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Container Port Selection in West Africa: A Multi-Criteria Decision Analysis

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Abstract

The West Africa gross domestic product is expected to grow and port expansion projects will increase capacity by over 12 million TEUs (Twenty-Foot Equivalent Units) by 2020. With the economic potential that the region offers and the steady growth of container traffic, the port selection decision by shipping lines is complex because the region has a poor shipping infrastructure and political instability that impact transportation security supply chain services. This research applies a multi-attribute value theory (MAVT) with value-focused thinking (VFT) and alternative-focused thinking (AFT) methodologies to develop a shipping lines' container port selection decision models for West Africa. Criteria and port alternatives from a previous published study were used in the research. The study demonstrates that a decision analysis model can be developed based on available quantitative port data rather than using data from surveys, interviews and questionnaires, as done in previous publications. In both approaches the Abidjan Port is the best option for shipping lines and the worst option is the Lagos Port. The VFT approach offers graphical displays that help decision makers understand strengths, weaknesses, tradeoffs, and improvement opportunities for each port alternative.

Keywords: port selection, multi-attribute value theory, value-focused thinking, multi-criteria decision analysis, decision analysis.

1. Introduction

Ports are considered an integral part of maritime industry and global supply chains. Over 90 percent of global trade is carried by sea (IMO, 2012). A port's performance can influence the global trade, the growth of the regional economy, and the competitiveness of the supply chain. Therefore, port selection is critical for shipping lines to offer competitive services and add value to the supply chain of their customers. With global supply chains, port selection is a complex and dynamic decision, involving the analysis of multiple and conflicting criteria including port capacity, infrastructure, safety, location, intermodal links, security, service level, costs, etc. (Guy & Urli, 2006; Chou, 2010).

Therefore, port selection is an important strategic decision for shipping lines. Using multiple criteria decision analysis (MCDA) can be valuable for these complex decisions because it helps to structure and understand the problem with multiple and conflicting criteria (Belton & Stewart, 2002) and involves different stakeholders with their own values and objectives (Montibeller, 2005). Although MCDA methods have been used to analyze the port selection problem (Dyck & Ismael, 2015; Gohomene, Bonsal, Maistralis, Wang, & Li, 2015; Yeo, Ng, Lee, & Yang, 2014; Alanda & Yang, 2013; Chou, 2010; Chou, 2007; Ugboma, Ugboma, & Ogwude, 2006; Guy & Urli, 2006; Song & Yeo, 2004; Lirn, Thanopoulou, Beynon, & Beresford, 2004; Frankel, 1992) the literature is silent regarding the application of the multi-attribute value theory (MAVT) approach.

The purpose of this study is to investigate the container port selection decision of the main ports in West Africa, applying a MAVT with Value-Focused Thinking (VFT) and Alternative-Focused Thinking (AFT) methodologies.

More specifically, the study aims to achieve the following specific research objectives:

- To use a qualitative decision hierarchy (objectives and criteria) and alternatives of a recently published study, Gohomene et al. (Gohomene, Bonsal, Maistralis, Wang, & Li, 2015), in order to develop a MAVT model with a VFT methodology.

- To demonstrate that MAVT with VFT methodology can be used as a new approach to the port selection decision problems, and develop a framework for obtaining the quantitative port data to use decision analysis.
- To compare AFT vs VFT, describing their advantages and disadvantages. AFT, first identifies the current available alternatives and then evaluates the alternatives, while the VFT approach first involves an understanding of the values and then identifies the alternatives for the decision problem (Keeney, 1992).

The study will demonstrate that port selection decision analysis can be developed based on available quantitative port data rather than using data from surveys, interviews and questionnaires. This research identifies available sources of quantitative port data, to score the port alternatives against each of the measures of the value hierarchy, input that is necessary to develop the multi-attribute value function (MAVF) approach with local and global scales (Belton & Stewart, 2002). In addition, this study will use swing weights, which are based on the importance and scale variation of the criteria (Parnell & Trainor, 2009).

The paper is structured as follows. In Section 2, the port selection literature is presented. In Section 3, the MAVT with VFT methodology of the container port selection in West Africa is developed, as well as the AFT approach. In Section 4, the results of the research are discussed. The article concludes in Section 5 with a summary of the study's contributions and directions for future research.

2. Literature Review

The port selection topic has been investigated (Frankel, 1992; Murphy, Dalenberg, & Daley, 1988; Murphy, Daley, & Dalenberg, 1991; Murphy, 1992; Slack, 1985) and is an active research area due to the changes in the maritime industry and the different stakeholders involved in the port selection process. A review of the port selection literature, presenting a structured summary of the studies by classifying the studies based on type of research analytics, year, criteria, methodologies, etc., are documented in (De Icaza, 2017).

In general, the port selection literature includes multiple and conflicting criteria, has two or more port alternatives, concentrates on a geographic region, and focuses on the perspective of a decision maker such as freight forwarders, shipping lines, shippers, and port management, etc. The criteria used in the port selection literature have been identified based on surveys, interviews, Delphi approach, previous research, etc. Due to the competitiveness and changes in the maritime industry: technology, location, shipping line alliances, vessel and port capacity, environment, costs, operations, logistics development, etc. researchers have not agreed on a list of criteria to analyze the port selection decision problem (Sanchez, Ng, & Garcia-Alonso, 2011). As illustrated in Figue 1, the port selection literature demonstrates the use of multiple and conflicting criteria.

