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Intermodal transportation network design under uncertainty: case of the Hinterland of the port of Cotonou

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Abstract: *Since 2006, the Millennium Challenge Account program subsidizes a project to improve the performance of the Port of Cotonou, through modernization of infrastructure and management systems, and strengthening institutional reforms. But the project mainly concerns the port, not the development of its hinterland. However, no port can develop without its links with its hinterland. That's why we analyse the issues relating to the hinterland transport network. Thus, rail and road transportation networks will be examined. Also, we will investigate inland terminals in order to build up intermodal transportation which is almost non-operational. But in the case of freight transportation from and to the hinterland of the port of Cotonou, two uncertainties occurred. So, we have to deal with the variability of the traffic and the road capacity. Indeed, the road capacity is restricted by the level of the torrential rains in worst period, as some arcs of the road are damaged. As a first step, the objective of this paper is to determine the optimal number and locations of the terminals so that the total costs of the distribution network are minimized.*

Keywords*:* Intermodal transportation, Hinterland, Uncertainty, Port of Cotonou.

1. Introduction

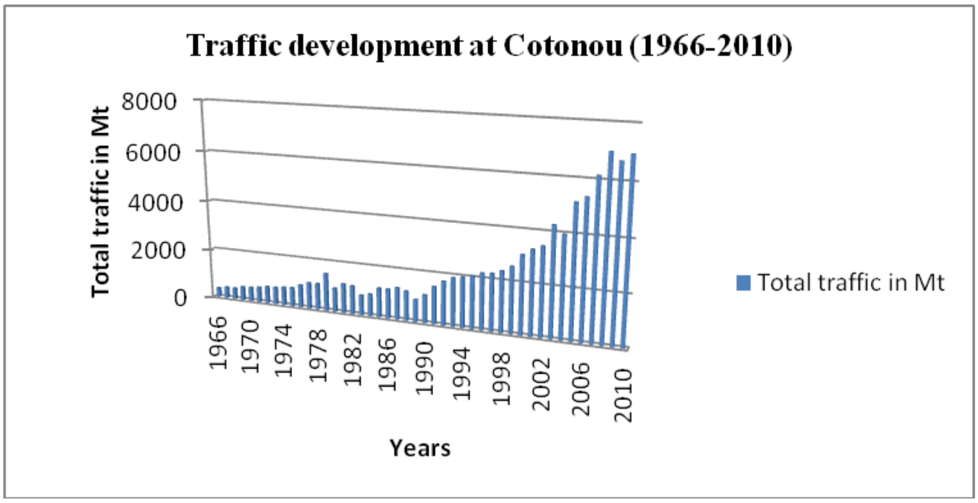
Republic of Benin has been eligible since 2006 for five years of the Millennium Challenge Account Program (MCAP). This subsidy agreement of approximately U.S. $ 307 million aims at increasing investment and the private sector activities in Benin. This program consists of four projects namely: "Access to Land", "Access to Financial Services", "Access to Justice "and finally "Market Access". On the other side, the neighbouring ports of the Port of Cotonou (Lome, Tema, and Abidjan) have not benefited from such investment project.
The first project, the "Market Access", represents 55.14% of the subsidies of MCAP. It aims at improving performance of the Port of Cotonou through modernisation of infrastructure and management systems and, strengthening institutional reforms in order to make it one of the most competitive ports in West Africa.
But the project mainly concerns the port, not the development of its hinterland. However, no port can develop without links with its hinterland. Our main purpose is to determine how to optimise the expected growth of flows to and from hinterland countries in order to avoid

congestion in this port, increase its market share and make economies of scale, in short increase its performance, with respect to uncertainties in traffic variability and road capacity. Hence, the objective of this research is to analyze the issues related to the hinterland of the port of Cotonou and to improve freight transportation network in this region. The remainder of this paper is organised as follows: the next section highlights the development of the traffic at the port of Cotonou. Section 3 presents the foreland of the port of Cotonou while section 4 shows hinterland's development. Section 5 contains the description of our mathematical model while section 6 presents and analyses the obtained intermodal transportation for the hinterland of the port of Cotonou. The section 7 states for conclusion and discussion.

