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Decision Support System for Container Port Selection using Multiple-Objective Decision Analysis

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy in Engineering with a Concentration in Industrial Engineering

by

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Abstract

Ports are essential for maritime transportation and global supply chains since they are nodes that connect the sea- and land-based modes of transportation. With containerization and supply chains stimulating global trade, ports are challenged to adjust to changes in the market to create value to their customers. Therefore, this dissertation research focuses on the container port selection decision analysis to provide information to help shipping lines select the best port for their shipping networks. Since the problem is complex, dynamic, and involves multiple and conflicting criteria, the research proposes to use the multi-objective decision analysis with Value-Focused Thinking approach. The first chapter analyzes the port selection literature by timeline, journals, geographical location, and focus of the studies. Also, the research identifies the multiple criteria used in the port selection literature, as well as the models and approaches used for the analysis of the port selection decision problem. The second chapter develops a container port selection decision model for shipping lines using ports in West Africa. This model uses a multi-attribute value theory with valued-focused thinking and Alternative-Focused Thinking methodologies. The third chapter develops a port selection decision support system for shipping lines to select the best port in the U.S. Gulf Coast considering the impact of the Panama Canal's expansion. The decision support system uses the multi-objective decision analysis with Value-Focused Thinking approach, incorporating the opinion of an industry expert for the development of the value model. It also includes a cost model to quantify the cost of the alternatives. A Monte Carlo simulation is used to help decision makers understand the value and cost risks of the decision. The contribution of this research is that it provides a tool to decision makers of the shipping lines industry to improve the decision making process to select the port that will add the most affordable value to the global supply chains of their customers. In

addition, researchers can use the proposed methodology for future port selection studies in other regions and from the perspectives of other stakeholders.

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First and foremost, I would like to give my deepest thanks to my wonderful wife and children for their endless patience, understanding, support, and encouragement throughout the completion of my Ph.D. program. Thank you for your understanding, not only of the decreased amount of time we spent while living together, but also during the months we were separated while I worked on the achievement of my challenging goal.

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It would be impossible to make it through without the blessing and guidance of God, who gave me the passion and determination needed to overcome difficult moments and successfully complete the doctoral program.

Dedication

This dissertation is dedicated to my beloved wife, Zoribel, my daughter, Ana Sofia, and my son, Alonso, for their sacrifices, support, and love over the years of my doctoral studies.

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1. Introduction

Over the years, maritime transportation has been the essential mechanism for connecting regional markets, expanding trade among countries, and facilitating transportation of goods in the global economy.

The international seaborne trade volumes, by millions of tons loaded, have grown from 2,605 to 10,047 between 1970 and 2015 (UNCTAD, 2016). In addition, more than 90% of the world's trade goes by sea, which means that it is the most important mode of goods transportation in the global economy (IMO, 2016). It is expected that maritime transportation activities continue expanding and positively impacting the global economy due to trends such as the impact of globalization, advances in technology, expansion of the Panama and Suez Canals, ecommerce, and the contribution of developing countries to the world economy.

Since ports are the connection nodes between sea and land transportation, their operations and services are essential to enable global trade. In addition, due to globalization and the competitiveness of the market environment, ports are integrated elements of supply chains in order to add value and smooth the movement of goods among trading partners.

Organizations have recognized that global supply chains and logistics have a direct impact on the efficiency of their operations. Therefore, the selection of reliable partners, especially ports, is essential to minimize delays, add value to the product flow, and achieve the efficiency levels required to satisfy the end users.

In addition, most global supply chains are characterized by the use of containerized ocean transport. The containerization has been the main development in the maritime industry in the past 30 years (Fransoo & Lee, 2013). Containerized segment of the international seaborne trade, measured in millions of tons loaded, has grown from 102 to 1,687 from 1980 to 2015

(UNCTAD, 2016). The World Bank (2016) estimates that the global port container traffic, measured in Twenty Foot Equivalent Units (TEUs), has grown from 224,774,536 to 679,264,658 between 2000 and 2014. In addition to the development of the containerized shipping industry, there is a trend of bigger vessels, which have grown from 4300 TEUs in 1998 to 18,000 TEUs in 2015 (Tran & Haasis, 2015). Therefore container ports have been forced to increase their capacities, adopt new technologies, improve their operational efficiency, offer value added services, and adopt to environmental regulations, to satisfy their users.

Since the container port industry is characterized by an uncertain, dynamic, and competitive environment, shipping lines must strategically select the best port for their shipping network services considering multiple and conflicting criteria. Therefore, the focus of this dissertation is to study the container port selection decision analysis from the perspective of shipping lines.

The contribution of this dissertation is to offer a decision support system using the Multi-Objective Decision Analysis (MODA) with the Value-Focused Thinking (VFT) approach, which has not been fully used in the port selection literature.

Multiple objectives are appropriate since the port selection literature is characterized by the use of numerous criteria that can be grouped in the following areas: location, infrastructure, efficiency, logistics/ supply chain services, administration, and costs.

In Chapter 2, the research analyzes the port selection literature by timeline, journals, geographical location and focus of the studies. Also, the research identified the multiple criteria used in the port selection literature, as well as the models and approaches used for analyses of the port selection decision problem. In addition, the literature review presents a summary of the port selection articles with all the characteristics previously mentioned. The analysis of the literature helped to identify research gaps and then suggest development of potential future research topics.

The application of the multi-attribute value theory (MAVT) with valued-focused thinking (VFT) and Alternative-Focused Thinking (AFT) methodologies in a port selection decision problem is presented in Chapter 3. The research develops a container port selection decision model for shipping lines in West Africa. The criteria and port alternatives of the research were obtained from a published port selection study that applied a different analysis technique, the Analytic Hierarchy Process (AHP). The research 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 addition, the research focuses on ports located in developing countries, which are significantly contributing to the total global seaborne trade (UNCTAD, 2016).

Chapter 4 presents the development of the port selection decision support system for shipping lines to select the best port in the U.S. Gulf Coast considering the impact of the Panama Canal expansion. The decision support system uses the MODA with VFT approach, as well as input from an industry expert for the development of the value hierarchy and the swing weight matrix. In addition, the research presents a cost model to quantify the cost of the alternative ports compared to their value using the MODA approach. Also, the decision support system includes a probabilistic model, identifying uncertainties that affect the port selection decision and uses the Monte Carlo simulation to provide decision makers with a better understanding of the risks of the port selection decision.

The purpose to developing the decision support system is demonstrate the port data exists and the preference judgements can be made to provide a tool to assist decision makers in the selection of the best container port.

Bibliography

Fransoo, J., & Lee, C. (2013). The critical role of ocean container transport in global supply chain performance. *Production and Operations Management*, 22(2), 253-268.

IMO. (2016). *International Maritime Organization*. Retrieved from https://business.un.org/en/entities/13 (accessed January 2016).

Tran, N., & Haasis, H. (2015). An empirical study of fleet expansion and growth of ship size in container liner shipping. *International Journal of Production Economics*, 241-253.

UNCTAD. (2016). *Review of Maritime Transport.* Geneva: United Nations.

World Bank. (2016). *Container Port Traffic*. Retrieved from http://data.worldbank.org/indicator/IS.SHP.GOOD.TU?end=2014&start=2000&view=chart (accessed January 2016).

2. Port Selection Analysis: Trends and Gaps

Rivelino R. De Icaza H. Gregory S. Parnell John Aloysius

Abstract

Corporations have created global supply chains to meet the needs of their customers and increase profits. The maritime industry is a critical enabler for the global economy. Around 80% of global trade involves maritime transportation and is handled by ports. Port selection should be integrated into the global supply chain decision-making process in order to reduce costs, inventory levels, and lead times and to add value to the final customers and stakeholders. This research reviews and analyzes the port selection literature by timeline, journals, geographical location, and focus of the studies. In addition, by synthesizing the findings from previous literature, this paper identifies the multiple objectives used in port selection research, and describes the models and approaches used for port selection decision-making. Research gaps are identified, providing suggestions for future research. Because port selection is complex and dynamic and includes multiple objectives in an evolving landscape, a future research agenda suggests using a global rather than a regional focus, and assessing the problem from the viewpoint of multiple stakeholders.

Keywords: Port selection, multiobjective decision analysis, supply chain management, logistics, Panama Canal expansion, transportation.

2.1 Introduction

Ports are vital to global supply chains and the maritime industry. Globalization has increased over the years, allowing companies to expand their markets and supply chain across borders, relying more on global outsourcing strategies or third party companies to complete their services, and by expanding the use of ports. In 2012, international seaborne trade increased at a faster rate than the world economy, with volumes increasing at an estimated 4.3 per cent and about 9.2 billion tons of goods being loaded in ports worldwide (UNCTAD, 2013). The seaborne trade has reflected a steady growth over the years as seen in Figure 2.1 below.

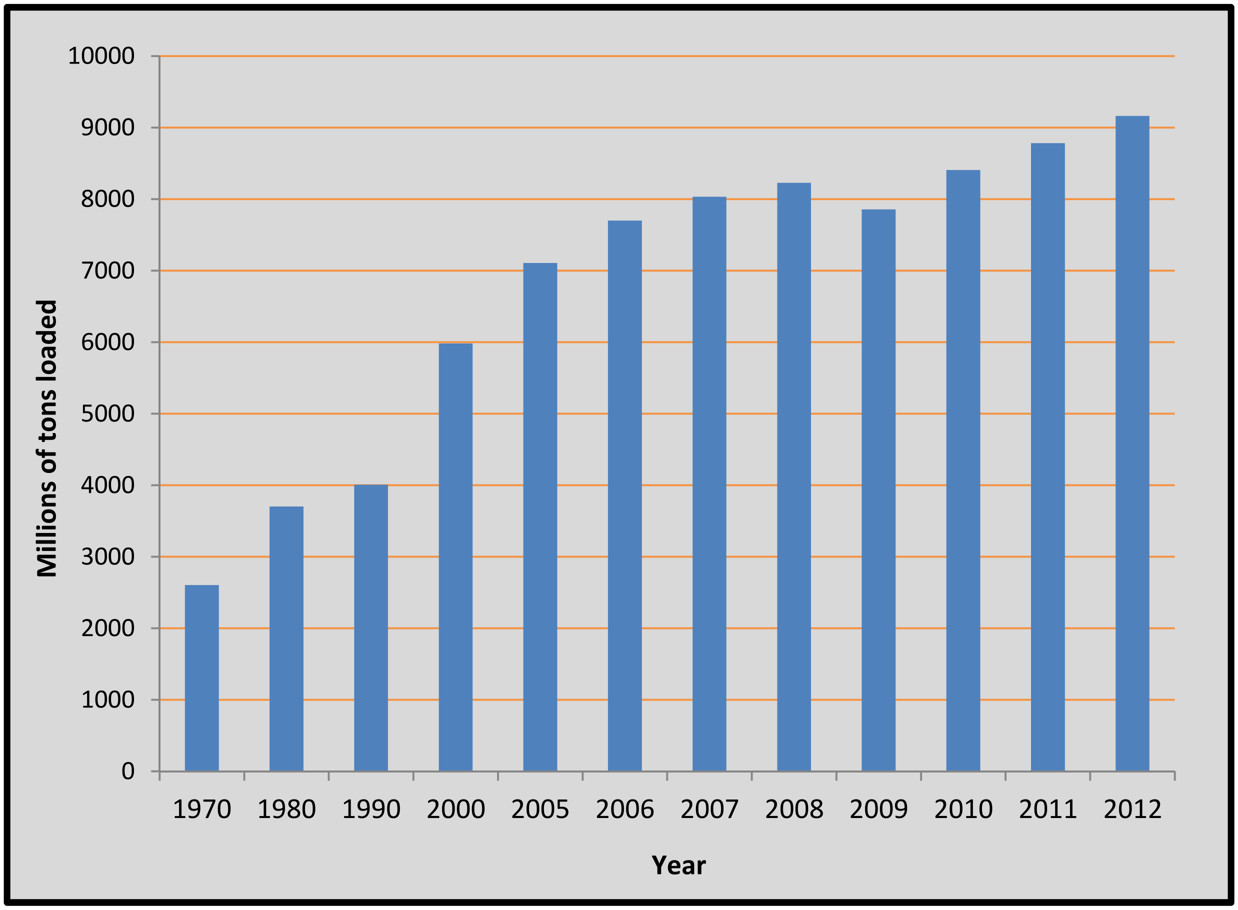

Figure 2.1 - International Seaborne Trade - Source: (UNCTAD, 2013)

In the past, ports were independent units offering services to users, operating with a low degree of competition and contributing primarily as logistic facilitators. Currently, ports are becoming more integrated into global supply chains to offer competitive services, intermodal solutions and low costs, and improving their operations and services to customers.

Increasingly, there is recognition of the need for a view of supply chain management as a comprehensive system. It is not possible to view supply chain activities in isolation and to make decisions that do not take into account the effect of those decisions on the total supply chain. The Council for Supply Chain Management (CSCMP) defines supply chain management as follows: "*encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies. Supply Chain Management is an integrating function with primary responsibility for linking major business functions and business processes within and across companies into a cohesive and high-performing business model. It includes all of the logistics management activities noted above, as well as manufacturing operations, and it drives coordination of processes and activities with and across marketing, sales, product design, finance, and information technology.*" (Mentzer, Stank, & Esper, 2008)

In a global supply chain, the main port selection objectives have changed over the years, requiring port managers to constantly analyze and examine the new requirements of port users, stakeholders, and global markets so that ports can offer the best services to remain attractive and competitive in the market. The port selection decision is a multiobjective, complex and dynamic problem, which must be (1) viewed in relation to the effect on various stakeholders in the global supply chain and the issues of concern to those stakeholders, and (2) examined regularly to guarantee that changes in the global market are considered in order to operate as effectively and efficiently as possible.

The Panama Canal Expansion and increase in containerization (Figure 2.2) are examples of important changes in the maritime industry and ports must react to opportunities to offer their users the best possible alternatives to their global supply chains and operations. The Panama Canal plays an important role in the global shipping industry, linking ship traffic between the Pacific and Atlantic Oceans and handling 5 percent of the world's trade with approximately 14,000 ships passing through the canal each year (Rodrigue, 2010). In addition, each year approximately 275 million tons of cargo are carried by the Panama Canal and 70 percent of the canal containerized freight is going to or coming from the United States (Knight, 2008) **.**

The Panama Canal is undergoing an expansion to construct a third set of locks and deepening the channel through the canal and Lake Gatun in order to increase the capacity to accommodate larger ships. The new locks will accommodate the Post-Panamax ships which are able to handle up to 13,0000 TEU (Twenty-foot Equivalent Units) as opposed to the current maximum capacity of 5,000 TEU of the Panamax ships (Panama Canal Authority, 2006). The Panama Canal expansion project was scheduled to be completed between seven or eight years, in time for its 100^{th} anniversary celebrations in 2014, but because of contract disputes about cost overruns and worker strikes, it was not completed until 2016.

Containerization plays an important role in international trade, facilitating transportation of goods all over the world to different markets and, at the same time, providing better reliability, flexibility, and costs of freight distribution (Notteboom, 2008)**.** Ocean shipping lines typically operate containerships on published schedules of sailings and closed routes, also known as cycles, strings or loops (Ronen, 2011). Ronen defines a route as a sequence of calling ports assigned to containerships. For many decades containerized trade has been the fastest-growing market segment, accounting for over 16 per cent of global seaborne trade by volume in 2012 and more than half by value in 2007 (UNCTAD, 2013). Also this segment has shown a positive trend in the international seaborne trade over the years as reflected in Figure 2.2.

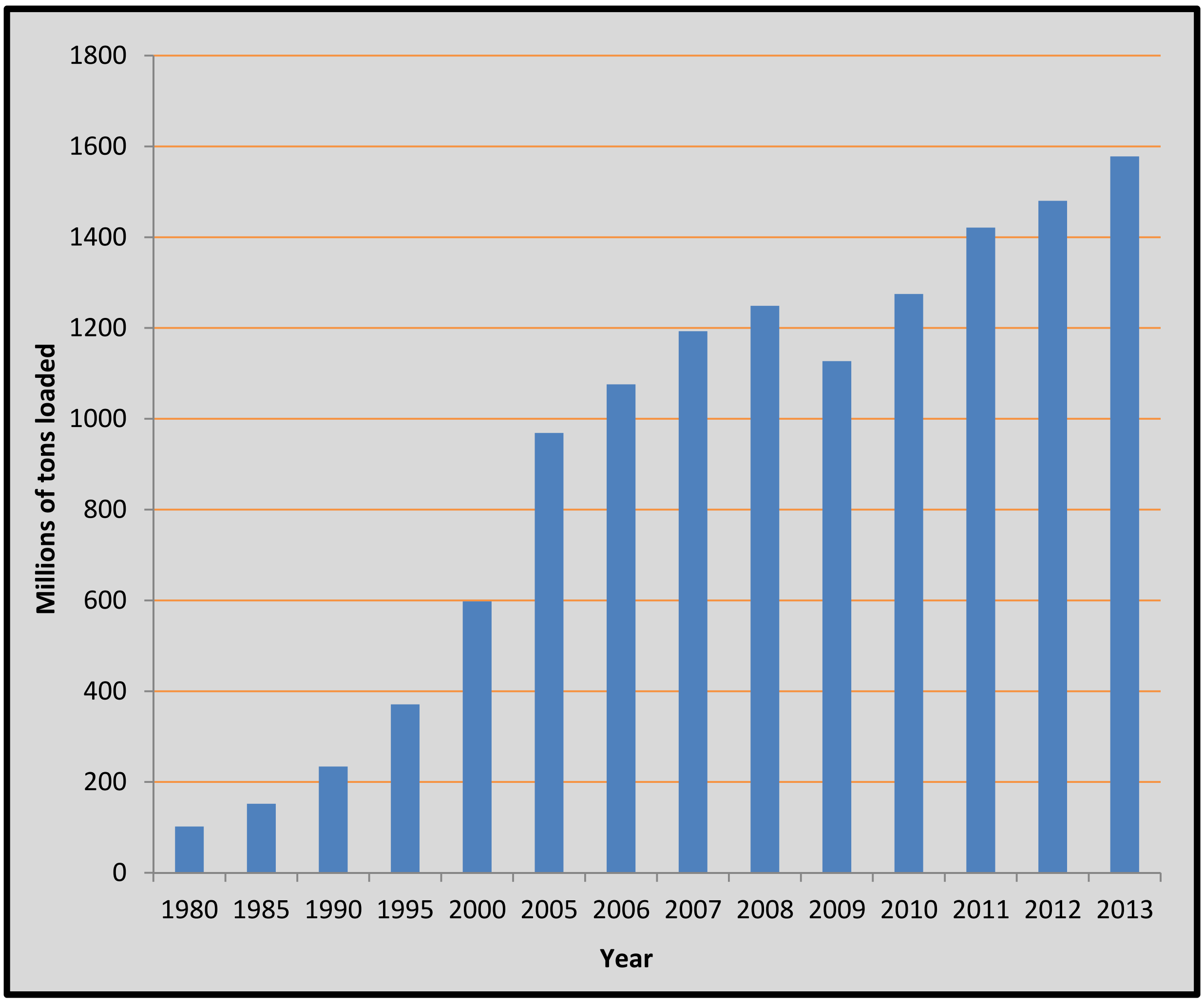

Figure 2.2 - Seaborne Trade - Container Segment, Source (UNCTAD, 2013)

The containership segment of the Panama Canal is the main driving force of traffic growth. As an example, during fiscal the year 2005, this segment accounted for 98 million PCUMS[1] tons, which represented 35% of the total PCUMS volume passing through the Canal and 40% of its revenues. In addition, in the containerized cargo segment of the Panama Canal, trade between Northeast Asia and the U.S. East Coast reflects the highest Canal transit growth rate. This route alone represents more than 50% of the PCUMS volume of the containerized cargo segment passing through the Canal and is anticipated to become a key Panama Canal growth driver (Panama Canal Authority, 2006)

The purpose of this research is to review and analyze the port selection literature, describe the geographic region and focus used in port selection analyses, identify port selection objectives used by the different authors, and describe the models applied in port selection research. This analysis of the literature on port selection, will identify research gaps and then suggest development of potential future research topics to improve port selection decision making.

This chapter is organized as follows: section 2 describes the research methodology; section 3 analyzes the port selection literature; section 4 presents a discussion of the findings; section 5 describes important elements to be considered in future research; and section 6 provides a conclusion.

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[1] Acronym for Panama Canal Universal Measurement System. The PCUMS ton is the unit used at the Canal to establish tolls, and measures vessels volumetric cargo capacity. A PCUMS ton is equivalent to approximately 100 cubic feet of cargo space, and a 20-foot-long container is equivalent to approximately 13 PCUMS tons (Panama Canal Authority, 2006)

2.2 Research Methodology

2.2.1 Conceptual Framework and Theory

The goal of supply chain management is to predict and plan production and transportation to meet the needs of customers and to minimize inventory of suppliers (Chang, Ouzrout, Nongaillard, Bouras, & Jiliu, 2014). Key strategic considerations in global supply chains are the selection of partners, the transportation segment, and decisions affecting the operations of the supply chain. Figure 2.3 illustrates the conceptual model, showing a global supply chain with its partners and the transportation logistics segment, which includes port selection. The conceptual framework in this study assumes that the port selection issue should be analyzed as part of the global supply chain and cannot be studied separately without taking into account the supply chain and logistics operations. Steven & Corsi (2012) suggest that logistics activities within the supply chain should be viewed as a system with ports taking a central role in the supply chain, both receiving the freight in the origin country and dispatching it in the destination country. Ports should be considered elements in a supply chain that delivers value to shippers, third party service providers and shipping lines. The movement of freight containers through the transportation segment of the supply chain involves three components: 1) inland transportation (truck, rail or intermodal) of the freight containers to the port of landing and from the port of discharge to move the freight to the next supply chain partner; 2) the handling of containers through the port terminals, which includes the unloading and loading of containers into the ship; 3) and the maritime transportation of the containers by ship. Therefore, the port's role in supply chain management is to facilitate supply chain performance by providing efficient and high quality services to facilitate supply chain integration and better logistics performance (Panayides & Song, 2012).

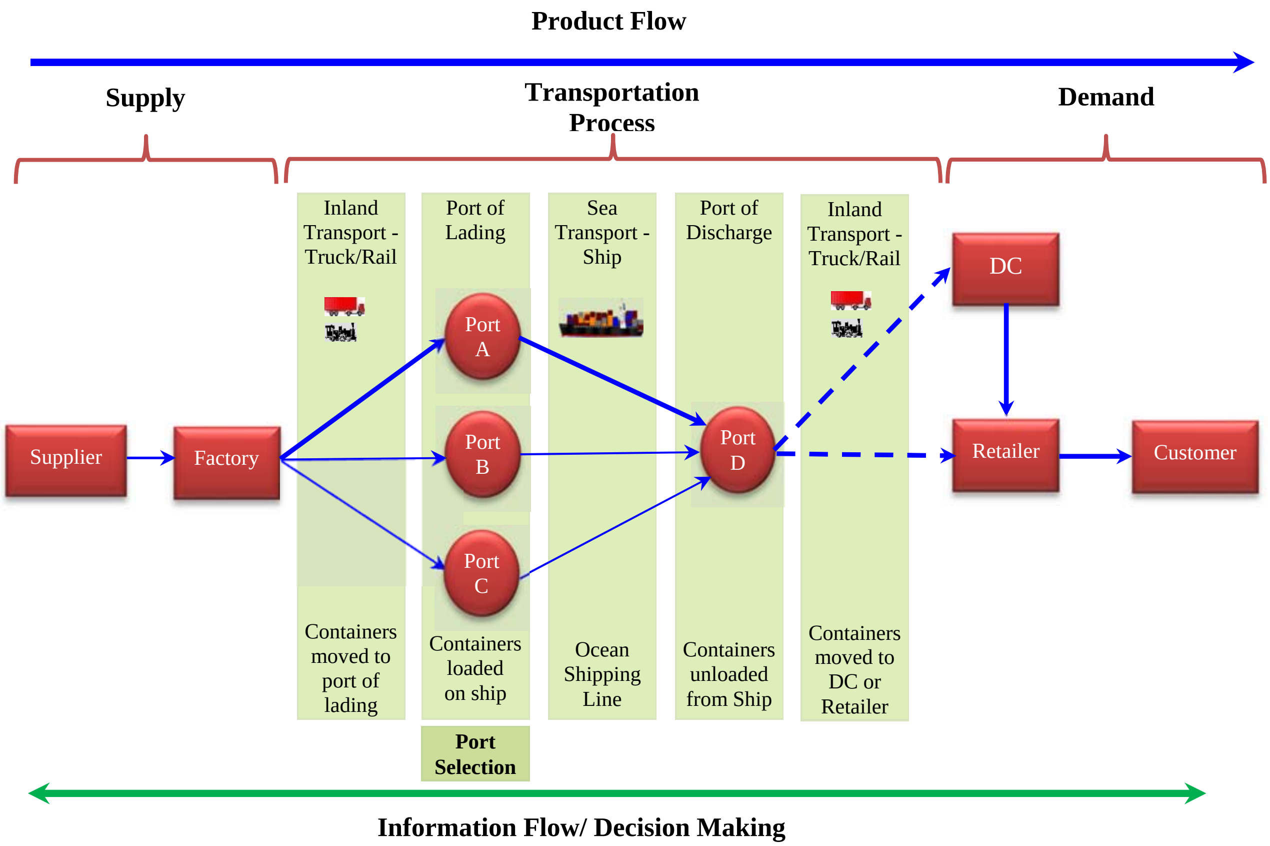


Figure 2.3 - Port Selection integrated in Global Supply Chain - Source: Authors

Port selection decision-making is performed by the shipping lines, which offer a global network to move freight internationally. However, with globalization and growing regional competition, shipping lines have made strategic alliances and mergers to respond better to global shippers (Wang & Cullinane, 2006). Some have gone further to own and operate dedicated container terminals to offer better schedules, intermodal capabilities, logistics services and enhanced efficiency in the management of global supply chains (Haralambides, Cariou, & Benacchio, 2002). Tongzon (2002) suggests that shippers can be classified as follows: 1) having a long-term contract with shipping lines, in which shippers are dependent on the shipping line's port of call decision; 2) using freight forwarders, who are responsible for selecting the port and route for the shippers; and 3) being an independent shipper, which must decide the port and route to use to move the international freight. The common factor in the three options is that global routes are offered by the shipping lines in order to move the international freight of shippers within its global supply chain. Therefore, freight forwarders and independent shippers can plan and decide what ports to use based on the availability provided by the shipping lines.

Systems theory states that the various parts of the system are linked together and can only be understood using a holistic approach (Magala & Sammons, 2008). The systems approach provides a holistic view of supply chains in order to fully understand their parts.

Therefore, we should analyze the port selection issue considering that it is linked to other parts of the supply chain such as the logistics operations, manufacturers, distribution centers, and final customers.

2.2.2 Identification of Relevant Literature

The research method applied is the analysis of existing data. This method is essential to academic research because it creates a foundation for advancing knowledge and uncovers areas where research is needed (Webster & Watson, 2002). The main goal was to analyze the existing port selection literature to determine scope of the research, the timeline of the research articles, and the journals that have published the research, as well as the geographic location, the focus, the objectives, and the methodologies used to analyze port selection decisions.

The identification of relevant literature used a structured approach that was not restrained to one set of journals or geographic region. The purpose of the analysis was to capture the relevant articles, focusing on port selection. Because this research does not focus on port performance, port competitiveness, transport choice, hubs, etc., articles about those subjects were not included. The databases used for the literature review consisted of the following online academic databases: EBSCO Academic Search Complete, ProQuest, Web of Science, and Google Scholar. Journal articles were selected using keyword searches of English language scholarly journals. The initial keywords used were “port selection AND maritime” and “port choice AND maritime” contained anywhere in the text. The preliminary result from the first three databases was 6,000 articles. Most of the articles did not meet the defined search criteria because they did not focus on port selection.

To refine the results, an additional search was conducted, but with the keywords “port selection” and “port choice” contained in the title of the articles, which yielded a total of 465 articles. The next step involved the reading of the abstracts to determine whether the article met the defined search criteria. This process yielded 28 articles.

Finally, the last step involved reading the 28 articles and reviewing the bibliographies of the relevant articles (Webster & Watson, 2002). The goal was to find any articles, books, conference proceedings, etc. on port selection not obtained by the keyword search. By these procedures, explained in a workflow in Appendix 2.C, a total of 35 articles were identified and are summarized in Appendix 2.A.

2.3 Literature Review Analysis

One of the goals of the literature analysis is to present a summary of the 35 port selection articles (Appendix 2.A). For each article, it includes the author, geographic region, focus and type of model. This table facilitates the analysis by comparing the characteristics of the articles.

Port selection has been an active research topic since the mid-80s, being consistent in the last decade as shown in Figure 2.4 and reflecting the importance of the topic for the transportation, logistics, supply chains and global economy through the years. Before 1985, studies concentrated on broad decisions, focusing on carrier, modal or transport selection, while research 1985 and onward focused on more specific topics, such as motor carrier selection objectives and water port selection (Murphy P. R., 1992).

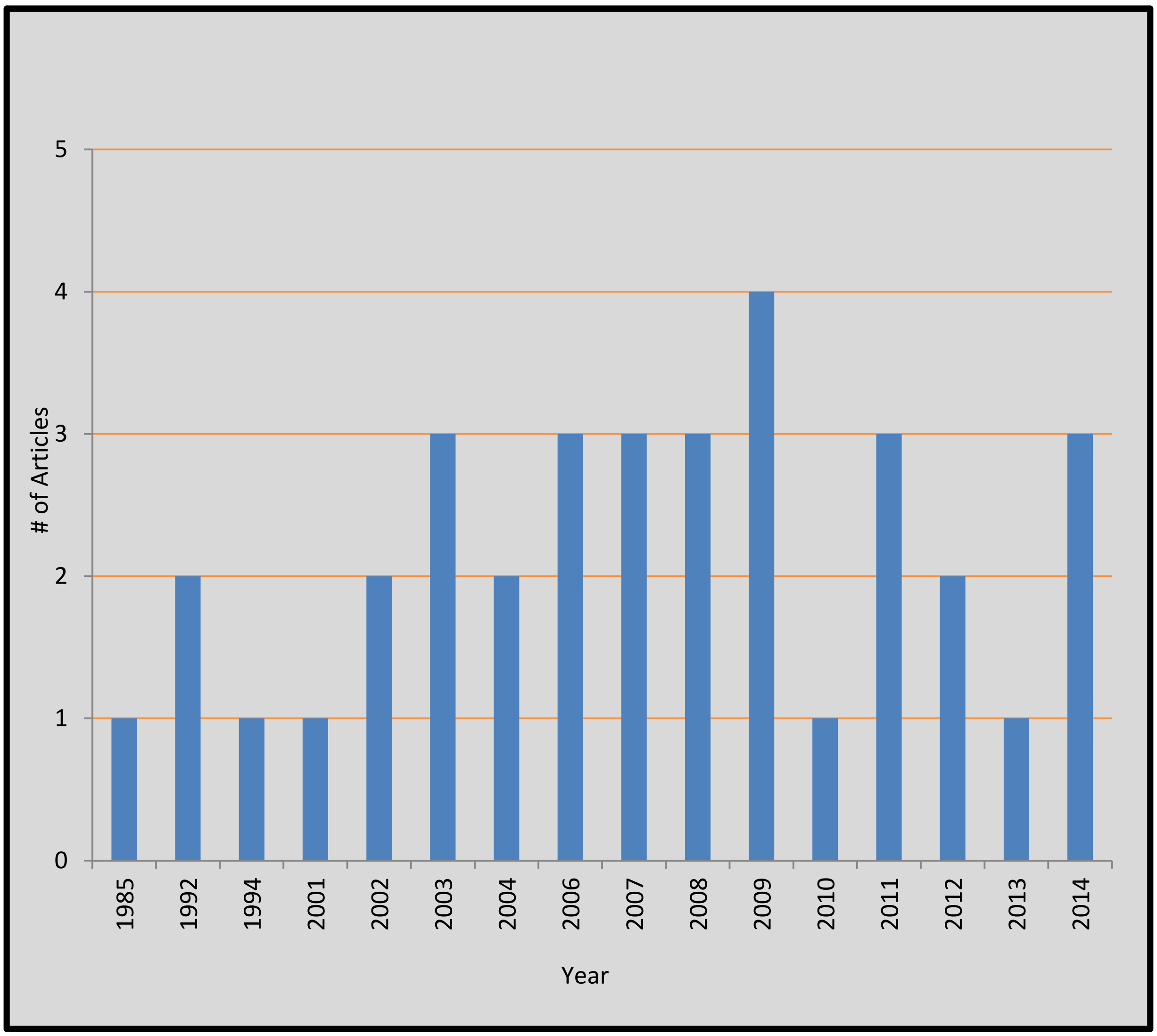


Figure 2.4 - Port Selection Articles by Year - Source: Authors

Another goal of this study is to identify the publishers of the port selection articles. Figure 2.5 shows the distribution of port selection articles by journal. From the graph, most of the port selection articles were published in the *Maritime Economics & Logistics Journal*, the *Maritime Policy & Management Journal* and the *Transportation Research Part E Journal*. Other important journals that have published port selection articles are the *Transportation Journal* and *Marine Policy*.