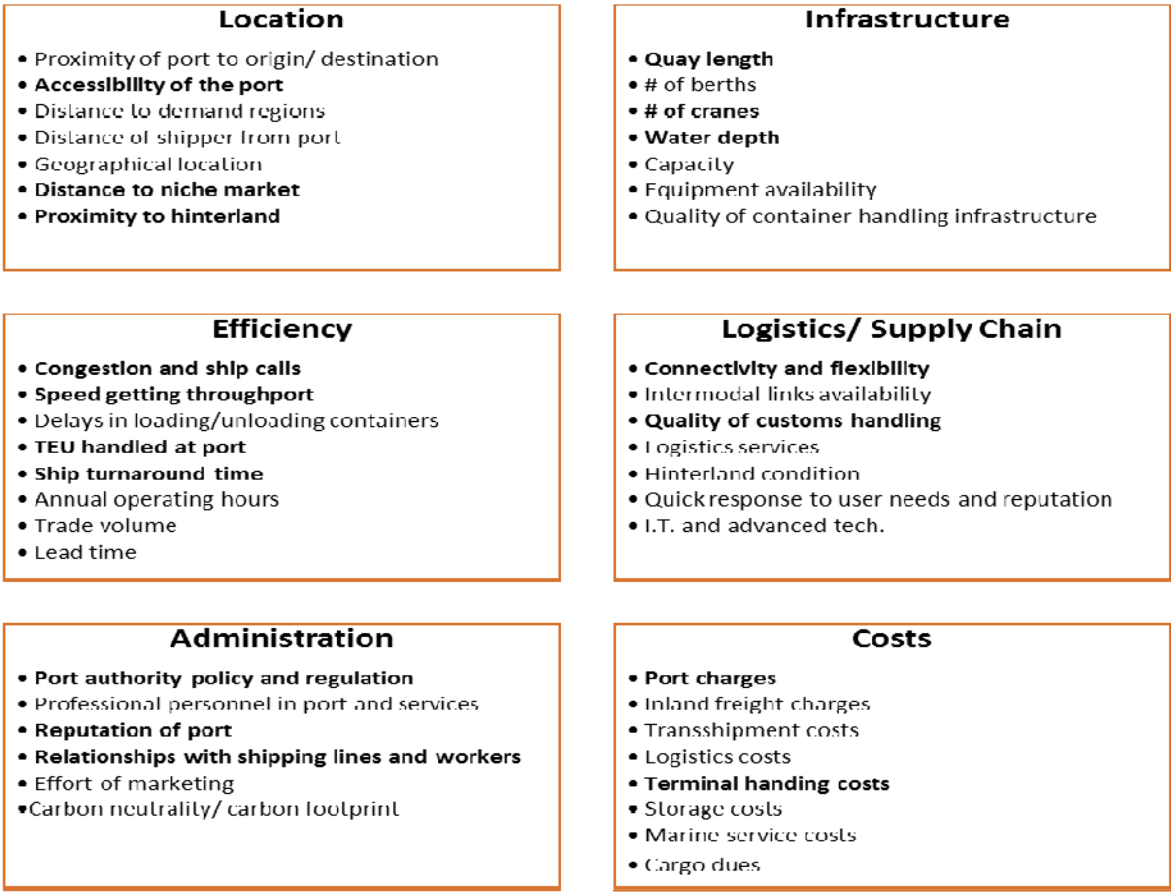

Figure 1. Multiple and conflicting criteria in port selection research - source: (De Icaza, 2017).

* Bold criteria are related to criteria in Figure 3.

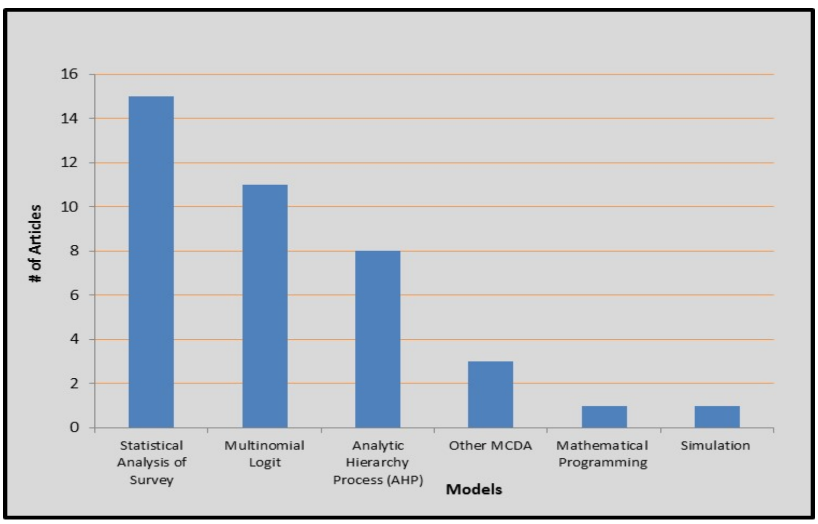

Figure 2. Models Applied to Port Selection Articles - Source: (De Icaza, 2017)

In addition, different methodologies have been used to analyze the port selection problem, as illustrated in Figure . Most of the port selection research have used the Statistical Analysis of Survey methodology, using interviews or surveys data from stakeholders (Chang, Lee, & Tongzon, 2008; De Langen, 2007; Grosso & Monteiro, 2009; Kim, 2014; Mangan, Lalwani, & Gardner, 2002; Murphy, 1992; Murphy & Daley, 1994; Ng, 2006; Panayides & Song, 2012; Sanchez, Ng, & Garcia-Alonso, 2011; Slack, 1985;Tongzon, 2002; Tongzon, 2009; Tongzon & Sawant, 2007; Wiegmans, Hoest, & Notteboom, 2008).

Multinomial Logit Model has been another popular method applied in the port selection literature. Some of the studies used subjective data for the development of the methodology (Nir, Lin, & Liang, 2003; Tiwari, Itoh, & Doi, 2003; Wu, Liu, & Peng, 2014); other studies concentrated on existing data to develop their model (Garcia-Alonso & Sanchez-Soriano, 2009; Malchow & Kanafani, 2001; Malchow & Kanafani, 2004; Steven & Corsi, 2012; Tang, Low, & Lam, 2011; Veldman, Garcia-Alonso, & Vallejo-Pinto, 2011; Veldman & Bückmann, 2003); while (Magala & Sammons, 2008) presented a new port selection modelling approach based on a conceptual framework.

The AHP developed by Saaty (1980) is a structured technique for dealing with complex decision-making problems and enables decision makers to represent the interaction of multiple factors in complex and unstructured situations. AHP has been used on several port selection problems (Alanda & Yang, 2013; Chou, 2010; Frankel, 1992; Gohomene, Bonsal, Maistralis, Wang, & Li, 2015; Lirn, Thanopoulou, Beynon, & Beresford, 2004; Song & Yeo, 2004; Ugboma, Ugboma, & Ogwude, 2006; Dyck & Ismael, 2015). The studies used input data based on pairwise comparison judgements of the decision criteria. Other MCDA methods that have been applied to the port selection research are the Fuzzy MCDM method (Chou, 2010; Yeo, Ng, Lee, & Yang, 2014) and the outranking method PROMETHEE (Guy & Urli, 2006).

The review of literature demonstrates that port selection is a multicriteria decision problem and there is a lack of research using MAVT; therefore, this research will demonstrate quantitative data exists to enable the development of a MAVT model for the port selection decision problem and illustrate the benefits of MAVT. Ralph Keeney (1992) described the two different decision making thinking styles: VFT and AFT approaches. The latter is the traditional and more common approach, which concentrates first on a current set of alternatives and then selects the best choice based on the values and preferences applied to them. This approach limits the decision maker creativity and new opportunities exploration (Wright & Goodwin, 1999). In contrast, VFT focuses first on understanding and using the values and objectives, and later on the evaluation of alternatives (current set and an ideal alternative) to achieve these values (Keeney, 1992; Keeney, 1994). According to a VFT survey paper (Parnell et al., 2013), which included 89 journal articles in a period of 18 years, it was observed that VFT was used on 65% of the articles to evaluate alternatives and 32% of the articles to design or improve alternatives. This study will develop the MAVT with VFT for the container port selection decision in West Africa, to evaluate, rank, and improve the port alternatives.

3. Research Methodology

3.1 MAVT With VFT for the Container Port Selection Decision Model

MAVT with VFT methodology has been selected to develop a shipping lines' container port selection decision model in West Africa using the decision hierarchy (4 objectives and 16 criteria, Figure 3) and port alternatives of a recent published study (Gohomene, Bonsal, Maistralis, Wang, & Li, 2015). The alternative-focused thinking (AFT) approach will also be developed in order to compare the results of both approaches for the container port selection decision problem. The axioms and conditions of the MAVT approach are defined by Keeney and Raiffa (1976). Belton and Stewart (2002) provides an in-depth explanation of the approach.