2. Traffic development at the port of Cotonou

The analysis of the evolution of the total traffic at the port of Cotonou from 1966 to 2010 (*figure 1*) reveals a traffic with slow growth, from just under 400 000 tons to 2 million tons in 1995. In contrast, growth was rapid between 1996 and 2000 up to 3 million tons, then even faster between 2001 and 2005, crossing the threshold of 5 million tons and finally stabilized at around 7 million tons up in 2010.

Figure 1: Total traffic evolution at the port of Cotonou from 1966 to 2010 (,000 t)



Source: M. Lihoussou based on Cotonou port statistics

Indeed, after the first expansion of the port, that doubled the capacity of handling traffic, the Port of Cotonou with the support of National Authorities, has been working to improve productivity and services. Thus already in 1994, the traffic reached two million tons, substantially Benin imports and exports, but also traffic in transit to landlocked countries of the hinterland, including Niger (Charlier, 1995). These successive efforts of the port modernization with largely dimensioned facilities, contributed to a boom in domestic traffic and in hinterland traffic. For this author, the possible establishment of gantry would make Cotonou a mini-hub for container traffic to and from Central Africa and Nigeria, which face respectively problems of draught and congestion. Thus, according to the traffic outlook for Cotonou, the medium variant provided an evolution of the total traffic without trans-shipment to about 8 million tons per year by 2020. It is clear that this traffic is already at 7 million tons per year in 2010 and could exceed this level, thus limiting the capacity of loading and unloading of the port. *Figure 2* shows the level of congestion in the port through the parked trucks and difficulty of movement within the port enclosure but also near the port.

Figure 2: Congestion of the port of Cotonou

Source: M. Lihoussou (2012)

3. Ports foreland

Foreland is considers as "*the ocean-ward mirror of hinterland, referring to the ports and overseas markets linked by shipping services from the port. It is above all a maritime space with which a port performs commercial relationships, namely its overseas customers*" (Rodrigue et al., 2009). In our knowledge, very little consideration has been devoted to the foreland studies. But for Rodrigue et al., 2009, "*this point has achieved greater weight recently, with the emergence of door-to-door services and networks, where the port is seen as one link in through transport chains. In such a context, the port becomes one element of the maritime / land interface which insures the continuity of global freight circulation*."