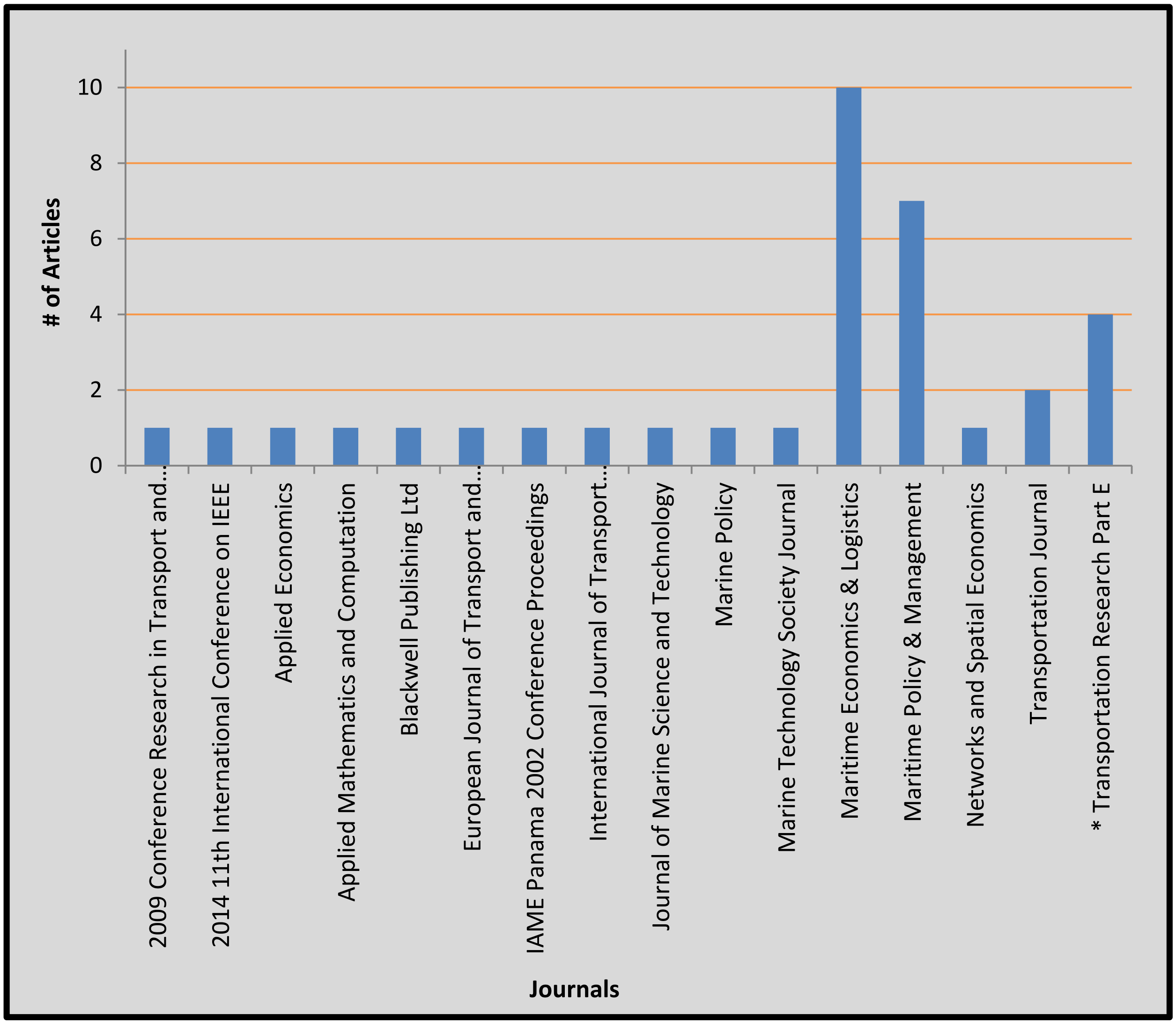


Figure 2.5 - Port Selection Articles by Journal - Source: Authors
* **Includes old Journal name, The Logistics and Transportation Review**

Appendix 2.A lists the different geographic regions used in the port selection literature. Table 2.1 shows the geographic regions used by the 10 most cited port selection articles according to the Google Scholar database. Two important port selection objectives are the geographic location of ports and regions of high demand. A port is considered competitive if it has good connectivity, a range of high demand regions that can easily be reached, and access to several modes of transportation (van Asperen & Dekker, 2013)

Citation Rankings	Author	Geographic Region
1	(Slack, 1985)	North America Mid-West, Southern Ontario and Western Europe
2	(Lirn, Thanopoulou, Beynon, & Beresford, 2004)	Global
3	(Murphy P. R., 1992)	International
4	(Malchow & Kanafani, 2004)	USA
5	(Malchow & Kanafani, 2001)	USA
6	(Ng, 2006)	Northern Europe
7	(Tongzon J. L., 2009)	Southeast Asia
8	(Veldman & Bückmann, 2003)	West Europe
9	(Chou C. , 2007)	Taiwan
10	(Nir, Lin, & Liang, 2003)	West Coast of Taiwan

Table 2.1 - Geographical Regions of the 10 Most Cited Port Selection Articles

Another common practice in the port selection literature is to develop research studies based on the perspectives of stakeholders in the decision process. Figure 2.6 shows the distribution of port selection articles by stakeholders. The graph shows that most of the studies have focused on shippers, freight forwarders or carriers because they are the main stakeholders involved in maritime trade. Sanchez, Ng, & Garcia Alonso (2011) noted the same trend in their research and explained that most of the literature is concentrated on shipping lines and freight forwarders. Many port selection research studies have tried to find reasons for why one port is selected over others under consideration. In the articles reviewed, a number of terms (criteria, characteristics, factors, variables, attributes, determinants, etc.) are used by the various authors to explain the influences in the port selection decision. In order to keep consistency through this research, the word objective will replace the variety of terms used in past articles. Appendix 2.B shows a comprehensive summary table of the multiple objectives used in the port selection literature.

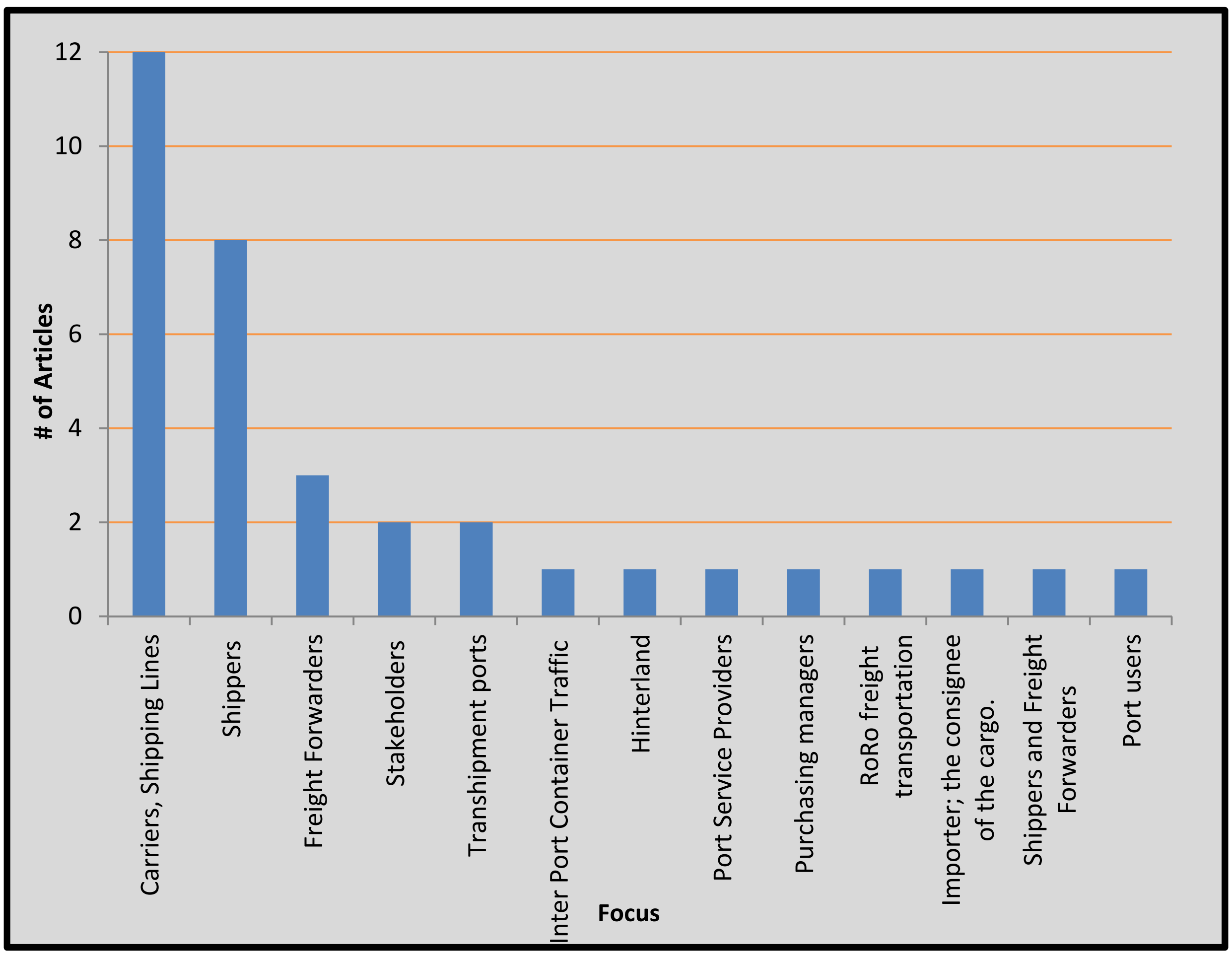


Figure 2.6 - Port Selection Articles by Focus - Source: Authors

In addition, Figure 2.7 illustrates the objectives used by the most cited articles on port selection according to Google Scholar database. Ng (2006) found that there is not one objective that dominated users' port selection behaviors. Port selection objectives have shifted over time because of the technological development of ports to provide the best efficiency and increased services to their customers (Yeo, Ng, Lee, & Yang, 2014).

(Slack, 1985)

- Security
- Size
- Inland freight rates
- Port charges
- Quality of customs handling
- Free time
- Congestion
- Port equipment
- Number of sailings
- Proximity of ports
- Possibility of intermodal links

(Lirn, Thanopoulou, Beynon, & Beresford, 2004)

- Security
- Size
- Inland freight rates
- Port charges
- Quality of customs handling
- Free time
- Congestion
- Port equipment
- Number of sailings
- Proximity of ports
- Possibility of intermodal links

(Malchow & Kanafani, 2004)
(Malchow & Kanafani, 2001)

- Oceanic distance
- Inland distance
- Sailing headway
- Vessel capacity
- Prob. of port last visited (2004)

(Chou C. , 2007)

- Port location
- Hinterland economy
- Port physical
- Port efficiency
- Cost

(Ng, 2006)

- Monetary cost
- Tie efficiency
- Geographical location
- Cases of delays in loading/unloading
- Record of damage during container-handling
- Custom procedures
- Port authority policy and regulation
- Accessibility of the port
- Quality of port infrastructure in container-handling
- Quality of port superstructure in container-handling
- IT and advanced technology
- Dedicated terminals and facilities for transshipment
- Supporting industries
- Quality of other services
- Availability of professional personnel in port
- Preference of shipping lines' clients/shippers
- Relations between port operator and shipping lines
- Efforts of marketing on the port by port authority
- Reputation of port within the region
- Speed in responding to liner's new demands and requests

(Murphy P. R., 1992)

- Handling charges
- Loss and damage
- Equipment availability
- Pickup and delivery
- Shipment information
- Claims handling
- Large and/or odd-sized freight
- Large volume shipments
- Special handling

(Tongzon J. L., 2009)

- Frequency of ship visits
- Operational efficiency
- Adequacy of port infrastructure
- Location
- Competitive port charges
- Quick response to port users' needs

(Veldman & Bückmann, 2003)

- Costs
- Time
- Inter arrival time in port
- Hinterland modes

(Nir, Lin, & Liang, 2003)

- Travel time
- Travel cost
- Route and frequency

Figure 2.7 - Objectives Used in Most Cited Port Selection Articles - Source: Authors

2.3.1 Port Selection Objectives of Stakeholders

One of the first researchers who investigated port selection focused on the objectives shippers used to select a port, concentrating his study on the containerized traffic between the North American Mid-West and Western Europe. He found through interviews with shippers that the decision makers were more motivated by the prices and service considerations of land and ocean carriers and less motivated by port infrastructures (Slack, 1985).

Subsequently, Murphy (1992) investigated port selection for international shipments from the perspectives of different parties involved in the decision, such as international ports, international water carriers, international freight forwarders, larger U.S. shippers, and smaller U.S. shippers. The study concluded that ports, carriers, freight forwarders and their customers differ when evaluating the relative and absolute importance of port selection objectives.

Later, a similar study was developed for port selection, but it included the perspective of the purchasing/materials managers. The authors found that purchasing managers and shippers had similar considerations regarding the objectives used for port selection. (Murphy & Daley, 1994).

2.3.2 Port Selection Topic Analyzed with Different Methodologies

In the 2000s, port selection remained important because of expansion and improvements in transportation. The growing research on port selection reflected the application of different models, in which most of the studies used the statistical analysis of surveys, the multinomial choice logit model, and the Analytic Hierarchy Process (AHP). Kim (2014) explained that port selection research studies used different models in the past and each of them has its own characteristics and limitations. Figure 2.8 shows the different models that have been applied to port selection studies, from which the three most common methods can be clearly identified.

The following sections will briefly describe the articles, grouped by the models applied in port selection literature.

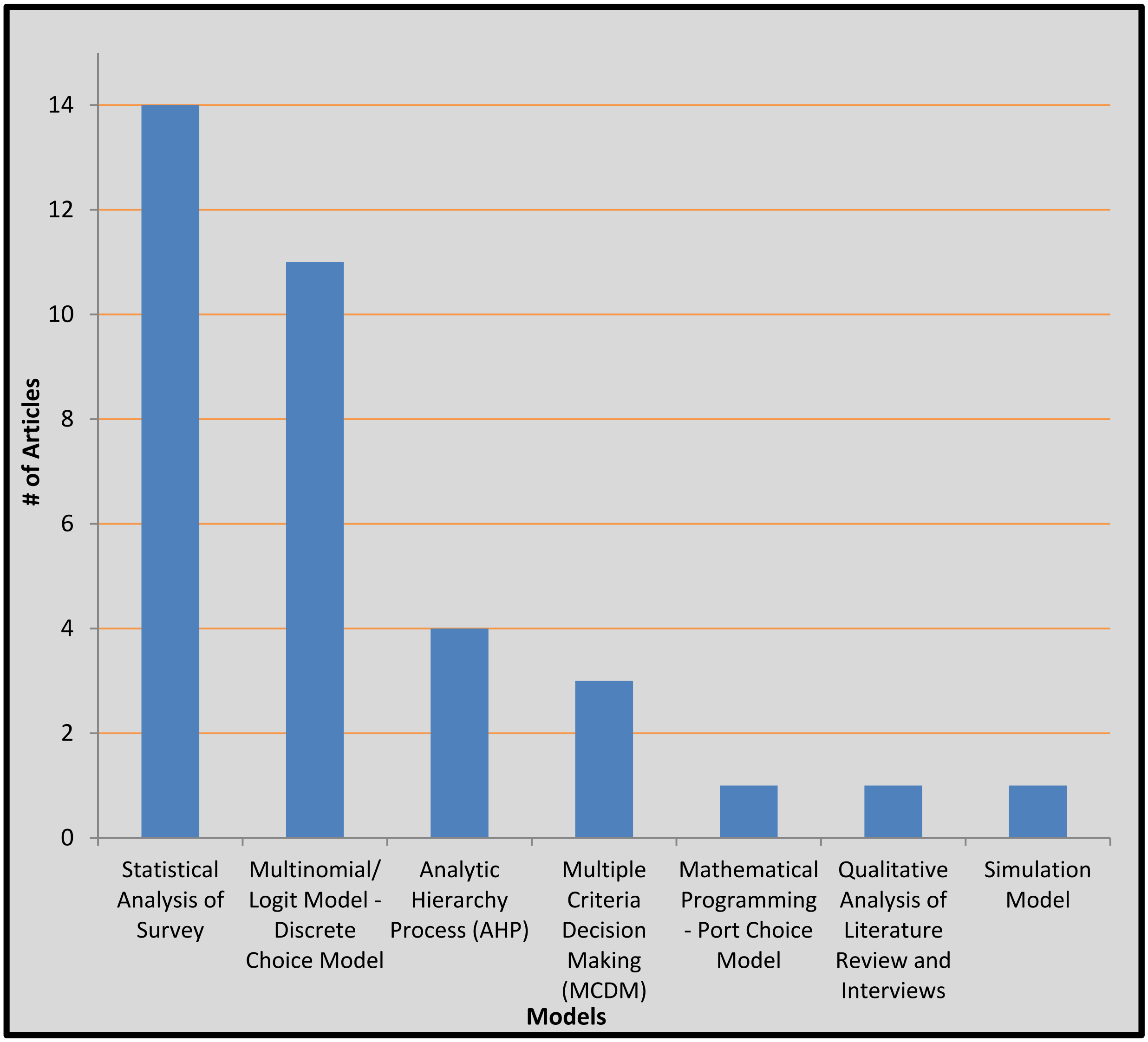


Figure 2.8 - Models Applied to Port Selection Articles - Source: Authors

2.3.2.1 Port Selection Articles with Statistical Analysis of Survey Methodology

The statistical analysis of survey is currently the most popular methodology used by researchers to investigate the port selection problem. These studies also identified the most important objectives that affect the port selection decision from the perspectives of different stakeholders such as shippers, freight forwarders, and shipping lines. Appendix 2.B has the summary of all objectives used in the port selection literature.

One of the studies used survey data to identify and explain the objectives for port selection focused on freight forwarders located on industrial Centers in Malaysia (Penang), Singapore and Thailand (Bangkok). Through the use of surveys, data was collected to investigate the port choice and performance objectives. This study found that port efficiency is the most important objective for port selection, while reputation for cargo damage is the least important (Tongzon J. , 2002).

Similarly, Sanchez, Ng & Garcia Alonso (2011) investigated the most important objectives that determine port attractiveness from the focus of service providers for ports located in Asian and Latin American countries. The main objectives that affected the port attractiveness were efficiency, cases of delay, and the accessibility of ports.

Panayides & Song (2012) investigated the port selection objectives from the perspective of users, including the aspects of logistics and supply chains in the analysis. The major objectives of port selection by shipping lines were adequacy of port facilities (berth capacity), service (flexibility in meeting the customers' special needs), costs (navigation costs and cargo – handling costs) and availability of information systems (EDI availability, cargo-handling and cargo-tracing information).

Grosso & Monteiro (2009) investigated the main objectives affecting the selection of container ports of freight forwarders in the Port of Genoa. Based on the questionnaire and the Factor Analysis Method, the authors found that the main objectives affecting port selection were port connectivity, port cost and productivity, electronic information, and logistics of the container.

Tongzon (2009) examined freight forwarders in Southeast Asia. The findings show that efficiency is the most attractive objective, followed by shipping frequency, adequate infrastructure, and location. Chang, Lee & Tongzon (2008) investigated the main objective for port selection by applying a survey to shipping companies. The findings yielded six important objectives: local cargo volume, terminal handling charge, berth availability, port location, transshipment volume, and feeder network. Ng (2006) researched the container transshipment in Northern Europe, where shipping lines indicated that the most important objectives affecting port selection were the monetary costs, time efficiency, geographical location, and service quality. De Langen (2007) compared the results of shippers and freight forwarders in Austria, resulting in both having similar views on the matter, but with shippers having a less price-elastic demand. Mangan, Lalwani & Gardner (2002) used a triangulated research methodology incorporating quantitative and qualitative work to model port/ferry choice in RoRo (Roll-on/roll-off) freight transportation in the Ireland/UK and Ireland/ Continental Europe markets. Tongzon & Sawant (2007) employed the stated preference and revealed preference approach by applying a survey to shipping lines located in Malaysia and Singapore. Through the application of Binary Logistic Regression (BLR) and Model Selection, no consistency was found between the two approaches. The stated preferences showed that efficiency was the most important objective for port selection while the revealed preference approach found that port charges and a wide range of port services were the most important objectives for shipping lines.

Recently, Kim (2014) investigated the typology of port choice from the users' perspective in South Korea by applying a Q-methodology. Four distinct group types were defined: service and cooperation oriented, location and cost saver, on-time and task achiever, and capacity and infrastructure friendly groups. The results reflected that the first group considered that service, cooperation and support toward port users were the most important objectives. The second group considered geographic positioning and cost reduction to be the most important objectives. The third group selected on-time transportation and completing mission completion as the most important objectives. Finally, the fourth group emphasized freight handling capacity and port infrastructure as the most important objectives.

2.3.2.2 Port Selection Articles with Multinomial Logit Model – Discrete Choice Model

Malchow & Kanafani (2001) explained the selection of ports from shipments exported from the US using data from1999 and focusing on four objectives: ocean distance, inland distance, sailing frequency, and vessel capacity. Results from this study showed that only the first two objectives made the port less attractive.

The same authors expanded the model by adding new objectives and applying a choice model to the assignment of shipments to vessels/ports in order to evaluate the competition between ports. The results showed the same two objectives found in the previous research were still the most important for the attractiveness of the port. In addition, the authors found that port managers consistently consider location to be the most important objective (Malchow & Kanafani, 2004).

Tiwari, Itoh & Doi (2003) modeled the port choice behavior of shippers in China using a choice of 14 objectives based on shipping line and port combinations. The most important objectives for port selection were the distance of the shipper from port, distance to the destination (for exports), distance from the origin (for imports), port congestion, and the shipping line's fleet size.

Nir, Lin & Liang (2003) investigated the shippers' demand behavior on port choice in Taiwan using three kinds of models: basic, experienced, and competitive. Another study used objectives such as transport cost, transit time, frequency of service, and indicators of service quality, with the goal of quantifying the routing choice, and deriving a demand function for port traffic forecasting and for the economic and financial evaluation of container port projects in Western Europe (Veldman & Bückmann, 2003)**.**

Other relevant research on port selection that has applied the logit models are (Garcia-Alonso & Sanchez-Soriano, 2009; Magala & Sammons, 2008; Steven & Corsi, 2012; Tang, Low, & Lam, 2011; Veldman, Garcia-Alonso, & Vallejo-Pinto, 2011; Wu, Liu, & Peng, 2014)

2.3.2.3 Port Selection Articles with Analytic Hierarchy Process (AHP) Model

Other port selection researchers have used the Analytic Hierarchy Process (AHP). Lirn, Thanopoulou, Beynon, & Beresford (2004) used the AHP to investigate transshipment port selection by global carriers. After collecting data from 20 port users and 20 transshipment service providers, the authors found that both global container carriers and port service providers agreed on the most important service objectives for transshipment port selection. The study concluded that most important objectives for the global container terminal industry are the following: handling cost of containers, proximity to main navigation routes, proximity to import/ export areas, basic infrastructure condition, and existing feeder network.

Similarly, Ugboma, Ugboma & Ogwude (2006) using data from Nigeria discovered the most important shipper objectives that impact port selection decisions. The study found that for efficiency, port charges, quick response to port users' needs, and reputation for cargo damage, Port Harcourt Port Complex (PHPC) was the most preferred, while Ro-Ro (Roll-on/roll-off) Port (RRP) was the least preferred. Also, Frankel (1992) used the AHP with quantitative and qualitative measures to select the most effective shipping policy.

In addition, Chou (2010) applied the AHP to investigate the Taiwan carrier port choice and identify the weights of every objective impacting the port selection decision. The study was conducted in a multiple port region in Taiwan. Oceangoing route carriers' main concerns were depth of containership berth; port charge, tax, rent and cost; and port loading/discharging efficiency. On the other hand, coasting route carriers' main concerns are hinterland economy; port charge, tax, rent and cost; and port loading/ discharging efficiency.

2.3.2.4 Port Selection Articles with Multiple Criteria Decision Making Method (MCDM)

Using a multiple criteria decision making approach, Chou (2007) investigated the transshipment container port selection problem using weights for each objective, which were collected from a top decision maker at a shipping company in Taiwan. Using a Fuzzy Multiple Criteria Decision Making Method (FMCDM), the author found that for container port selection, shipping companies are mostly concerned with the following objectives: the volume of import/export/ transshipment containers, cost, port efficiency, port facilities, and port location.

Guy & Urli (2006) employed a multicriteria analysis as an analytical tool for the selection of container ports by shipping lines in Montreal and New York. Using a set of seven objectives defined from Lirn et al (2004) and Song & Yeo (2004) and defining weights for each objective, rankings from all alternatives were evaluated by the PROMETHE I method. From the 49 simulated combinations of alternatives, the Port of New York was the preferred choice for shipping lines. In addition, the findings showed that shipping lines considered both the port location and the availability of options to specific areas of the hinterland to be important objectives.

Recently, Yeo, Ng, Lee, & Yang (2014) studied the selection of important Northeast Asian container ports from the perspective of shipping lines in an uncertain environment. They used a survey to obtain port selection objectives (port service, hinterland condition, availability, convenience, logistic cost, regional center, and connectivity) and used the Fuzzy Evidential Reasoning method and the IDS software.

2.3.2.5 Other Methodologies Applied to Port Selection

Other research has used different methodologies from the ones explained above to study the port selection problem. Chou (2009) performed an empirical study of port choice behavior from the perspective of shippers in Taiwan. The author presented two mathematical programming models, one model without the frequency of ship callings and the second model including this characteristic. The results of the research provided a comparison of the actual port choices of shippers versus the port choice models, ultimately the research found that the model with frequency of ship calling had less error than the other alternative.

Van Asperen & Dekker (2013) developed a simulation model to measure performance of the container rerouting flexibility by ports in a route of China-Western Europe, specifically from the Shanghai port to five alternative ports in Western Europe (La Spezia in Italy, Antwerp in Belgium, Hamburg in Germany, Rotterdam in The Netherlands, and Southampton in the United Kingdom). The simulation model included three scenarios: decentralized strategy (DEC), centralized strategy (CEN) and European Distribution Center (EDC) or regional warehouse strategy. In addition, the research presented a sensitivity analysis to evaluate the robustness of the findings. The results of the simulation showed that EDC strategy had the lowest average total costs while the CEN strategy had the highest total cost and the longest lead time. The DEC strategy had the best performance regarding lead time.

By applying a theoretical model, Wiegmans, Hoest & Notteboom (2008) investigated the port choice and container terminal selection for deep-sea container carriers in the Hamburg–Le Havre range, which includes large container load centers such as Rotterdam, Antwerp, Hamburg, Bremerhaven and Le Havre among others. The port choice objectives were defined based on the literature review, and after the analysis of the interview responses it was concluded that the port choice was more important than terminal selection for the carriers. In addition, they found that the port choice behavior was mainly affected by next to service, costs, fit of the port in the trade, requirements imposed by the alliance structure they operate in, shippers/customers location and relations, strategic considerations of shipping lines (existing contracts, market entry and penetration), and arrangements between the shipping line and incumbent terminal operators (dedicated terminal facilities). Besides the strategic considerations, port choice behavior was affected by availability of hinterland connections, reasonable tariffs, and immediacy of consumers. On the other hand, for the terminal selection findings, as long as the capacity and availability of terminal handling was sufficient, then the most important objectives were speed, handling costs, reliability and hinterland connections.

2.4 Discussion

Port selection has been an active area of research as illustrated in Figure 2.3. Port selection has gained more importance in recent decades because of the benefits of globalization. The findings from the review are as follows:

a) Port selection research studies have been published in different academic maritime and transportation journals. Due to the increasing importance of global supply chains, it is expected that more research on port selection will be published in those journals. It is important to provide a roadmap for researchers, and this review provides a summary.

b) We found that the research focused on national (country level) or regional areas, rather than taking into account the global perspective. Chang et al. (2008) advocate a more global view. In addition, we found no articles on the impact of the Panama Canal Expansion on port selection. This is significant because of the anticipated effects on global trade from the expansion (Rodrigue, 2010)

c) Port selection research has focused on stakeholders such as shipping lines, shippers, and freight forwarders who move the freight from origin to destination. With the emphasis on total supply chain management, a more comprehensive view that takes into account the many other stakeholders that are an integral part of a global supply chain needs to be incorporated into the research.

d) The port selection decision is complex and dynamic and involves different stakeholders with different objectives (See Appendix 2.B). In addition, managers and other port stakeholders do not have a practical managerial tool or methodology that guides them on port selection decision making. Many models such as Statistical Analysis, Multinomial/ Logit Discrete Choice, Analytic Hierarchy Process (AHP), Multiple Criteria Decision Making (MCDM), etc. were used in port selection studies (See Appendix 2.A). It was interesting that while multiple objectives are a major feature of port selection topic, a major multi-criteria technique, Multi-objective Decision Analysis, has not been used in port selection literature. The potential to use this technique provides an opportunity for future research.

2.5 Future Research

Port selection problems involve multiple objectives that interact under a complex and dynamic environment; therefore, the Multi-objective Decision Analysis (MODA) methodology could be used to analyze the port selection decision process. MODA is a structured decision analysis technique which includes a formal, mathematical method of making trade-offs in presence of multiple and conflicting objectives, involving complex decisions under uncertainty (Keeney & Raiffa, 1993).

One of the most valuable characteristics of the proposed model is the Value-Focused Thinking approach, which structures the decision framework by concentrating on the values of the stakeholders rather than using the set of initially available alternatives (Keeney R. L., 1992). In addition, developing a MODA model and applying the Value-Focused-Thinking approach is beneficial because it will guide port selection decision makers to recognize and identify decision opportunities and to create better alternatives (Keeney R. L., 1994).

In addition, future research on port selection could include the influences of the Panama Canal Expansion completed in 2016. Ports and global supply chains will be impacted with the expansion. Therefore, a potential topic for future research on port selection would analyze the container freight movement through the Northeast Asian Transpacific route to the US East Coast, which is one of the most important routes that could be affected by the Panama Canal expansion.

2.6 Conclusion

Ports are vital for the supply chains, global maritime trade, and the global economy. Over the last decades, ports have demonstrated a significant increase in demand and will continue increasing capacity and services. Several researchers have investigated the port selection problem using different geographical regions, focuses, objectives, and models. The different results obtained in the port selection research studies reflect a variety of preferences of the stakeholders related to the port selection decision making process. This research contributes to the literature on port selection by providing a comprehensive analysis of all relevant studies on this topic and proposing a new methodology, the Multi-objective Decision Analysis.

Bibliography

Chang, L., Ouzrout, Y., Nongaillard, A., Bouras, A., & Jiliu, Z. (2014). Multi-criteria decision making based on trust and reputation in supply chain. *International Journal of Production Economics*, 362-372. doi:10.1016/j.ijpe.2013.04.014.

Chang, Y. T., Lee, S. Y., & Tongzon, J. L. (2008). Port selection factors by shipping lines: Different perspectives between trunk liners and feeder service providers. *Marine Policy*, 877-885. doi:10.1016/j.marpol.2008.01.003.

Chou, C. (2007). A fuzzy MCDM method for solving marine transshipment container port selection problems. *Applied Mathematics and Computation*, 435-444. doi:10.1016/j.amc.2006.07.125.

Chou, C. (2010). AHP model for the container port choice in the multiple-ports region. *Journal of Marine Science and Technology*, 221-232. Retrieved from http://jmst.ntou.edu.tw/marine/18-2/221-232.pdf.

Chou, C. C. (2009). An empirical study on port choice behaviors of shippers in a multiple-port region. *Marine Technology Society Journal*, 71-77. doi:http://dx.doi.org/10.4031/MTSJ.43.3.7.

De Langen, P. (2007). Port competition and selection in contestable hinterlands; the case of Austria. *European Journal of Transport and Infrastructure Research*, 1-14. Retrieve from http://ejtir.tudelft.nl/issues/2007_01/pdf/2007_01_01.pdf.

Frankel, E. (1992). Hierarchical logic in shipping policy and decision-making. *Maritime Policy & Management*, 211-221. doi:10.1080/751248662.

Garcia-Alonso, L., & Sanchez-Soriano, J. (2009). Port selection from a hinterland perspective. *Maritime Economics & Logistics*, 260-269. doi:10.1057/mel.2009.9.

Grosso, M., & Monteiro, F. (2009). Relevant strategic criteria when choosing a container port- the case of the port of Genoa. *Research in Transport and Logistics*, 299. Retrieved from http://openaccess.dogus.edu.tr:8080/xmlui/bitstream/handle/11376/346/9789944578929.pdf?sequence=1#page=309.

Guy, E., & Urli, B. (2006). Port selection and multicriteria analysis: an application to the Montreal-New York alternative. *Maritime Economics & Logistics*, 169-186. doi:10.1057/palgrave.mel.9100160.

Haralambides, H., Cariou, P., & Benacchio, M. (2002). Costs, benefits and pricing of dedicated container terminals. *International Journal of Maritime Economics*, 4(1), 21-34. doi: 10.1057/palgrave/ijme/9100031.

Keeney, R. L. (1992). *Value-Focused Thinking: A path to creative decisionmaking.* Harvard University Press. ISBN 0674931971.

Keeney, R. L. (1994). Creativity in decision making with Value-Focused Thinking. *Sloan Management Review*, 33-33. Retrieved from http://faculty.insead.edu/delquie/msp/Download%20Solutions/Value-Focused%20Thinking%20(SMR).pdf.

Keeney, R. L., & Raiffa, H. (1993). *Decisions with multiple objectives: preferences and value trade-offs.* Cambridge university press. ISBN 0471465100.

Kim, J. Y. (2014). Port user typology and representations of port choice behavior: A Q-methodological study. *Maritime Economics & Logistics*, 16(2), 165-187. doi:10.1057/mel.2013.26.

Knight, K. (2008). *The implications of Panama Canal expansion to US ports and coastal navigation economic analysis.* Institute for Water Resources, US Army Corps of Engineers, 27. Retrieved from http://www.iwr.usace.army.mil/Portals/70/docs/iwrreports/WhitePaperPanamaCanal.pdf.

Lirn, T., Thanopoulou, H., Beynon, M., & Beresford, A. (2004). An application of AHP on transhipment port selection: a global perspective. *Maritime Economics & Logistics,*, 70-91. doi:10.1057/palgrave.mel.9100093.

Magala, M., & Sammons, A. (2008). A new approach to port choice modelling. *Maritime Economics & Logistics*, 9-34. doi:10.1057/palgrave.mel.9100189.

Malchow, M., & Kanafani, A. (2001). A disaggregate analysis of factors influencing port selection. *Maritime Policy & Management*, 265-277. doi:10.1080/03088830110060840.

Malchow, M., & Kanafani, A. (2004). A disaggregate analysis of port selection. *Transportation Research Part E: Logistics and Transportation Review*, 317-337. doi:10.1016/j.tre.2003.05.001.

Mangan, J., Lalwani, C., & Gardner, B. (2002). Modelling port/ferry choice in RoRo freight transportation. *International Journal of Transport Management*, 15-28. doi:10.1016/S1471-4051(01)00003-9.

Mentzer, J. T., Stank, T. P., & Esper, T. L. (2008). Supply chain management and its relationship to logistics, marketing, production, and operations management. *Journal of Business Logistics*, 29(1), 31-46. doi: 10.1002/j.2158-1592.2008.tb00067.x.

Murphy, P. R. (1992). Port selection criteria: an application of a transportation research framework. *Logistics and Transportation Review*, 28(3). Retreived from http://trid.trb.org/view.aspx?id=371197.

Murphy, P., & Daley, J. (1994). A comparative analysis of port selection factors. *Transportation Journal*, 15-21. Retrieved from http://www.jstor.org/stable/20713220.

Ng, K. (2006). Assessing the attractiveness of ports in the North European container transhipment market: an agenda for future research in port competition. *Maritime Economics and Logistics*, 234-250. doi:10.1057/palgrave.mel.9100158.

Nir, A., Lin, K., & Liang, G. (2003). Port choice behaviour--from the perspective of the shipper. *Maritime Policy & Management*, 165-173. doi:10.1080/0308883032000069262.

Notteboom, T. &. (2008). Containerisation, box logistics and global supply chains: The integration of ports and liner shipping networks. *Maritime Economics & Logistics*, 10(1), 152-174. doi:10.1057/palgrave.mel.9100196.

Panama Canal Authority. (2006). *Proposal for the expansion of the Panama Canal third set of locks project. Accessed at www. pancanal. com/eng/plan/documentos/propuesta/acp-expansion-proposal.*

Panayides, P., & Song, D. (2012). Determinants of Users' Port Choice. *The Blackwell Companion to Maritime Economics*, 599-622. doi:10.1002/9781444345667.

Rodrigue, J. P. (2010). *Factors impacting North American freight distribution in view of the Panama Canal expansion.* Van Horne Institute. Retreived from http://people.hofstra.edu/jean-paul_rodrigue/downloads/Panama%20Canal%20Study%202011%20Final.pdf.

Ronen, D. (2011). The effect of oil price on containership speed and fleet size. *Journal of the Operational Research Society*, 62(1), 211-216. doi: http://0-dx.doi.org.library.uark.edu/10.1057/jors.2009.169.