3.1.1 Using a Decision Hierarchy from Literature

The value hierarchy is fundamental to determine what is important for the decision problem and to provide the basis for the evaluation of the value model (Davis, Deckro, & Jackson, 2000). The value hierarchy shown in Figure 3 was constructed using the decision hierarchy (set of 16 criteria clustered in 4 groups) of a recent published journal article (Gohomene, Bonsal, Maistralis, Wang, & Li, 2015) using AHP. They identified important criteria for the West African container port selection decision by identifying 30 criteria from their literature review and interviews with experts. The criteria were reduced to 16 (Figure 3) using a survey conducted to a panel of four experts on container shipping in West Africa (3 senior managers and 1 senior lecturer from academia).

3.1.2 Convert Decision Hierarchy to Value Hierarchy

The first step of the VFT process was to develop a multi-attribute value model that provides a framework for the evaluation of the alternatives (Figure 3). The main purpose of the value model is described in level 1 of the value hierarchy. Then, it is divided in 4 general groups (level 2), and subsequently the set of criteria is presented in level 3 of the hierarchy. Finally, attributes (level 4) were identified for each of the 16 criteria.

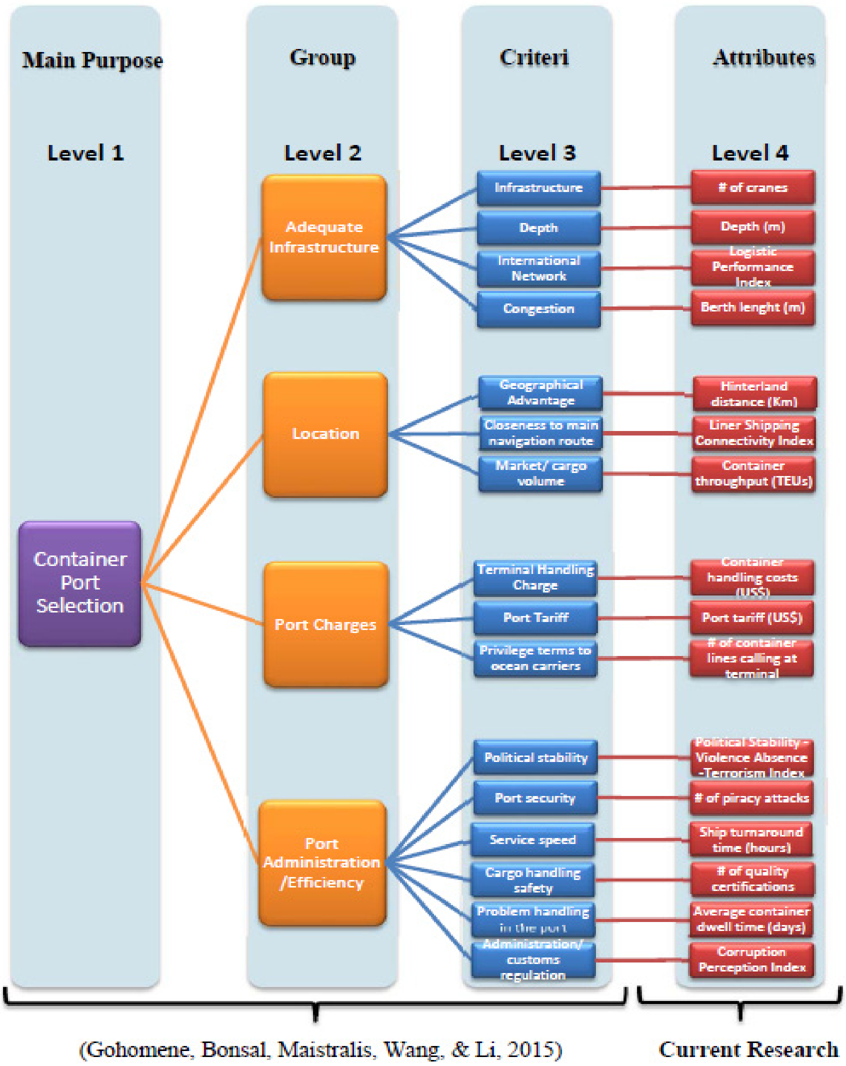

Figure 3. Value hierarchy for the container port selection value model

3.1.3 Defining the Attributes

For each criteria of the value model, an attribute was identified (Figure 3). Attributes serve as a measure of performance to evaluate how well an alternative performs with respect to the criteria on the value model (Belton & Stewart, 2002; Keeney, 1992). In addition, two types of scales can be used for the attributes, natural and constructed. Natural scales are already well-known and commonly interpreted by people, while constructed value scales are developed for a specific decision problem (in which a natural scale does not exists) and use a set of qualitative levels to assess the criteria (Belton & Stewart, 2002).

The goal of this research was to identify quantifiable attributes with natural scales and ready available data for each attribute of the value model. Through research, we identified data available on the internet (reports, documents, etc.) from different reliable sources to score alternatives against each of the attributes of the port selection value model (Table 1). It is one of the most critical steps of the research because it demonstrates that available data can be collected to evaluate a container port selection decision.

Using the collected research data shown in Table 1, extreme points of the scales for each attribute were defined and shown in Table 2. Extreme points of the scales are important to develop the scales and partial value functions of the model. Since VFT approach uses Global scale, it goes from the minimum acceptable level (column 3) to the ideal level (column 5) for each attribute. Data for the Ideal Port (Ideal Level) is related to one of the top ports in Africa, Port Said East located in Egypt, which is ranked among the top 50 world container ports (World Shipping Council, 2016).

Regarding the Best Level, column 4 on Table 2, it is an extreme point of the scale for the AFT approach, which is explained in section 3.2.1.

Table 1. Alternative scoring for each attribute

Ports	# of cranes	Depth (m)	Logistics Performance Index (1-5)	Berth length (m)	Hinterland distance (Km)	Liner Shipping Connectivity Index (0-100)	Container throughput (TEUs)	Container handling costs (US$)	Port tariff (US$)	# of container lines calling at terminal	Political Stability/ Terrorism Index (0-100)	# of piracy attacks	Ship turnaround time (hours)	# of quality certifications	Average container dwell time (days)	Corruption Perception Index (0-100)
Abidjan Port	22	11.5	2.76	1,000	1238	21.9	783,102	260	12005	29	12.62	3	1	3	12	32
Dakar Port	18	13	2.62	660	2075	12.9	450,008	160	12402	22	41.26	0	24	3	7	43
Lagos Port	22	13.5	2.81	1,005	1376	22.9	1,062,389	155	19963	16	5.34	18	12	1	42	27
Lome Port	11	12	2.32	430	1272	19.1	223,465	220	3973	21	39.32	2	1	1	13	29
Tema Port	16	11.5	2.63	574	1181	21.7	833,771	168	3442	25	40.78	4	32	1	25	48
Ideal Port/ Port Said East	76	16	5	1,200	1000	61.8	8,810,990	151	3000	32	100	0	1	5	5	100
Source	(Port Report Africa, 2014)		(World Bank LPI, 2014)	(Dyck & Ismael, 2015)		(World Bank WDI, 2014)	(UNCTAD STAT, 2014)	(Dyck & Ismael, 2015)	(CATRAM Consultants, 2013)	(Port Report Africa, 2014)	(World Bank WGI, 2014)	(ICC International Maritime Bureau ,2015)	(Knoema - Port Databse, 2014)	(Port of Abidjan, Ivory Coast, n.d.)	(Dyck & Ismael, 2015)	(Transparency International, 2014)

