the volume of other products.

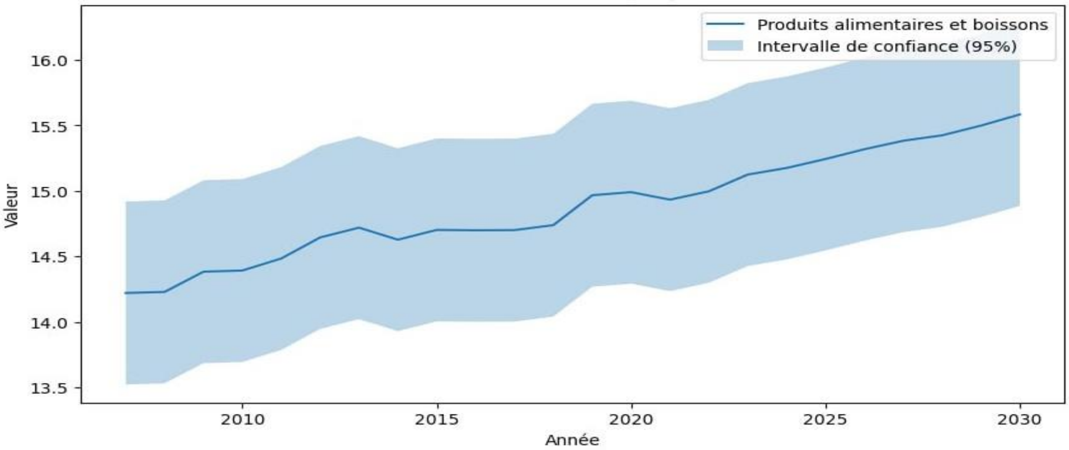

Figure 12. Development trend of food and beverage products.

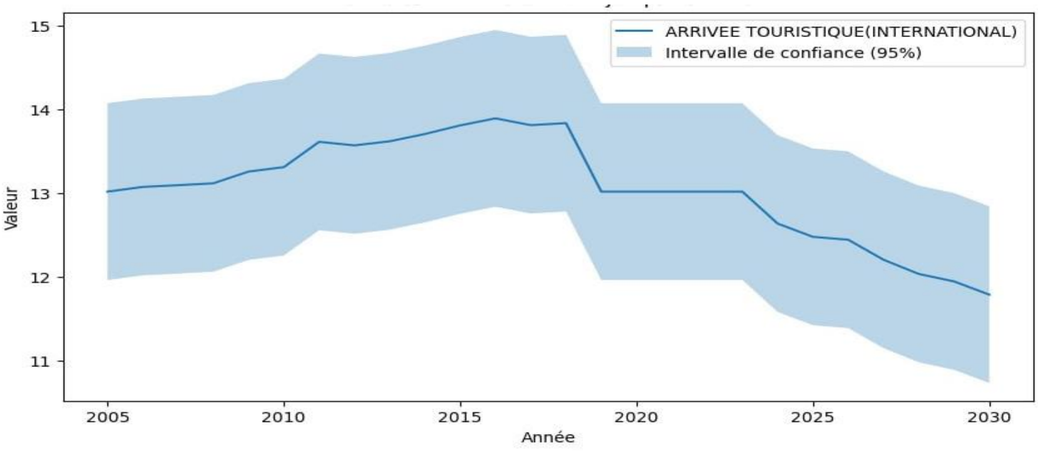

Figure 13. Evolutionary trend in the number of tourist arrivals in Cameroon.

3.4. Ability of projects to meet the needs of the port hinterland in terms of transport and logistics

The main project planned by the National Port Master Plan in terms of transport for the development of the port of Douala, is the improvement of the land service to the port of Douala, for sections of the roads coming from Edéa and Limbé, in the peripheral districts of the city. However, the current reality shows that the connectivity of Cameroonian maritime ports with their hinterlands is a crucial challenge to overcome for their development.