Sanchez, R., Ng, A., & Garcia-Alonso, L. (2011). Port Selection Factors and Attractiveness: The Service Providers' Perspective. *Transportation Journal*, 141-161. doi:10.5325/transportationj.50.2.0141.

Slack, B. (1985). Containerization, inter-port competition, and port selection. *Maritime Policy and Management*, 293-303. Retrieved from http://search.proquest.com/docview/14317590?accountid=8361.

Song, D., & Yeo, K. (2004). A competitive analysis of Chinese container ports using the analytic hierarchy process. *Maritime Economics & Logistics*, 34-52. doi:10.1057/palgrave.mel.9100096.

Steven, A., & Corsi, T. (2012). Choosing a port: An analysis of containerized imports into the US. *Transportation Research Part E: Logistics and Transportation Review*, 881-895. doi:10.1016/j.tre.2012.02.003.

Tang, L., Low, J., & Lam, S. (2011). Understanding port choice behavior—a network perspective. *Networks and Spatial Economics*, 65-82. doi:10.1007/s11067-008-9081-8.

Tiwari, P., Itoh, H., & Doi, M. (2003). Shippers' port and carrier selection behaviour in China: a discrete choice analysis. *Maritime Economics & Logistics*, 23-39. doi:10.1057/palgrave.mel.9100062.

Tongzon, J. (2002). Port choice determinants in a competitive environment. *In Proceedings of Annual Conference and Meeting of the International Association of Maritime Economists.* Panama: IAME. Retreived from Http://www.Cepal.org/Transporte/perfil/iame_papers/proceedings/Tongzon.Doc.

Tongzon, J. L. (2009). Port Choice and freight forwarders. *Transportation Research Part E: Logistics and Transportation Review,* 186-195. doi:10.1016/j.tre.2008.02.004.

Tongzon, J. L., & Sawant, L. (2007). Port choice in a competitive environment: from the shipping lines' perspective. *Applied Economics,*, 477-492. doi:10.1080/00036840500438871.

Ugboma, C., Ugboma, O., & Ogwude, I. (2006). An analytic hierarchy process (AHP) approach to port selection decisions–empirical evidence from Nigerian ports. *Maritime Economics & Logistics*, 251-266. doi:10.1057/palgrave.mel.9100160.

UNCTAD. (2013). *Review of Maritime Transport (RMT). Retrieved from http://unctad.org/en/pages/PublicationWebflyer.aspx?publicationid=753.* New York and Geneva. Retrieved from http://unctad.org/en/PublicationsLibrary/rmt2013_en.pdf.

van Asperen, E., & Dekker, R. (2013). Centrality, flexibility and floating stocks: A quantitative evaluation of port-of-entry choices. *Maritime Economics & Logistics*, 72-100. doi:10.1057/mel.2012.22.

Veldman, S., & Bückmann, E. (2003). A model on container port competition: an application for the west European container hub-ports. *Maritime Economics & Logistics*, 3-22. doi:10.1057/palgrave.mel.9100058.

Veldman, S., Garcia-Alonso, L., & Vallejo-Pinto, J. (2011). Determinants of container port choice in Spain. *Maritime Policy & Management*, 509-522. doi:10.1080/03088839.2011.597450 .

Wang, T., & Cullinane, K. (2006). The efficiency of European container terminals and implications for supply chain management. *Maritime Economics & Logistics*, 8(1), 82-99. doi: http://0-dx.doi.org.library.uark.edu/10.1057/palgrave.mel.9100151.

Webster, J., & Watson, R. T. (2002). Analyzing the past to prepare for the future: Writing a literature review. *Management Information Systems Quarterly*, 26(2), 3. Retrieved from http://intranet.business-science-institute.com/pluginfile.php/247/course/summary/Webster%20%20Watson.pdf.

Wiegmans, B., Hoest, A., & Notteboom, T. (2008). Port and terminal selection by deep-sea container operators. *Maritime Policy & Management*, 517-534. doi:http://0-dx.doi.org.library.uark.edu/10.1080/03088830802469329.

Wu, Y., Liu, J., & Peng, C. (2014). Analysis of port and inland transport mode selection. *In Service Systems and Service Management (ICSSSM) 2014 11th International Conference* (pp. 1-6). IEEE. doi:10.1109/ICSSSM.2014.6874030.

Yeo, G., Ng, A., Lee, P., & Yang, Z. (2014). Modelling port choice in an uncertain environment. *Maritime Policy & Management*, 251-267. doi:10.1080/03088839.2013.839515.

Appendix

Appendix 2.A - Port Selection Literature Review Summary

Author	Geographic Region	Focus	Model
(Slack, 1985)	North America Mid-West, Southern Ontario and Western Europe	Shippers of containerized trade	Statistical Analysis of Survey
(Frankel, 1992)	Country Level	Liner cargo	Analytic Hierarchy Process (AHP)
(Murphy P. R., 1992)	International shipments	Stakeholders	Statistical Analysis of Survey - Univariate and Multivariate Analysis
(Murphy & Daley, 1994)	Ohio, Western Pennsylvania and Northern West Virginia	Purchasing managers	Statistical Analysis of Survey
(Malchow & Kanafani, 2001)	USA	Carriers	Multinomial/ Logit Model - Discrete Choice Model
(Mangan, Lalwani, & Gardner, 2002)	Ireland/UK and Ireland/ Continental Europe markets	RoRo freight transportation	Statistical Analysis of Survey
(Tongzon J. , 2002)	Southeast Asian	Freight Forwarders	Statistical Analysis of Survey
(Veldman & Bückmann, 2003)	West Europe	Shippers	Multinomial/ Logit Model - Discrete Choice Model
(Nir, Lin, & Liang, 2003)	West Coast of Taiwan	Shippers	Multinomial/ Logit Model - Discrete Choice Model - Basic Model, Experienced Model and Competitive Model
(Tiwari, Itoh, & Doi, 2003)	China	Shippers	Multinomial/ Logit Model - Discrete Choice Model
(Lirn, Thanopoulou, Beynon, & Beresford, 2004)	Global perspective	Carriers	Analytic Hierarchy Process (AHP)
(Malchow & Kanafani, 2004)	USA	Carriers	Multinomial/ Logit Model - Discrete Choice Model

Appendix 2.A (Cont.)

Author	Geographic Region	Focus	Model
(Guy & Urli, 2006)	Montreal and New York	Shipping lines	Multiple Criteria Decision Making (MCDM) (not concerned with decision support) PROMETHEE I (for rankings)
(Ng, 2006)	Northern Europe	Transshipment ports	Statistical Analysis of Survey
(Ugboma, Ugboma, & Ogwude, 2006)	Nigerian Ports	Shippers	Analytic Hierarchy Process (AHP)
(De Langen, 2007)	Austria	Shippers and forwarders	Statistical Analysis of Survey
(Tongzon & Sawant, 2007)	Singapore and Malaysia	Shipping lines	Statistical Analysis of Survey - Binary Logistic Regression (BLR)
(Chou C. , 2007)	Taiwan	Transshipment ports	Fuzzy multiple criteria decision making method (FMCDM)
(Magala & Sammons, 2008)	General	Shippers	Multinomial/ Logit Model - Discrete Choice Model
(Chang, Lee, & Tongzon, 2008)	Global	Shipping lines	Statistical Analysis of Survey - Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis
(Wiegmans, Hoest, & Notteboom, 2008)	Hamburg–Le Havre range (Europe)	Deep-sea container carriers	Qualitative Analysis of Literature Review and Interviews
(Chou C. C., 2009)	Taiwan	Shippers	Mathematical Programming - Port Choice Model
(Grosso & Monteiro, 2009)	Port of Genoa	Freight forwarders	Statistical Analysis of Survey - Factor Analysis Method
(Tongzon J. L., 2009)	Southeast Asia	Freight Forwarders	Statistical Analysis of Survey
(Garcia-Alonso & Sanchez-Soriano, 2009)	Spanish Peninsular ports (Algeciras, Barcelona, Bilbao and Valencia)	Hinterland	Multinomial Logit Model - Discrete Choice Model
(Chou C. , 2010)	Taiwan	Shipping lines	Analytic Hierarchy Process (AHP)

Appendix 2.A (Cont.)

Author	Geographic Region	Focus	Model
(Sanchez, Ng, & Garcia-Alonso, 2011)	Asian and Latin American countries	Port Service providers	Statistical Analysis of Survey
(Veldman, Garcia-Alonso, & Vallejo-Pinto, 2011)	Spanish provinces	Inter Port container traffic distribution	Logit Model
(Tang, Low, & Lam, 2011)	Major Asian Ports	Shipping lines	Multinomial/ Logit Model - Discrete Choice Model - Network-based Integrated Choice Evaluation (NICE)
(Panayides & Song, 2012)	International	Shipping lines	Statistical Analysis of Survey
(Steven & Corsi, 2012)	Pittsburgh metropolitan area	Importer; the consignee of the cargo	Multinomial/ Logit Model - Discrete Choice Model
(van Asperen & Dekker, 2013)	China – Western Europe route	Shippers	Simulation Model
(Yeo, Ng, Lee, & Yang, 2014)	Northeast Asian container ports	Shipping Lines	Multiple Criteria Decision Making (MCDM) - Fuzzy Evidential Reasoning (FER)
(Wu, Liu, & Peng, 2014)	South China	Stakeholders	Multinomial/ Logit Model - Discrete Choice Model
(Kim, 2014)	South Korea	Port users	Statistical Analysis of Survey - Q Methodology

Appendix 2.B - Objectives Used in Port Selection Literature

Author	Objectives	
(Slack, 1985)	• Security • Size • Inland freight rates • Port charges • Quality of customs handling • Free time	• Congestion • Port equipment • Number of sailings • Proximity of ports • Possibility of intermodal links
(Frankel, 1992)	• Cargo volume sharing • Cargo freight revenue sharing	• Cargo operations profit sharing • Cargo type allocation
(Murphy P. R., 1992)	• Has loading and unloading facilities for large and/ or odd-sized freight • Allows for large volume shipments • Has low freight handling shipments • Provides a low frequency of loss and damage	• Has equipment variable • Offers convenient pickup and delivery times • Provides information concerning shipment • Offer assistance in claims handling • Offers flexibility in meeting special handling equipment
(Murphy & Daley, 1994)	• Shipment information • Loss and damage performance • Low freight charges • Equipment availability	• Convenient pickup and delivery • Claims handling ability • Special handling ability • Large volume shipments • Large and odd sized freight
(Malchow & Kanafani, 2001)	• Oceanic Distance • Inland distance (origin of shipment n to port j)	• Frequency of sailing (by carrier i from port j to the destination of shipment n) • Average size of vessels (sailed by carrier i from port j to the destination of shipment n)
(Mangan, Lalwani, & Gardner, 2002)	• Space available when needed on ferry • Sailing freq./convenient sailing times • Risk of cancellation/delay • Port and ferry on fastest overall route • Proximity of ports to origin/destination • Cost of ferry service/discounts	• Speed of getting to/through ports • Port/ferry on cheapest overall route • Ferry suitable for unacc. or special cargo • Delays due to driving ban, tacho etc. • Availability of info on sailing options • Facilities for drivers • Opportunity for driver rest break • Preference of consignor/consignee • Intermodal/connecting transport links
(Tongzon J. , 2002)	• Frequency of ship visits • Operational efficiency • Adequacy of port infrastructure	• Location • Competitive port charges • Quick response to port users' needs and port's reputation for cargo damage

Appendix 2.B (Cont.)

Author	Objectives	
(Veldman & Bückmann, 2003)	• Costs • Time	• Inter arrival time in port • Hinterland modes
(Nir, Lin, & Liang, 2003)	• Travel time • Travel cost	• Route and frequency
(Tiwari, Itoh, & Doi, 2003)	• Ship calls • Total TEU handled at the port • # of berths • # of cranes • Water depth • Routes offered • Usage factor	• Port and loading charges • TEU handled during the year • Fleet size • Distance of shipper from port • Type of trade • Distance of foreign port in nautical miles
(Lirn, Thanopoulou, Beynon, & Beresford, 2004)	• Port physical and technical infrastructure • Port geographical location	• Port management and administration • Carrier's terminal costs
(Malchow & Kanafani, 2004)	• Oceanic distance to the destination from port • Inland distance to port • Average headway between voyages by carrier from port to destination	• Average size of vessels sailed by carrier from port to destination • Probability that port would be the last visited by the vessel
(Guy & Urli, 2006)	• Port infrastructures, • Cost of port transit for a carrier	• Port administration • Geographical location
(Ng, 2006)	• Monetary cost • Time efficiency • Geographical location • Cases of delays in loading/unloading containers • Record of damage during container-handling • Custom procedures • Port authority policy and regulation • Accessibility of the port • Quality of port infrastructure in container-handling • Quality of port superstructure in container-handling	• I.T. and advanced technology • Dedicated terminals and facilities for transshipment • Supporting industries • Quality of other services • Availability of professional personnel in port • Preference of shipping lines' clients/shippers • Relations between port operator and shipping lines • Efforts of marketing on the port by port authority • Reputation of port within the region • Speed in responding to liner's new demands and requests

Appendix 2.B (Cont.)

Author	Objectives	
(Ugboma, Ugboma, & Ogwude, 2006)	• Port efficiency, adequate infrastructure • Frequency of ships visits • Quick response to port users' needs	• Location • Port charges • Ports reputation for cargo damage
(De Langen, 2007)	• Historical reasons/tradition • Personal relations in port • Price • Quality of port • Total transport costs • Quality and service • Port choice is continuously re-assessed	• Lower price can compensate a lower service level • More ports offer an attractive price/quality, cargo is distributed over various ports • Current port provides satisfactory services, there is no reason to change ports, even if price advantages exist
(Tongzon & Sawant, 2007)	• Efficiency • Location • Adequacy of infrastructure • Port charges • Connectivity	• Cargo size • Wide range of port services • Connectivity • Cargo size • Wide range of port services
(Chou C. , 2007)	• Port location • Hinterland economy • Port physical	• Port efficiency • Cost • Other conditions
(Magala & Sammons, 2008)	• Accessibility to markets • Connectivity • Level of integration in the supply chain • Overall port efficiency	• Efficiency of supply chain interfaces and links • Supply chain total cost • Level of supply chain coordination • Type of service • Carbon neutrality/carbon footprint
(Chang, Lee, & Tongzon, 2008)	• Port location • Water draft • Feeder connection • Land connection • Worldwide reputation • Port due • Terminal handling charge (THC) • Cargo volume • Transshipment cargo volume • Niche market	• Import and export cargo balance • Cargo profitability • Berth availability • Reliability of service • IT availability • Customs regulation • Mgt./worker relation • Communication with staff • Special requirement • Competing carriers • Slot exchange

Appendix 2.B (Cont.)

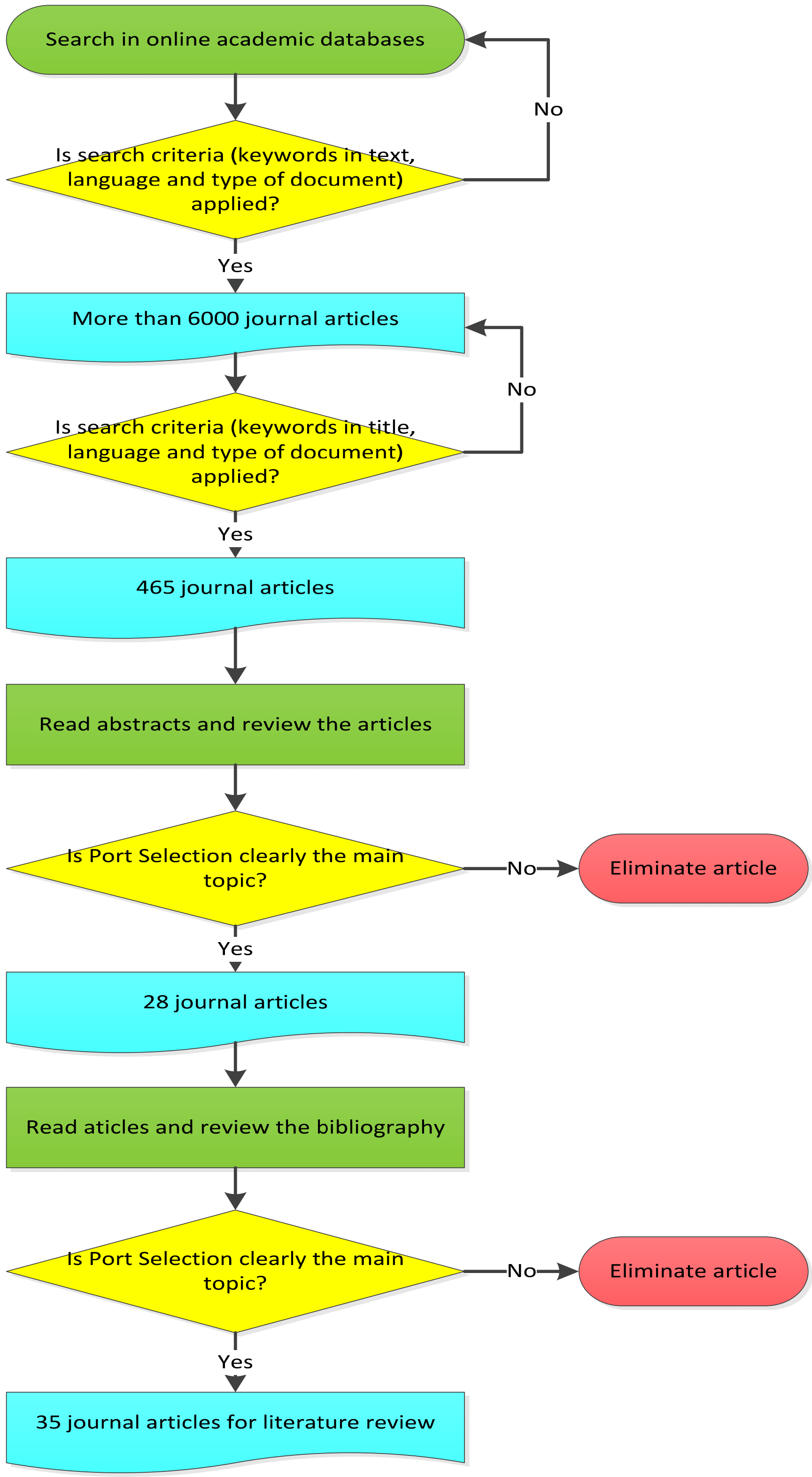
Author	Objectives	
(Wiegmans, Hoest, & Notteboom, 2008)	• Transshipment costs • Speed • Reliability • Flexibility	• Quay length • Immediacy of hinterland connections • Congestion chance on the terminal • Capacity
(Chou C. C., 2009)	• Inland transportation costs • Volume of foreign trade container assigned by shippers • Volume of exported/imported trade to/from Taiwan	• Share rate of capacity of vessels assigned by carriers to visit port • Volume of foreign trade containers from origin zone
(Grosso & Monteiro, 2009)	• Connectivity of the port • Cost and Port Productivity	• Electronic information • Logistics of the container
(Tongzon J. L., 2009)	• Frequency of ship visits • Operational efficiency • Adequacy of port infrastructure	• Location • Competitive port charges • Quick response to port users' needs and port's reputation for cargo damage
(Garcia-Alonso & Sanchez-Soriano, 2009)	• Port-province distance • Appeal of port	• Aversion to distance • Distance from province i to port j
(Chou C. , 2010)	• Port charge, tax, rent and cost • Port operation efficiency • Load/ discharge efficiency	• Size and efficiency of container yard • Hinterland economy • Depth of berth
(Sanchez, Ng, & Garcia-Alonso, 2011)	• Monetary cost • Time efficiency • Geographical location • Cases of delays in loading/unloading containers • Record of damage during container-handling • Custom procedures • Port authority policy and regulation • Accessibility of the port • Quality of port infrastructure in container-handling • Quality of port superstructure in container-handling	• I.T. and advanced technology • Dedicated terminals and facilities for transshipment • Supporting industries • Quality of other services • Availability of professional personnel in port • Preference of shipping lines' clients/shippers • Relations between port operator and shipping lines • Efforts of marketing on the port by port authority • Reputation of port within the region • Speed in responding to liner's new demands and requests

Appendix 2.B (Cont.)

Author	Objectives	
(Veldman, Garcia-Alonso, & Vallejo-Pinto, 2011)	• Inland costs • Maritime costs	• Total costs • Hub port effects
(Tang, Low, & Lam, 2011)	• Number of port calls; • Draught • Trade volume • Port cargo traffic	• Ship turnaround time • Annual operating hours; • Port charges • Availability of inter-modal transports
(Panayides & Song, 2012)	• Adequacy of port facilities • Efficiency • Costs	• Service • Information system availability • Intermodal and value added service
(Steven & Corsi, 2012)	• Crane productivity • Port Congestion • Manage (private governance) • Carrier size • Carrier frequency	• Fitted freight charges • Oceanic transit time • Inland transit • Shipper size • Berths
(van Asperen & Dekker, 2013)	• Demand regions • Location of the ports • Container tracking • Costs	• Distance from each port to the demand regions • Cost per trip • Demand volume
(Yeo, Ng, Lee, & Yang, 2014)	• Port service • Hinterland condition • Availability • Convenience	• Logistics costs • Regional center • Connectivity
(Wu, Liu, & Peng, 2014)	• Monetary cost • Lead time	• Customs policies and quality of services
(Kim, 2014)	• Service- and cooperation-oriented type • Location and cost saver	• On-time and task achiever • Capacity and infrastructure friendly type

Source: Authors

Appendix 2.C - Article Selection Workflow



Appendix 2.D - Certification of Student Work

UNIVERSITY OF ARKANSAS

College of Engineering
Department of Industrial Engineering

Kim LaScola Needy, PhD
Dean of Graduate School and International Education
University of Arkansas

March 7, 2017

I am writing to verify that Rivelino R. De Icaza H. completed more than 51% of the work for the chapter titled "Port Selection Analysis: Trends and Gaps" in his dissertation. He is also the first author of this article.

Sincerely,

G. S. Parnell
DR. GREGORY S. PARNELL
Research Professor and Director, M.S. in Operations Management

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The University of Arkansas is an equal opportunity/affirmative action institution.

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

Rivelino R. De Icaza H. Gregory S. Parnell

Abstract

The West Africa gross domestic product is expected to grow to 6.2 percent in 2016 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 affects transportation security in 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. Our study develops decision analysis model based on available quantitative port data rather than using data from surveys, interviews and questionnaires, as done in previous publications. In both studies 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 compared to the best port in Africa.

Keywords: Port selection, multi-attribute value theory, Value-Focused Thinking, multi-criteria decision analysis, decision analysis.

3.1 Introduction

Ports are an integral part of the maritime industry and global supply chains. Over 90 percent of global trade is 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 C. , 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 C. , 2010) (Chou C. , 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 (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 them, while the VFT approach first involves an understanding of the values

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 measures (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 and AFT methodologies of the container port selection in West Africa are developed. In Section 4, the results of the research are discussed. The articled concludes in Section 5 with a summary of the study’s contributions and directions for future research.

3.2 Literature Review

The port selection topic has been investigated (Frankel, 1992) (Murphy, Dalenberg, & Daley, 1988) (Murphy, Daley, & Dalenberg, 1991) (Murphy P. R., 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. Details about 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 et al (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 Figure 3.1, the port selection literature demonstrates the use of multiple and conflicting criteria.

* Bold criteria are related to criteria in Figure 3.

Figure 3.1 - Multiple and Conflicting criteria in Port Selection Research - Source: (De Icaza, Parnell, & Aloysius, 2017)

In addition, different methodologies have been used to analyze the port selection problem, as illustrated in Figure 3.2

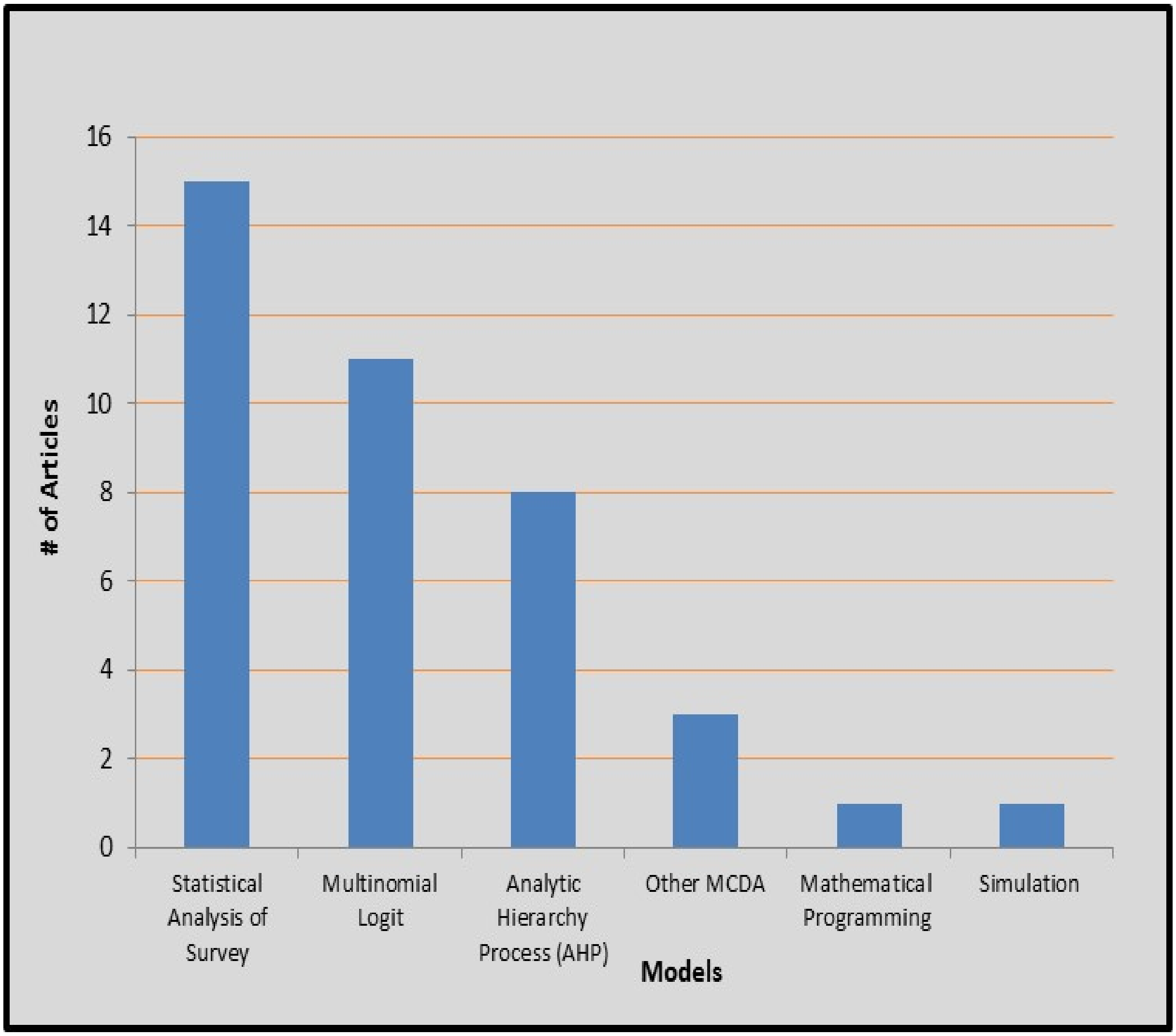


Figure 3.2 - Models Applied to Port Selection Articles - Source: (De Icaza, Parnell, & Aloysius , 2017)

We briefly review the MCDA papers. 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 many port selection problems (Alanda & Yang, 2013) (Chou C. , 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 C. , 2010) (Yeo, Ng, Lee, & Yang, 2014) and the outranking method PROMETHEE (Guy & Urli, 2006).

The review of the port selection literature has shown that it involves a multicriteria decision problem and the lack of research using MAVT. Our research will demonstrate quantitative data exists to enable the development of a MAVT model for the port selection decision problem.

3.3 Using Value-Focused Thinking

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 values and preferences. AFT 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) to achieve these values (Keeney R. L., 1992) (Keeney R. L., 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.

3.4 Research Methodology

3.4.1 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, by using the value hierarchy (4 objectives and 16 criteria, Figure 3.3) and port alternatives of a recent published study (Gohomene, Bonsal, Maistralis, Wang, & Li, 2015). The Alternative-Focused Thinking (AFT) approach is also developed in order to compare the results of both approaches for the container port selection decision problem. The MAVT approach is defined by Keeney and Raiffa (1976). Belton and Stewart (2002) provides an in-depth explanation of the approach.

3.4.1.1 Using a Value Hierarchy from Literature

The value hierarchy identifies what is important for the decision problem and to provide the basis for the evaluation of alternatives (Davis, Deckro, & Jackson, 2000). The value hierarchy shown in Figure 3.3 was constructed using the hierarchy (set of 16 criteria clustered in 4 groups) of a recent published journal article (Gohomene, Bonsal, Maistralis, Wang, & Li, 2015). Gohomene et al (2015) investigated a similar decision problem as the one presented in this research, but using the AHP methodology. They obtained the set of important criteria for the West African container port selection decision beginning with a list of 30 criteria by using literature review and interviews with experts. The criteria were reduced to 16 (Figure 3.3) by using a survey conducted to a panel of four experts on container shipping in West Africa (3 senior managers and 1 senior lecturer from academy).

3.4.1.2 Convert Decision Hierarchy to Value Hierarchy

The first step of the VFT process was to develop a multi-attribute value model that can provide a framework for the evaluation of the alternatives (Figure 3.3). The purpose of the value model is described in level 1 of the value hierarchy. Then, it is divided in 4 criteria 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.

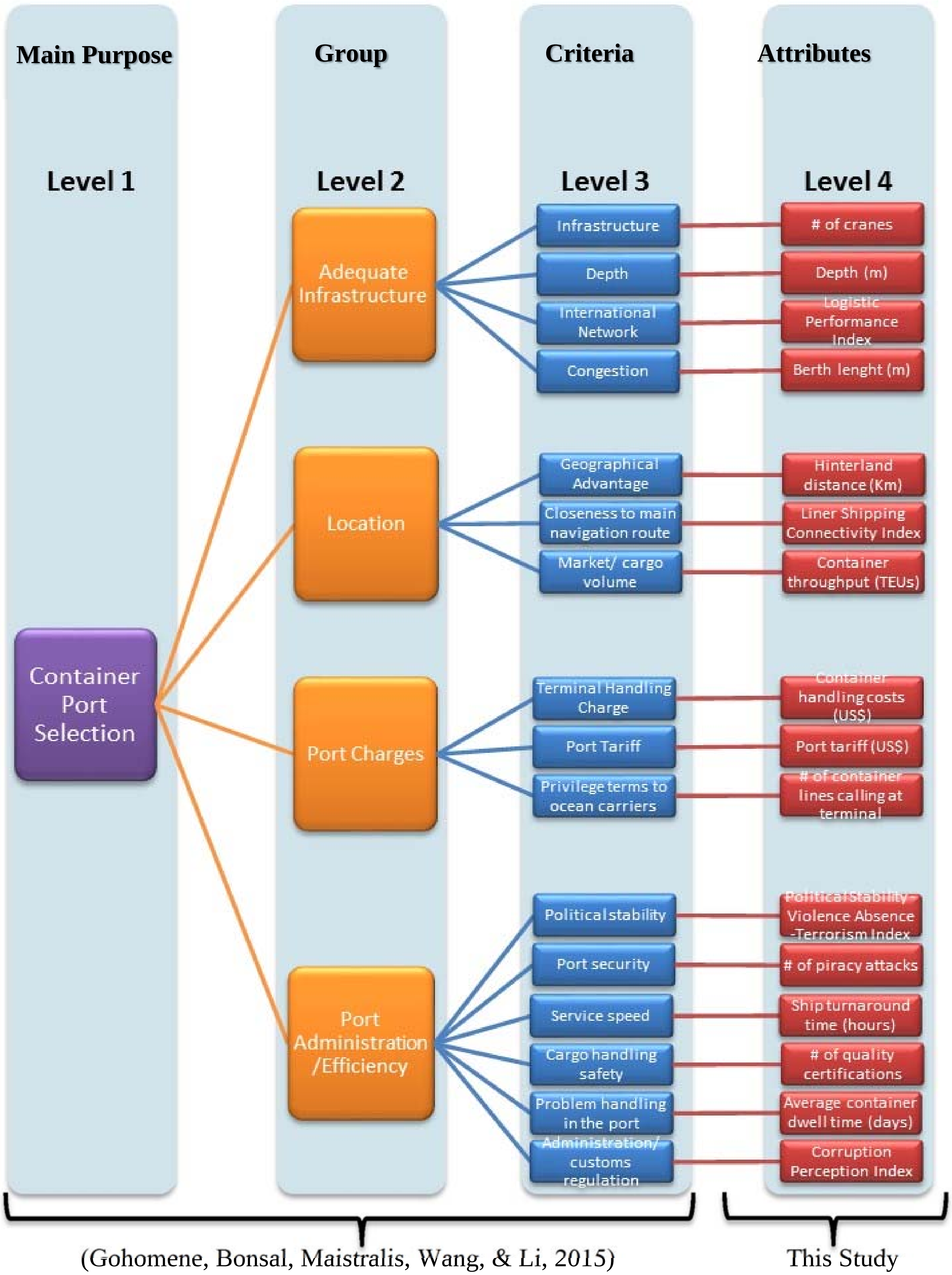


Figure 3.3 - Value Hierarchy for the Container Port Selection Value Model.

3.4.1.3 Defining the Attributes

For each criteria of the value model, an attribute was identified (Table 3.3). 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 R. L., 1992). In addition, two types of scales can be used for the attributes, natural and constructed. Natural scales are already well-known and commonly available, while constructed value scales are developed for a specific decision problem (in which a natural scale does not exists) and use a set of 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 3.1). This was one of the most critical steps of the research because it demonstrated that available data is available to evaluate port selection decision.

Using the collected research data shown in Table 3.1, extreme points of the scales for each attribute were defined (Table 3.2). 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 3.2, it is an extreme point of the scale for the AFT approach, which is explained in section 3.4.2.

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 3.1 - Alternative Scoring for each Attribute

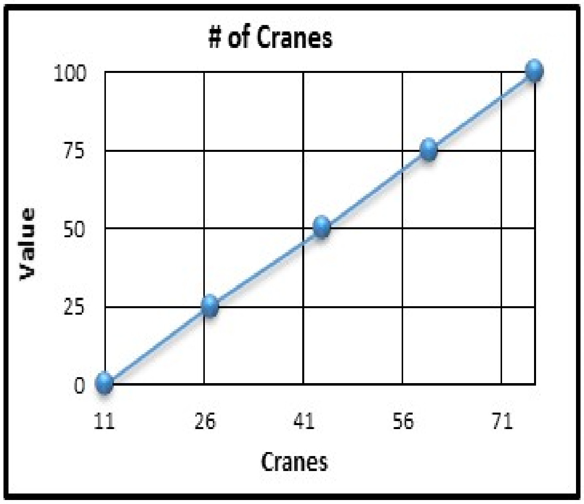
Criteria (1)	Attribute (2)	Min Acceptable Level (3)	* Best Level (4)	** Ideal Level (5)	Curve Shape (6)	Source (7)
Port Infrastructure	# of cranes	11	22	76	Linear	(Port Report Africa 2014)
Port depth	Depth (meters)	11.5	13.5	16	Convex	(Port Report Africa 2014)
Intermodal network	Logistic Performance 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)

Table 3.2 - Attribute Data to Develop Partial Value Functions

3.4.1.4 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 3.2) (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. Partial value functions of the value model are shown in Appendix 3.A and the tables with intervals and ranking used for the Difference Method are shown in Appendix 3.B. 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 is shown in Figure 3.4. On the other hand, other partial value functions have a concave or convex curve shape, e.g., depth in meters, shown in Figure 3.4. In this example, the value increase is significantly higher once the port registers higher meters of depth resulting in a convex shape curve.