Table 2. Attribute data to develop partial value functions

Criteria (1)	Attribute (2)	Min Acceptable Level (3)	* Best Level (4)	** Ideal Level (5)	Curve Shape (6)	Source (7)
Port Infrastructure	# of cranes	11	22	76	Linear	(Port Report Africa 2014)
Port depth	Depth (meters)	11.5	13.5	16	Convex	(Port Report Africa 2014)
Intermodal network	Logistic Performance Index (1-5)	2.32	2.81	5	Linear	(World Bank LPI, 2014)
Congestion	Berth length (meters)	430	1005	1200	Linear	(Dyck & Ismael, 2015)
Geographical advantage	Hinterland distance (Kilometers)	2075	1181	1000	Concave	(Dyck & Ismael, 2015)
Closeness to main navigation routes	Liner shipping Connectivity Index (0-100)	12.9	22.9	61.8	Linear	(World Bank WDI, 2014)
Market/ cargo volume	Container throughput (TEUs)	0.22	1.06	8.81	Linear	(UNCTAD STAT, 2014)
Terminal handling charge	Container handling costs (US$)	260	155	151	Linear	(Dyck & Ismael, 2015)
Port tariff	Port Tariff (US$)	19963	3442	3000	Linear	(CATRAM Consultants, 2013)
Privileged terms to ocean carriers	# of container lines calling at terminal	16	29	32	Linear	(Port Report Africa 2014)
Political stability	Political Stability and Absence of Violence/ Terrorism Index (0-100)	5.34	41.26	100	Convex	(World Bank WGI, 2014)
Port security	# of piracy attacks	18	0	0	Convex	(ICC International Maritime Bureau , 2015)
Service speed	Ship turnaround time (hours	32	1	1	Convex	(Knoema - Port Databse, 2014)
Cargo handling safety	# of quality certifications	1	3	5	Linear	*** (Port of Abidjan, Ivory Coast, 2016)
Problem handling in the port	Average container dwell time (days)	42	7	5	Convex	(Dyck & Ismael, 2015)
Port administration and customs regulation	Corruption Perception Index (0-100)	27	48	100	Linear	(Transparency International, 2014

***Data used for the AFT method (Local Scale). **Data Used for VFT method (Global Scale). ***Data from different websites:** (Port Autonome de Dakar [Autonomous Port of Dakar], 2016)**;** (Bolloré Africa Logistics Nigeria, 2014)**;** (Port Autonome de Lome [Autonomous Port of Lome], 2012)**;** (Tema Port, 2014)**;** (Suez Canal Container Terminal, 2016)

3.1.4 Create Partial Value Functions

Partial value functions were created for each attribute of the value model in order to convert the different attribute scales into one standard unit of measure, so that port alternatives of the value model could be evaluated. Since the VFT approach uses a global scale, the endpoints of the attribute scales are the minimum acceptable and ideal levels of performance for each attribute (Table 2) (Belton & Stewart, 2002); which were valued with a 0 and 100 value scale.

Partial value functions were developed by applying the Difference Method (Watson & Buede, 1987). The method assumes that value functions are monotonically increasing or decreasing. Five points were used to develop each partial value function, the 2 endpoints and 3 midpoints.. Most partial value functions are linear, which means that each unit of increase in the attribute corresponds to the same increase in the value. The partial value function related to the number of cranes attribute was developed using this rationale, as shown in Figure 4. On the other hand, other partial value functions have a concave or convex curve shape, which is the case of depth in meters, shown in Figure 4. In this example, the value increase is significantly higher once the port registers higher meters of depth resulting in a convex shape curve.

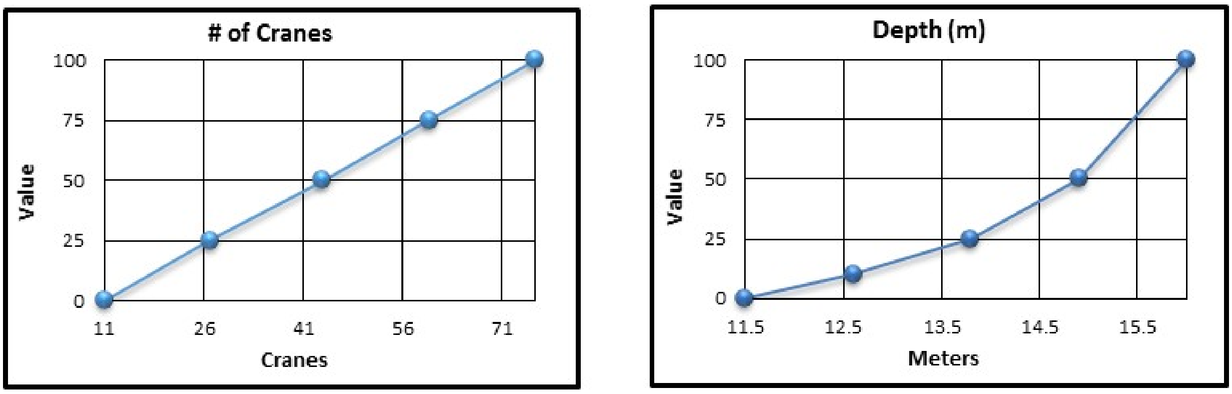

Figure 4. Examples of partial value functions with linear and convex curve shapes

3.1.5 Assigning Weights using the Swing Weight Matrix

Weights are critical in the MAVT because they quantify the trade-offs between attributes. Weights were assigned to the attributes of the value model using the Swing Weight Matrix method (Parnell & Trainor, 2009). The approach considers that weights are based not only on the level of the importance of the attribute (columns in Table 3), but also on their variation of the scale (rows in Table 3) (Kirkwood, 1997).

As shown in the columns of Table 3, three levels of importance were created to classify the attributes in the matrix: External Critical Attributes, Performance and Costs Indicators, and Value Added Features. The first level of importance refers to national or regional characteristics beyond the control of the port; the second level of importance uses quantitative measures of past port performance; and the last one refers to services and characteristics that may provide future operational efficiencies.

The scale variation of the attributes are represented by the gap between the minimum acceptable and ideal scale of the attributes. Three levels (small, medium and large) were used to classify the scale variation of attributes in the matrix as shown in the rows of Table 3. Percentage change calculations were used to classify the attributes in the groups.

Table 3. Swing weight matrix for the VFT Approach

		Level of Importance of Attributes								
		External Critical Attributes	**SW**	**NW**	**Performance and Costs Indicators**	**SW**	**NW**	**Value Added Features**	**SW**	**NW**
Gap btw Min. Accep. and Ideal	Large	Political stability	100	0.12	Container throughput (TEUs)	65	0.08	# of cranes	45	0.05
		Liner shipping connectivity index	90	0.11	Ship turnaround time	55	0.07	# of quality certifications	30	0.04
	Medium	Corruption perception index	80	0.09	Average container Dwell Time	50	0.06	Berth length (m)	15	0.02
		# of piracy attacks	75	0.09	Port tariff	40	0.05			
		Hinterland distance (Km)	70	0.08						
	Small	Depth (m)	50	0.06	Container Handling Costs	35	0.04			
					# of container lines calling at terminal	30	0.04			
					Logistics Performance Index	15	0.02			

SW: Swing Weights (f_i) -- **NW**: Normalized weights (Sum of **NW** equals to 1).