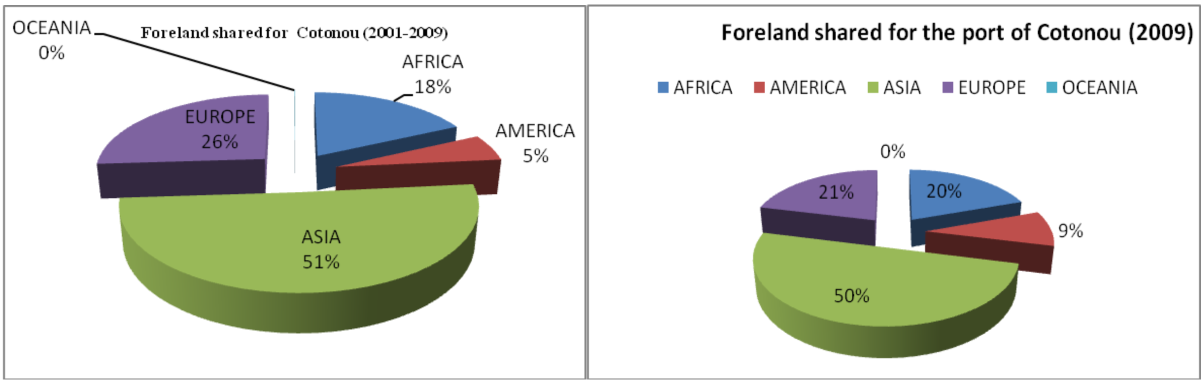
3.1. Foreland of the port of Cotonou

The geographical position of the Port of Cotonou is an important asset. The relatively flat topography and rolling of Benin, except the chain of Atacora in North-West, provides a natural corridor for North countries. Cotonou, located on the southern edge of the city is a port with a regional focus since its colonial creation. Its natural assets can be evaluated in two parts, namely: geographical location and physical data. Several ships from various ports around the world attend more than once the Port of Cotonou. Furthermore, ports statistics show that in 2010 about 13.500 ships operate in particular the lines Europe-COA and America-COA (COA: West Coast African including Cotonou). So, major maritime relations of this port are with Europe and America. But it should be stressed that since the 90s, a growth in trade with Asia has changed completely this configuration giving a weight roughly equivalent to Europe and Asia (Charlier and Tossa, 1995).

3.2. Foreland development for the port of Cotonou

From the 2000s already, the trade growth between Benin and China confirmed the high weight of Asia in the maritime trade with Cotonou, far ahead of Europe and America. Imported from Asia are mainly textiles, electrical / electronic, hardware or goods at very low unit value such as plastic containers, children's toys or paraffin candles (Alix Y., 2012). Back to Asia include products like export logs bucked forest, tropical products (cashews and shea), scrap metal for recycling industry in China, but also cotton, where major interest in the management of empty containers in return. However, if the whole of West and Central African coasts, over 60% of capacity deployed by shipping lines still concern the markets of northern Europe and that services to Asia represent only 30%., in Cotonou, the weight of Asia reached 50%, leaving about 22% in Europe for the year 2009(see *figure 3*).

Figure 3: Foreland shared for the port of Cotonou (2001-2009)



Source: M. Lihoussou, 2012 (based on port statistics)

4. Ports hinterlands

Hinterland *is a land space over which a transport terminal, such as a port, sells its services and interacts with its clients. It accounts for the regional market share that a terminal has relative to a set of other terminals servicing this region. It regroups all the customers directly bounded to the terminal. The terminal, depending on its nature, serves as a place of convergence for the traffic coming by roads, railways or by sea/fluvial feeders (Rodrigue et al*., 2009). For Vigarié A. (1979), the hinterland of a port can be defined as "*the land of the space in which it sells its services and, therefore, recruited its customers*." However, he addresses two types of hinterland: "*fundamental hinterland is the area in which customer port, strongly represented, sells most of its services and lines of competition, where it is in competition with its neighbours*."

In our knowledge, the development of global trade deeply changed the relationship between the points on networks such as ports and their areas of influence. Interdependence between seaport gateways and their hinterlands is a first principle which supports seaport development (Charlier, 1983). A few key factors have facilitated the rise of gateways competing for contestable hinterlands (Hoyle, 1988; Ferrari et al., 2010). It becomes difficult to draw the hinterland’s shape as its extension can largely vary with respect to commodity (Blauwens and Van de Voorde, 1988) and transport mode.

4.1. Hinterland’s importance

Far as we know, the first analysis of port hinterlands is provided by Sargent, 1938, followed by Morgan, 1951 who shows that the hinterland of a port is different for each commodity. Taaffe et al., 1963 have analysed increasing concentration of transport flows on a few corridors to the hinterland. They propose model for hinterland connections development enhanced by Hoyle, 1988. Moreover Bird, 1963 describes spatial change of port complexes and Van Klink, 1995 stresses that ports increasingly create networks with hinterland nodes to enhance the competitive position. Rodrigue, 2004 emphasise the importance of corridors to the hinterland. Thus, Notteboom and Rodrigue, 2004 introduce the concept of *island formations* which *are regional inland nodes that serve not only a local market, but a much broader regions*, that can give a port a competitive edge in a hinterland. De Langen and Chouly, 2004 point out the importance of analysing hinterland access as an inter-organisational issue.