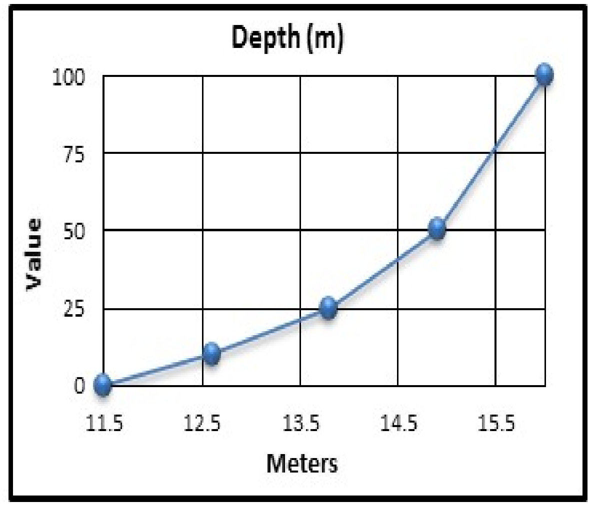


Figure 3.4 - Examples of Partial Value Functions with Linear and Convex curve shapes

3.4.1.5 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 3.3), but also on their variation of the scale (rows in Table 3.3) (Kirkwood, 1997).

As shown in the columns of Table 3.3, 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 3.3. Percentage change calculations were used to classify the attributes in the groups.

Gap btw Min. Accep. and Ideal		Level of Importance of Attributes								
		External Critical Attributes	**SW**	**NW**	**Performance and Costs Indicators**	**SW**	**NW**	**Value Added Features**	**SW**	**NW**
	Large	Political stability	100	0.12	Container throughput (TEUs)	65	0.08	# of cranes	45	0.05
	Large	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
	Medium	# of piracy attacks	75	0.09	Port tariff	40	0.05			
	Medium	Hinterland distance (Km)	70	0.08						
	Small	Depth (m)	50	0.06	Container Handling Costs	35	0.04			
	Small				# of container lines calling at terminal	30	0.04			
	Small				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 essential characteristic to provide services.
**Value added services or characteristics to improve service or being different from competition.
***Port services and characteristics that may provide operational efficiencies.

Table 3.3 - Swing Weight Matrix for the VFT Approach

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 3.3) 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 3.3). The final step is to calculate the normalized swing weights (NW column in Table 3.3) to sum to 1 for use in the additive value model. The formula to normalize the swing weights is:

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

Where f_i is the unnormalized 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.

3.4.1.6 Single Dimensional Value Calculations

Single dimensional values (Table 3.4) for each alternative under each attribute were calculated using the partial value functions. This data is fundamental for the overall evaluation of alternatives.

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

Table 3.4 - Single Dimensional Value Calculations for each Attribute

3.4.1.7 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 (Table 3.5). The Hypothetical Best alternative is a hypothetical alternative with the best score on each attribute.

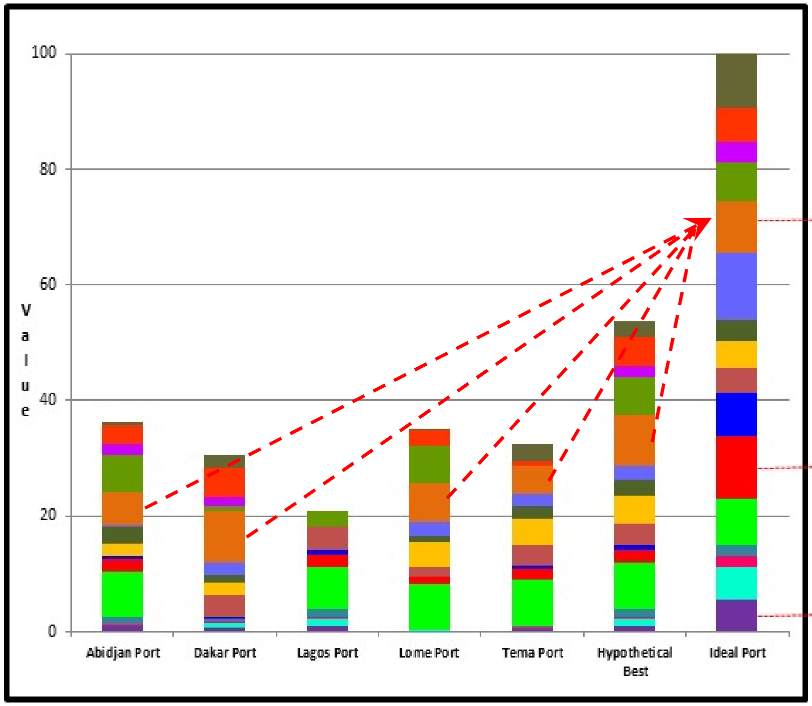
In addition, for a better illustration of the magnitude each attribute contributes to the overall value of each alternative, the value component graph (Table 3.5) and the floating value component chart (Table 3.6) were developed for the value model.

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	

Table 3.5 - Overall Value and Ranking of Alternatives of the Value Model

3.4.1.8 Identifying Value Gaps

The VFT approach offers the information to identify opportunities to improve the existing alternatives (Keeney R. L., 1992). Alternatives were evaluated using the Value Component Charts (Figure 3.5, Figure 3.6, and Figure 3.7) in order to identify performance of each alternative and compare attribute value gaps for each alternative against the ideal alternative. These value gaps can help shipping lines identify 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 3.6) 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 3.7, 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 3.7) is *port depth in meters*. On the other hand, there is not a value gap for *ship turnaround time in hours*, because the Abidjan Port (Best Port) has the same value as the Ideal Port.



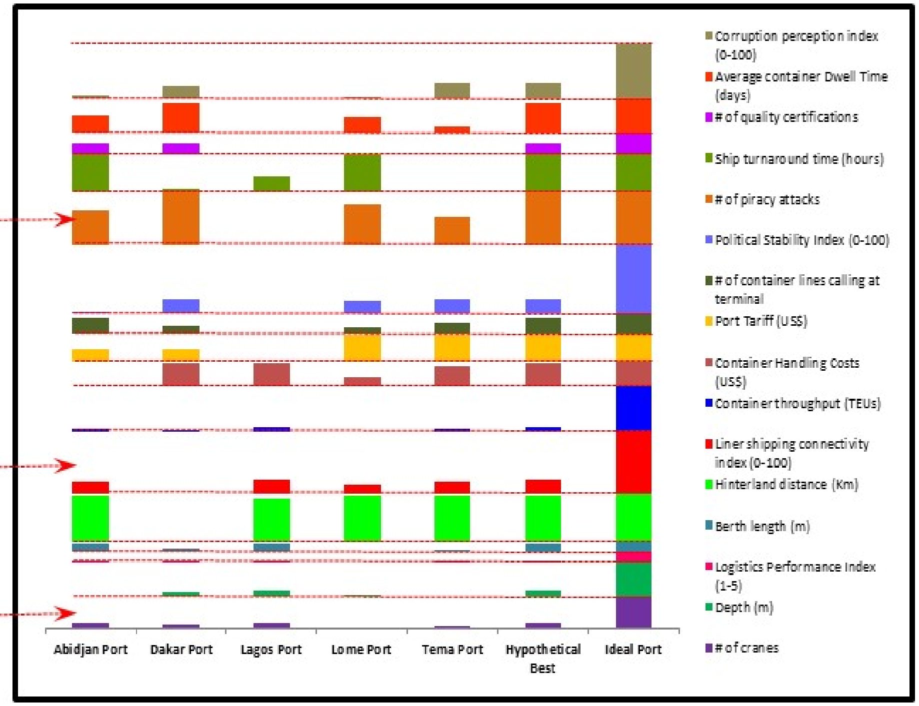


Figure 3.5 - Value Component Chart (left)

Figure 3.6 - Floating Value Component Chart (right)

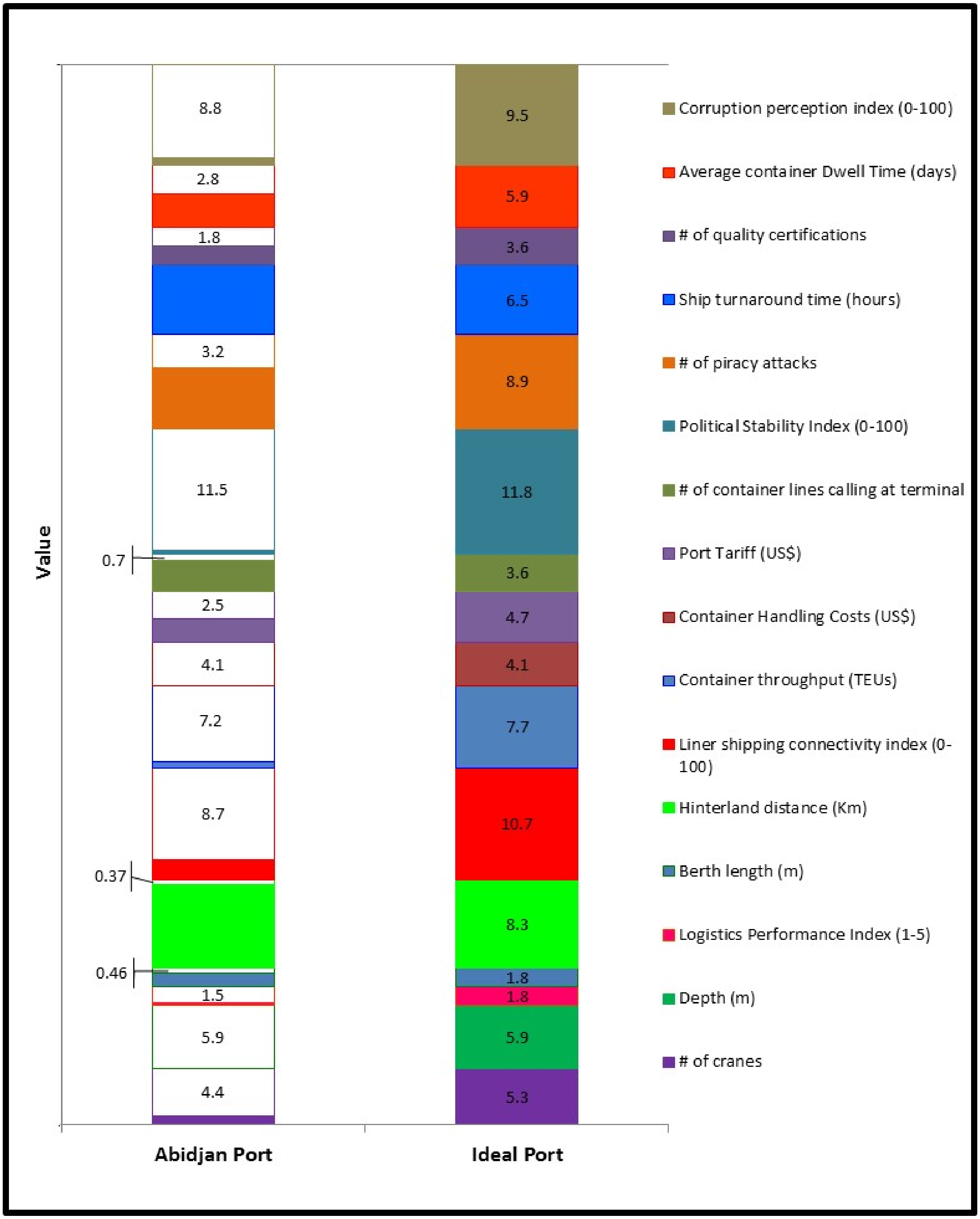


Figure 3.7 - Value Gaps between Best and Ideal Alternatives of Value Model.

3.4.2 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 R. L., 1992). To simplify the illustration of the AFT approach, only the steps and data that differs from the VFT approach will be presented.

3.4.2.1 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 in Table 3.2); which in turn, numerical standard unit of measure of 0 and 100 will be assigned respectively for the development of the partial value functions (Appendix 3.C). Figure 3.8 illustrates two examples of partial value functions for the AFT approach, which comparing to the VFT partial value functions (Appendix 3.A), the only difference will be on the highest value level of performance of each attribute.

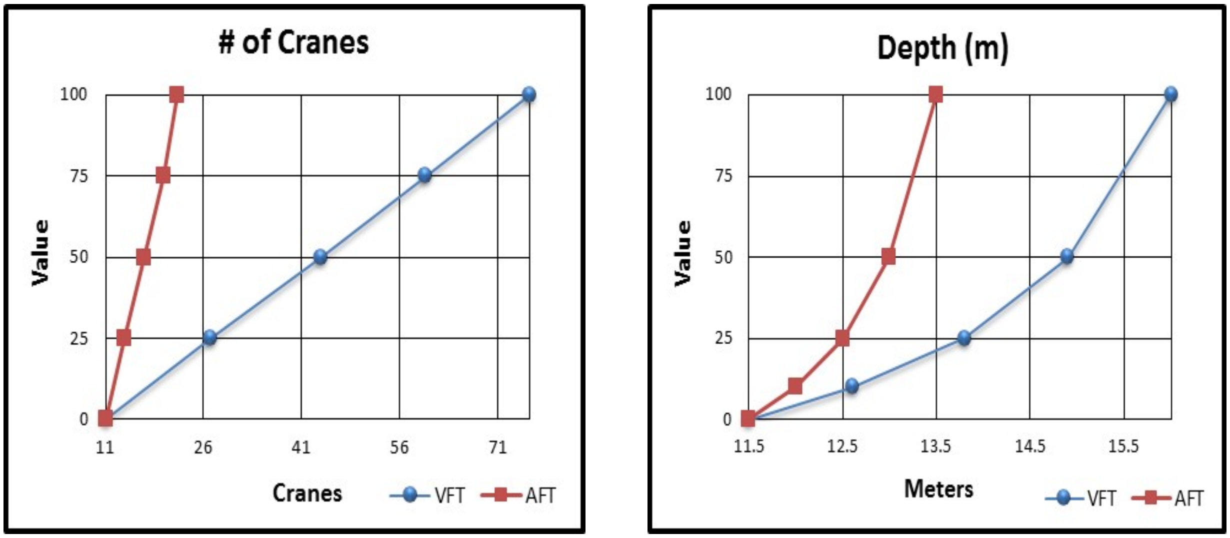


Figure 3.8 - Examples of Partial Value Functions for the AFT Approach and VFT Approach

3.4.2.2 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 3.2); 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 3.6.

<table>
<tr><th></th><th></th><th colspan="9">Level of Importance of Attributes</th></tr>
<tr><th></th><th></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 3.6 - Swing Weight Matrix for the AFT Approach

3.4.2.3 Single Dimensional Value Calculations and Overall Evaluation of Alternatives

Using the new AFT partial value functions (Appendix 3.C) and the alternative scores presented above (Table 3.1), single dimensional value calculations for each alternative under each attribute was developed (Table 3.7). 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 3.8. In addition, the overall value for each alternative of the AFT approach is presented on the value component chart of Table 3.9. The value component chart provides the contribution of each attribute to the overall value of the alternative compared to the hypothetical best alternative.

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 3.7 - Single Dimensional Value Calculations for each Attribute

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	

Table 3.8 - Overall Value and Ranking of Alternatives for the AFT Approach

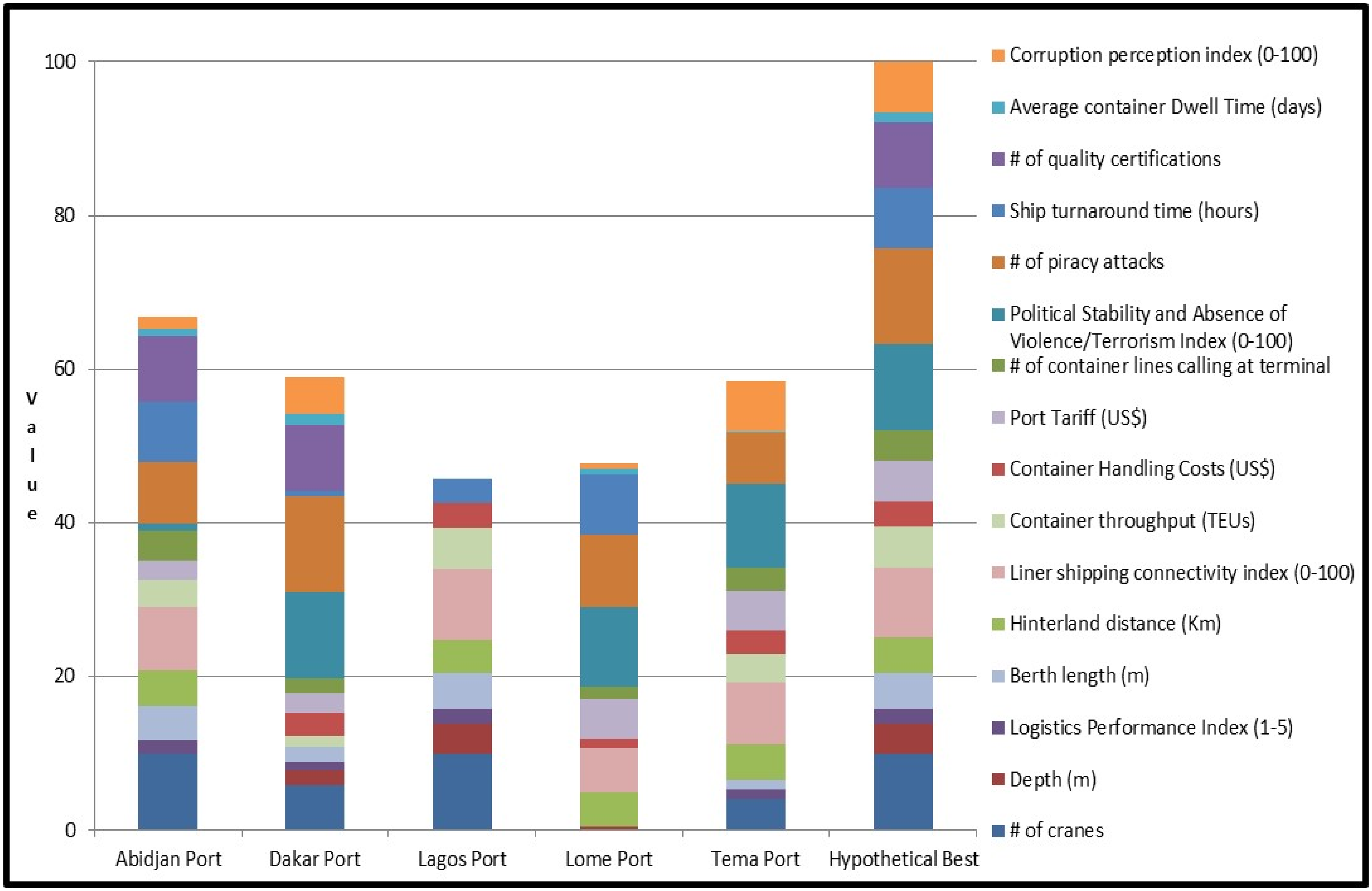


Figure 3.9 - Value Component Chart for the AFT Approach

3.4.3 Comparing VFT vs AFT Results

Based on the VFT and AFT results shown in Table 3.9, 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.

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**

Table 3.9 - Comparison of Alternative Overall Values between VFT and AFT

3.5 Discussion

The applicability of the MAVT with VFT approach for a port selection decision problem has been demonstrated and compared with the traditional AFT approach. In order to evaluate 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 (Table 3.5, Table 3.6, and Table 3.7) 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 3.10 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 3.11) (Parnell, Bresnick, Tani, & Johnson, 2013). Triangles were used to identify the two nondominated 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).

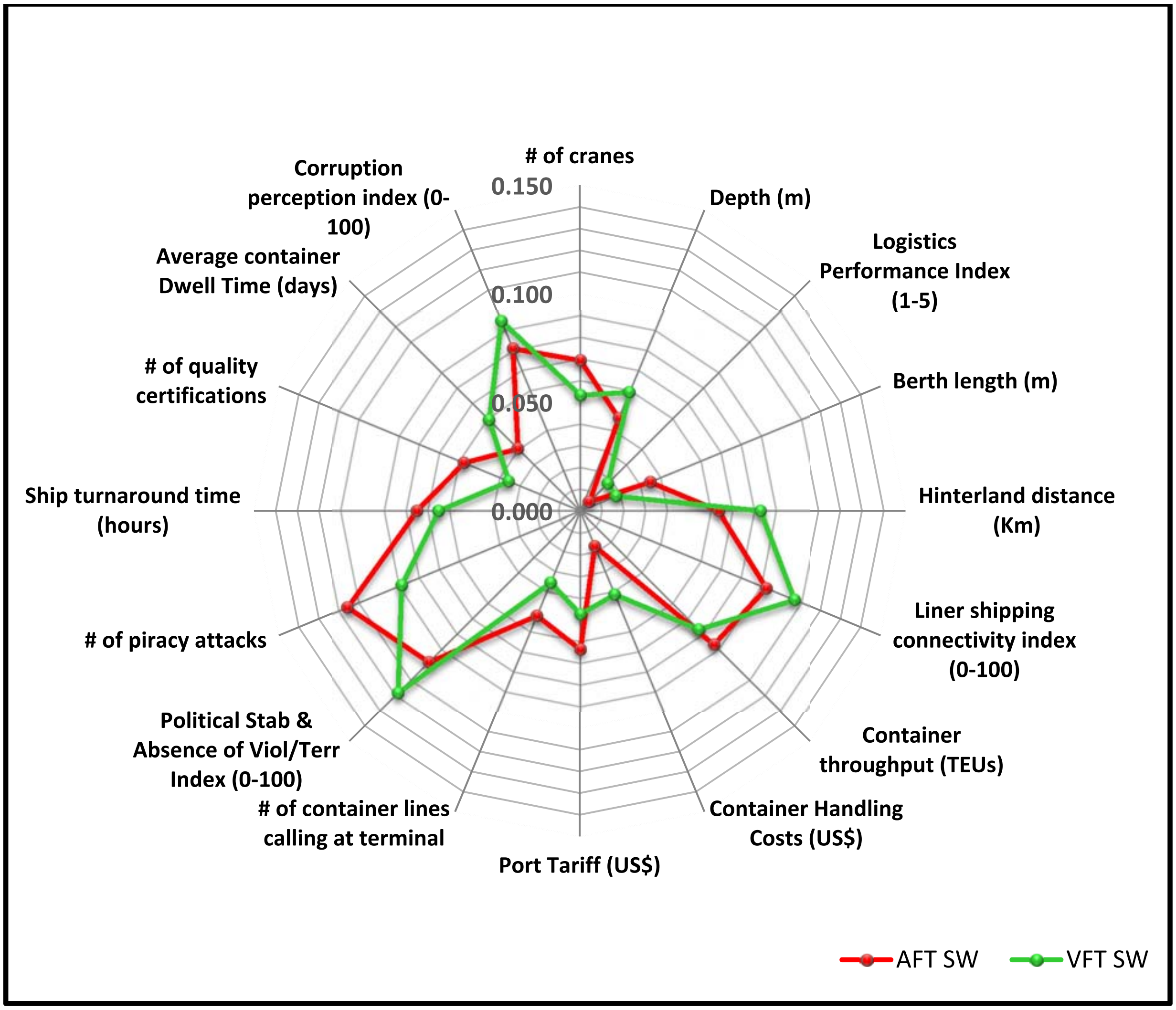


Figure 3.10 - Weight Comparison of AFT vs VFT Approaches

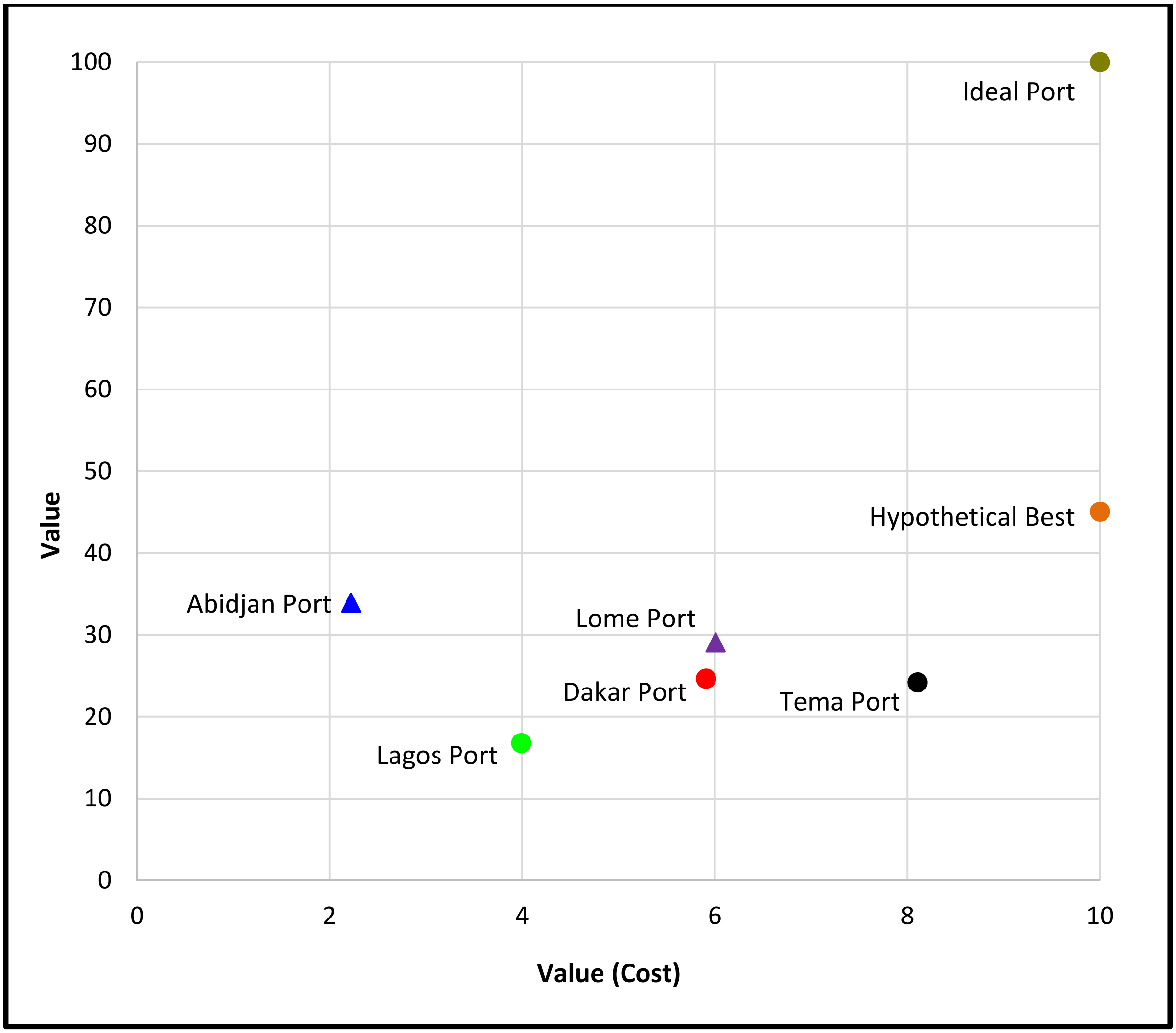


Figure 3.11 - Cost Value vs Value for the VFT Approach

3.6 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.

Bibliography

Alanda, A., & Yang, Z. (2013). Hub-Port Choice in West Africa. In International Forum on Shipping, Ports and Airports (IFSPA) (pp.405-413).

Belton, V., & Stewart, T. (2002). *Multiple criteria decision analysis: an integrated approach.* Boston: Kluwer.

Bolloré Africa Logistics Nigeria. (2014). Retrieved from http://www.bollore-africa-logistics-kenya.com/about-us/bollore-africa-logistics-in-kenya/iso-90012008-certification.html (accessed January 2016).

CATRAM Consultants. (2013). *Market study on container terminals in West and Central Africa.*

Chang, Y. T., Lee, S. Y., & Tongzon, J. L. (2008). Port selection factors by shipping lines: Different perspectives between trunk liners and feeder service providers. *Marine Policy*, 32(6), 877-885.

Chou, C. (2007). A fuzzy MCDM method for solving marine transshipment container port selection problems. *Applied Mathematics and Computation*, 186(1), 435-444.

Chou, C. (2010). AHP model for the container port choice in the multiple-ports region. *Journal of Marine Science and Technology*, 18(2), 221-232.

Davis, C., Deckro, R., & Jackson, J. (2000). A value focused model for a C4 network. *Journal of Multicriteria Decision Analysis*, 9(4), 138.

De Langen, P. (2007). Port competition and selection in contestable hinterlands; the case of Austria. *European Journal of Transport and Infrastructure Research*, 7(1), 1-14.

Dyck, G., & Ismael, H. (2015). Multi-Criteria Evaluation of Port Competitiveness in West Africa Using Analytic Hierarchy Process (AHP). *American Journal of Industrial and Business Management*, *5(06)*, 432-446.

Frankel, E. (1992). Hierarchical logic in shipping policy and decision-making. *Maritime Policy & Management*, 19(3), 211-221.

Garcia-Alonso, L., & Sanchez-Soriano, J. (2009). Port selection from a hinterland perspective. *Maritime Economics & Logistics*, 11(3), 260-269.

Gohomene, D., Bonsal, S., Maistralis, E., Wang, J., & Li, K. (2015). The Attractiveness of Ports in West Africa: Some Lessons from Shipping Lines' Port Selection. *Growth and Change.*

Grosso, M., & Monteiro, F. (2009). Relevant strategic criteria when choosing a container port-the case of the port of Genoa. *Research in Transport and Logistics*, 299.

Guy, E., & Urli, B. (2006). Port selection and multicriteria analysis: an application to the Montreal-New York alternative. *Maritime Economics & Logistics*, 8(2), 169-186.

ICC International Maritime Bureau. (2015). *Piracy and Armed Robbery Againts Ships.* London. Retrieved from http://www.hellenicshippingnews.com/wp-content/uploads/2015/01/2014-Annual-IMB-Piracy-Report-ABRIDGED.pdf (accessed January 2016).

IMO. (2012). *International Maritime Organization. International Shipping Facts and Figures – Information Resources on Trade, Safety, Security, Environment.* Maritime Knowledge Centre. London. Retrieved from http://www.imo.org/en/KnowledgeCentre/ShipsAndShippingFactsAndFigures/TheRoleandImportanceofInternationalShipping/Documents/International%20Shipping%20-%20Facts%20and%20Figures.pdf (accessed March 2016).

Keeney, R. L. (1992). *Value-Focused Thinking: A path to creative decisionmaking.* Harvard University Press.

Keeney, R. L. (1994). Creativity in decision making with Value-Focused Thinking. *Sloan Management Review*, 35(4), 33.

Keeney, R. L., & Raïffa, H. (1976). *Decisions with multiple objectives: preferences and value tradeoffs.* New York: Wiley.

Kim, J. Y. (2014). Port user typology and representations of port choice behavior: A Q-methodological study. *Maritime Economics & Logistics*, 16(2), 165-187.

Kirkwood, C. (1997). *Strategic Decision Making Multiobjective Decision Analysis with Spreadsheets.* Belmont, California: Wadsworth Publishing Company.

Knoema - Port Databse. (2014). Retrieved from https://knoema.com/PRTDT2016 (accessed February 2016).

Lirn, T., Thanopoulou, H., Beynon, M., & Beresford, A. (2004). An application of AHP on transhipment port selection: a global perspective. *Maritime Economics & Logistics,*, 6(1), 70-91.

Magala, M., & Sammons, A. (2008). A new approach to port choice modelling. *Maritime Economics & Logistics*, 10(1), 9-34.

Malchow, M., & Kanafani, A. (2001). A disaggregate analysis of factors influencing port selection. *Maritime Policy & Management*, 28(3), 265-277.

Malchow, M., & Kanafani, A. (2004). A disaggregate analysis of port selection. *Transportation Research Part E: Logistics and Transportation Review*, 40(4), 317-337.

Mangan, J., Lalwani, C., & Gardner, B. (2002). Modelling port/ferry choice in RoRo freight transportation. *International Journal of Transport Management*, 1(1), 15-28.

Montibeller, G. (2005). From (and to) a new generation of multi-criteria decision analysts: an introduction to the field and a personal view on its future. *In Keynote Papers–YOR14 Conference.* The Operational Research Society Press: Birmingham (ISBN 0 903440 33 4).

Murphy, P. R. (1992). Port selection criteria: an application of a transportation research framework. *Logistics and Transportation Review*, 28(3), 237.

Murphy, P., & Daley, J. (1994). A comparative analysis of port selection factors. *Transportation Journal*, 15-21.

Murphy, P., Dalenberg, D., & Daley, J. (1988). A contemporary perspective of international port operations. *Transportation journal*, 23-32.

Murphy, P., Daley, J., & Dalenberg, D. (1991). Selecting links and nodes in international transportation: an intermediary's perspective. *Transportation journal*, 33-40.

Ng, K. (2006). Assessing the attractiveness of ports in the North European container transhipment market: an agenda for future research in port competition. *Maritime Economics and Logistics*, 8(3), 234-250.

Nir, A., Lin, K., & Liang, G. (2003). Port choice behaviour--from the perspective of the shipper. *Maritime Policy & Management*, 30(2), 165-173.

Panayides, P., & Song, D. (2012). Determinants of Users' Port Choice. *The Blackwell Companion to Maritime Economics*, 599-622.

Parnell, G., & Trainor, T. E. (2009). Using the Swing Weight Matrix to Weight Multiple Objectives. *In INCOSE International Symposium (Vol. 19, No. 1, pp. 283-298).*

Parnell, G., Bresnick, T., Tani, S., & Johnson, E. (2013). *Handbook of decision analysis (Vol. 6).* New Jersey: John Wiley & Sons.

Parnell, G., Hughes, D., Burk, R., Driscoll, P., Kucik, P., MoraleS, B., & Nunn, L. (2013). Invited Review—Survey of Value-Focused Thinking: Applications, Research Developments and Areas for Future Research. *Journal of Multi-Criteria Decision Analysis*, 20(1-2), 49-60.

Port Autonome de Dakar [Autonomous Port of Dakar]. (2016). Retrieved from http://www.portdakar.sn/index.php (accessed January 2016).

Port Autonome de Lome [Autonomous Port of Lome]. (2012). Retrieved from http://www.togo-port.net/index.php?option=com_content&view=article&id=204:le-port-de-lome-certifie-iso-9001-version-2008&catid=43:actualites&Itemid=104 (accessed February 2016).

Port of Abidjan, Ivory Coast. (2016). Retrieved from http://www.bollore-africa-logistics.com/en/ports-and-terminals/ (accessed February 2016).