3.5. Location of port development projects in relation to hinterland areas

The “face-to-face interviews and focus groups” carried out as part of the development of the SNADDT enabled numerous elements to emerge. Figure 14 shows the frequency of key terms discussed during face-to-face interviews.

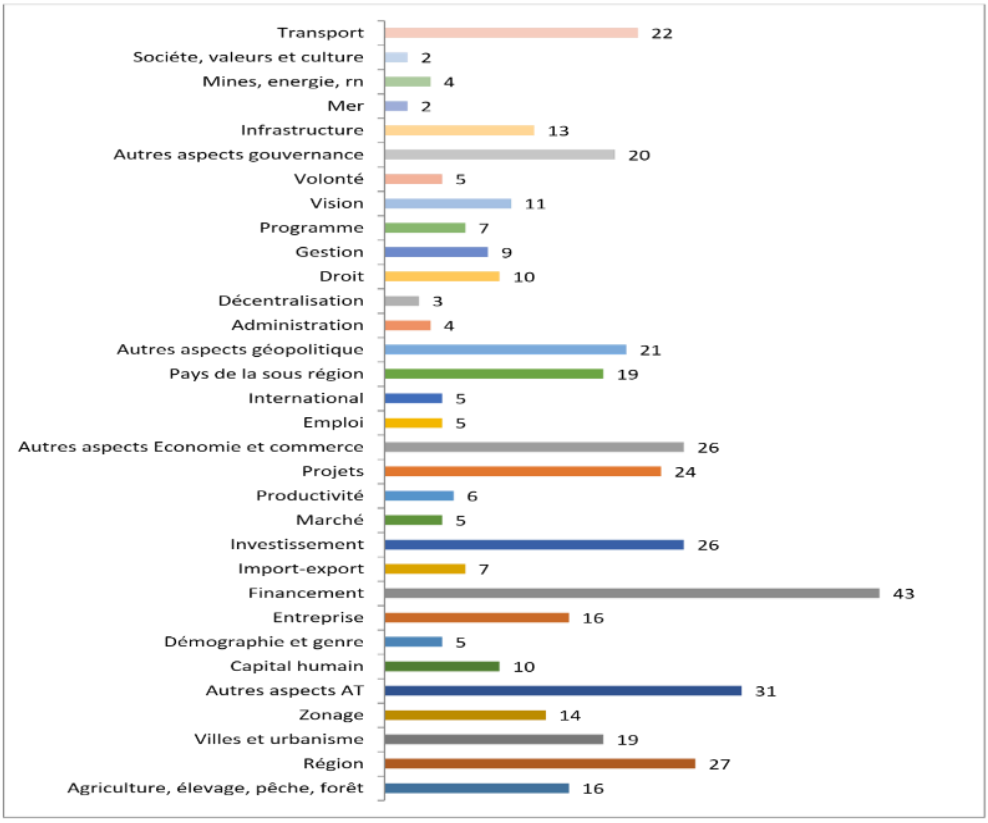

Figure 14. The frequency of key terms discussed during face-to-face interviews.
Source: Master Plan for Sustainable Development and Planning of the Territory of Cameroon.

Figure 15 illustrates the actor-actant positioning and the determining relationships for the industry according to the interviews carried out with the actors as part of the development of the SNADDT.