*Characteristic beyond the control of the port and/or an essential characteristic to provide the service.

**Value added services or characteristics to improve service or being different from competition.

***Port services and characteristics that may provide operational efficiencies.

Attributes with higher level of importance and large variation were placed on the top left corner of the matrix while attributes with the opposite characteristics were placed on the lower right corner of the matrix. Level of importance and variation of the scale of the attributes decrease from left to right and top to bottom respectively. The next step was to assign the swing weights (f_i) (SW column in Table) to the attributes. For this research, it was determined that range of swing weights are between 15 (lowest) and 100 (highest), which means that swing weight of the best attribute is around 6 times more than the worst attribute. Then, swing weights were assigned to the rest of the attributes relative to the highest weighted attribute by swinging the attribute from its worst to its best level (Montibeller, 2005). Weights descended in magnitude as we moved on the diagonal from the top left to the bottom right of the swing weight matrix (Table 3). The final step is to calculate the normalized swing weights (NW column in Table 3) to sum to 1 for use in the additive value model. The formula to normalize the swing weights is shown below:

$$w_i = \frac{f_i}{\sum_{i=1}^{16} f_i}$$

Where f_i is the swing weight assigned for the i^{th} attribute; i=1 to n for the number of attributes; and w_i are the normalized swing weights.

3.1.6 Single Dimensional Value Calculations

Single dimensional values (Table 4) for each alternative under each attribute were calculated using the partial value functions. This data is fundamental for the overall evaluation of alternatives.

Table 4. Single dimensional value calculations for each attribute

Ports	# of cranes	Depth (m)	Logistics Performance Index (1-5)	Berth length (m)	Hinterland distance (Km)	Liner Shipping Connectivity Index (0-100)	Container throughput (TEUs)	Container handling costs (US$)	Port tariff (US$)	# of container lines calling at terminal	Political Stability/ Terrorism Index (0-100)	# of piracy attacks	Ship turnaround time (hours)	# of quality certifications	Average container dwell time (days)	Corruption Perception Index (0-100)
Abidjan Port	17	0	16	74	96	19	7	0	47	81	3	64	100	50	53	7
Dakar Port	11	15	11	30	0	0	3	92	45	38	20	100	10	50	87	22
Lagos Port	17	21	18	75	89	21	10	96	0	0	0	0	41	0	0	0
Lome Port	0	5	0	0	95	13	0	37	94	31	19	76	100	0	47	3
Tema Port	8	0	11	19	97	18	7	84	98	56	20	52	0	0	18	29
Ideal Port/ Port Said East	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

3.1.7 Overall Evaluation of Alternatives

Finally, the MAVT yields the overall value for the alternatives of the value model using the additive value model (Belton & Stewart, 2002; Keeney & Raïffa, 1976).

$$v(x) = \sum_{i=1}^{n=16} w_i \, v_i \,(x_i)$$

Where, $v(x)$ is the alternatives's value; i=1 to n is the number of attributes; x_i is the alternative's score on the ith attribute; $v_i(x_i)$ is the partial value function of a score of x_i; w_i is the weight of the i^{th} attribute. Based on the additive value model, the overall values and ranking of the alternatives were obtained and shown in

Table 5. The Hypothetical Best alternative is a hypothetical alternative with the best score on each attribute.In addition, for a better illustration of the magnitude each attribute contributes to the overall value of each alternative, the value component graph (Figure 5) and the floating value component chart (Figure 6) were developed for the value model.

Table 5. Overall value and ranking of alternatives of the value model

Ports	Total Value - VFT	Ranking
Abidjan Port	36	1
Lome Port	35	2
Tema Port	32	3
Dakar Port	31	4
Lagos Port	21	5
Hypothetical Best	54	
Ideal Port	100	

3.1.8 Identifying Value Gaps

The VFT approach offers the opportunity to improve the decision making process through the evaluation of the alternatives (Keeney, 1992). Alternatives were evaluated using the Value Component Charts (Figures 5-7) in order to identify performance of each alternative and also compare attribute value gaps for each alternative against the ideal alternative. These value gaps can help shipping lines to know the strengths and weaknesses of the port alternatives. On the other hand, container port authorities can benefit from the value gap analysis by identifying areas in which there is room for improvement for the port to improve their levels of service. The floating value component chart (Figure 6) illustrates the value gaps for each attribute of the alternatives of the value model against the ideal alternative. In addition, the white block above each attribute of the Abidjan Port alternative (Best Port) bar in Figure 7, represents the value gap compared to the ideal port. Significant value gaps exist in several attributes. For example the largest value gap between the best and ideal alternative (Figure 7) is related to the attribute: port depth in meters. On the other hand, there is not a value gap for the attribute: ship turnaround time in hours, because the Abidjan Port (Best Port) has the same value as the Ideal Port.