The development of containerisation and intermodality expands land penetration of maritime containers by creating landbridges. Hoyle, 1983 and, Hoyle and Charlier, 1995 have discussed some of the complexities of hinterland topology, and concluded that the idea of the hinterland no longer has any relevance in advanced societies and in context of intermodalism. Thus, hinterlands which were captive and natural are shared and contestable; also the perception on port markets has changed from being monopolistic or oligopolistic to competitive.

Hence, conventional perspectives based on distance-decay are ill-fitted to address this new reality. In this respect, a fundamental role is played by the effectiveness of inland connections (Ferrari et al., 2010). And then, Ferrari et al., 2006, 2010 discuss the gravitational forces and frictions, and reshaping port hinterland to emphasis the explanatory power of distance in defining ports hinterlands. Debrie and Guerrero, 2008 support this trend while some authors assert that the hard competitive game among the top players defines a hinterland as a spatial job, in which the port choice is not necessarily related to the inland distance (Notteboom, 1997; Olivier and Slack, 2005). Therefore, the distance would seem to have become only one of the different parameters that contribute to determine the share of the inland market of a port. Morgan, 1951 and De Langen, 2007 make a difference between captive and contestable hinterlands. The authors show that contestable hinterlands exist in regions where no single port has a clear cost advantage over competing ports. Addressing the Lugirian case of port hinterland accessibility, Ferrari et al., 2010 show that a crucial factor in inter-port competition turned out to be the penetration capacity in hinterland and that inland terminals have an important role in enlarging port market areas, as their strategic location may represent an attractive gravitational factor, reducing the frictions generated by the distance.

4.2. Hinterland development for the port of Cotonou

Inter-port competition closely explains ports hinterland development, that why many authors address this issue. Hoyle and Charlier, 1995 studying the inter-port competition in East Africa by using ports traffic volumes, highlight little competition between the two major ports of the region (Mombasa and Dar es Salaam), but argue that the real competition is further inland. They stress that intermodalism has become a key issue in hinterland competition (see also Janguo, 1994 and Mumba, 1994). This findings are consistent with Ferrari et al., 2010, who address Lugirian port hinterland accessibility and show that inland terminals confirm their primary role in enlarging port market areas, as their strategic location may represent an attractive gravitational factor, reducing the frictions generated by the distance (see Feo-Valero et al., 2011 for the importance of inland leg). Furthermore, Huybrechts et al., 2002; assume that strategic positioning is an instrument for port competition analysis.

However, in West Africa, ports still protect their captive hinterlands. The competition is not yet hard. Hence, port-hinterland relations and port concept retain considerable relevance (Hoyle and Charlier, 1995; Charlier and Tossa, 1995). Indeed, the natural gateway of Niger is the port of Cotonou, so all its oil and mining traffic, and the most general cargoes traffics use this transit route. This landlocked country (LLDC) is becoming increasingly important for the port of Cotonou. Indeed, its annual population growth is quite high with a rate of about 3.5% in 2010 (Banque Mondiale, 2010; INS, 2010), then sustained increase in imports to meet the needs of its population of about 15.5 million (Banque Mondiale, 2010; INS, 2010) and its high mining area potential could increase exports.

Burkina-Faso shares its oil traffic between the ports of Cotonou (small share) and Abidjan (most important). Since the political instability of Côte d'Ivoire, the balance of its traffic is mainly shared between the ports of Lome and Tema. The traffic of Mali uses the ports of Abidjan, San Pedro, Takoradi and at a very less extent the port of Cotonou. Furthermore, the port of Cotonou has good opportunities with its neighbour robust economic growth since year 2009. Indeed, Nigeria has good economic outlook for the future, despite the global economic crisis (BAD, OCDE, PNUD, CEA, 2011). But weaknesses occur and are related to the permanent congestion and the inefficiency of its ports, the growing insecurity, currency and language problems. So, the port of Cotonou is the transit port of Nigeria and this position should improve with the MCAP. However, inter-port competition becomes increasingly important even whether it's not reached the developed countries stage (see Hoyle and Charlier, 1995; Charlier and Tossa, 1995), changing the port hinterland relationships and making a new market share. Port hinterlands move gradually from captive to contestable position, that's why inter-port competition has to be addressed.