Port Report Africa. (2014). Retrieved from http://www.portoverview.com (accessed May 2016).

Saaty, T. (1980). *The analytic hierarchy process: planning, priority setting, resources allocation.* New York: McGraw.

Sanchez, R., Ng, A., & Garcia-Alonso, L. (2011). Port Selection Factors and Attractiveness: The Service Providers' Perspective. *Transportation Journal*, 50(2), 141-161.

Slack, B. (1985). Containerization, inter-port competition, and port selection. *Maritime Policy and Management*, 12(4), 293-303.

Song, D., & Yeo, K. (2004). A competitive analysis of Chinese container ports using the analytic hierarchy process. *Maritime Economics & Logistics,* 6(1), 34-52.

Steven, A., & Corsi, T. (2012). Choosing a port: An analysis of containerized imports into the US. *Transportation Research Part E: Logistics and Transportation Review,* 48(4), 881-895.

Suez Canal Container Terminal. (2016). Retrieved from http://www.scctportsaid.com/organization_hsse.php (accessed February 2016).

Tang, L., Low, J., & Lam, S. (2011). Understanding port choice behavior—a network perspective. *Networks and Spatial Economics*, 11(1), 65-82.

Tema Port. (2014). Retrieved from http://www.ghanaports.gov.gh/page/19/Port-Highlights (accessed February 2016).

Tiwari, P., Itoh, H., & Doi, M. (2003). Shippers' port and carrier selection behaviour in China: a discrete choice analysis. *Maritime Economics & Logistics*, 5(1), 23-39.

Tongzon, J. (2002). Port choice determinants in a competitive environment. *In Proceedings of Annual Conference and Meeting of the International Association of Maritime Economists.* Panama: IAME.

Tongzon, J. L. (2009). Port Choice and freight forwarders. *Transportation Research Part E: Logistics and Transportation Review*, 45(1), 186-195.

Tongzon, J. L., & Sawant, L. (2007). Port choice in a competitive environment: from the shipping lines' perspective. *Applied Economics*, 39(4), 477-492.

Transparency International. (2014). Retrieved from Corruption Perception Index 2014: Results: https://www.transparency.org/cpi2014/results (accessed February 2016).

Ugboma, C., Ugboma, O., & Ogwude, I. (2006). An analytic hierarchy process (AHP) approach to port selection decisions–empirical evidence from Nigerian ports. *Maritime Economics & Logistics*, 8(3), 251-266.

UNCTAD STAT. (2014). Retrieved from unctadstat.unctad.org/wds/ (accessed January 2016).

Veldman, S., & Bückmann, E. (2003). A model on container port competition: an application for the west European container hub-ports. *Maritime Economics & Logistics*, 5(1), 3-22.

Veldman, S., Garcia-Alonso, L., & Vallejo-Pinto, J. (2011). Determinants of container port choice in Spain. *Maritime Policy & Management*, 38(5), 509-522.

Watson, S., & Buede, D. (1987). *Decision synthesis: the principles and practice of decision analysis.* New York: Cambridge University Press.

Wiegmans, B., Hoest, A., & Notteboom, T. (2008). Port and terminal selection by deep-sea container operators. *Maritime Policy & Management*, 35(6), 517-534.

World Bank LPI. (2014). Retrieved from http://lpi.worldbank.org/international/global (accessed January 2016).

World Bank WDI. (2014). Retrieved from http://wdi.worldbank.org/tables (accessed January 2016).

World Bank WGI. (2014). Retrieved from http://info.worldbank.org/governance/wgi (accessed January 2016).

World Shipping Council. (2016). Retrieved from http://www.worldshipping.org/about-the-industry/global-trade/top-50-world-container-ports (accessed March 2016).

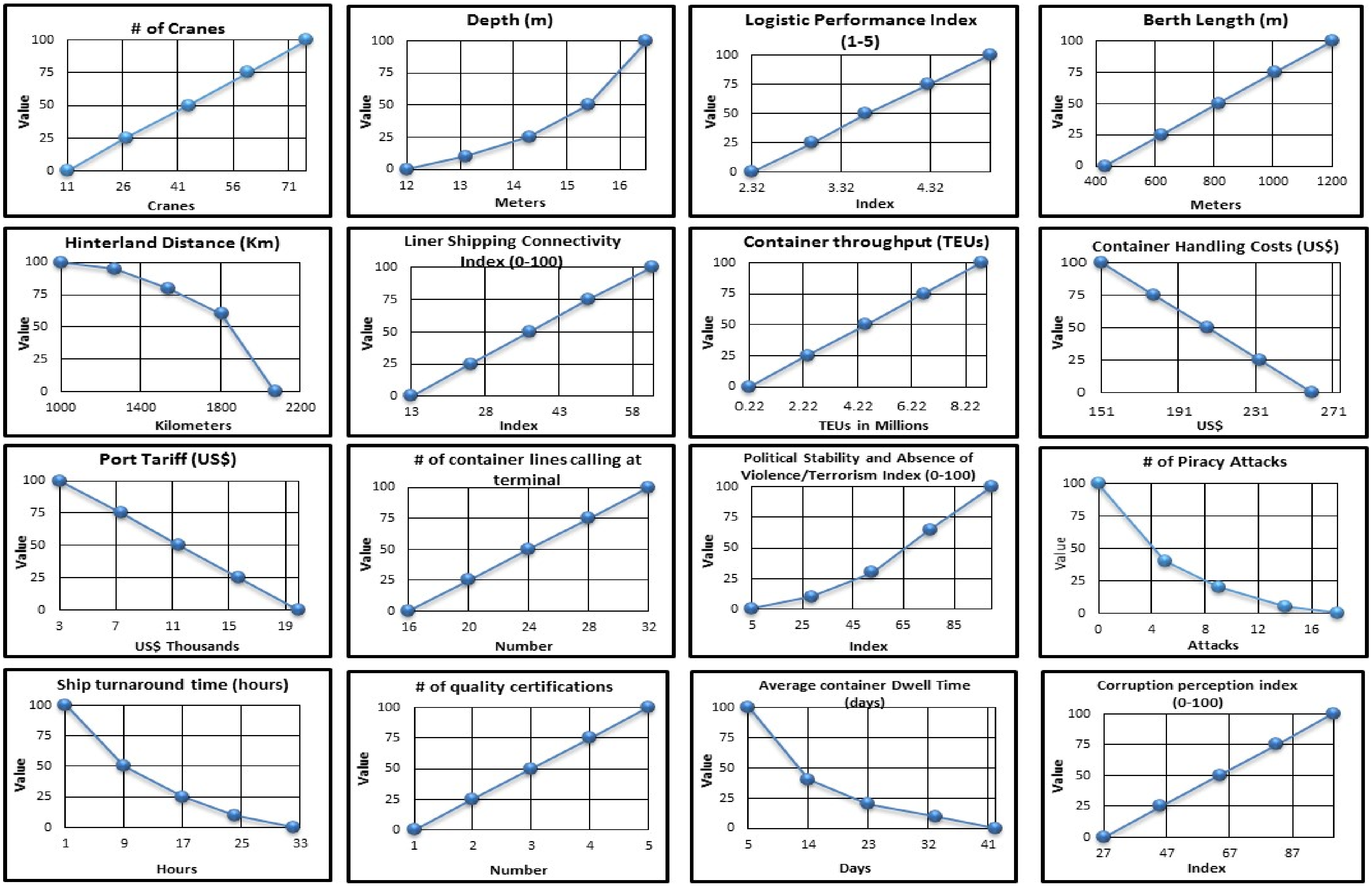
Wright, G., & Goodwin, P. (1999). Future-focussed thinking: combining scenario planning with decision analysis. *Journal of Multicriteria Decision Analysis*, 8(6), 311.

Wu, Y., Liu, J., & Peng, C. (2014). Analysis of port and inland transport mode selection. *In Service Systems and Service Management (ICSSSM) 2014 11th International Conference* (pp. 1-6). IEEE.

Yeo, G., Ng, A., Lee, P., & Yang, Z. (2014). Modelling port choice in an uncertain environment. *Maritime Policy & Management*, 41(3), 251-267.

Appendix

Appendix 3.A - Partial Value Functions of VFT Value Model



Appendix 3.B - Intervals and Ranking of Partial Value Functions with Convex and Concave Curve Shapes of the VFT Value Model

Convex Increasing			
Depth (m)			
From	To	Increase in Value	
11.5	12	1	Lowest
12.6	13	2	
13.8	14	3	
14.9	16	4	Highest

Preference: More depth

Increase in depth yields an increase in value

Concave Decreasing			
Hinterland dist. (Km)			
From	To	Decrease in Value	
1000.0	1269	1	Lowest
1269	1538	2	
1538	1806	3	
1806	2075	4	Highest

Preference: Less hinterland distance

Increase in distance yields a decrease in value

Convex Increasing			
Political Stability			
From	To	Increase in Value	
5.34	29	1	Lowest
29	53	2	
53	76	3	
76	100	4	Highest

Preference: More political stability

Increase in stability yields an increase in value

Convex Decreasing			
# of piracy attacks			
From	To	Increase in Value	
0	5	1	Highest
5	9	2	
9	14	3	
14	18	4	Lowest

Preference: Less piracy attacks

Increase in attacks yields a decrease in value

Convex Decreasing			
Ship turnaround time (hours)			
From	To	Increase in Value	
1	9	1	Highest
9	17	2	
17	24	3	
24	32	4	Lowest

Preference: Less turnaround time

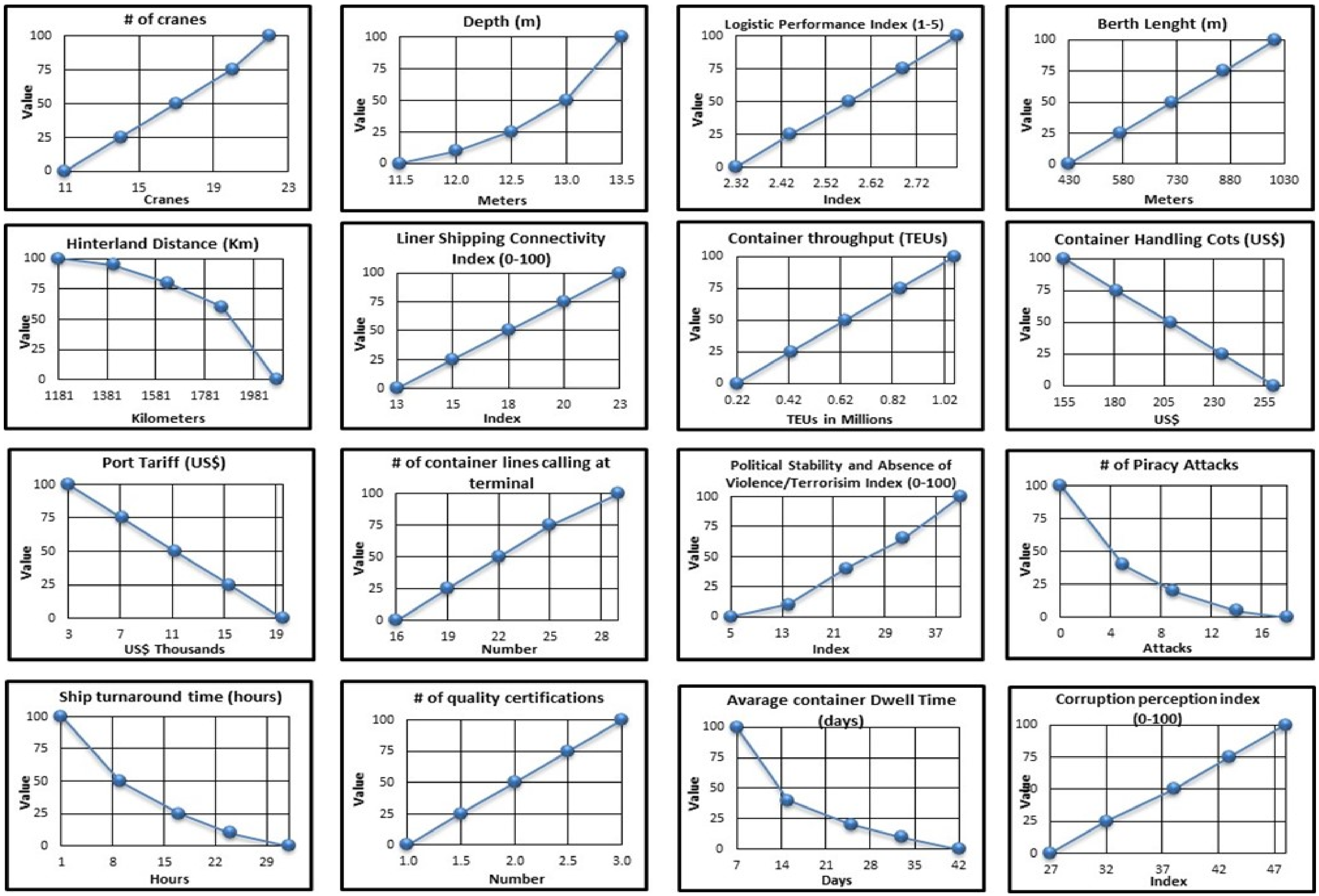
Increase in time yields a decrease in value

Convex Decreasing			
Average container Dwell Time (days)			
From	To	Increase in Value	
5	14	1	Highest
14	23	2	
23	33	3	
33	42	4	Lowest

Preference: Less dwell time

Increase in dwell time yields a decrease in value

Appendix 3.C - Partial Value Functions of AFT Mode



Appendix 3.D - Intervals and Ranking of Partial Value Functions with Convex and Concave Curve Shapes of the AFT Value Model

Convex Increasing			
Depth (m)		Increase in Value	
From	To		
11.5	12	1	Lowest
12	12.5	2	
12.5	13	3	
13	13.5	4	Highest

Preference: More depth

Increase in depth yields an increase in value

Concave Decreasing			
Hinterland dist. (Km)		Decrease in Value	
From	To		
1181.0	1405	1	Lowest
1405	1628	2	
1628	1852	3	
1852	2075	4	Highest

Preference: Less hinterland distance

Increase in distance yields a decrease in value

Convex Increasing			
Political Stability		Increase in Value	
From	To		
5.34	14.3	1	Lowest
14.32	23.3	2	
23.3	32.2	3	
32.28	41.2	4	Highest

Preference: More political stability

Increase in stability yields an increase in value

Convex Decreasing			
# of piracy attacks		Increase in Value	
From	To		
0	5	1	Highest
5	9	2	
9	14	3	
14	18	4	Lowest

Preference: Less piracy attacks

Increase in attacks yields a decrease in value

Convex Decreasing			
Ship turnaround time (hours)		Increase in Value	
From	To		
1	9	1	Highest
9	17	2	
17	24	3	
24	32	4	Lowest

Preference: Less turnaround time

Increase in turnaround time yields a decrease in value

Convex Decreasing			
Average container Dwell Time (days)		Increase in Value	
From	To		
7	15	1	Highest
15	25	2	
25	33	3	
33	42	4	Lowest

Preference: Less dwell time

Increase in dwell time yields a decrease in value

Appendix 3.E - Certification of Student Work

UNIVERSITY OF ARKANSAS

College of Engineering
Department of Industrial Engineering

Kim LaScola Needy, PhD
Dean of Graduate School and International Education
University of Arkansas

March 7, 2017

I am writing to verify that Rivelino R. De Icaza H. completed more than 51% of the work for the chapter titled "Container Port Selection in West Africa: A Multi-Criteria Decision Analysis" in his dissertation. He is also the first author of this article.

Sincerely,

G. S. Parnell
DR. GREGORY S. PARNELL
Research Professor and Director, M.S. in Operations Management

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The University of Arkansas is an equal opportunity/affirmative action institution.

4. Port Selection Decision Support System: The influence of Panama Canal Expansion in Gulf Coast Ports

Rivelino R. De Icaza H.   Gregory S. Parnell   Edward A. Pohl

Abstract

In today's competitive global markets, ports play a vital role in global supply chain operations. A port selection decision-support system was developed to support shipping lines decisions to select the best port in the U.S. Gulf Coast after the Panama Canal Expansion. Since port selection is complex, dynamic, and includes multiple objectives, a Multi-Objective Decision Analysis technique with Value-Focused Thinking was applied for the decision-support system, including industry expert guidance for the development of the value model. In addition, a cost model was developed to quantify the cost. Monte Carlo simulation was used to analyze the uncertainties incorporated in the value and cost model of the decision-support system. The results show that Houston port is the best alternative in the Gulf Coast. The port selection decision-support system is a tool that provides an advantage to be applied in any region of the world and facilitates a port selection decision to shipping lines, port managers and other stakeholders.

Keywords: Port selection, decision support system, Value-Focused Thinking, multiple objective decision analysis, Panama Canal Expansion.

4.1 Introduction

Ports play a strategic role in global supply chains (Tongzon J. L., 2009) in today's competitive markets. Port services are affected by growing container traffic volumes due to the introduction of larger vessels (Loh & Thai, 2015) (UNCTAD, 2015), the 2016 opening of the Panama Canal Expansion (DOT-MARAD, 2013), and the continuous growth of global containerized trade which is expected to be 4.1 percent in 2016 (Nightingale, 2016). Therefore, it will be vital for shipping lines and shippers to make cost effective port selection decisions that will avoid disruptions in their global supply chains.

U.S. West Coast ports are particularly affected by the concentrated container traffic volumes since they handle 69% of the Northeast Asia imports. In 2010, the U.S imported 10.2 million TEUs with 37.1 million TEUs forecasted for 2040, which represents 61 and 71 percent of the U.S. waterborne total respectively (DOT-MARAD, 2013). The shipping line demand is driven by the main U.S. retailers such as Wal-Mart, Target, Best Buy, Home Depot and Lowe's (JOC, 2016). Therefore, the Panama Canal Expansion is expected to impact the U.S. container trade volume, flow, and port development by offering an alternative route to the Gulf Coasts ports from the congested West Coast ports (Bhadury, 2016). The new alternative is attractive because it reduces transportation costs by using larger ships and more reliable because it avoids the congested intermodal transportation from the West Coast (DOT-MARAD, 2013) (Rodrigue J.P., 2010) (Figure 4.1).

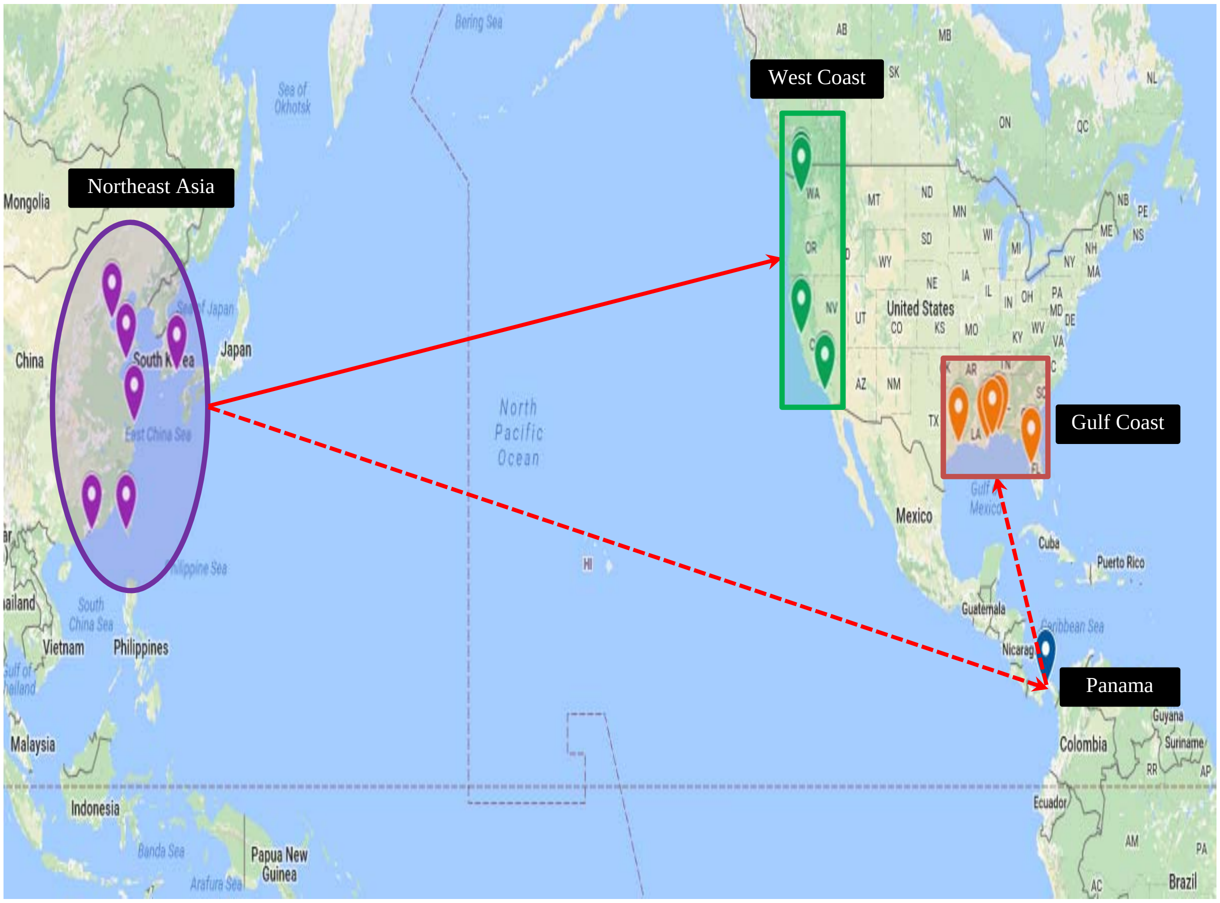


Figure 4.1 - Northeast Asia Transpacific routes to the U.S. West and Gulf Coast Ports

The impact that the Panama Canal expansion will have in the East and Gulf Coast ports is uncertain, but it is estimated that it could attract up to 25 percent of the container traffic from the congested West Coast (CanagaRetna, 2010). Therefore, shipping lines will be performing port selection decisions to efficiently integrate new ports into their global supply chains. However, port selection decisions are complex since multiple and conflicting criteria are involved, including: port infrastructure, capacity, intermodal services, security, weather, etc. (Chou C.C., 2010).

The literature has shown that there is a large set of criteria to investigate the port selection problems. Port selection studies have been conducted using mainly the following techniques:

statistical analysis of surveys, multinomial logit model, and Analytical Hierarchy Process (AHP) models. However, no researchers have reported the use of the Multiobjective Decision Analysis (MODA) on port selection decisions. The most recent studies using each approach are cited in the next section, and details about the port selection literature are documented in De Icaza et al (2017), which presents a structured summary of the studies classified based on the type of analytics (Figure 4.2), year, criteria, methodologies, etc.,

Therefore, since multiple criteria are important in port selection and shipping lines should have a practical tool for the port selection decision, the purpose of this study is to develop a Port Selection Decision Support System (PSDSS), which will integrate the MODA approach (Keeney & Raïffa, 1976) (Kirkwood, 1997) with VFT technique (Keeney R. L., 1992), and a cost model for use by shipping lines in the main U.S. Gulf Coast container ports.

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

- To demonstrate that a PSDSS can be developed using MODA with VFT as a new approach to the port selection decision problem, incorporating available quantitative port data, instead of data from surveys, interviews and questionnaires.
- To obtain input from an industry expert on different stages of the MODA, including the following: the review of attributes and value functions; and the development of the Swing Weight Matrix (Parnell & Trainor, 2009).
- To integrate a cost model in the PSDSS which helps decision makers to identify the value versus cost trade-offs (Parnell, Bresnick, Tani, & Johnson, 2013).
- To use probabilistic modelling with Mont Carlo simulation in the PSDSS to provide decision makers with a better understanding of the critical uncertainties.

- The resultant PSDSS tool may serve as a foundation for future research on port selection in other regions and can be tailored to the needs of the users.

The paper is structured as follows. In Section 2, the port selection literature is presented. This is followed by the description of the PSDSS structure in Section 3. Results are discussed in Section 4 and the article concludes in Section 5 with a summary of the study's contributions and directions for future research.

4.2 Literature Review

Port selection research has been conducted from the perspectives of carriers, shippers, port managers, stakeholders and others, and has relied on three main methods: statistical analysis of surveys (Grosso & Monteiro, 2009) (Kim, 2014) (Panayides & Song, 2012) (Sanchez, Ng, & Garcia-Alonso, 2011); multinomial logit model (Steven & Corsi, 2012) (Tang, Low, & Lam, 2011) (Veldman, Garcia-Alonso, & Vallejo-Pinto, 2011) (Wu, Liu, & Peng, 2014); and Analytical Hierarchy Process (AHP) (Ugboma, Ugboma, & Ogwude, 2006) (Dyck & Ismael, 2015) (Gohomene, Bonsal, Maistralis, Wang, & Li, 2015). Lam and Dai (2012) developed a decision support system but based on the AHP approach.

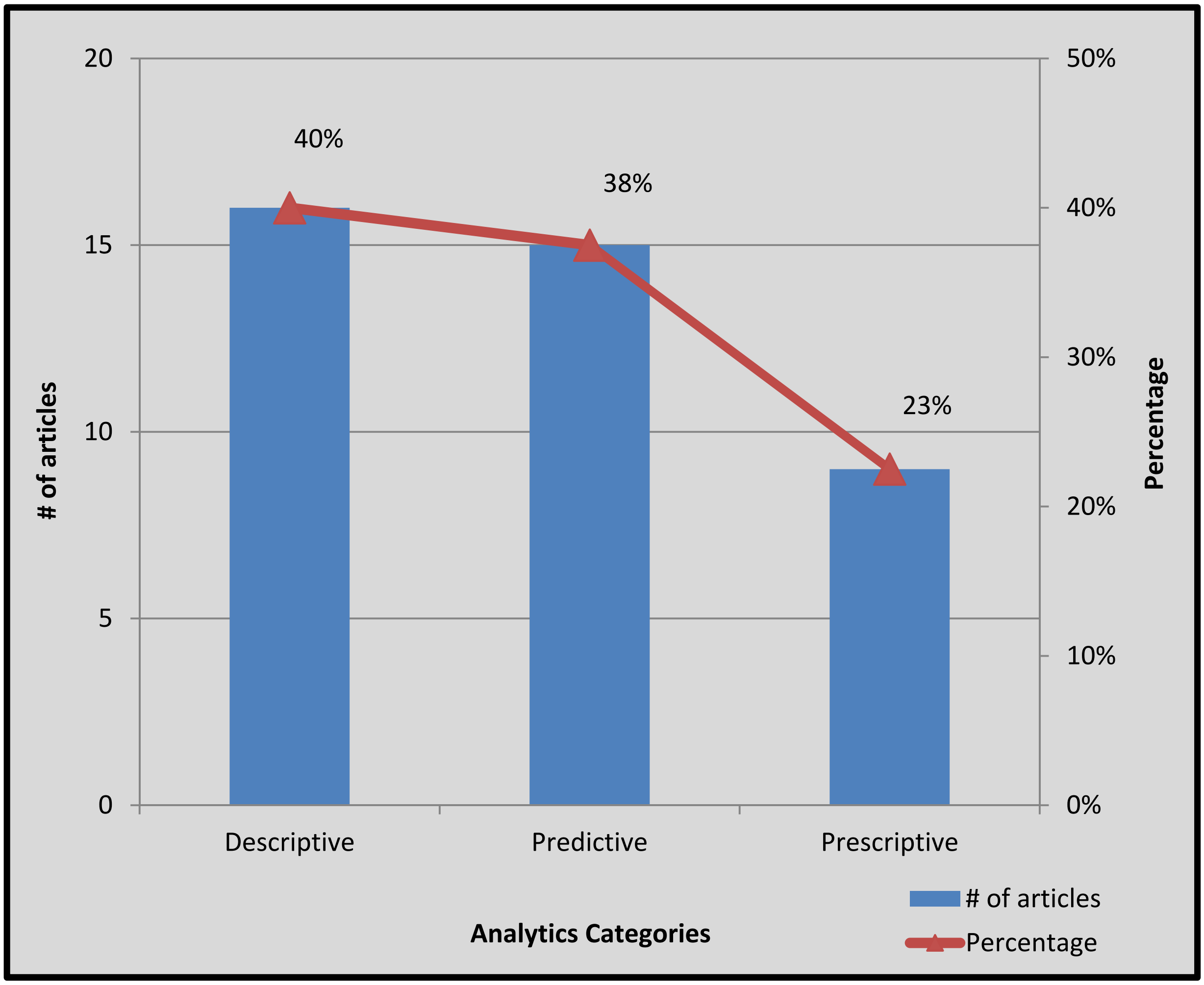


Figure 4.2 - Distribution of Port Selection articles by Analytics Categories

The descriptive analytic category includes the studies that used statistical analysis of surveys. These studies examined the important factors or criteria that influenced the port selection decision. The discrete choice model (multinomial logit model) and AHP studies fall under the Predictive and Prescriptive analytic category respectively.

Figure 4.3 presents the multiple and conflicting criteria that have been used in port selection literature. Based on this list, fundamental objectives, means objectives, and attributes were selected in order to develop the value hierarchy of the PSDSS that will be presented in the next section.

Location

- Proximity of port to origin/ destination **(m)**
- Accessibility of the port **(m)**
- Distance to demand regions **(m)**
- Distance of shipper from port **(m)**
- Geographical location **(m)**
- Distance to niche market **(m)**
- Proximity to hinterland **(m)**

Infrastructure

- Quay length **(v)**
- # of berths **(v)**
- # of cranes **(v)**
- Water depth **(v)**
- Capacity **(f)**
- Equipment availability **(m)**
- Quality container handling infrastructure **(m)**

Efficiency

- Ship calls **(f)**
- Speed getting through port **(m)**
- Delays in loading/unloading containers **(m)**
- TEU handled at port **(v)** **(f)**
- Ship turnaround time **(m)**
- Annual operating hours **(m)**
- Trade volume **(m)**
- Lead time **(m)**

Logistics/ Supply Chain

- Connectivity and flexibility **(m)**
- Intermodal links availability **(v)**
- Quality of customs handling **(m)**
- Logistics services **(m)**
- Hinterland condition **(m)**
- Quick response to user needs and reputation **(m)**
- I.T. and advanced tech **(m)**
- Congestion **(m)**

Administration

- Port authority policy and regulation **(m)**
- Professional personnel in port and services **(m)**
- Reputation of port **(m)**
- Relationships with shipping lines **(f)**
- Effort of marketing **(m)**
- Carbon neutrality/ carbon footprint **(m)**

Costs

- Port charges
- Inland freight charges
- Transshipment costs
- Logistics costs
- Terminal handing costs
- Storage costs
- Marine service costs
- Cargo dues

(m): means objective, (f): fundamental objective, (v): value measure

Figure 4.3 - Multiple Objectives from Port Selection Literature - Source: (De Icaza, Parnell, & Aloysius, 2017)

The literature contains only one port selection decision support system (Lam & Dai, 2012), which offers the advantage of being web-based, but only considers 6 common criteria in its analysis, including the port charges.

4.3 PSDSS Structure

The main components of the PSDSS are illustrated in Figure 4.4. For this study, the user is a shipping line, but the PSDSS can be adjusted for use by port managers, shippers, etc. The decision analysis approach integrated in the PSDSS is the MODA with VFT, which is a systematic methodology with the ability to create insights and provide decision makers the opportunity to tailor the analysis to specific situations (Feng & Keller, 2006). A cost model is implemented in the PSDSS because port selection decisions are not based only on the value of the port, but also on the costs. A probabilistic model will assess the uncertainties in the port selection decision. The tool was developed in Excel, with fields designed for user data entry, which provide the advantage of being a friendly interface known by most people (Ewing & Baker, 2009). The Monte Carlo simulation was performed using @Risk 7.5 software. The use quantitative port data, input from an industry expert, and data from published studies were used in the MODA approach and are explained in the next sections.

The PSDSS will offer users the flexibility to add or delete any number of criteria in their analyses, obtain a ranked list of port alternatives, and get the results from a cost model, thus generating important elements that can drive for a better decision. Moreover, the PSDSS will provide a significant contribution to the literature and an important tool for shipping lines.

Port Selection Decision Support System (PSDSS)

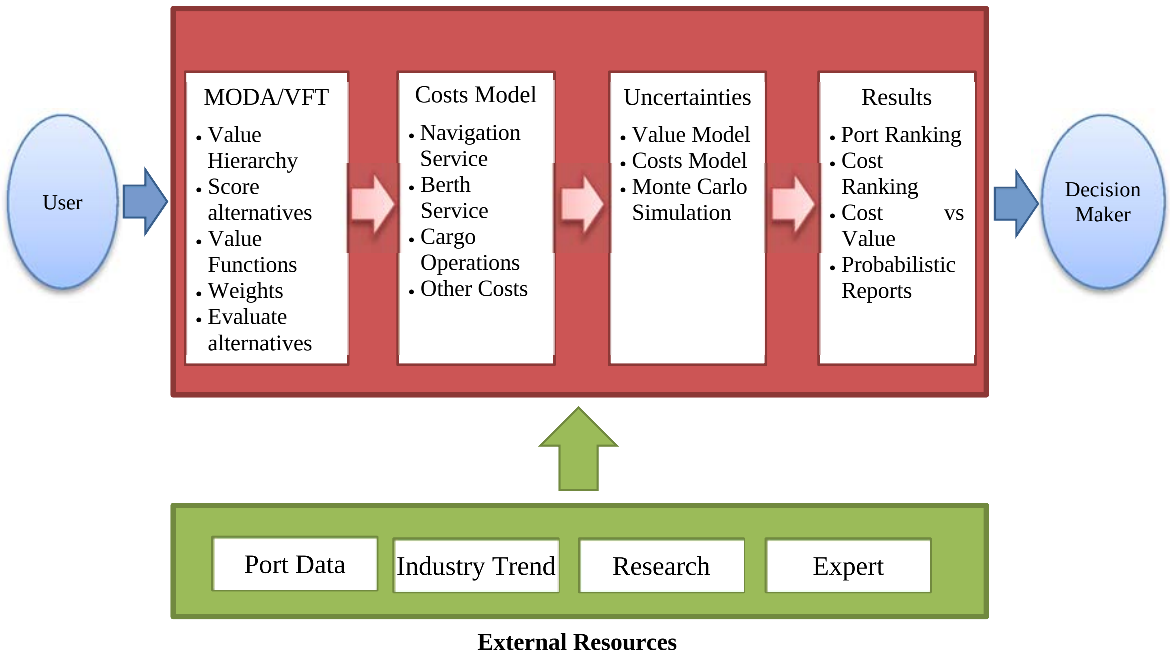


Figure 4.4 - Structure of the Port Selection Decision Support System (PSDSS)

4.3.1 Value Hierarchy Development

The initial step of the MODA methodology is the development of the value hierarchy, which helps to structure the decision problem by specifying the following levels: decision objective, functions, fundamental objectives, and value measures. A well-structured value hierarchy allows better qualitative and quantitative analysis of the decision problem (Parnell, Bresnick, Tani, & Johnson, 2013). The first level of the value hierarchy contains the overall objective of the research, which is the shipping lines selection of the best container port in the U.S Gulf Coast. The second level of the hierarchy involves the categories that provide value to the decision makers. Criteria were binned into four port categories: providing competitive port structure, providing high performance container handling capacity, offering port intermodal services, and providing environment policies and stable weather conditions. The third level encompasses the fundamental objectives which relate to the essential and controllable objectives of a decision maker's preferences; and the fourth level comprises the value measures which are metrics to assess alternative performance for each fundamental objective (Keeney R. L., 1992) (Keeney & von Winterfeldt, 2011). The logic of the third and fourth levels is explained in the next two sections. The PSDSS value hierarchy is presented in Figure 4.5.