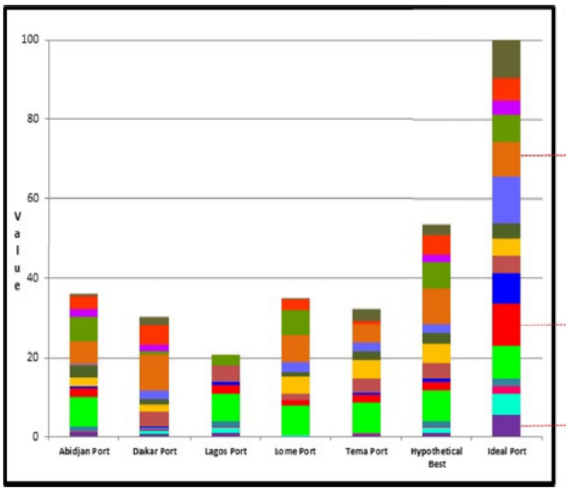

Figure 5. Value component chart

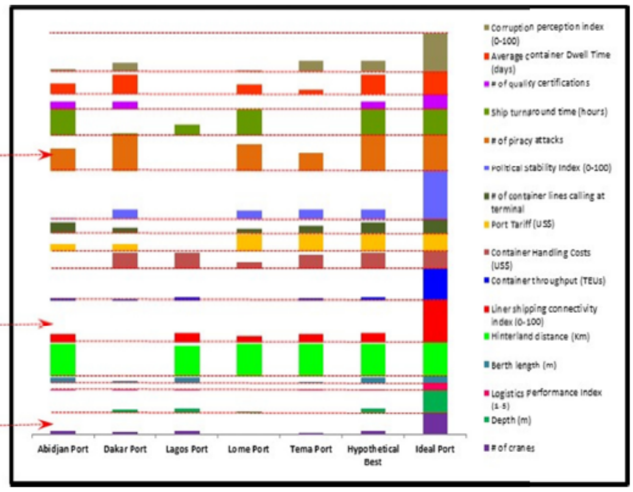

Figure 6. Floating value component chart

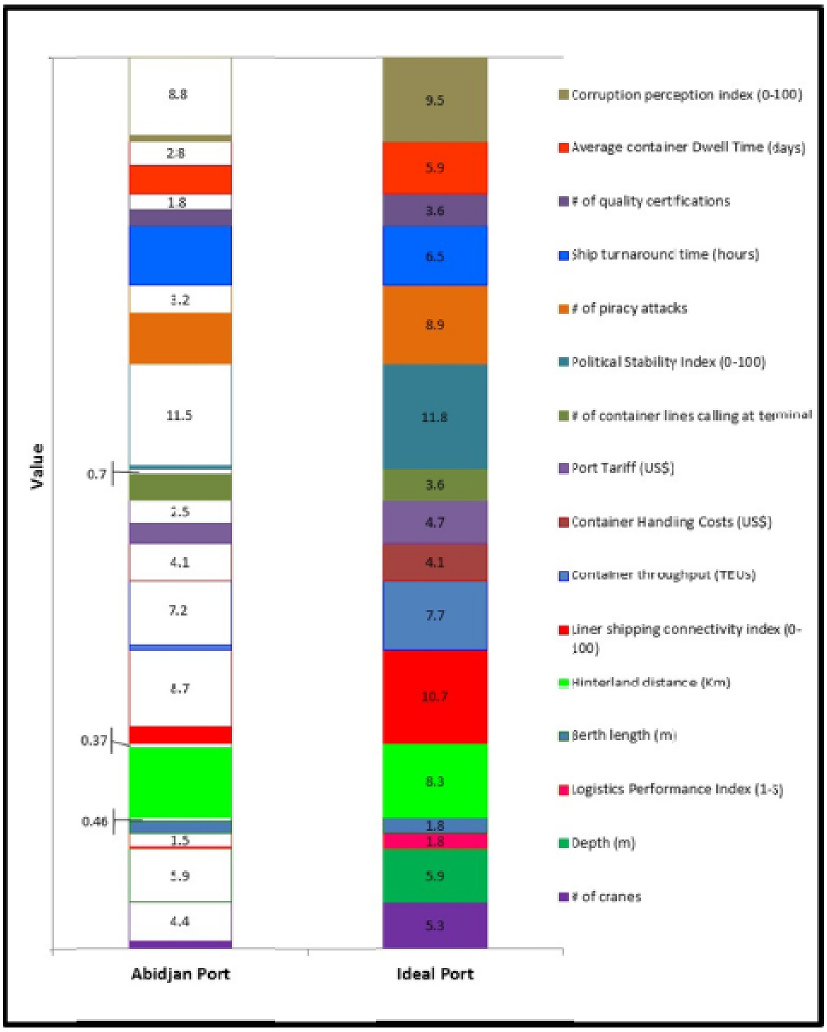

Figure 7. Value gaps between best and ideal alternatives of value model

3.2 Alternative Focused Thinking Approach (AFT)

One of the goals of this research is to compare the results of the container port selection decision problem using the two approaches, VFT and AFT. The AFT approach concentrates on the alternatives of a decision problem (Keeney, 1992). To simplify the illustration of the AFT approach, only the steps and data that differs from the VFT approach will be presented.

3.2.1 Attribute Scale and Partial Value Functions

Since the AFT approach uses a local scale, the set of port alternatives involves only the current available ports (Abidjan, Dakar, Lagos, Lome, and Tema) for the container port selection decision problem, not including the Ideal alternative. Therefore, attribute scales will go from the minimum acceptable to the best level of performance for each attribute (Columns 3 and 4 inTable 2); which in turn, numerical standard unit of measure of 0 and 100 will be assigned respectively for the development of the partial value functions. Figure 8 illustrates two examples of partial value functions for the AFT approach, which comparing to the VFT partial value functions , the only difference will be on the highest value level of performance of each attribute.

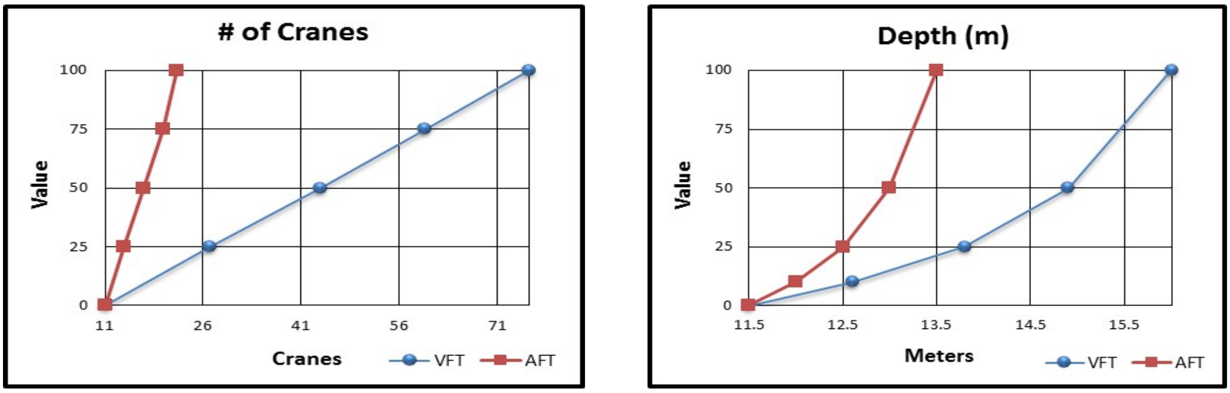

Figure 8. Examples of partial value functions for the AFT Approach and VFT Approach

3.2.2 Assigning Weights Using the Swing Weight Matrix

In addition, since the variation of the scale of each attribute has changed (Columns 3 and 4 in Table 2); then, the swing weight matrix for the AFT approach was reassessed following the same procedure explained in section 3.1.5. The swing weight matrix for the AFT approach is shown in Table 6.

Table 6. Swing weight matrix for the AFT approach

<table>
<tr><th colspan="2"></th><th colspan="9">Level of Importance of Attributes</th></tr>
<tr><th colspan="2"></th><th>External Critical Attributes</th><th>SW</th><th>NW</th><th>Performance and Costs Indicators</th><th>SW</th><th>NW</th><th>Value Added Features</th><th>SW</th><th>NW</th></tr>
<tr><td rowspan="8">Gap btw Min. Accep. and Ideal</td><td rowspan="2">Large</td><td># of piracy attacks</td><td>100</td><td>0.12</td><td rowspan="2">Container throughput (TEUs)</td><td rowspan="2">75</td><td rowspan="2">0.09</td><td># of cranes</td><td>60</td><td>0.07</td></tr>
<tr><td>Political stability</td><td>85</td><td>0.10</td><td># of quality certifications</td><td>50</td><td>0.06</td></tr>
<tr><td rowspan="4">Medium</td><td>Liner shipping connectivity index</td><td>80</td><td>0.09</td><td>Ship turnaround time</td><td>65</td><td>0.08</td><td rowspan="4">Berth length (m)</td><td rowspan="4">30</td><td rowspan="4">0.03</td></tr>
<tr><td rowspan="3">Corruption perception index</td><td rowspan="3">70</td><td rowspan="3">0.08</td><td>Port tariff</td><td>55</td><td>0.06</td></tr>
<tr><td># of container lines calling at terminal</td><td>45</td><td>0.05</td></tr>
<tr><td>Average container Dwell Time</td><td>35</td><td>0.04</td></tr>
<tr><td rowspan="2">Small</td><td>Hinterland distance</td><td>55</td><td>0.06</td><td>Container Handling Costs</td><td>15</td><td>0.02</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Depth (m)</td><td>40</td><td>0.05</td><td>Logistics Performance Index</td><td>5</td><td>0.01</td></tr>
</table>

SW: Swing Weights (f_i) -- **NW**: Normalized weights (Sum of **NW** equals to 1).