To address inter-port competition in our study, total and transit traffic are compared from 2004 to 2008 for the four ports (Abidjan, Cotonou, Lome and Tema). We choice this time window because of the data's availability for all the ports studied. Data are gathered from ports statistics on their websites and triangulated with LLDCs Shippers Council's data. However, as we know that currently for oil and used cars, some ports have natural advantage; the net total traffic, without oil and cars, is given in *table 1* while transit traffic is given *table 2*. Transit traffic is the traffic through the port from or to other countries, in our case, hinterland countries. As it can be seen in the two tables below, Abidjan has high volume for total traffic while Cotonou has high volume for transit traffic.

Table 1: Comparison of ports total traffic in 1000 Tons (2004-2008)

YEAR	**2004**	**2005**	**2006**	**2007**	**2008**
COTONOU	3969	5153	5369	6152	6998
LOME	3299	3452	3531	4429	4937
TEMA	11288	12637	11371	8868	9182
ABIDJAN	17770	18662	18856	21378	22080

Source: Ports statistics

Table 2: Comparison of ports transit traffic in 1000 Tons (2004-2008)

YEAR	**2004**	**2005**	**2006**	**2007**	**2008**
TEMA	764	875	870	844	866
ABIDJAN	530	762	1002	1278	1016
LOME	1095	1221	1394	1862	2093
COTONOU	1242	2041	2474	2849	3414

Source: Ports statistics

These outcomes show the strong position of the port of Abidjan in region, as the leader. His challenger is Tema while Cotonou is more competitive than Lome. Hence, this port might be ranked first by the port users (freight forwarders and shippers). However, considering transit traffic, we could note that Cotonou ranked first followed by Lome. We can conclude that Cotonou and Lome are both transit ports, and Cotonou is first for hinterland market share attraction, where it has a dominant position. This strategic position is enforced by its Nigerian transit traffic with no, or at least, very weak competition. Future studies will evaluate the reliability of these results. Furthermore, as intermodal has become a key issue in hinterland competition (Hoyle and Charlier, 1995), it seems necessary to know how hinterland network service is designed.

5. Model

According to the European Conference of Ministers of Transport., 1997, intermodal freight transport is defined as the movement of goods in one and the same loading unit or vehicle by successive modes of transport without handling of the goods themselves when changing modes. Many theories are mobilized to give better understanding of intermodal transportation (see Crainic et al., 2007 for review). The key objectives of intermodal freight transportation are both to minimize total transportation costs and enhance sustainable transportation through modal shift from road to rail, waterways or short sea shipping (see Notteboom, 2010).

To create a rail-road intermodal network for the hinterland of a port, we have to find optimal locations for terminals according to the existing rail and road network and according to the flows from and to this port. The first model is based on the one developed in Arnold et al., 2001.

In this study, a set of commodities, A, may be shipped from their origin h (Port) to their destinations $i \in N$ either directly or via a consolidation terminal $k \in T$. A set of commodities, E, have also to be moved from node $i \in N$ to the port. The main decisions addressed by the models are the number and the locations of consolidation terminals as well as the product flow pattern through the system, either directly from the origin to destination by road or through a consolidation terminal, i.e. rail-road transport. The problem can be stated as follow:

5.1. Inputs:

n = the number of sites for potential terminal indexed by $k \in T$

p = the number of terminal to locate

N = the set of nodes, to which is associated a flow from or to the Port

A = the set of commodities to be moved from the port to the destinations (imports)