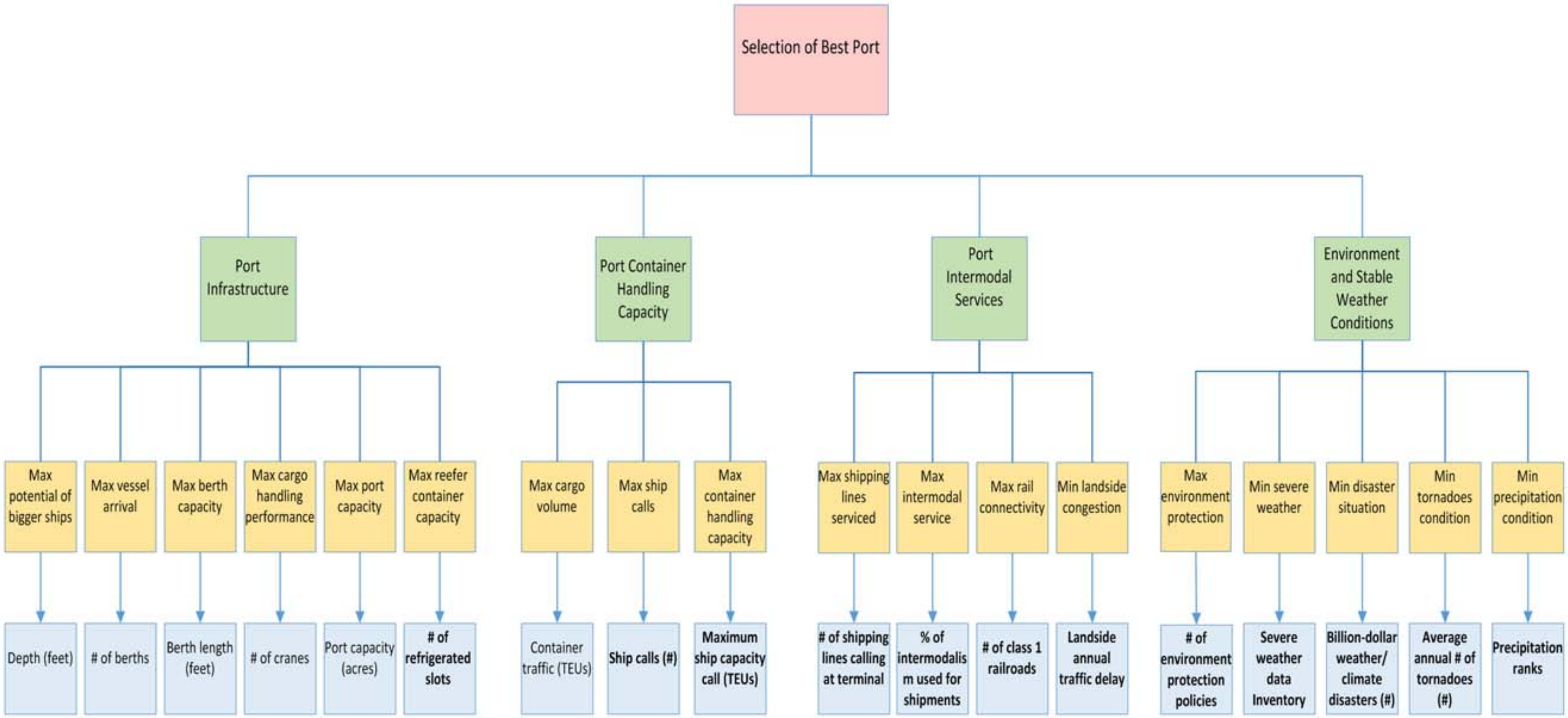
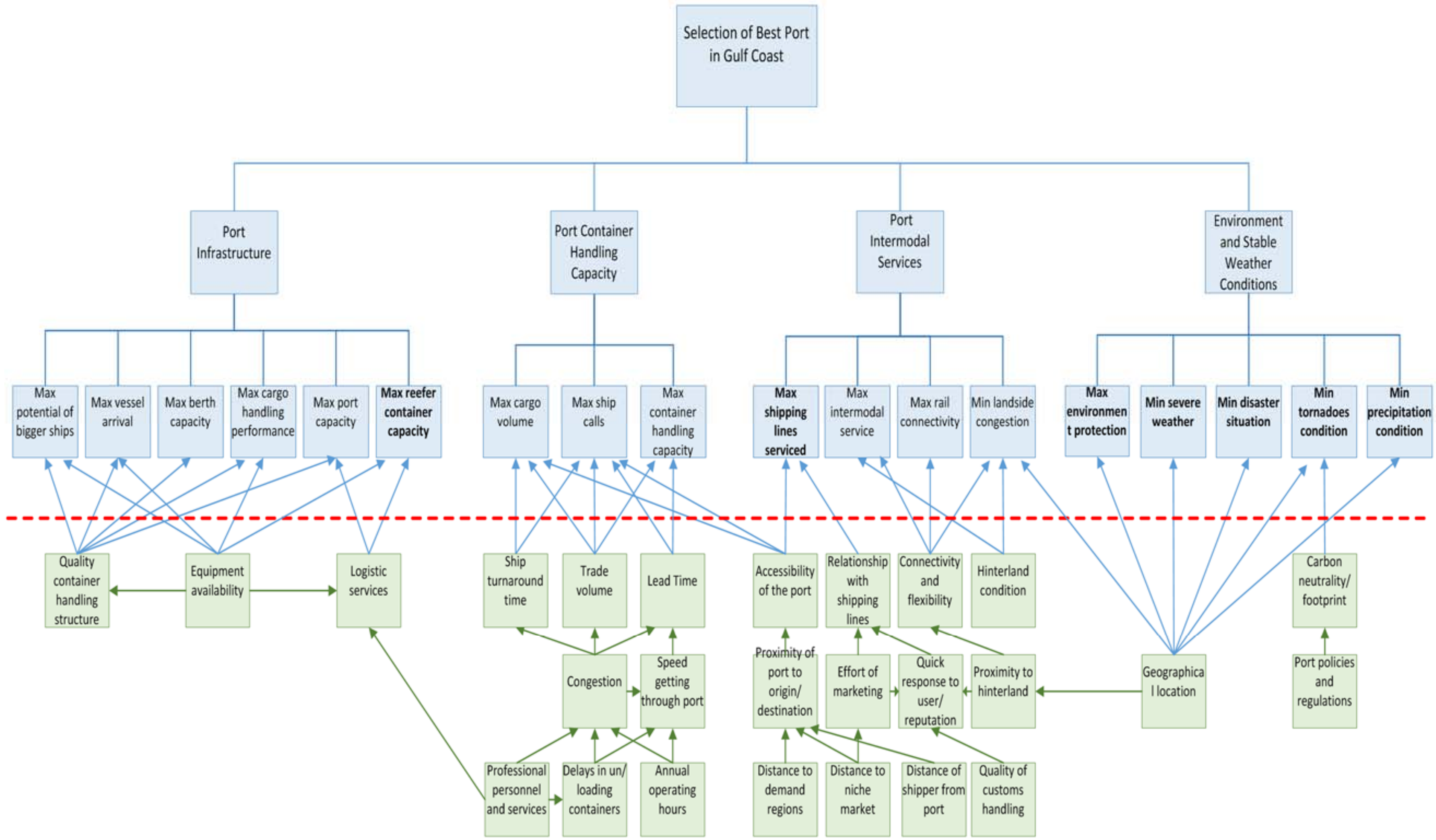


Figure 4.5 - Value Hierarchy for the Port Selection Decision Support System

4.3.1.1 Identifying Fundamental Objectives

Fundamental objectives describe the matter of direct concern to decision makers and stakeholders, while means objectives describe the performance that helps to achieve one or more of the fundamental objectives (Simon & Regnier, 2014). To have a complete list of fundamental objectives for the decision problem, Keeney (1994) suggests a means-ends network. The initial set of fundamental and means objectives were identified from the literature review (Figure 4.3), and Figure 4.6 connects the means objectives to the fundamental objectives hierarchy. Appendix 4.A shows the flowchart to create and link fundamental and means-end objectives.



Fundamental objectives hierarchy (Above dashed line); Means-ends objectives network (Below); Arrow means “influences”; Bold: not in literature review

Figure 4.6 - Connecting fundamental objectives hierarchy and means-ends objectives network

4.3.1.2 Selecting Value Measures

Value measures can have natural scales, commonly known and interpreted by people, and constructed scales, developed for a particular decision problem to evaluate the fundamental objective (Kirkwood, 1997). The goal of this research was to identify quantifiable value measures with natural scales and readily available data to evaluate the achievement of the port selection fundamental objectives. Appendix 4.B presents the flowchart for the creation of value measures to be added to the value hierarchy of a general decision analysis problem. For this research, some of the value measures were identified from the literature review (Figure 4.3), specifically the ones related to port infrastructure. Others required more investigation to find the appropriate value measures. Merrick (2008) suggests that decision makers prefer to include expert judgements on their analyses since their inputs are critical to the decision problem. The final list of value measures (Table 4.1) was reviewed by an industry expert, an Operations Manager working in CMA CGM (Compagnie Maritime d'Affrètement Compagnie Générale Maritime), one of the lead shipping lines of the market. Two video conference meetings were held with the expert to discuss the final list of value measures and the elicitation of weights which will be explained in later sections.

4.3.2 Identifying and Scoring the Alternatives

The next step of this methodology is to score each alternative on each value measure. Since the decision problem is to select the best container port in the U.S Gulf Coast for shipping lines, the following main ports of that area were selected as the alternatives of the decision problem: Port of Houston, Port of New Orleans, Port of Mobile, Port of Gulfport, and Port of Tampa. As the VFT approach uses an ideal level of performance to assess the current alternatives of the decision problem, an ideal alternative is included in the analysis by using the port of Los Angeles, which is one of the top container ports of the U.S. Through research, we identified data available on the internet (reports, documents, etc.) from different reliable sources to score alternatives on each of the value measures (Table 4.1).

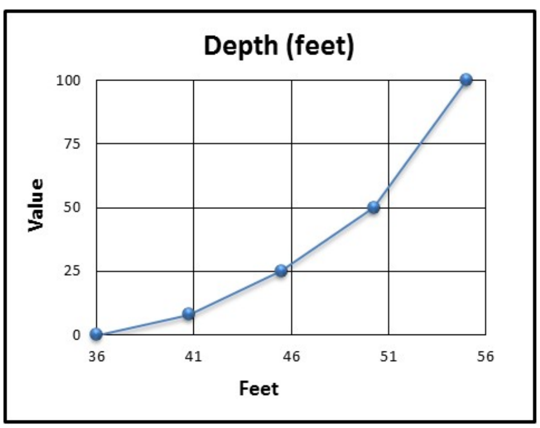
Ports	Depth (feet)	# of berths	Berth length (feet)	# of cranes	Port capacity (acres)	# of refrigerated slots	Contrainer traffic (TEUs)	Ship calls (#)	Max ship capacity call (TEUs)	# of container lines calling at terminal	% of Intermodalism used for shipments (%)	# of class 1 railroads	Landside annual traffic delay (Hours)	# of environment protection policies	Severe Weather Data Inventory (#)	Billion-Dollar Weather and Climate Disasters Events (#)	Average annual # of tornadoes (#)	Precipitation ranks
Houston	45	10	4,300	22	428	879	1,664,448	1,015	6,732	21	8.8	2	203,173	7	7	83	155	120
New Orleans	45	3	3,000	6	85	585	329,768	536	6,732	10	5.1	6	39,159	3	7	50	37	103
Mobile	45	3	2,900	4	156	216	174,731	166	6,732	11	13.4	5	10,396	1	12	57	43	99
Gulfport	36	10	7,074	2	250	1,000	149,269	107	982	3	6.5	2	4,463	4	9	62	43	86
Tampa	43	2	2,900	2	138	104	38,049	57	5,762	4	16.8	1	71,628	5	11	43	66	77
Ideal Port	55	23	30,629	72	1,693	3,518	5,912,415	1,156	17,859	46	19.8	6	4,000	9	7	27	11	50
Source	Ports	Ports	Ports	Ports	Ports	Ports	(USACE, 2014)	(MARAD, 2015)	(MARAD, 2015)	Ports	(DOT, 2014)	Ports	(Schrank et al., 2015)	Ports	(NOAA, 2015)	(NCEI, 2015)	(NOAA, 2010)	(NCEI, 2015)

Ports: each port website

Table 4.1 - Alternative Scoring for each Attribute

4.3.3 Developing the Value Functions

Value functions convert the different value measure scales into one normalized unit of measure, which usually can have the following ranges: 0-1, 0-10, or 0-100 (Parnell, Bresnick, Tani, & Johnson, 2013). On the x-axis is the scale of the value measure. For this research, the least and most desirable levels of the value measures will have a normalized value of 0 and 100 respectively, which is reflected in the y-axis of the value function. Table 4.2 identifies the extreme points of the value measures, as well as the shape of the curve and its rationale. Value functions were developed by applying the Difference Method (Watson & Buede, 1987), which assumes that they are monotonically increasing or decreasing. Five points were used to develop each value function: the two extreme points and three midpoints. For this research, most partial value functions are linear, which means that each unit of increase in the value measure corresponds to the same increase in the value (Figure 4.7). Other value functions have a concave or convex curve shape, as is the case of the depth value measure, in which the value increase is significantly higher once the port registers higher depth, resulting in a convex shape curve (Figure 4.7).



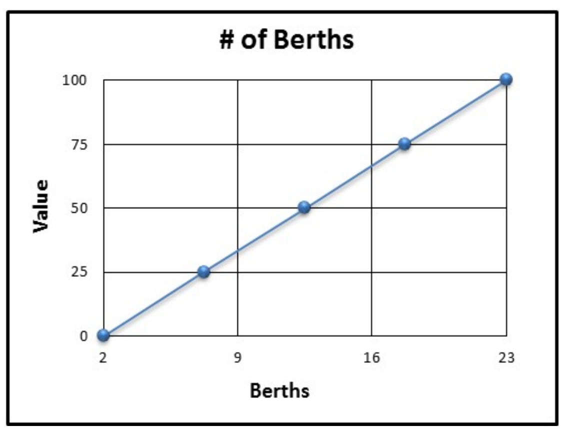


Figure 4.7 - Examples of Value Functions with Convex and Linear curve shapes

Value measures	Unit	Min. Acceptable Level	Ideal Level	Curve Shape	Rationale
Depth	feet	36	55	Convex	High depth increments more valuable
# of berths	#	2	23	Linear	Each increment is equally valuable
Berth length	feet	2,900	30,629	Linear	Each increment is equally valuable
# of cranes	#	2	72	Linear	Each increment is equally valuable
Port capacity	acres	85	1,693	Concave	High capacity increments more valuable
# of refrigerated slots	#	104	3,518	Linear	Each increment is equally valuable
Contrainer Traffic	TEUs	38,049	5,912,415	Concave	High container traffic increments more valuable
Ship Calls	#	57	1,156	Linear	Each increment is equally valuable
Maximum Ship Capacity Call	TEUs	982	17,859	Linear	Each increment is equally valuable
# of shipping lines calling at terminal	#	3	46	Linear	Each increment is equally valuable
% of Intermodalism used for shipments originating in state	%	5.1	19.8	Concave	High intermodalism increments more valuable
# of Class 1 Railroads	#	1	6	Concave	High class 1 railroad increments more valuable
Landside annual traffic delay	Hours	203,173	4,000	Convex	High landside traffic increments less valuable
# of environmental protection policies	#	1	9	Linear	Each increment is equally valuable
Severe Weather Data Inventory	#	12	7	Convex	High severe weather increments less valuable
Billion-Dollar Weather and Climate Disasters Events	#	83	27	Convex	High disaster situation increments less valuable
Average Annual # of Tornadoes	#	155	11	Convex	High tornadoes increments less valuable
Precipitation Ranks	#	120	50	Linear	Each increment is equally valuable

Table 4.2 - Data for the Value Functions of the Model

4.3.4 Obtaining Weights

Weights are important because they help decision makers prioritize conflicting objectives (Dillon-Merrill, Parnell, G. S., Buckshaw, Hensley, & Caswell, 2008). Weights can be assigned to each value measure of the value model using the Swing Weight Method (Parnell & Trainor, 2009), based on the level of importance as well as the variation of the scale for each value measure. After ensuring that the industry expert had an understanding of the swing weight method, then weights were elicited in order to complete the swing weight matrix (Table 4.3). The three levels of importance were used to classify the value measures: critical (necessary port service or infrastructure to attend shipping lines), moderate (port value added services that increase efficiency and/or weather events with high frequency of occurrence), and minor (objectives with low impact on port operations and/or weather events with low frequency of occurrence). The scale variation of the value measures is represented by the gap between the minimum acceptable and ideal points on the scale. Three levels (small, medium and large) were used to classify the scale variation of the value measures as shown in the rows of the matrix (Table 4.3).

Value measures with a higher level of importance and large scale 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. Levels of importance and variations of the scale of the value measure decrease from left to right and top to bottom respectively; therefore, weights descend in magnitude as we move diagonally from the top left to the bottom right of the swing weight matrix. Finally, swing weights must be normalized to sum to one for use in the additive value model, which will be presented in the next section. The formula to normalize the swing weights is shown below:

$$w_i = \frac{f_i}{\sum_{i=1}^{18} f_i}$$

Where f_i is the swing weight assigned for the i^{th} value measure; $i = 1$ to $n = 18$ for the number of value measures; and w_i are the normalized swing weights.

Highest Weight		Level of importance of the attributes								
		Critical	Swt	Mwt	Moderate	Swt	Mwt	Minor	Swt	Mwt
Gap btw Min Accep. and Ideal	Large	Depth (feet)	100	0.110	# of shipping lines calling at terminal	60	0.066	Landside annual traffic delay (Hours)	35	0.039
		Berth length (feet)	95	0.105	Maximum Ship Capacity Call (TEUs)	55	0.061	Precipitation Ranks	25	0.028
		# of cranes	90	0.099	% of Intermodalism used for shipments originating in state (%)	50	0.055			
	Medium	Contrainer Traffic (TEUs)	85	0.094	Severe Weather Data Inventory (#)	40	0.044	# of environmental protection policies	20	0.022
		Ship Calls (#)	75	0.083				Billion-Dollar Weather and Climate Disasters Events (#)	15	0.017
		# of berths	70	0.077						
	Small	Port capacity (acres)	45	0.050	# of refrigerated slots	30	0.033	# of Class 1 Railroads	10	0.011
								Average Annual # of Tornadoes (#)	5	0.006

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

Table 4.3 - Swing Weight Matrix

4.3.5 Evaluating and Ranking Alternatives

All required elements (value measures, value functions, and weights) have been determined in order to apply the additive value model (Keeney & Raïffa, 1976), which will provide the deterministic value for each alternative of the PSDSS. The additive value model can be written as follows:

$$v(x) = \sum_{i=1}^{n=18} w_i \, v_i\,(x_i)$$

Where, $v(x)$ is the alternative's value; $i = 1\ to\ n$ is the number of value measures; x_i is the alternative's score on the ith value measure; $v_i\ (x_i)$ is the value function that converts each value measure score x_i to a normalized scale; and w_i is the swing weight of the i^{th} value measure. The additive value function assumes the mutual preferential independence condition for its value measures (Keeney & Raïffa, 1976) (Kirkwood, 1997).

The PSDSS deterministic total value and ranking of the alternatives are shown in Table 4.4. The Hypothetical Best alternative is an alternative developed using the best score of each attribute. Shipping line decision makers can easily determine the best port among the alternatives based on the inputs defined through the process. In addition, the PSDSS provides the value component and floating charts (Figure 4.8), which help visualize the magnitude of each value measure within the overall value of each alternative.

Ports	Total Value	Ranking
Houston	38	1
New Orleans	21	2
Mobile	19	3
Gulfport	16	4
Tampa	14	5
Hypothetical Best	49	
Ideal Port	100	

Table 4.4 - Overall Value and Ranking of Alternatives of the PSDSS

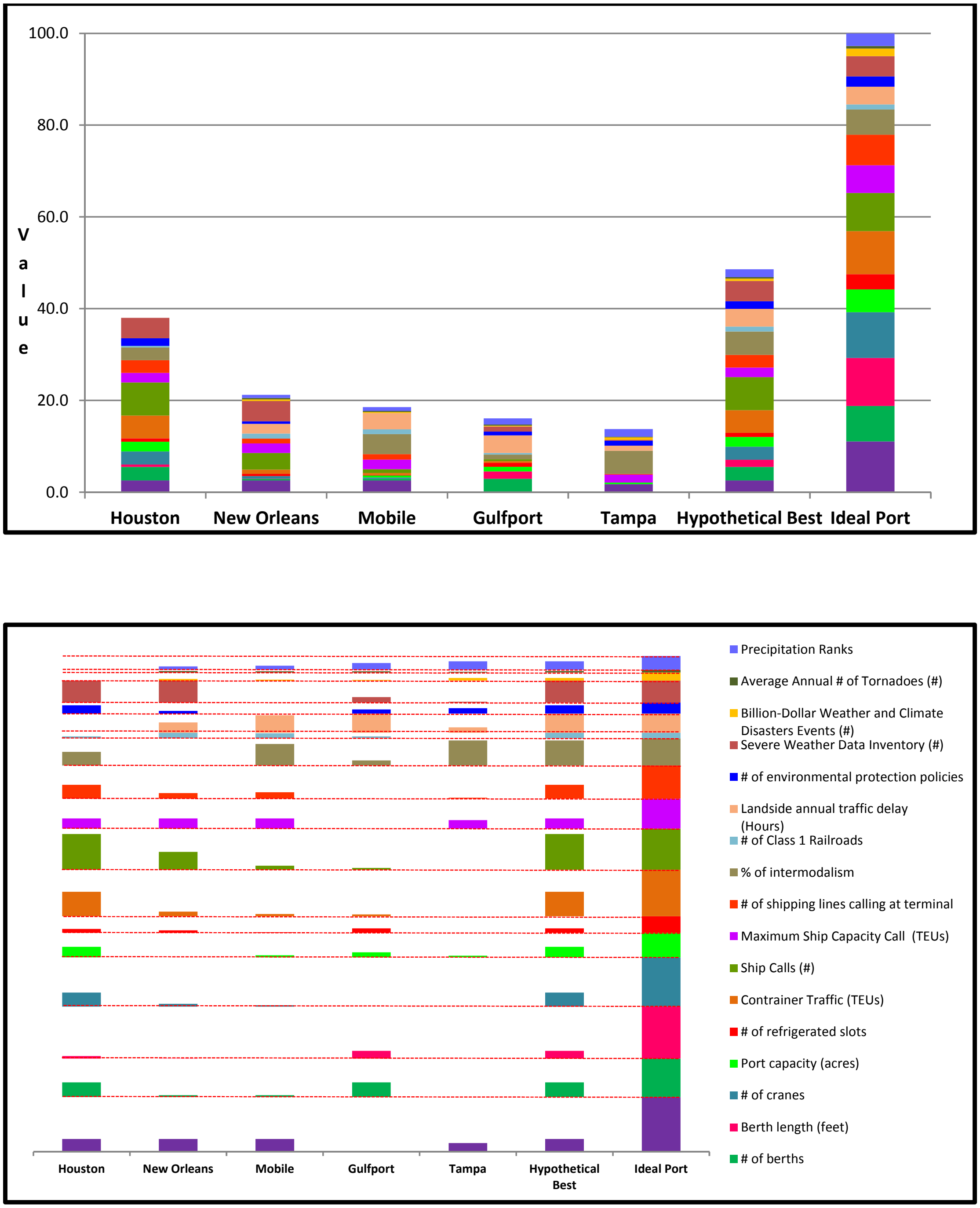


Figure 4.8 - Value Component and Floating Chart

4.3.6 Identifying Value Gaps by using VFT

PSDSS offers significant insights to decision makers by providing value gaps for the value measures. For a VFT perspective, it is very clear that the Gulf Coast ports have a long way to go to provide the capabilities of the ideal port (Port of Los Angeles). Value gaps can be determined using the value component chart (Figure 4.8) by comparing the alternatives of the decision problem against the ideal alternative, and thus providing decision makers with decision opportunities (Keeney R. L., 1993) (Parnell, Bresnick, Tani, & Johnson, 2013). As a result, decision makers will be able to make better decision analyses by identifying strengths and weaknesses of the alternatives. Figure 4.9 shows the value gaps between the best port alternative (Port of Houston) and the Ideal Port for each of the value measure of the PSDSS. Table 4.5 shows a ranking of the top value gaps for the model, depth, berth length, and # of cranes value measures. Port decision makers can interpret those gaps as opportunities to improve on those areas in order to offer better services.

Ranking	Value Measure	Value Gap
1	Berth length	9.97
2	Depth	8.49
3	# of cranes	7.10
4	# of berths	4.79
5	Contrainer Traffic	4.44

Table 4.5 - Ranking of Value Gaps

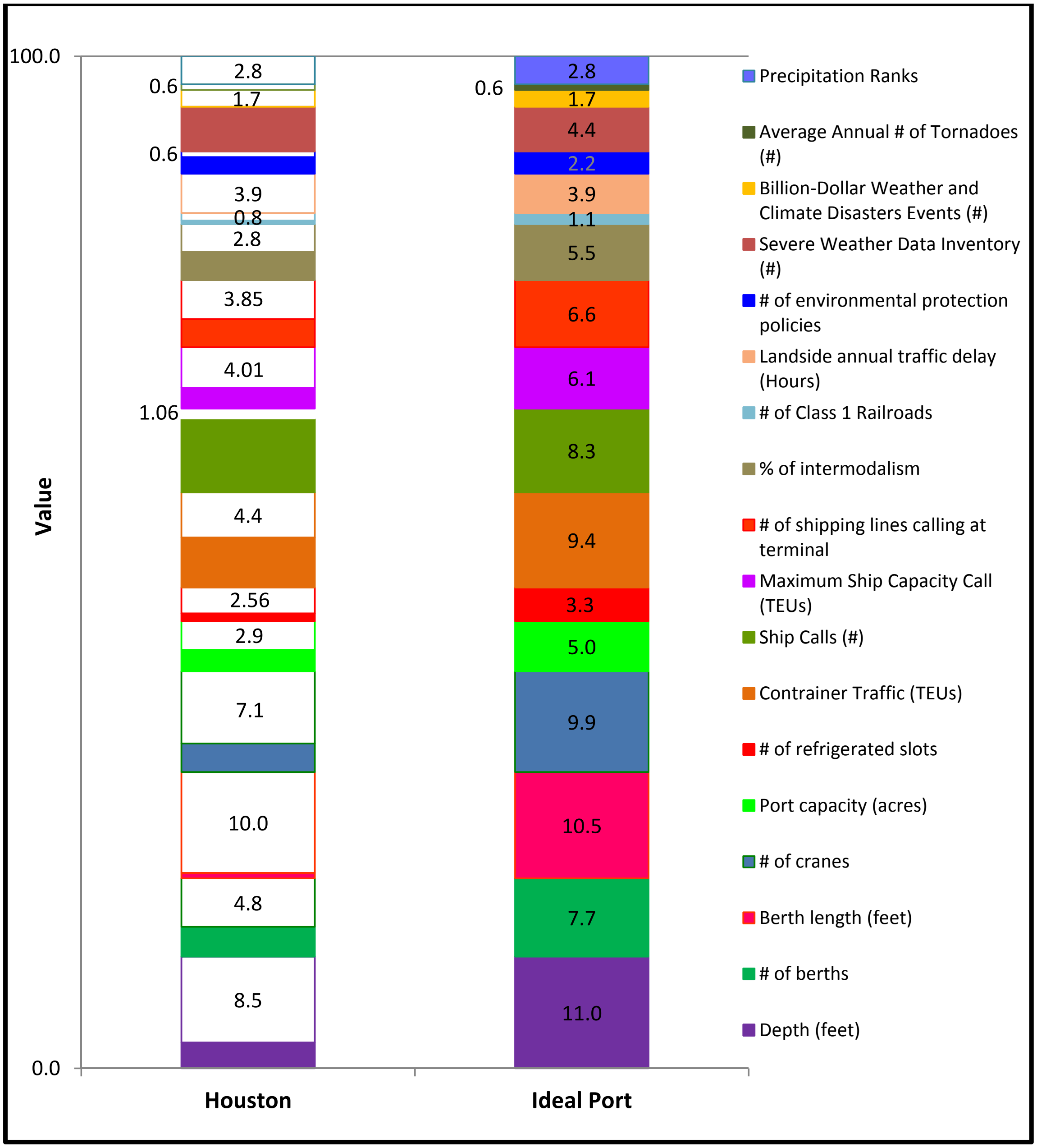


Figure 4.9 - Value Gaps between Best and Ideal Alternatives of the PSDSS

4.3.7 Cost Model of the PSDSS

Costs could be included in the PSDSS value hierarchy as a value measure, but many decision analysts and decision makers prefer value versus cost trade-off analysis (Parnell, Bresnick, Tani, & Johnson, 2013) (Hilliard, Parnell, & Pohl, 2015). Therefore, a cost model (Seedah, Harrison, Boske, & Kruse, 2013) was developed to calculate the cost incurred by shipping lines for using each port alternative. The structure of the cost model is presented below, and it proposes that the port call total cost by a single vessel can be calculated based on the following port service groups: Navigation Services, Berth Services, Cargo Operations, and Other Costs. Therefore, the total cost equation is formulated as follows:

$$\mathbf{C_T = C_N + C_B + C_C + C_O}$$

Where $\mathbf{C_T}$: the total cost of the vessel port call by the shipping line

$\mathbf{C_N}$: costs related to navigation services

$\mathbf{C_B}$: costs related to berth services

$\mathbf{C_C}$: costs related to cargo operations

$\mathbf{C_O}$: all other costs related to services that a port can provide to customers

The costs related to Navigation Service group involves the services and facilities that vessels need to travel from open sea to a stationary or secure area in the port (port dues and pilotage). The second group of costs, Berth Services, consists of all services and facilities provided to the vessel when it is secured in the berth (dockage and wharfage). The Cargo Operations group includes the services and actions associated with the vessel's cargo handling (cargo handling, storage and terminal use). The last group, Other Costs, includes services the vessel may require while staying at the berth (harbor safety, refrigerated containers, and water). Details about the equation for each cost are presented in Appendix 4.C. Cost data and the assumptions described below were used to calculate the total cost for each alternative. The cost data within each group were obtained from publicly available tariffs posted on the websites of each port alternative. However, since shipping lines negotiate confidential charges with ports, the total cost calculated in this research should be taken as an estimate rather than the real cost paid by the shipping lines. Nevertheless, strategic planning managers use the non-confidential prices in order to estimate the cost differences between port alternatives that influence the port selection decision for their global supply chains (Seedah, Harrison, Boske, & Kruse, 2013).

The assumptions required to calculate the costs of the model are described in Table 4.6. These are the shipping line vessel technical specifications and the port call scenario. Since this information is available on the shipping lines' websites, a specific vessel (CMA CGM Tarpon) from the Trans-Pacific route service (Pacific ExpressPX3) offered by the CMA CGM shipping line was used in this model.

Vessel Specifications	CMA CGM Tarpon	Port Call	CMA CGM Tarpon
Capacity (TEUs)	5,095	Duration (days)	2
Capacity (# of containers)	3,306	Days of containers in yard	3
Length Over All - LOA (Feet)	964.93	Container in port yard (tons)	46,284
Draft (Feet)	36		
Breadth Extreme (Feet)	105.64		
Reefer Points	330		
Deadweight (ton)	67,170		
Gross Tonnage (ton)	53,675		

Table 4.6 - Assumptions for the PSDSS Cost Model

Based on the information presented above, the PSDSS Cost Model results for each port alternative are presented in Table 4.7 together with the results of the value from the MODA model. In addition, the cost vs value graph (Figure 4.10) is useful for decision makers because it helps them identify dominated alternatives in the decision problem. From the graph, it can be determined that the New Orleans Port is preferable to the ports of Mobile and Gulfport because it has higher value for lower costs. Therefore, decision makers can limit their final decision to the two best alternatives, the Port of Houston, which has a higher value but also a higher cost, and the Port of New Orleans, which has a lower value for the lower cost.

Ports	Total Value	Total Costs (US$)
Houston	38	601,622
New Orleans	21	340,650
Mobile	19	451,913
Gulfport	16	478,028
Tampa	14	283,999
Ideal	1000	708,449

Table 4.7 - Total Value and Costs for each alternative of the PSDSS

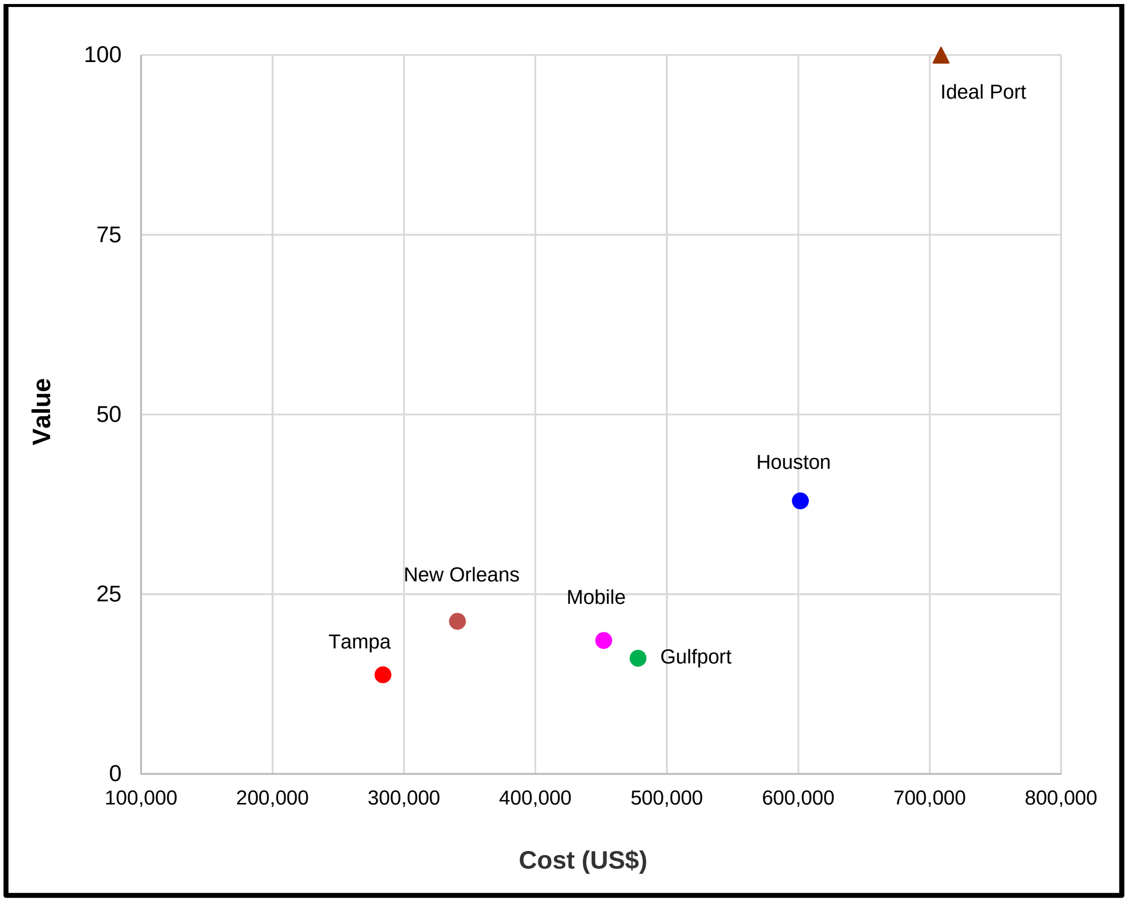


Figure 4.10 - Cost vs Value for the alternatives of the PSDSS

4.3.8 Applying Probabilistic Modelling using Monte Carlo Simulation

Since the value and cost models include variables that shipping lines cannot control, uncertainties are included in those critical variables so that decision makers can identify the best alternative.