*Characteristic beyond the control of the port and/or an essential characteristic to provide the service.

**Value added services or characteristics to improve service or being different from competition.

***Port services and characteristics that may provide operational efficiencies.

Table 7. Single dimensional value calculations for each attribute

Ports	# of cranes	Depth (m)	Logistics Performance Index (1-5)	Berth length (m)	Hinterland distance (Km)	Liner Shipping Connectivity Index (0-100)	Container throughput (TEUs)	Container handling costs (US$)	Port tariff (US$)	# of container lines calling at terminal	Political Stability/ Terrorism Index (0-100)	# of piracy attacks	Ship turnaround time (hours)	# of quality certifications	Average container dwell time (days)	Corruption Perception Index (0-100)
Abidjan Port	100	0	90	99	99	90	67	0	48	100	8	64	100	100	63	25
Dakar Port	58	50	60	40	0	0	27	95	46	50	100	100	10	100	100	75
Lagos Port	100	100	100	100	96	100	100	100	0	0	0	0	41	0	0	0
Lome Port	0	10	0	0	98	62	0	38	97	42	92	76	100	0	55	10
Tema Port	42	0	63	25	100	88	73	88	100	75	98	52	0	0	20	100
Hypothetical Best	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table 8. Overall value and ranking of alternatives for the AFT Approach

Ports	Total Value - AFT	Ranking
Abidjan Port	66	1
Tema Port	61	2
Dakar Port	56	3
Lome Port	50	4
Lagos Port	44	5
Hypothetical Best	100	

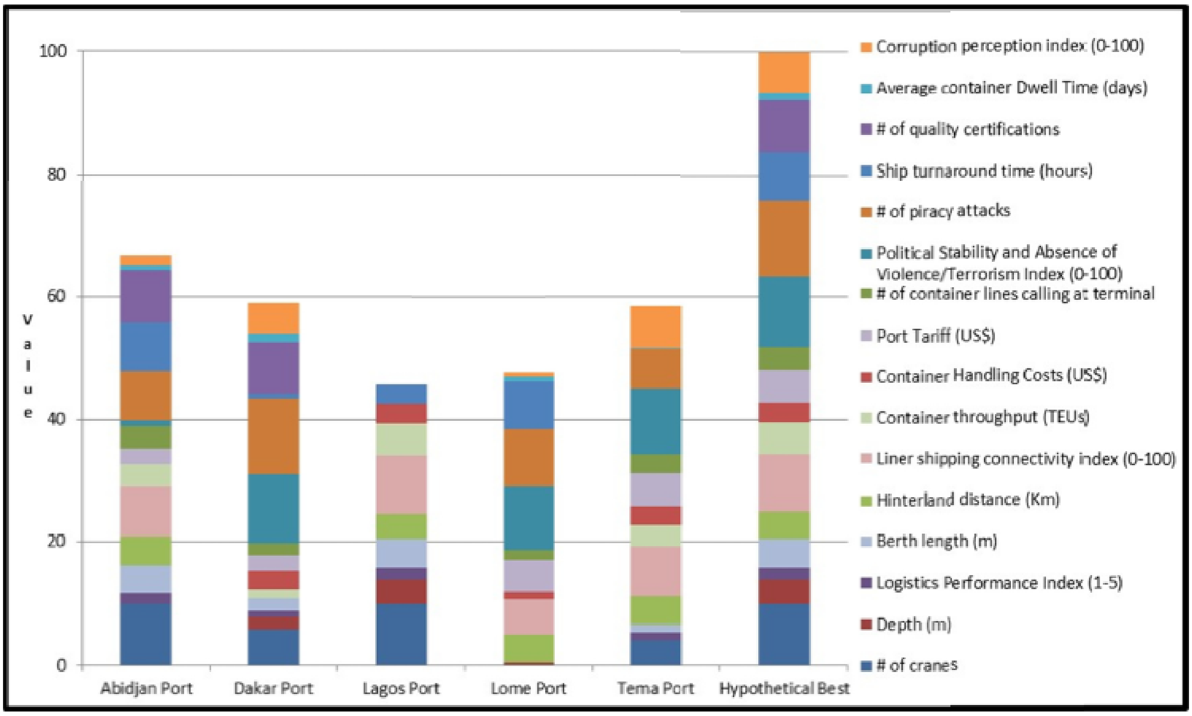

Figure 9. Value component chart for the AFT Approach

3.2.3 Single Dimensional Value Calculations and Overall Evaluation of Alternatives

Using the new AFT partial value functions and the alternative scores presented above (Table 1), single dimensional value calculations for each alternative under each attribute was developed and shown in Table 7. Finally, using the additive value model (See section 3.1.7), the overall value of each alternative was calculated for the AFT approach. The Hypothetical Best alternative was included among the alternatives of the model, so that decision makers can develop comparisons and insights.

The overall values and ranking of the port alternatives are presented in Table 8. In addition, the overall value for each alternative of the AFT approach is presented on the value component chart of Figure 9. The value component chart provides the contribution of each attribute to the overall value of the alternative compared to the hypothetical best alternative.

3.3 Comparing VFT vs AFT Results

Based on the VFT and AFT results shown in Table 9, Abidjan Port is the highest value alternative in West Africa for the shipping lines. Both approaches provide the same highest and lowest value alternatives. However, the 2nd, 3rd, and 4th ranked alternatives are not the same.

Table 9. Comparison of alternative overall values between VFT and AFT

Alternatives	VFT		AFT	
	Value	Ranking	Value	Ranking
Abidjan Port	36	**1**	66	**1**
Lome Port	35	**2**	50	**4**
Tema Port	32	**3**	61	**2**
Dakar Port	31	**4**	56	**3**
Lagos Port	21	**5**	44	**5**

4. Discussion

The applicability of the MAVT with VFT approach for a port selection decision problem has been demonstrated in this research and also compared with the traditional AFT approach. In order to score port alternatives, available quantitative port data was used, rather than using data from surveys and questionnaires. Decision makers can obtain more insights using MAVT with VFT rather than with AFT, because it concentrates on the understanding of the values of the decision makers and allows comparison of the current alternatives with the ideal situation, rather than just focusing on the current alternatives.

Analyzing the overall value gaps for the VFT approach, Abidjan Port has the opportunity to improve in the following attributes: depth, container handling costs, political stability, and corruption perception, in order to be closer to the ideal port of the region. Abidjan Port shows dominance over other alternatives for most of the other attributes of the value model. The value gaps charts (Figure 5, Figure 6 and Figure 7) were used to understand better how the overall value for each port alternative is constructed and what attributes can be defined as strengths and weaknesses for each port alternative of the VFT value model.