E = the set of commodities to be moved from the destinations to the port (exports).

c_{ij}^{1a} = road transportation cost per ton of commodity received a $\in A$, $i \in N \cup T \cup \{h\}$ and $j \in N \cup T$

c_{ij}^{1e} = road transportation cost per ton of commodity sent $e \in E$, $j \in N \cup T \cup \{h\}$ and $i \in N \cup T$

c_{ij}^{2a} = rail transportation cost per ton of commodity received $a \in A$, $i \in T \cup \{h\}$ and $j \in T$

c_{ij}^{2e} = rail transportation cost per ton of commodity sent $e \in E$, $i \in T$ *and* $j \in T \cup \{h\}$

t^{1a} = trans-shipment cost from sea to road per ton of commodity received $a \in A$

t^{2a} = trans-shipment cost from sea to rail per ton of commodity received $a \in A$

t_k^a = trans-shipment cost from rail to road per ton of commodity received $a \in A$ in the terminal $k \in T$

t_k^e = trans-shipment cost from road to rail per ton of commodity sent $e \in E$, in the terminal $k \in T$

t_h^{1e} = trans-shipment cost from road to sea per ton of commodity sent $e \in E$

t_h^{2e} = trans-shipment cost from rail to sea per unit of commodity sent $e \in E$

u_k = the capacity of a consolidation terminal located at site $k \in T$

o_i^e = total quantity in ton of commodity sent, $e \in E$ from the node $i \in N$

d_i^a = total quantity in ton of commodity received $a \in A$ *at the* node $i \in N$

5.2 Decision variables:

Here are the different variables used in the model:

$y_k =$ 1 if a terminal is located at node $k \in T$

0 otherwise

$x^a_{hki} =$ 1 if the flow of commodity *a* from the Port to node $i \in N$ is trans-shipped in terminal $k \in T$,

0 otherwise

$x^e_{ikh} =$ 1 if the flow of commodity *e* from the node $i \in N$ to the Port is trans-shipped in terminal $k \in T$,

0 otherwise

$w^a_{hi} =$ 1 if the flow of commodity *a* from the Port to node $i \in N$ is not trans-shipped,

0 otherwise

$w^e_{ih} =$ 1 if the flow of commodity *e* from $i \in N$ to the Port is not trans-shipped,

0 otherwise

5.3. Objective function

The objective function consists in minimizing the total transportation cost.

$$
\begin{aligned}
Minimise \sum_{k\in T}\sum_{i\in N}(\sum_{a\in A}(d_i^a(t^{2a}+c_{hk}^{2a}+t_k^{1a}+c_{ki}^{1a})x_{hki}^a) \\
+\sum_{e\in E}(o_i^e(t_h^{2e}+c_{ik}^{1e}+t_k^{1e}+c_{kh}^{2e})x_{ikh}^e)) \\
+\sum_{i\in N}(\sum_{a\in A}\ (d_i^a(t_h^{1a}+c_{hi}^{1a})w_{hi}^a \\
+\sum_{e\in E}\ o_i^e(t_h^{1e}+c_{ih}^{1e})w_{ih}^e)
\end{aligned}
\qquad (1)
$$

5.4. Constraints

$$\sum_{k\in T} y_k = p \qquad (2)$$

$$w_{hi}^a + \sum_{k\in T} x_{hki}^a = 1 \qquad \forall\ i \in N,\ a \in A \qquad (3)$$

$$w_{ih}^e + \sum_{k\in T} x_{ikh}^e = 1 \qquad \forall\ i \in N,\ e \in E \qquad (4)$$

$$x_{hki}^a \le y_k \qquad \forall\ i \in N,\ \forall k \in T, \forall\, a \in A \qquad (5)$$