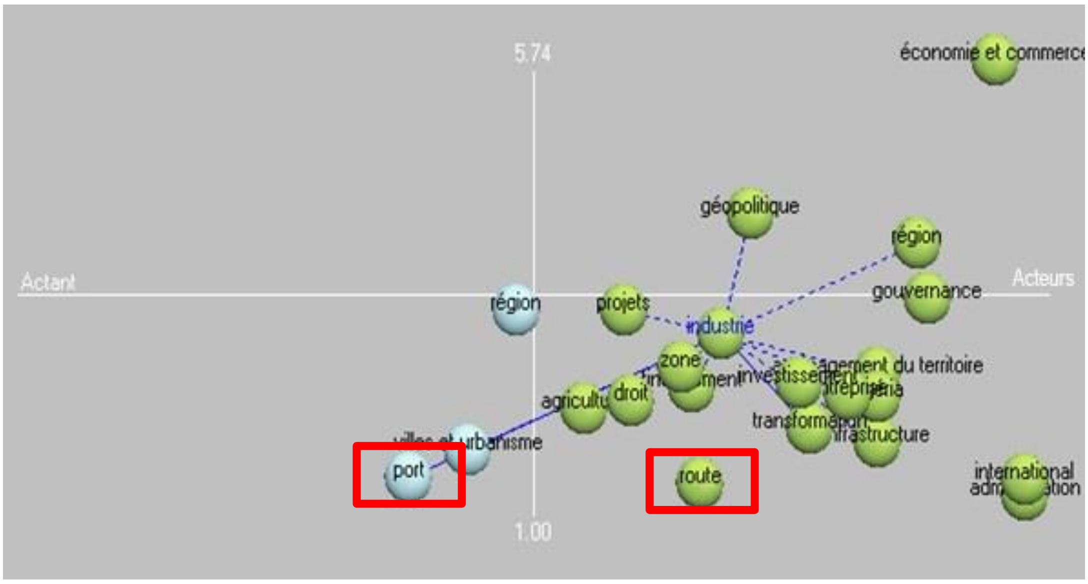

Figure 15: The actor-actant positioning and the determining relationships for the industry according to the interviews carried out with the actors as part of the development of the SNADDT.
Source: Master Plan for Sustainable Development and Planning of the Territory of Cameroon.

These results sufficiently show the low accessibility of hinterland areas to port development projects established by the National Port Master Plan of Cameroon.

3.6. Comparison of existing and planned port infrastructure with hinterland needs in terms of ship types and handling

Given the limited data available for evaluating port capacity, the average gross tonnage, the overall occupancy rate (at various levels) of the quays, and the annual number of ships arriving at the port are the leading indicators of port capacity for the study. Figure 16, 17, 18, 19, and 20 below illustrate the port capacity needs generated by the port hinterland of Cameroon.

Figure 20 above shows a steady growth since 2020 in the number of vessels needed to meet the needs of the Douala port hinterland. There is an increase of about 81% in 2030 compared to the number of vessels in 2020. This observation implies an urgent increase or extension of the quays at the port of Douala. In Figure 19, observed from 2025, a rate of gantries varying between 16 and 17 movements per hour (mph) at the port of Douala. This confirms the direction of port development regarding handling equipment at the port of Douala, as planned by the National Port Master Plan. However, from 2023, Figure 18 shows a gradual decrease in the occupancy rate at various levels until 2030. The growth of containerization can explain this decrease. The port hinterland of Douala is increasingly opting for the containerization of its goods. As for Figure 17, we observe a very strong increase in the overall occupancy rate at the port of Douala, i.e., an increase of approximately 96% in 2026 compared to 2027, and an extreme increase observed from 2027. This exponential growth in the overall occupancy rate shows the urgent construction of new quays at the port of Douala and the need for very competitive port efficiency. The construction of new stations, as planned by the National Port Master Plan at the beginning of 2030, would not sufficiently meet the needs of the hinterland. Likewise, in Figure 16 above, we observe a strong increase in average gross tonnage. The Douala port hinterland urgently needs very large capacity ships for their products. This requires a strong draft and a good access channel to the port of Douala. The deepening of the access channel to the port of Douala is, therefore, not sufficient to meet the characteristics of the Douala port hinterland. This result demonstrates the need to construct a new deep-water port in Manoka as an extension port for the Douala port.