The PSDSS probabilistic modelling used the Monte Carlo simulation method, which relies on repeated random sampling and statistical analysis to compute the results. The model depends on a number of input parameters. The simulation is comprised of the following steps: to identify the uncertain input parameters of the deterministic model; to assign them probability distributions which reflect the uncertainties of those inputs; to define the outputs of the probabilistic model; and to run the simulation in order to calculate the output results of the model. The PSDSS uses influence diagrams to identify the uncertain input parameters of the value and cost models. The influence diagrams for the value and cost models of the PSDSS are shown in Figure 4.11 and Figure 4.12, respectively. The red ovals show the uncertain external factors that affect the model, and the blue ovals show the uncertainties (input parameters), in which probability distributions were assigned. A triangular probability distribution, which requires three parameters (minimum, base, and maximum), was selected to model the identified uncertainties. The base input parameter is the known value calculated in the deterministic model.

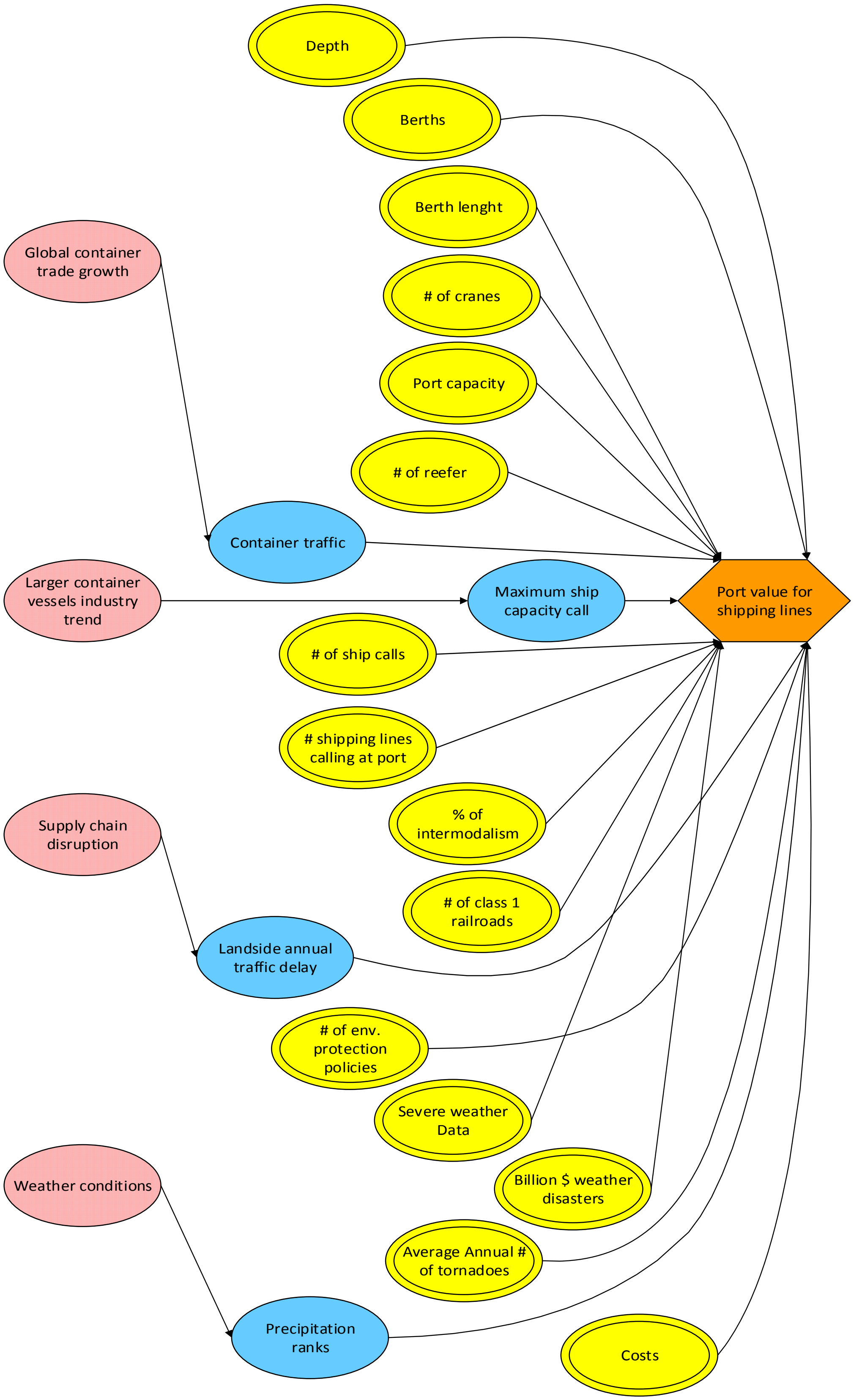


Figure 4.11 - Influence Diagram to identify Uncertainties in the Value Model

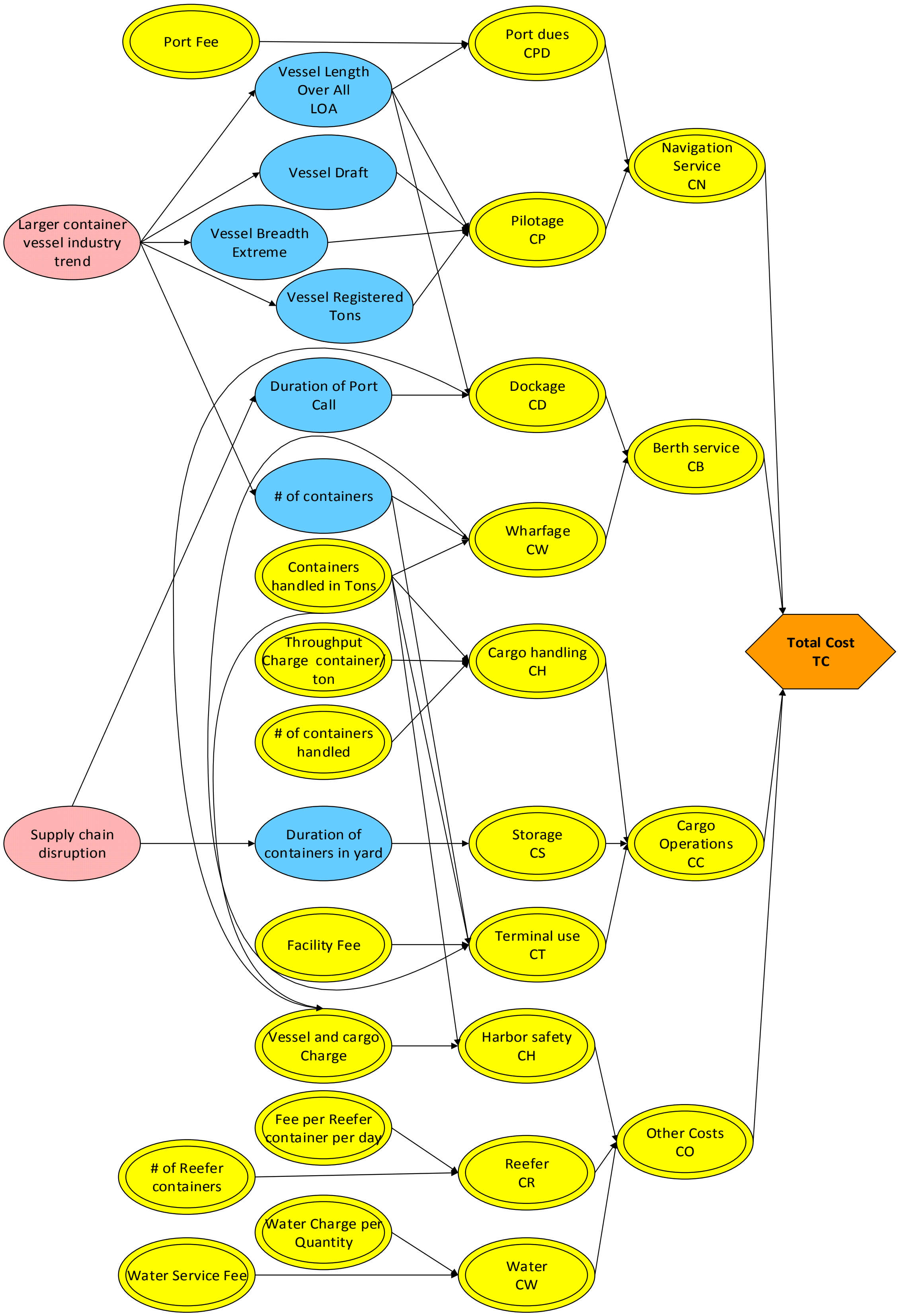
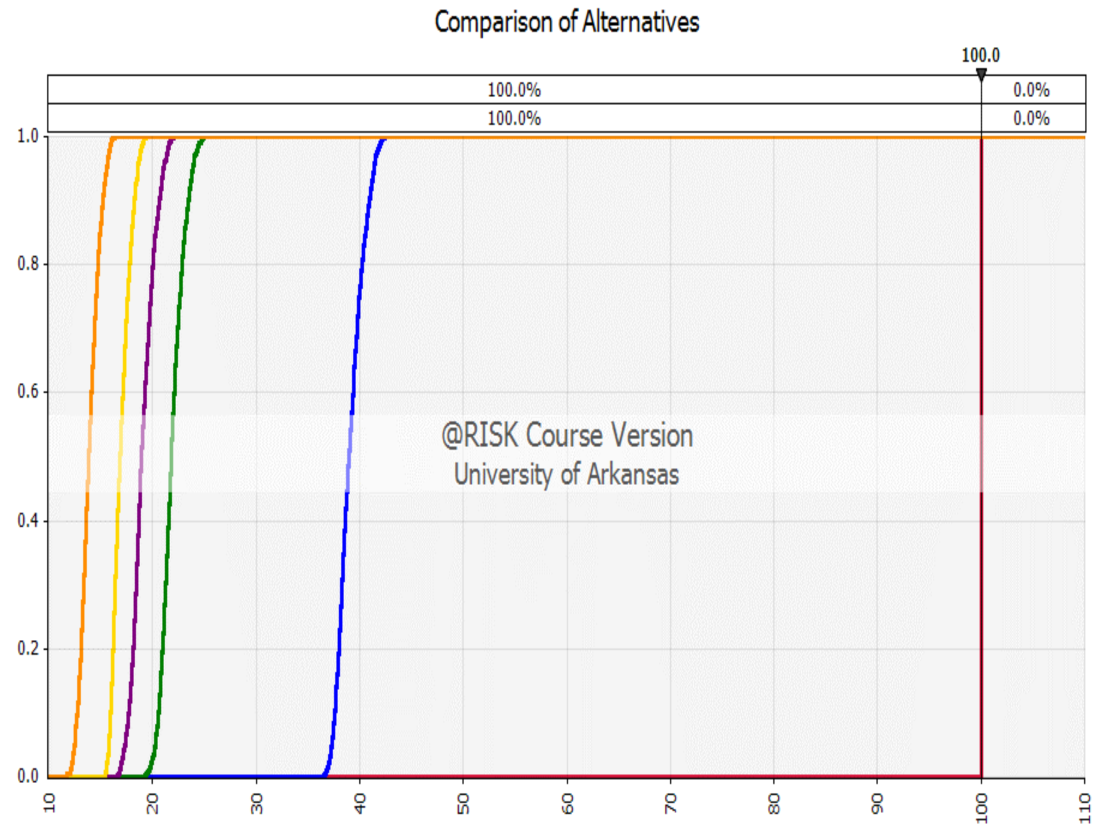


Figure 4.12 - Influence Diagram to identify uncertainties in the Cost Model

4.3.9 Monte Carlo Simulation for the Value Model

For the value model, the triangular probability distributions were applied to the following input parameters: 1) container traffic in TEUs, in which the minimum and maximum values were obtained applying the 1% and 16 % deviation from the base value of each port alternative, and the percentages correspond to the lowest and highest global container trade growth for the period 2009-2016 (UNCTAD, 2015); 2) Maximum ship capacity call, in which the minimum and maximum values correspond to the 2015 Maritime Administration statistics (MARAD, 2015) and to each port's depth, respectively; 3) Annual traffic delay, in which the minimum and maximum values of the distribution were obtained by applying the lowest and highest percentage changes of the annual traffic delay data from the period 1982-2014 (Schrank, Eisele, Lomax, & Bak, 2015) to the base value; 4) Precipitation ranks, in which the minimum and maximum values of the distribution correspond to the lowest and highest values of the precipitation rank data from 2002-2016 (NECI, 2016). Appendix 4.D shows the probability distribution data used for each input parameter.

Then, by running the Monte Carlo simulation, decision makers can capture the affect of the four uncertainties. The simulation was run for 10,000 iterations using the @RISK software from Palisade Corporation (Palisade Corporation, 2016). Figure 4.13 shows one of the graphical results of the Monte Carlo simulation, the cumulative ascending distributions of the port alternatives, illustrating the stochastic dominance of the Port of Houston over the other alternatives. The x-axis represents the value of the alternatives while the y-axis shows the probability.



Lines from right: Ideal, Houston, New Orleans, Mobile, Gulfport and Tampa

Figure 4.13 - Cumulative Ascending Distribution of the Port Selection Alternatives

In addition, using the statistics summary from the simulation, a box plot graph (Figure 4.14) was created in excel. It displays the comparison among the alternatives and shows the ranges of values for each alternative. The ends of the red boxes represent the upper (75%) and lower (25%) quartiles, while the whiskers represent the maximum and minimum values of each alternative. The green dots represent the deterministic value.

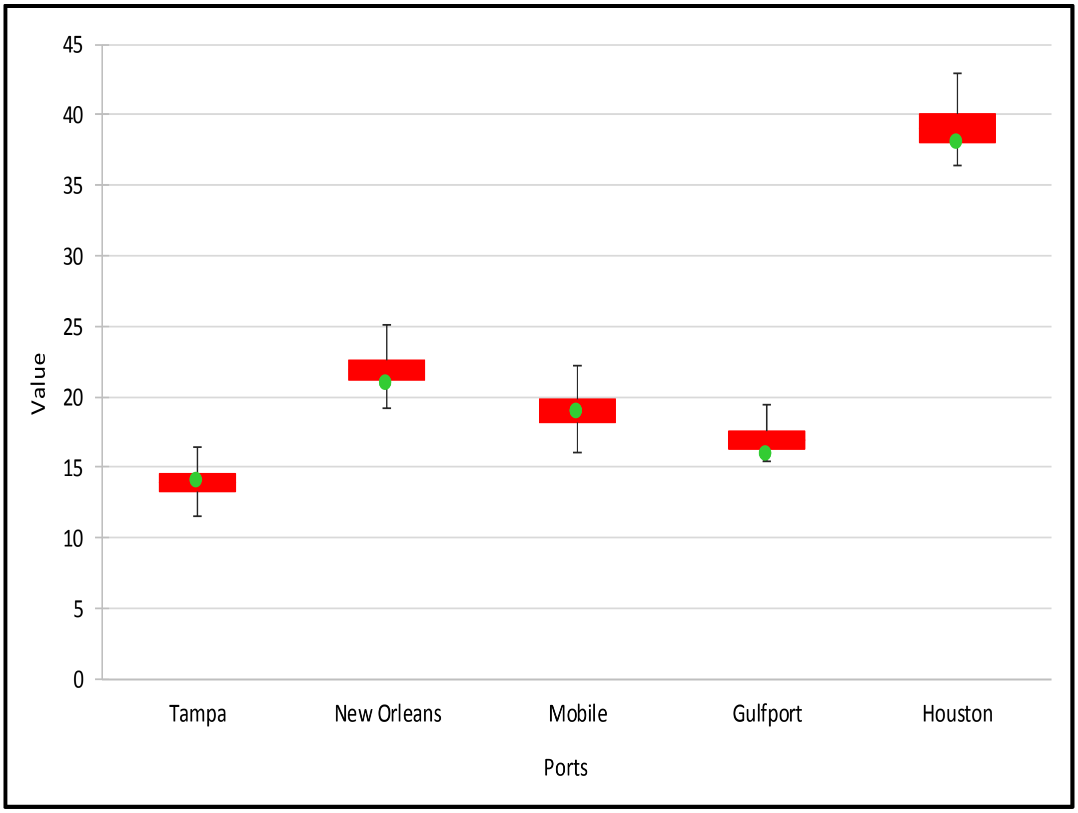


Figure 4.14 - Comparison of alternatives using Box Plot

Another simulation result that provides useful information to decision makers is the tornado graph (Figure 4.15), which displays the most important inputs of the model for any given output. The tornado graph's top bars represent the uncertainties that can have a significant affect on the output of the model. Regarding the Port of Houston, the precipitation ranks and the maximum ship capacity call are the uncertainties that decision makers must consider when evaluating this alternative.

Appendix 4.E to Appendix 4.W show the main Monte Carlo simulation graphical reports for the Port of Houston, as well as for the rest of port alternatives of the decision model.

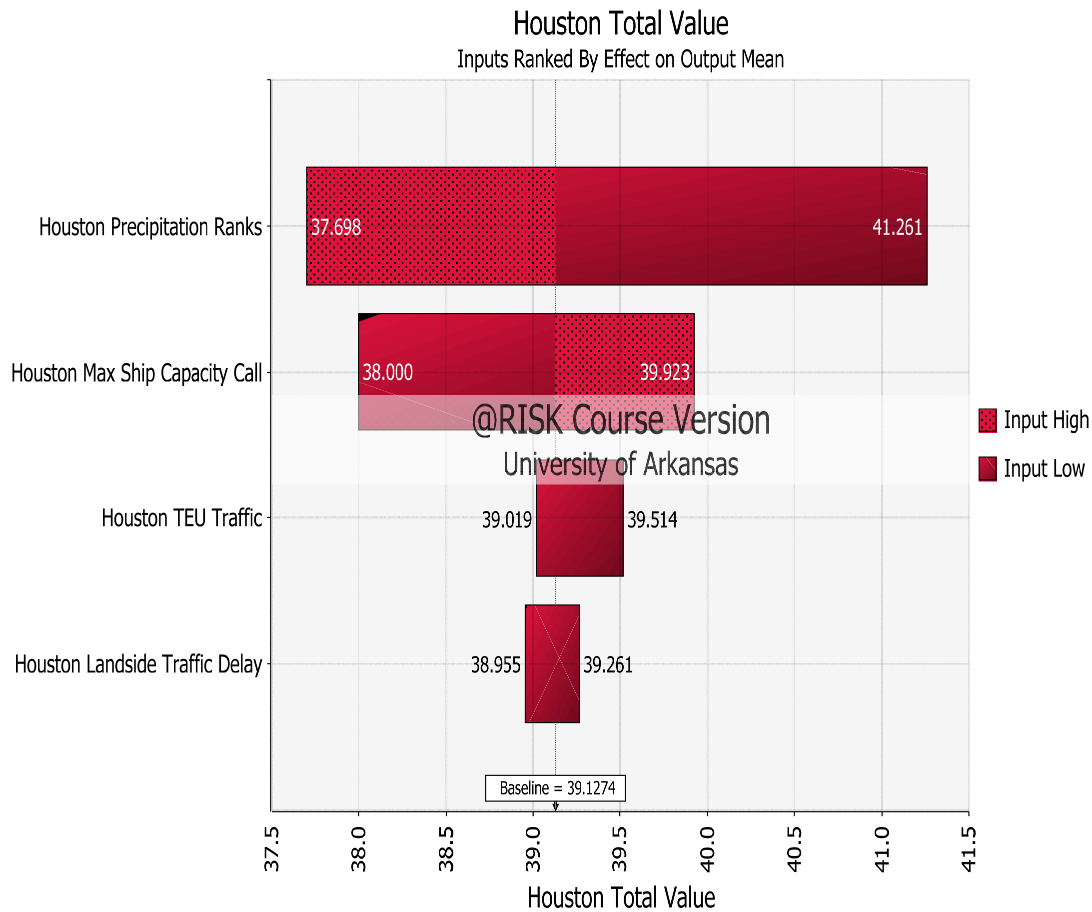


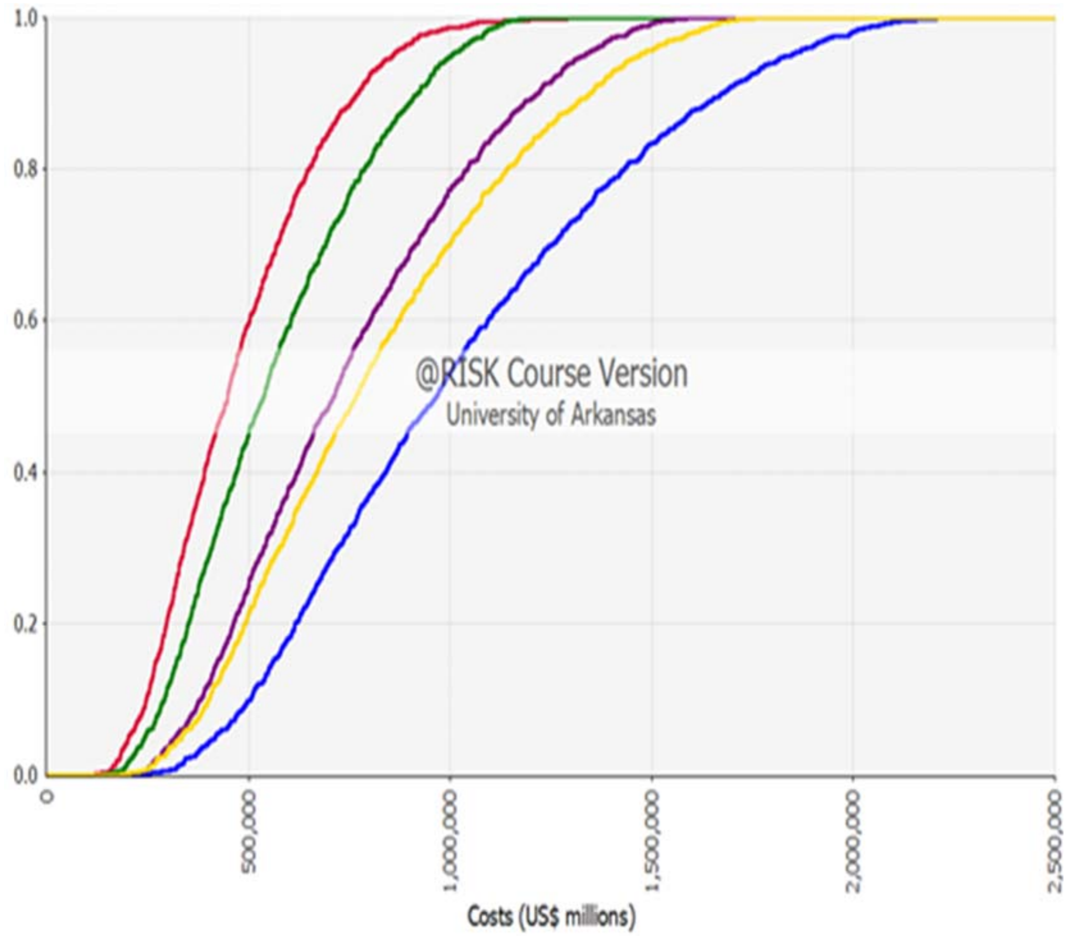
Figure 4.15 - Tornado Graph for Houston Port Alternative

4.3.9.1 Monte Carlo Simulation for the PSDSS Cost Model

The same Monte Carlo simulation method was used to get the cost model results. The initial step was to define the input parameters for the model. The influence diagram indicates that the uncertain external factors that impact the model are the larger container vessel industry trend and the supply chain disruptions. Based on these external factors, input parameters (uncertainties) for the model were identified with respect to the vessel size (vessel capacity, length over all [LOA], draft, breadth extreme, and gross tonnage), and to supply chain disruptions (duration of port call in days and days of containers in port yard). Then, triangular probability distributions were assigned to the input parameters of the first group by using standard vessel sizes. The three vessel sizes,-feeder, panamax and post-panamax,-

were used to apply the minimum, base, and maximum values of the probability distributions to each input parameter. The container vessels of three existing shipping lines APL Guam, CMA CGM Virginia, and Cosco Glory, were used to obtain vessel size specifications for the probability distributions of the input parameters. Regarding the input parameters of the second group, the minimum value was determined as one, as it is the minimum amount of days a vessel and containers can stay in the port. On the other hand, the maximum value for the duration of the port call and containers in the port yard were estimated as 5 and 40 days, respectively. Appendix 4.X shows the probability distribution data used for each input parameter.

The outputs of the probabilistic cost model were the total costs for each port alternative. Then, by running the Monte Carlo simulation for 10,000 iterations, the probabilistic results presented below were obtained. Figure 4.16 shows the cumulative ascending distribution of the alternatives for the cost model, in which Tampa port has the lowest cost representing the stochastic dominance among the alternatives. In addition, a box plot (Figure 4.17) was plotted using the statistics summary of the simulation for the comparison of alternatives. This graph can provide insights to decision makers since shows the cost ranges for each port alternative. The ends of the red boxes represent the upper (75%) and lower (25%) quartiles, while the whiskers represent the maximum and minimum values of each alternative. The blue dots represent the deterministic cost value.



From left: Tampa, New Orleans, Mobile, Gulfport and Houston

Figure 4.16 - Cumulative Ascending Distribution of the Cost Model Alternatives

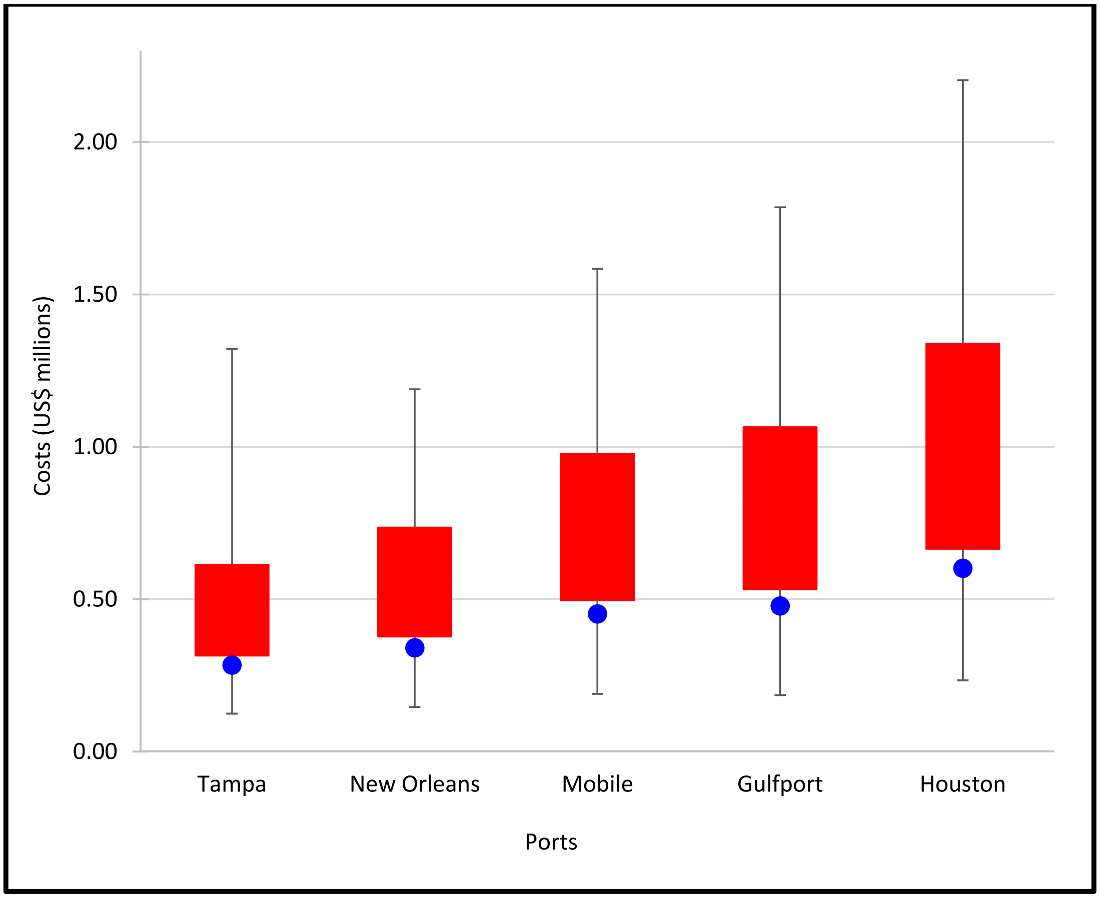


Figure 4.17 - Box Plot for the Port Selection Cost Model

In addition, simulation results provide the tornado graph (Figure 4.18), which displays the most important probability distribution inputs of the cost model for the Port of Houston alternative. Based on the tornado graph, the Port of Houston is sensitive to the vessel container capacity.

The tornado graph for the rest of port alternatives, as well as other main Monte Carlo simulation graphical reports for the cost model are shown in Appendix 4.Y to Appendix 4.QQ.

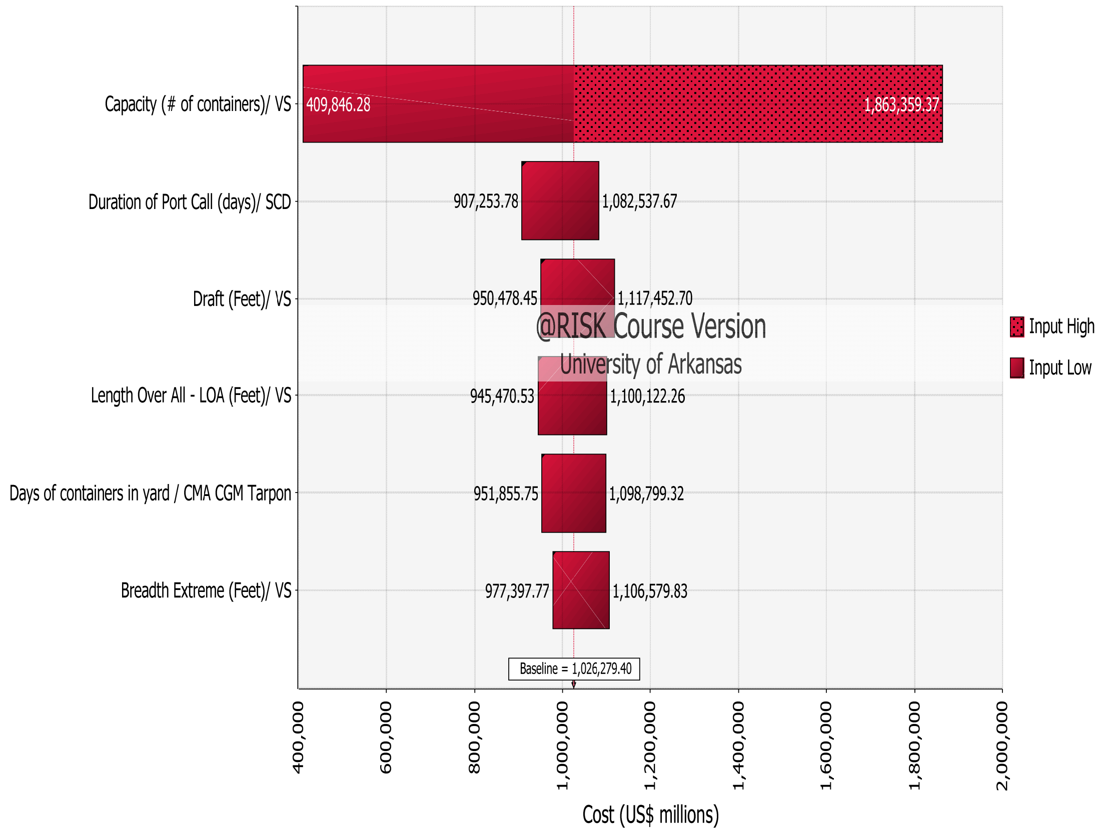


Figure 4.18 - Tornado Graph for Port of Houston Alternative

Finally, based on the simulation statistical summary reports of both probabilistic models presented in detail above, a box plot was created (Figure 4.19) to show the value ranges for the cost in the x-axis and the value in the y-axis for each port alternative of the PSDSS. Also, the deterministic value for each port alternative is represented by dots.

Therefore, Monte Carlo simulation provides enough results for decision makers to develop significant insights about the complex problem, and provide confidence of having understood the critical inputs that can affect the alternatives.