$$x_{ikh}^{e} \le y_k \qquad \forall\, i \in N,\ \forall k \in T,\ \forall\, e \in E \qquad (6)$$

$$\sum_{a\in A}\ \sum_{i\in N} d_i^a x_{hki}^a + \sum_{e\in E}\ \sum_{i\in N} o_i^e x_{ikh}^e \le u_k y_k, \qquad \forall k \in T \qquad (7)$$

$$y_k \in \{0,1\} \qquad \forall k \in T \qquad (8)$$

$$w_{hi}^a \in \{0,1\} \qquad \forall\, i\in N,\ \forall\, a \in A \qquad (9)$$

$$w_{ih}^e \in \{0,1\} \qquad \forall\, i\in N,\ \forall\, e \in E \qquad (10)$$

$$x_{ikh}^e \in \{0,1\} \qquad \forall\, i\in N,\ \forall\, k \in T,\ \forall\, e \in E \qquad (11)$$

$$x_{hki}^a \in \{0,1\} \qquad \forall\, i\in N,\ \forall\, k \in T,\ \forall\, a \in A \qquad (12)$$

The objective function minimizes the total transportation cost associated of distributing the commodities flows from and to the port and opening the consolidation centers. The first sum represents the costs of rail-road flows and the second sum the costs of road flows, whilst the third sum denotes terminal operating fixed cost. Constraint (2) denotes that p terminals are going to be located. The constraints (4) and (3) ensure that all the demand is satisfied while constraints (6) and (5) indicate that a trans-shipment is not possible, unless there is a terminal. Constraint (7) enforces the consolidation-terminal capacity constraint. Finally, constraints (8) to (12) standard non-negativity and integrality constraints.

6. Intermodal transportation network for the hinterland of the port of Cotonou

A real-world data set is provided from the port of Cotonou statistics. We use the data concerning the total quantities of goods transported from and to the port (imports and exports). The countries considered are Benin, Burkina-Faso, Mali, Niger and Nigeria. The origin-destination (O-D) matrixes are built up for the year 2010. On one hand, the main categories of commodities sent are wood; cotton; others products and uranium; cottonseed; hydrocarbons and liquid bulk; cashew nuts; shea nuts; perishable products; cakes; various goods. On the other hand, the main categories of commodities received by the hinterland of the port of Cotonou are: grains, clinker, gypsum, limestone and slag; fertilizers and insecticides; hydrocarbons; lubricants and bitumen; building materials; equipment; food; sulfur; vehicles and parts; various goods. To test our model, we aggregate the various commodities. The estimations of the transport and operations costs used are those from Limbourg and Jourquin (2009) based on the RECORDIT (2002) European research program, which compared the costs of intermodal and road-only solutions. Knowing that the average net weight of a twenty-foot equivalent unit (TEU) is about 15 t and container traffic statistics of the port of Cotonou for the year 2010, the (un)loading costs are estimated to 1.297 /t for all the different types of trans-shipment, the cost for road haulage is 0.072 /t.km and 0.042 /t.km for rail haulage. Future research will tackle the issue related to the estimation of real transport and operations costs for the main kinds of commodities of the previous paragraph. Rail stations are considered as potential locations for terminals.