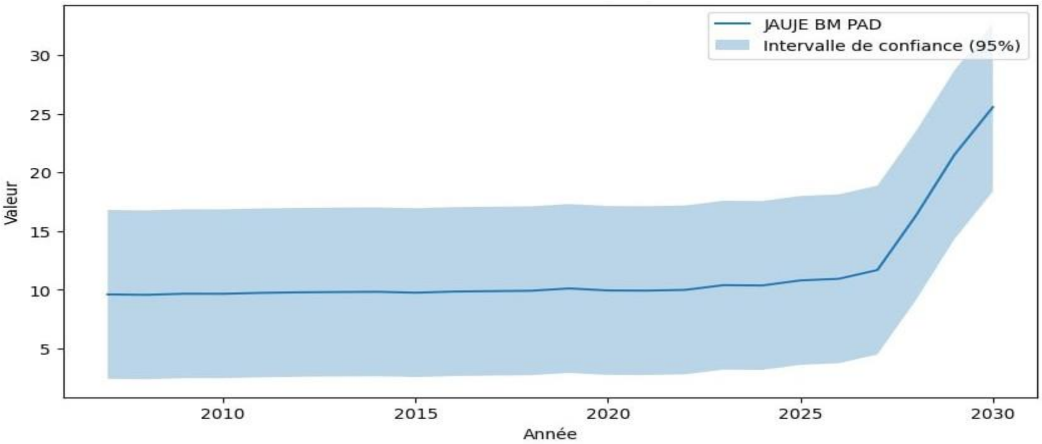

Figure 16. Evolutionary trend of gross tonnage at the port of Douala.

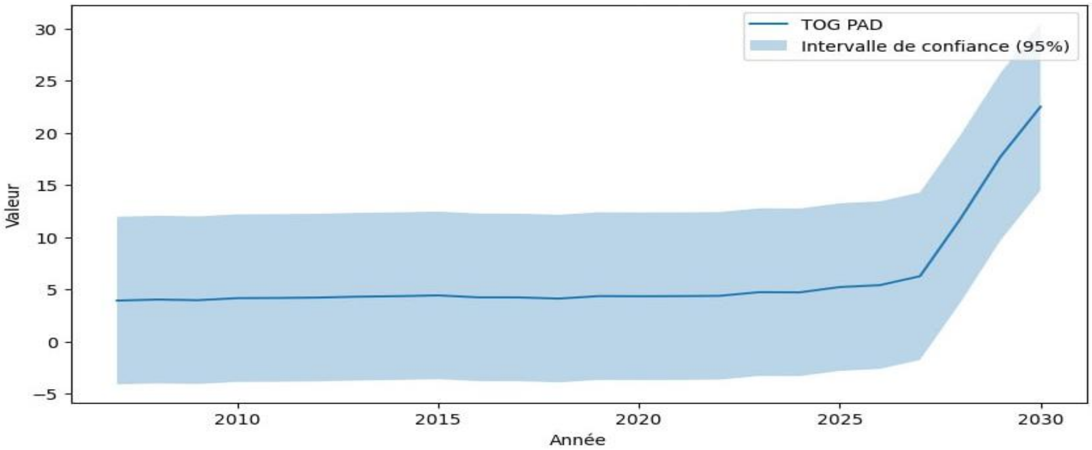

Figure 17. Evolutionary trend in the overall occupancy rate of platforms.