By using the swing weight method, it offers the advantage of assigning weight to attributes considering their level of importance and the gap between the minimum acceptable and ideal range scale, rather than using only a subjective approach. Figure 10 illustrates the variations of the weights between the two approaches.

Another observation is that attribute weights influence the final rankings on both methods. Sensitivity analysis was performed for every single attribute on weights and container handling cost is the only attribute that would result on a change of decision.

To obtain a cost versus value chart, the VFT value of the cost attributes were plotted against the value of the rest of the attributes in order to identify the cost effect on the dominant alternatives (Figure 11) (Parnell, Bresnick, Tani, & Johnson, 2013). Triangles were used to identify the two dominant alternatives, Abidjan Port which has the highest value but is the most expensive alternative and Lome Port which has the second best value and low cost among all alternatives. We believe this provides a useful perspective for decision makers that would be better with if the total costs were plotted against the value (See future research).

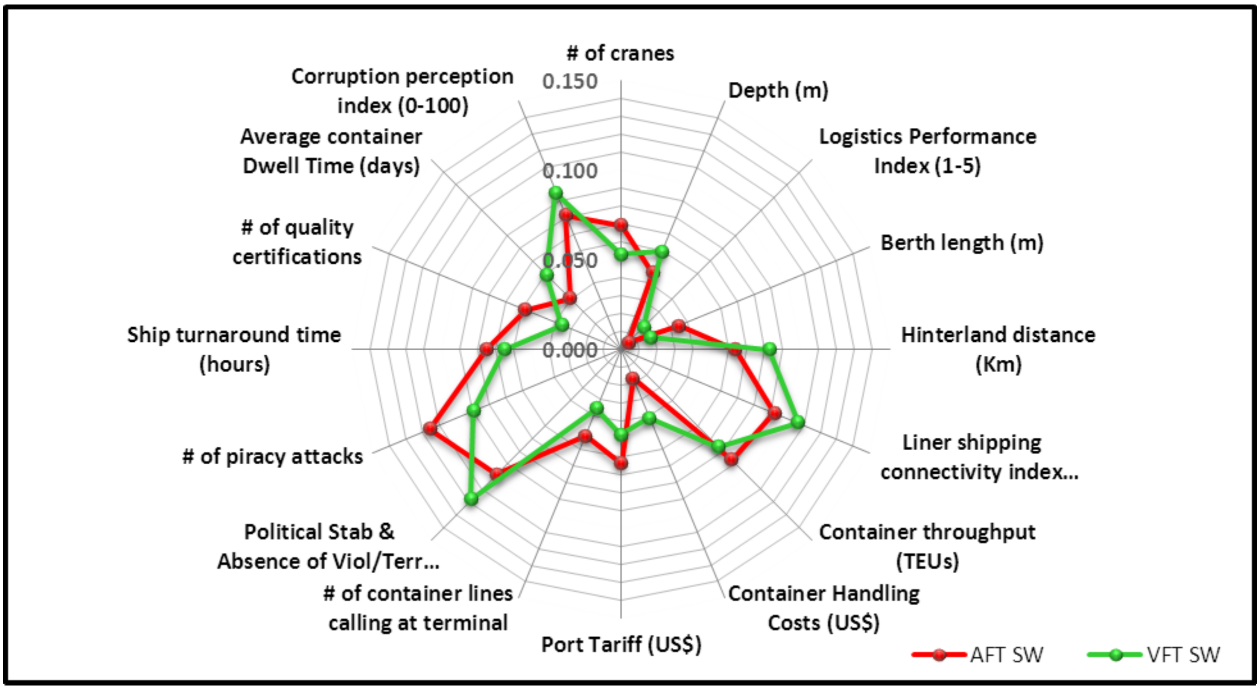

Figure 10. Weight comparison of AFT vs VFT Approaches

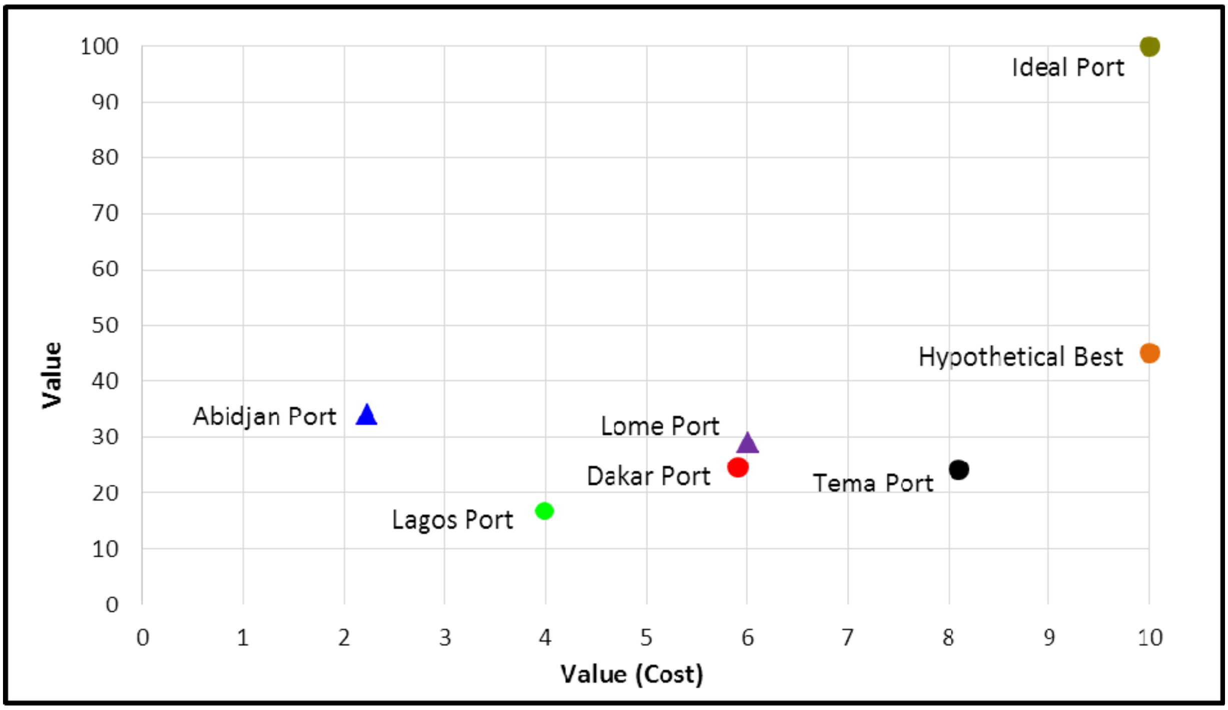

Figure 11. Cost value vs value for the VFT Approach

5. Future Research

Future work includes the port selection decision problem using MAVT with VFT, but in a different region such as a set of ports serving the Transpacific route (Asia to North America) through the Panama Canal. Since the expansion of the Panama Canal was completed recently, it is expected to increase the container traffic through this route using US ports. In addition, we plan to develop a lifecycle costs model separately and include both value and cost uncertainty.

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