They are located in Bohicon, Dassa, Parakou and Savè. Knowing all the input, the model is solved using the classical branch-and-cut CPLEX12 solver with the default parameters. Moreover, for each located terminal, we compute its market area which is the area where the intermodal transport passing through the terminal considered is cheaper than road transport or than an intermodal transport using another terminal. If one terminal (p = 1) has to be opened, it should be located in Parakou, its market area, include Burkina-Faso, Mali, Niger and the blue area represented in *figure 4*. If two terminals (p = 2) have to be opened, they should be located in Parakou and in Dassa. In this case, a part of the market area of the terminal located in Parakou is cannibalized by the market area of Dassa, represented in red (*figure 5*). If three terminals (p = 3) have to be opened, they should be located in Parakou, Dassa and Bohicon which has a very little market area represented in yellow (*figure 5*). The total transportation cost can't be reduced by adding another terminal. The total cost decreases when the number of terminals increases. This is true when p varies between zero to three. But, only the reduction due to the terminal located in Parakou is significant according to our assumptions. This result is consistent with the MCAP which projects to build up a dry port at Parakou. However, this result must be refined by taking into account the actual transportation costs in West Africa, the variation of transportation costs according to the type of commodity transported, the management of hazardous and perishable goods. Moreover, our model allows us to compute the variation of the ton-km transported by road for all these configurations, to assess the environmental impact and to compute the number of container trans-shipped at each terminal. These are useful indicators for the policy makers and for the operators. For example, the former indicator helps to determine the terminal design as well as the number and type of cranes needed.

Furthermore, a large railway interconnection network project has to link ECOWAS (Economic COmmunity of West African States) Countries with two railway major bands cross these countries, one coastal and the other Sahelian. Thus, rail lines from ports to inland link the above two bands, insuring West African countries interconnection. Our model should also be tested in this case, where more potential locations for terminals have to be considered.

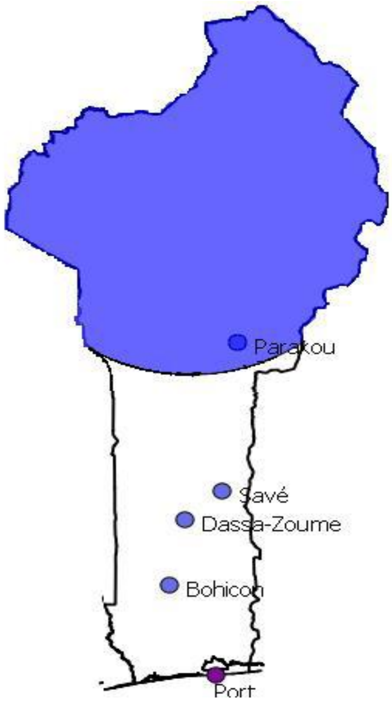


Figure 4: Configuration with one terminal

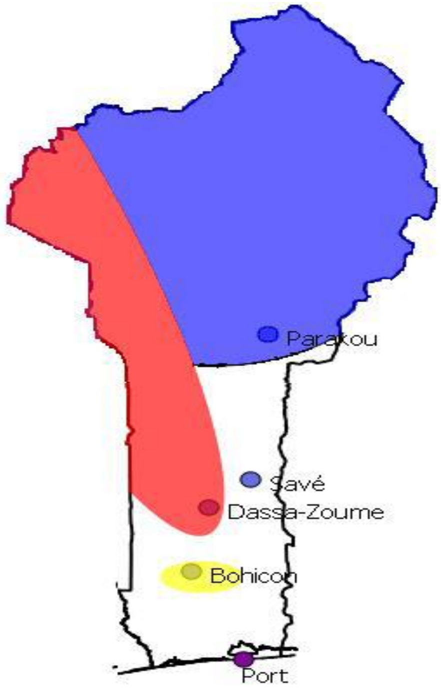


Figure 5: Configuration with three terminals

7. Conclusion

The main objective of our research is to find out how the port of Cotonou can achieve and maintain its competitive advantage in transit traffic with hinterland countries. Because high hinterland connectivity improves the competitive position of port and because intermodal transportation generates significant advantages such as sustainability, our research focus on the intermodal transportation network design for the hinterland of the Port of Cotonou. Therefore, a multi-product model has been formulated to find optimal locations for rail-road terminals.

Secondly, the obtained results show that only one terminal should be located. However, we have to find more accurate data about transportation costs in West Africa for each considered commodity to provide a decision support system to port authorities and operators.

Thirdly, future research has to handle the uncertainties in traffic variability and road capacity because road capacity is reduced by torrential rains four months per year: from April to July.

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