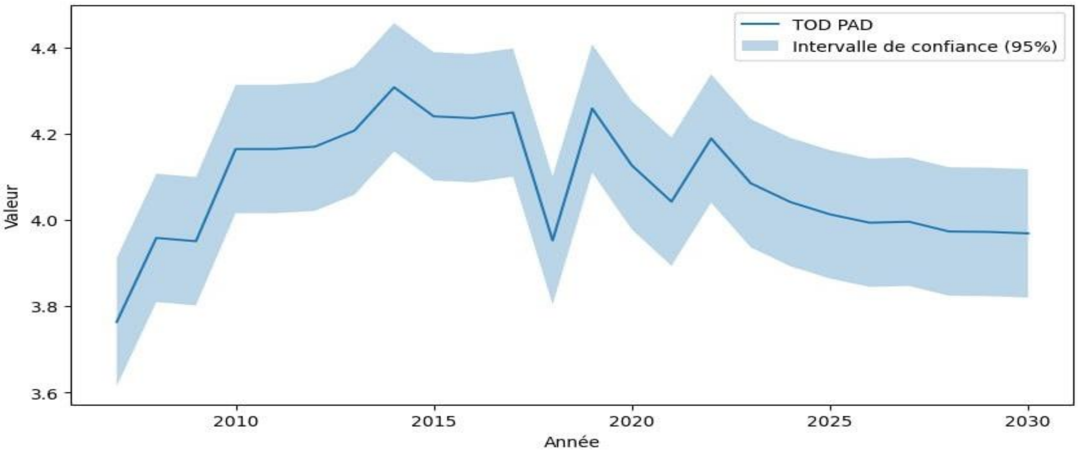

Figure 18. Evolutionary trend of the occupancy rate at various.

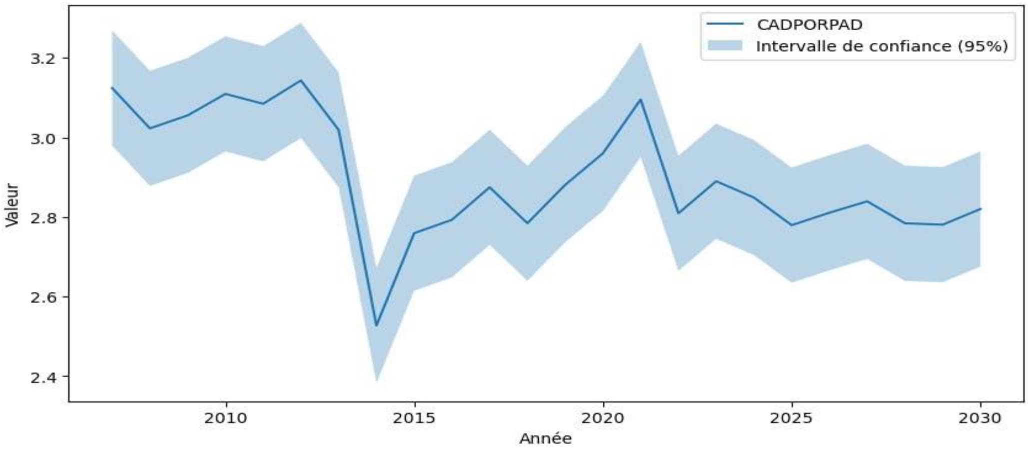

Figure 19. Evolutionary trend in the rate of gantry cranes.

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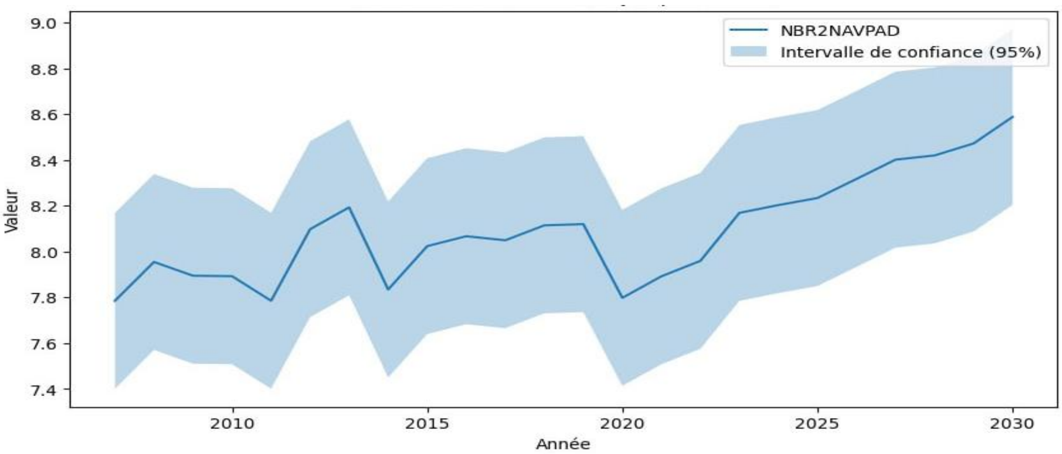

Figure 20. Evolutionary trend in the number of ships.
(NASPW= National Advanced School of Public Works -Yaoundé)

In short, although the national port master plan of Cameroon has been objectively designed, all the results above show that the capacity of the port supply established by it is not sufficient to meet the demand generated by the Cameroonian port hinterland. The factual element, such as constructing a new landing stage in Manoka, briefly supports this conclusion. The National Port Master Plan of Cameroon must necessarily be improved. Recommendations are given to this effect in the following section of this work.

3.7. Recommendation

All the results obtained and analyzed in the previous section sufficiently demonstrate that Cameroon's national strategic port development plan, although ambitious, does not fully align with the specific needs of the hinterland. This situation results in major challenges, including poor connectivity between ports and hinterland areas, the isolation of certain areas with high economic potential, the limited capacity of the port of Douala to accommodate large ships, the inefficiency of the port of Douala in the embarkation and disembarkation of ships and the inadequacy of logistics services. To resolve the inadequacies noted in the National Port Master Plan of Cameroon, the study recommends the effective implementation of the following initiatives: (i) The creation of a public-private investment fund for the development of the port hinterland; (ii) The acceleration of transport infrastructure financing mechanisms in public-private partnership (PPP) mode; (iii) The creation of a national consultancy office in the port sector; (iv) The establishment of infrastructure and equipment to protect against rain; (v) The construction of cruise terminals in different ports; (vi) Taking into account the connectivity of seaports as a fundamental pillar in Cameroon's National Port Master Plan. To this end, the objective and accelerated materialization of the logistics network established by the SNADDT is an absolute priority for developing Cameroonian maritime ports. Figure 21 gives an illustration of this network.

Figure 21. Logistics network for the competitive development of Cameroon's seaports.
Source: Master Plan for Sustainable Development and Planning of the Territory of Cameroon (SNADDT)

4. CONCLUSION

The main objective of this research is to characterize the current hinterland of Cameroonian maritime ports, to analyze the dynamics of goods flows in the port hinterland of Cameroon, and possibly to provide recommendations to enhance the National Port Master Plan, aiming to ensure the continued growth and development of Cameroon's maritime ports.

To achieve this, we used the SIM based on the Huff model and the penetrating power to help finely divide the hinterland division hierarchy of the leading Cameroonian port group, the Bayesian model, and mutual information to analyze needs in the port hinterland of Cameroon; and recommendations to make the Cameroon National Port Master Plan more relevant to the development of Cameroonian seaports. The results show that: the shape of the hinterland presents a funnel effect, and the scope of the contestable hinterland expands from the coast to the remote inland; Cameroon's National Port Master Plan must necessarily be improved to meet the needs of the Cameroonian port hinterland.

To this end, the main recommendations are: (i) The creation of a public-private investment fund for the development of the port hinterland; (ii) The acceleration of transport infrastructure financing mechanisms in public-private partnership (PPP) mode; (iii) The creation of a national consultancy office in the port sector; (iv) The establishment of infrastructure and equipment to protect against rain; (v) The construction of cruise terminals in different ports; (vi) Taking into account the connectivity of seaports as a fundamental pillar in Cameroon's National Port Master Plan.

The contribution of this article is multiple. Firstly, given the rarity of similar African studies, this research aids local stakeholders in making informed decisions regarding port development and planning for ports and their hinterlands. Secondly, this article proposes practical methods combining, on the one hand, the SIM with the power of penetration in the search for the hinterland. Thirdly, this paper's theoretical contribution is developing a robust port throughput forecasting model that considers epistemic uncertainties, such as model uncertainties (variable selection, assumptions, and procedures) and parameter uncertainties (quantity and quality of data used). The model is based on the influencing macroeconomic variables. Additionally, the paper's managerial contribution consists of developing a trustworthy framework for port throughput forecasting that can assist Cameroonian port authorities in rationalizing their investment choices based on future demand, preserving their ports' competitive edge, and expanding their market share.

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