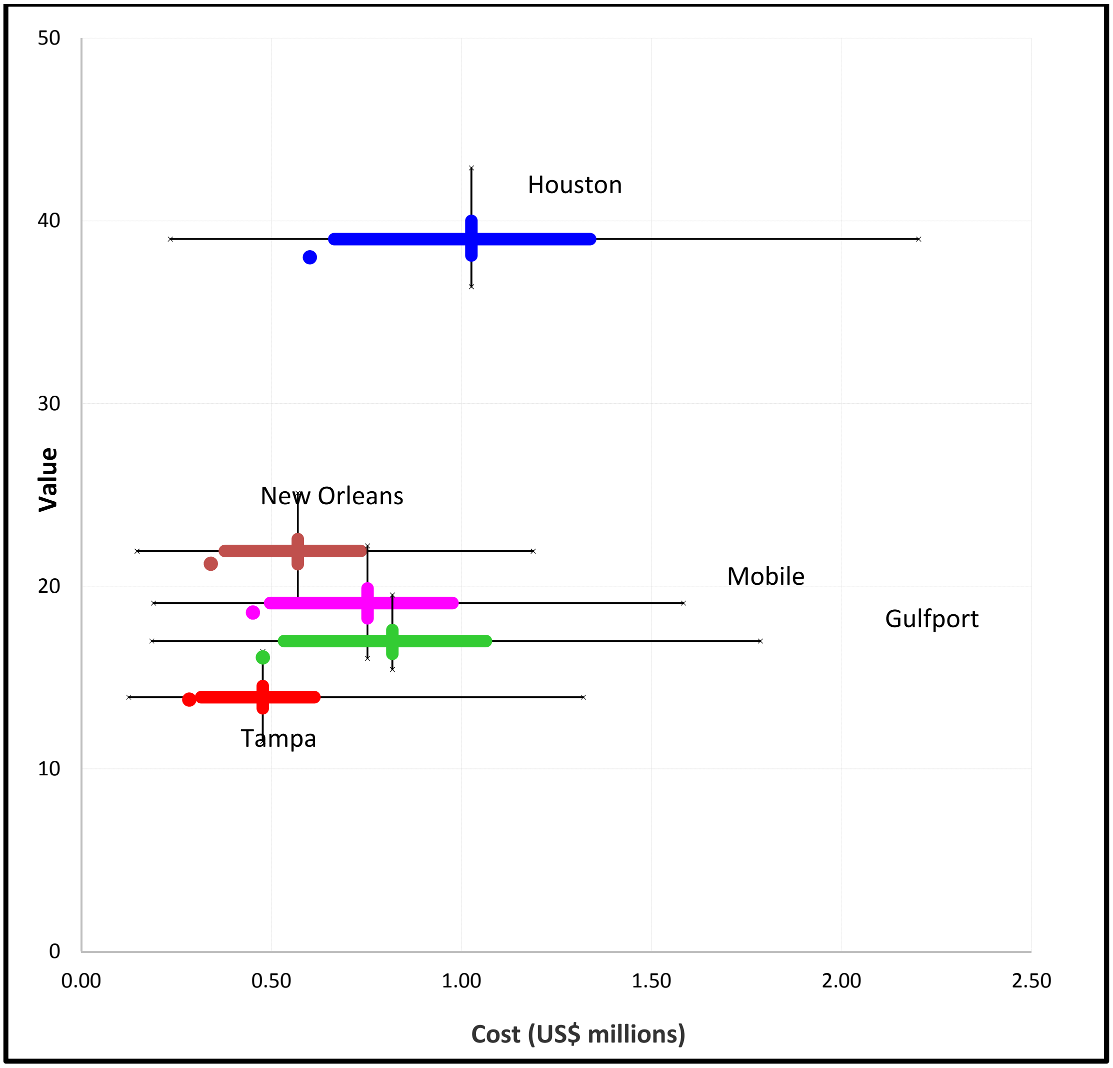


Figure 4.19 - Comparison of the Deterministic and Probabilistic Models of the PSDSS

4.4 Discussion

The PSDSS is a tool for shipping lines decision makers to determine the best port alternative for their customers. The decision support system offers the flexibility to have the number of objectives and alternatives that decision makers want to consider in the model. We demonstrated that quantitative port data is available to develop a port selection MODA. In addition, nominal cost data is also available in the port websites as tariff documents, so that shipping lines or other interested parties can develop a cost analysis model for the port selection. Based on the results of the MODA and the cost analysis, the value vs costs graph can be used by decision makers to obtain insights on the ports that can provide the most value per dollar.

Finally, by incorporating an industry expert in several stages of the MODA approach such as the confirmation of the value measures for the value hierarchy and the development of the weights of the value model, represented an added value to the quality of the PSDSS.

4.5 Future Research

Future work includes adding to this study a set of ports located in the U.S. East Coast, so that shipping lines could expand their alternatives considering the expansion of the Panama Canal.

Other area that can be investigated is the transshipment impact in port selection, since many U.S ports are currently under capacity considering the larger vessel industry trend.

Bibliography

Alanda, A., & Yang, Z. (2013). Hub-Port Choice in West Africa. In International Forum on Shipping, Ports and Airports (IFSPA) (pp.405-413).

Belton, V., & Stewart, T. (2002). *Multiple criteria decision analysis: an integrated approach.* Boston: Kluwer.

Bhadury, J. (2016). Panama Canal expansion and its impact on East and Gulf coast ports of USA. *Maritime Policy & Management*, 43(8), 928-944.

Bolloré Africa Logistics Nigeria. (2014). Retrieved from http://www.bollore-africa-logistics-kenya.com/about-us/bollore-africa-logistics-in-kenya/iso-90012008-certification.html (accessed January 2016).

CanagaRetna, S. (2010). *The Panama Canal Expansion and SLC State Ports.* Atlanta, Georgia: Southern Legislative Conference.

CATRAM Consultants. (2013). *Market study on container terminals in West and Central Africa.*

Chang, Y. T., Lee, S. Y., & Tongzon, J. L. (2008). Port selection factors by shipping lines: Different perspectives between trunk liners and feeder service providers. *Marine Policy,* 32(6), 877-885.

Chou, C. (2007). A fuzzy MCDM method for solving marine transshipment container port selection problems. *Applied Mathematics and Computation*, 186(1), 435-444.

Chou, C. (2010). AHP model for the container port choice in the multiple-ports region. *Journal of Marine Science and Technology*, 18(2), 221-232.

Davis, C., Deckro, R., & Jackson, J. (2000). A value focused model for a C4 network. *Journal of Multicriteria Decision Analysis*, 9(4), 138.

De Icaza, R., Parnell, G., & Aloysius , J. (2017). Port Selection Analysis: Trends and Gaps.

De Langen, P. (2007). Port competition and selection in contestable hinterlands; the case of Austria. *European Journal of Transport and Infrastructure Research*, 7(1), 1-14.

Dillon-Merrill, R., Parnell, G. S., G., Buckshaw, D., Hensley, W., & Caswell, D. (2008). Avoiding common pitfalls in decision support frameworks for Department of Defense analyses. *Military Operations Research*, 13(2), 19-31.

DOT-MARAD. (2013). *Panama Canal Expansion Study. Phase I Report: Developments in Trade and National and Global Economies.*

Dyck, G., & Ismael, H. (2015). Multi-Criteria Evaluation of Port Competitiveness in West Africa Using Analytic Hierarchy Process (AHP). *American Journal of Industrial and Business Management, 5(06)*, 432-446.

Ewing, B., & Baker, E. (2009). Development of a green building decision support tool: A collaborative process. *Decision Analysis*, 6(3), 172-185.

Feng, T., & Keller, L. (2006). A multiple-objective decision analysis for terrorism protection: Potassium iodide distribution in nuclear incidents. *Decision Analysis*, 3(2), 76-93.

Frankel, E. (1992). Hierarchical logic in shipping policy and decision-making. *Maritime Policy & Management*, 19(3), 211-221.

Garcia-Alonso, L., & Sanchez-Soriano, J. (2009). Port selection from a hinterland perspective. *Maritime Economics & Logistics*, 11(3), 260-269.

Gohomene, D., Bonsal, S., Maistralis, E., Wang, J., & Li, K. (2015). The Attractiveness of Ports in West Africa: Some Lessons from Shipping Lines' Port Selection. *Growth and Change.*

Grosso, M., & Monteiro, F. (2009). Relevant strategic criteria when choosing a container port-the case of the port of Genoa. *Research in Transport and Logistics*, 299.

Guy, E., & Urli, B. (2006). Port selection and multicriteria analysis: an application to the Montreal-New York alternative. *Maritime Economics & Logistics*, 8(2), 169-186.

Hilliard, H., Parnell, G., & Pohl, E. (2015). Evaluating the Effectiveness of the Global Nuclear Detection Architecture Using Multiobjective Decision Analysis. *Systems Engineering*, 18(5), 441-452.

ICC International Maritime Bureau. (2015). *Piracy and Armed Robbery Againts Ships.* London. Retrieved from http://www.hellenicshippingnews.com/wp-content/uploads/2015/01/2014-Annual-IMB-Piracy-Report-ABRIDGED.pdf (accessed January 2016).

IMO. (2012). *International Maritime Organization. International Shipping Facts and Figures – Information Resources on Trade, Safety, Security, Environment.* Maritime Knowledge Centre. London. Retrieved from http://www.imo.org/en/KnowledgeCentre/ShipsAndShippingFactsAndFigures/TheRoleandImportanceofInternationalShipping/Documents/International%20Shipping%20-%20Facts%20and%20Figures.pdf (accessed March 2016).

JOC. *Trans-Pacific Trade Special Coverage*. Retrieved from http://www.joc.com/special-topics/trans-pacific-trade (2016, December 2).

Keeney, R. L. (1992). *Value-Focused Thinking: A path to creative decisionmaking.* Harvard University Press.

Keeney, R. L. (1993). Creativity in MS/OR: Value-Focused Thinking—Creativity directed toward decision making. *Interfaces*, 23(3), 62-67.

Keeney, R. L. (1994). Creativity in decision making with Value-Focused Thinking. *Sloan Management Review*, 35(4), 33.

Keeney, R. L., & Raïffa, H. (1976). *Decisions with multiple objectives: preferences and value tradeoffs.* New York: Wiley.

Keeney, R., & Gregory, R. (2005). Selecting attributes to measure the achievement of objectives. *Operations Research*, 53(1), 1-11.

Keeney, R., & von Winterfeldt, D. (2011). A value model for evaluating homeland security decisions. *Risk Analysis*, 31(9), 1470-1487.

Kim, J. Y. (2014). Port user typology and representations of port choice behavior: A Q-methodological study. *Maritime Economics & Logistics*, 16(2), 165-187.

Kirkwood, C. (1997). *Strategic Decision Making Multiobjective Decision Analysis with Spreadsheets.* Belmont, California: Wadsworth Publishing Company.

Knoema - Port Databse. (2014). Retrieved from https://knoema.com/PRTDT2016 (accessed February 2016).

Lam, J., & Dai, J. (2012). A decision support system for port selection. *Transportation Planning and Technology*, 35(4), 509-524.

Lirn, T., Thanopoulou, H., Beynon, M., & Beresford, A. (2004). An application of AHP on transhipment port selection: a global perspective. *Maritime Economics & Logistics,*, 6(1), 70-91.

Loh, H., & Thai, V. (2015). Management of disruptions by seaports: preliminary findings. *Asia Pacific Journal of Marketing and Logistics*, 27(1), 146-162.

Magala, M., & Sammons, A. (2008). A new approach to port choice modelling. *Maritime Economics & Logistics*, 10(1), 9-34.

Malchow, M., & Kanafani, A. (2001). A disaggregate analysis of factors influencing port selection. *Maritime Policy & Management*, 28(3), 265-277.

Malchow, M., & Kanafani, A. (2004). A disaggregate analysis of port selection. *Transportation Research Part E: Logistics and Transportation Review*, 40(4), 317-337.

Mangan, J., Lalwani, C., & Gardner, B. (2002). Modelling port/ferry choice in RoRo freight transportation. *International Journal of Transport Management*, 1(1), 15-28.

MARAD. (2015). Retrieved from Maritime Data & Statistics: https://www.marad.dot.gov/resources/data-statistics/#trade-stats (accessed October 2016).

Merrick, J. (2008). Getting the right mix of experts. *Decision Analysis*, 5(1), 43-52. Retrieved from Merrick, J. R. (2008). Getting the right mix of experts. Decision Analysis, 5(1), 43-52.

Montibeller, G. (2005). From (and to) a new generation of multi-criteria decision analysts: an introduction to the field and a personal view on its future. *In Keynote Papers–YOR14 Conference.* The Operational Research Society Press: Birmingham (ISBN 0 903440 33 4).

Murphy, P. R. (1992). Port selection criteria: an application of a transportation research framework. *Logistics and Transportation Review*, 28(3), 237.

Murphy, P., & Daley, J. (1994). A comparative analysis of port selection factors. *Transportation Journal*, 15-21.

Murphy, P., Dalenberg, D., & Daley, J. (1988). A contemporary perspective of international port operations. *Transportation journal*, 23-32.

Murphy, P., Daley, J., & Dalenberg, D. (1991). Selecting links and nodes in international transportation: an intermediary's perspective. *Transportation journal*, 33-40.

NECI. (2016). *National Temperature and Precipitation Maps.* Retrieved from National Centers for Environmental Information: https://www.ncdc.noaa.gov/temp-and-precip/us-maps/ (accessed October 2016).

Ng, K. (2006). Assessing the attractiveness of ports in the North European container transhipment market: an agenda for future research in port competition. *Maritime Economics and Logistics*, 8(3), 234-250.

Nightingale, L. *Global box trade forecast to grow 4.1% in 2016*. Retrieved from Lloyd's List: http://www.lloydsloadinglist.com/freight-directory/news/Global-box-trade-forecast-to-grow-4.1-in-2016/66061.htm (2016, April 6).

Nightingale, L. (2016). *Global box trade forecast to grow 4.1% in 2016*. Retrieved from Lloyd's List: http://www.lloydsloadinglist.com/freight-directory/news/Global-box-trade-forecast-to-grow-4.1-in-2016/66061.htm (2016, April 6).

Nir, A., Lin, K., & Liang, G. (2003). Port choice behaviour--from the perspective of the shipper. *Maritime Policy & Management*, 30(2), 165-173.

Palisade Corporation. (2016, July 12). @Risks. Ithaca, New York, United States.

Panayides, P., & Song, D. (2012). Determinants of Users' Port Choice. *The Blackwell Companion to Maritime Economics*, 599-622.

Parnell, G., & Trainor, T. E. (2009). Using the Swing Weight Matrix to Weight Multiple Objectives. *In INCOSE International Symposium (Vol. 19, No. 1, pp. 283-298).*

Parnell, G., Bresnick, T., Tani, S., & Johnson, E. (2013). *Handbook of decision analysis (Vol. 6).* New Jersey: John Wiley & Sons.

Parnell, G., Hughes, D., Burk, R., Driscoll, P., Kucik, P., MoraleS, B., & Nunn, L. (2013). Invited Review—Survey of Value-Focused Thinking: Applications, Research Developments and Areas for Future Research. *Journal of Multi-Criteria Decision Analysis*, 20(1-2), 49-60.

Paté-Cornell, M., & Dillon, R. (2006). The respective roles of risk and decision analyses in decision support. *Decision Analysis*, 3(4), 220-232.

Port Autonome de Dakar [Autonomous Port of Dakar]. (2016). Retrieved from http://www.portdakar.sn/index.php (accessed January 2016).

Port Autonome de Lome [Autonomous Port of Lome]. (2012). Retrieved from http://www.togo-port.net/index.php?option=com_content&view=article&id=204:le-port-de-lome-certifie-iso-9001-version-2008&catid=43:actualites&Itemid=104 (accessed February 2016).

Port of Abidjan, Ivory Coast. (2016). Retrieved from http://www.bollore-africa-logistics.com/en/ports-and-terminals/ (accessed February 2016).

Port Report Africa. (2014). Retrieved from http://www.portoverview.com (accessed May 2016).

Rodrigue, J. (2010). *Factors impacting North American freight distribution in view of the Panama Canal expansion.* Van Horne Institute.

Saaty, T. (1980). *The analytic hierarchy process: planning, priority setting, resources allocation.* New York: McGraw.

Sanchez, R., Ng, A., & Garcia-Alonso, L. (2011). Port Selection Factors and Attractiveness: The Service Providers' Perspective. *Transportation Journal*, 50(2), 141-161.

Schrank, D., Eisele, B., Lomax, T., & Bak, J. (2015). *Urban Mobility Scorecard* . Texas A&M Transportation Institute and INRIX.

Seedah, D., Harrison, R., Boske, L., & Kruse, J. (2013). *Container Terminal and Cargo-Handling Cost Analysis Toolkit.* Austin, Texas: Center for Transportation Research - The University of Texas.

Simon, J., & Regnier, E. (2014). A value-focused approach to energy transformation in the United States Department of Defense. *Decision Analysis*, 11(2), 117-132.

Slack, B. (1985). Containerization, inter-port competition, and port selection. *Maritime Policy and Management*, 12(4), 293-303.

Song, D., & Yeo, K. (2004). A competitive analysis of Chinese container ports using the analytic hierarchy process. *Maritime Economics & Logistics*, 6(1), 34-52.

Steven, A., & Corsi, T. (2012). Choosing a port: An analysis of containerized imports into the US. *Transportation Research Part E: Logistics and Transportation Review*, 48(4), 881-895.

Suez Canal Container Terminal. (2016). Retrieved from http://www.scctportsaid.com/organization_hsse.php (accessed February 2016).

Tang, L., Low, J., & Lam, S. (2011). Understanding port choice behavior—a network perspective. *Networks and Spatial Economics*, 11(1), 65-82.

Tema Port. (2014). Retrieved from http://www.ghanaports.gov.gh/page/19/Port-Highlights (accessed February 2016).

Tiwari, P., Itoh, H., & Doi, M. (2003). Shippers' port and carrier selection behaviour in China: a discrete choice analysis. *Maritime Economics & Logistics,* 5(1), 23-39.

Tongzon, J. (2002). Port choice determinants in a competitive environment. *In Proceedings of Annual Conference and Meeting of the International Association of Maritime Economists.* Panama: IAME.

Tongzon, J. L. (2009). Port Choice and freight forwarders. *Transportation Research Part E: Logistics and Transportation Review*, 45(1), 186-195.

Tongzon, J. L., & Sawant, L. (2007). Port choice in a competitive environment: from the shipping lines' perspective. *Applied Economics*, 39(4), 477-492.

Transparency International. (2014). Retrieved from Corruption Perception Index 2014: Results: https://www.transparency.org/cpi2014/results (accessed February 2016).

Ugboma, C., Ugboma, O., & Ogwude, I. (2006). An analytic hierarchy process (AHP) approach to port selection decisions–empirical evidence from Nigerian ports. *Maritime Economics & Logistics*, 8(3), 251-266.

UNCTAD. (2015). *Review of Maritime Transport.* Geneva: United Nations.

UNCTAD STAT. (2014). Retrieved from unctadstat.unctad.org/wds/ (accessed January 2016).

Veldman, S., & Bückmann, E. (2003). A model on container port competition: an application for the west European container hub-ports. *Maritime Economics & Logistics*, 5(1), 3-22.

Veldman, S., Garcia-Alonso, L., & Vallejo-Pinto, J. (2011). Determinants of container port choice in Spain. *Maritime Policy & Management*, 38(5), 509-522.

Watson, S., & Buede, D. (1987). *Decision synthesis: the principles and practice of decision analysis.* New York: Cambridge University Press.

Wiegmans, B., Hoest, A., & Notteboom, T. (2008). Port and terminal selection by deep-sea container operators. *Maritime Policy & Management*, 35(6), 517-534.

World Bank LPI. (2014). Retrieved from http://lpi.worldbank.org/international/global (accessed January 2016).

World Bank WDI. (2014). Retrieved from http://wdi.worldbank.org/tables (accessed January 2016).

World Bank WGI. (2014). Retrieved from http://info.worldbank.org/governance/wgi (accessed January 2016).

World Shipping Council. (2016). Retrieved from http://www.worldshipping.org/about-the-industry/global-trade/top-50-world-container-ports (accessed March 2016).

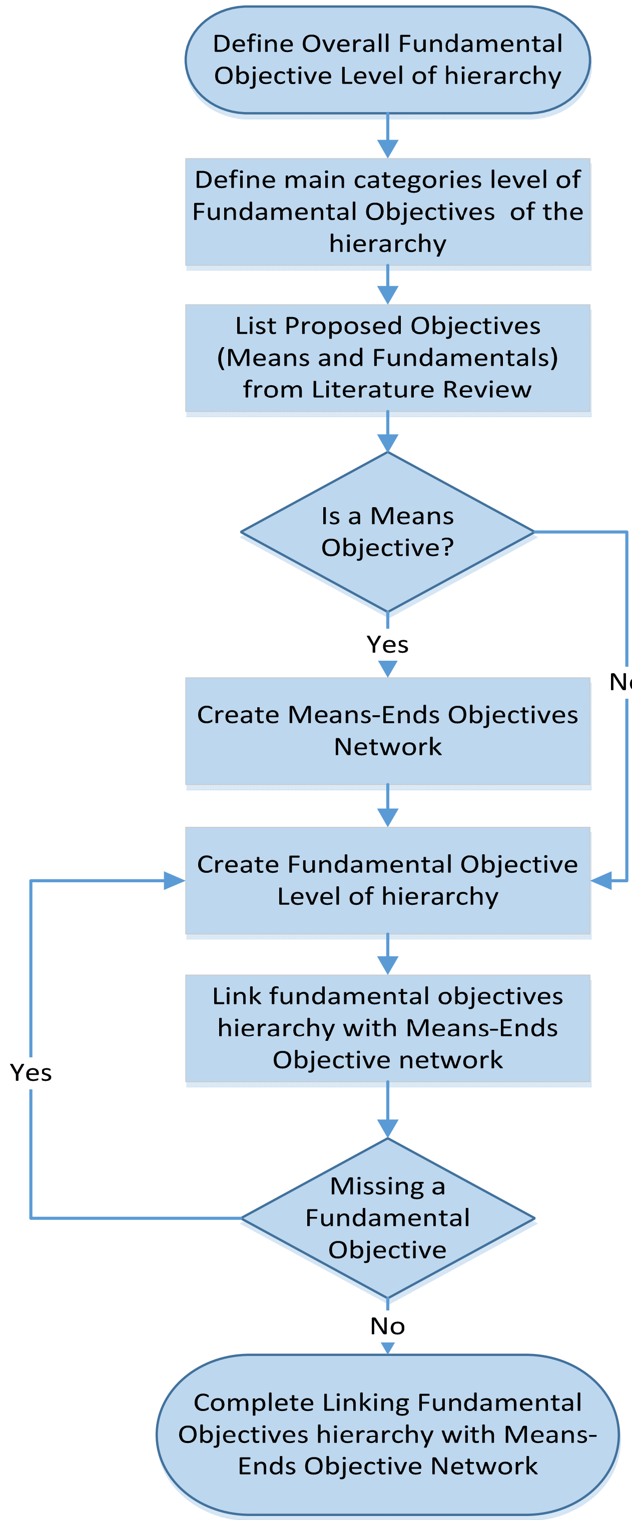
Wright, G., & Goodwin, P. (1999). Future-focussed thinking: combining scenario planning with decision analysis. *Journal of Multicriteria Decision Analysis*, 8(6), 311.

Wu, Y., Liu, J., & Peng, C. (2014). Analysis of port and inland transport mode selection. *In Service Systems and Service Management (ICSSSM) 2014 11th International Conference* (pp. 1-6). IEEE.

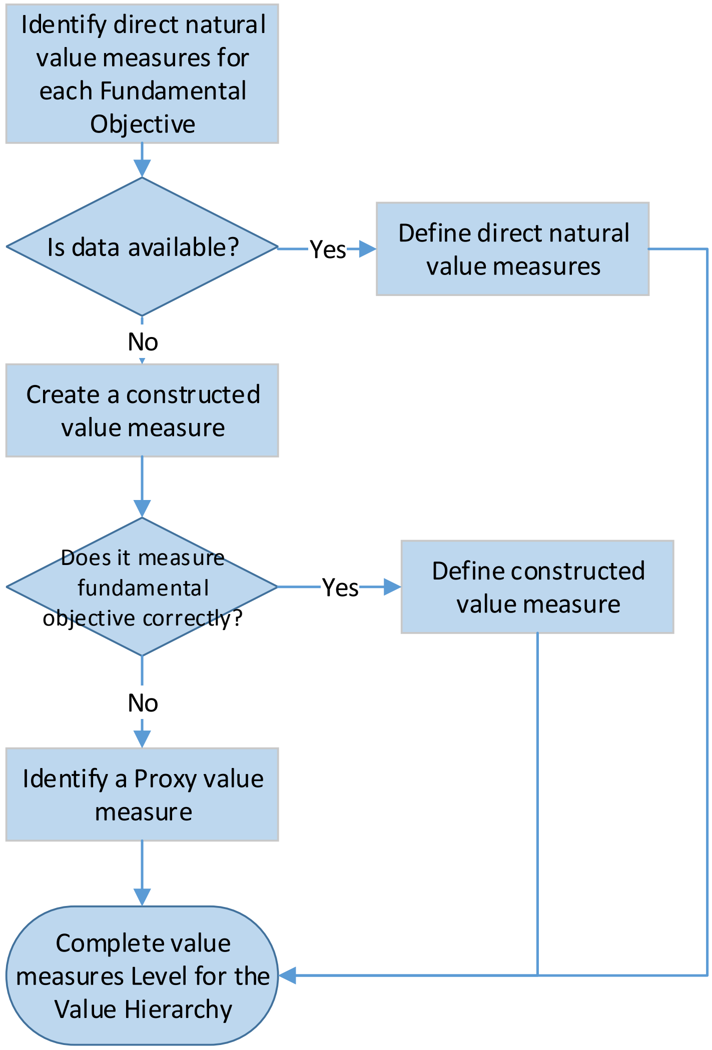
Yeo, G., Ng, A., Lee, P., & Yang, Z. (2014). Modelling port choice in an uncertain environment. *Maritime Policy & Management*, 41(3), 251-267.

Appendix

Appendix 4.A - Flowchart for the Creation and Linkage of Fundamental Objectives and Mean-End Objective



Appendix 4.B - Creating Attributes for the Value Hierarchy



Appendix 4.C - Cost Model Elements

Group	Cost	Equation (Seedah, Harrison, Boske, & Kruse, 2013)	Definition[1]
Navigation Service (C_N)	Port Dues	f { (size e.g length)$_{vessel}$; Fixed fee }	Charge assessed for vessels entering the jurisdictional limits of the Port Authority.
	Pilotage	f (vessel size, time in tow, distance traveled)$_{vessel}$	Charge assessed for vessel pilotage services from sea to terminal.
Berth Service (C_B)	Dockage	f (size, time at dock)$_{vessel}$	Charge assessed against a Vessel for berthing at a wharf, pier, bulkhead structure, or bank, or for mooring to a Vessel so berthed.
	Wharfage	f (type, volume, weight, size)$_{cargo}$	Assessed against the cargo or vessel on all cargo, empty containers, and bunker fuel passing when berthed at wharf or when moored in slip adjacent to wharf.
Cargo Operations (C_C)	Cargo Handling	f (type, volume, weight, size)$_{cargo}$	Charge assessed for containers loaded throughput and empty handling.
	Storage	f (type, volume, weight, size)$_{cargo}$	Service of providing warehouse or other terminal facilities for the storage of inbound or outbound cargo.
	Terminal Use	f (type, volume, weight, size)$_{cargo}$	Charge assessed on all cargo stuffed or stripped into or from Port Authority facilities
Other Costs (C_O)	Harbor Safety	f (% of dockage cost)$_{vessel}$ + f (volume, weight, size)$_{cargo}$	Charge assessed for responsibilities of security.
	Reefer	f (# of refrigerated containers)$_{cargo}$ x f (time)$_{service}$	Charge assessed for additional service-electrical power for refrigerated containers.
	Water	f (quantity needed)$_{water}$ + fee	Charge assessed for additional service of water supplied to vessel.

[1] **Tariff No. 8 - Port of Houston**

Appendix 4.D - Probability Distribution Data for the Monte Carlo Simulation of the Value Model

Container traffic growth uncertain Ranges (Container traffic in TEUs)			
	Min	**Base**	**Max**
Houston	1,650,916	1,664,448	1,931,388
New Orleans	327,087	329,768	382,655
Mobile	173,310	174,731	202,754
Gulfport	148,055	149,269	173,208
Tampa	37,740	38,049	44,151
Ideal Port	5,864,347	5,912,415	6,860,633

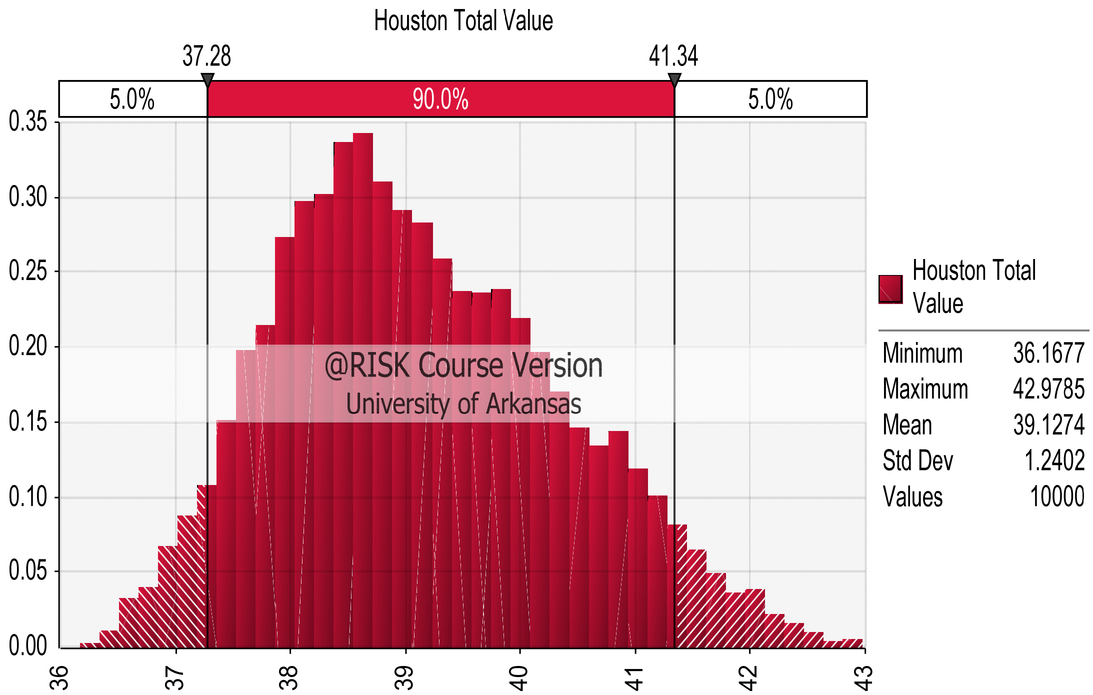
Max Ship Capacity Call (TEUs) uncertain Ranges			
	*** Min**	**Base**	**Max**
Houston	966	6,732	8,000
New Orleans	957	6,732	8,000
Mobile	974	6,732	8,000
Gulfport	962	982	4,200
Tampa	862	5,762	6,000
Ideal Port	1713	17,859	19,000

Appendix 4.D (Cont.)

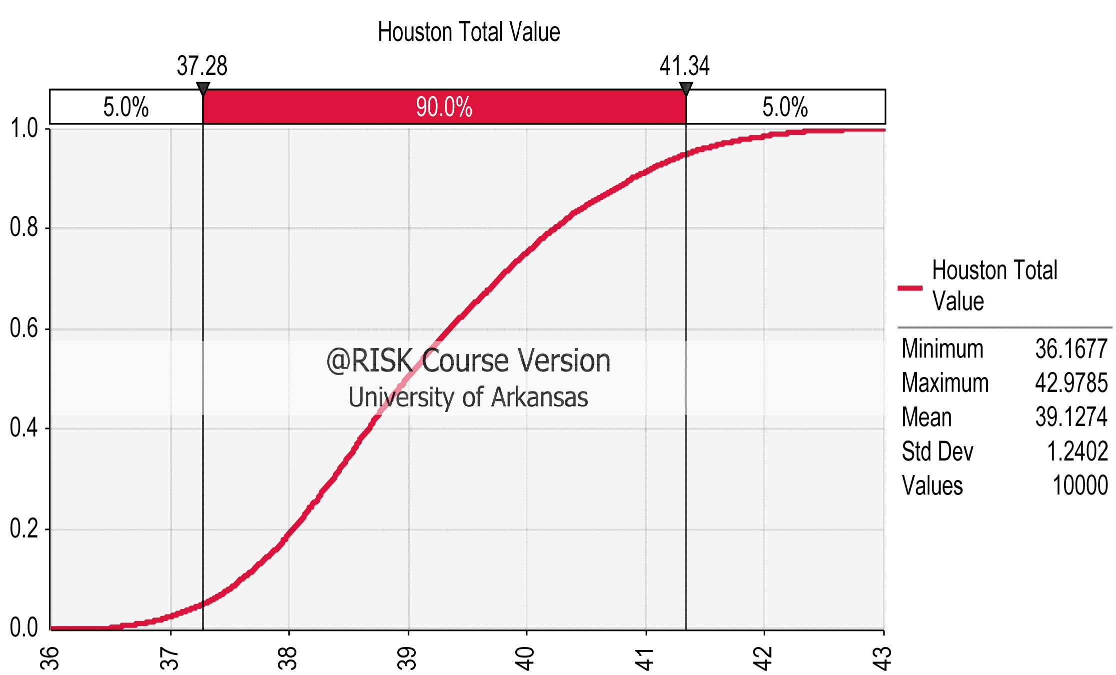
Supply chain disruptions uncertain Ranges (Annual Traffic Delay)			
	Min	**Base**	**Max**
Houston	196,107	203,173	223,432
New Orleans	34,263	39,159	45,328
Mobile	9,648	10,396	13,030
Gulfport	4,298	4,463	5,700
Tampa	66,538	71,628	80,210
Ideal Port	900	4,000	5,000

Weather Conditions (Precipitation Ranks)			
	Min	**Base**	**Max**
Houston	1	120	121
New Orleans	5	103	109
Mobile	3	99	114
Gulfport	6	86	107
Tampa	3	77	97
Ideal Port	1	3	13

Appendix 4.E - Histogram for Port of Houston



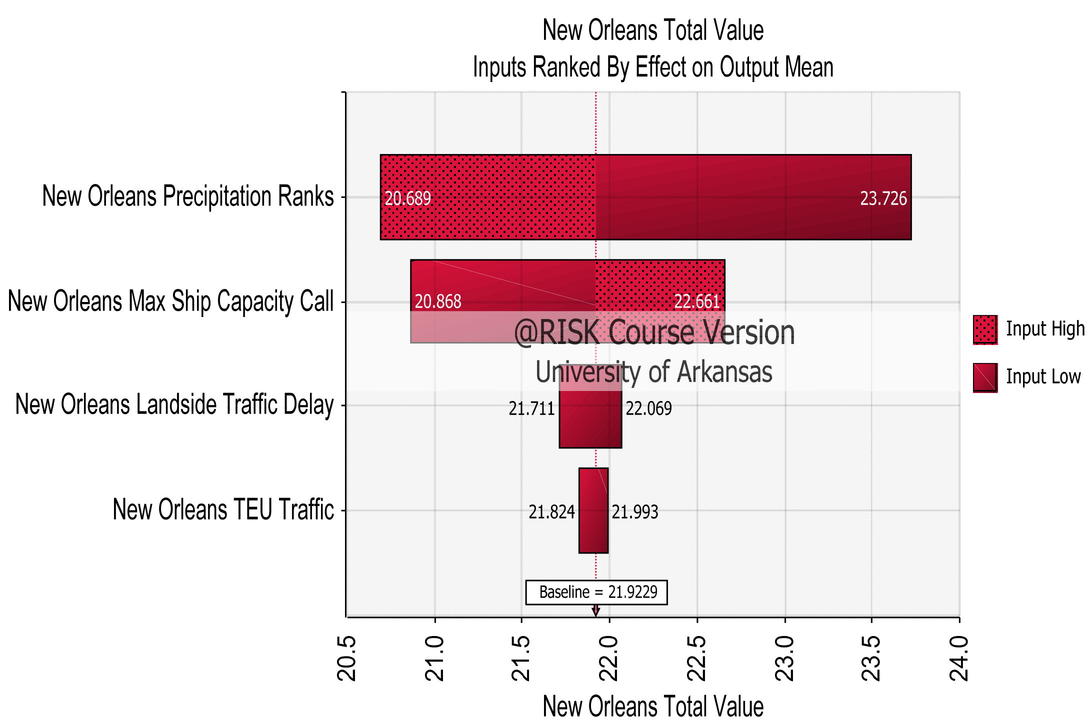
Appendix 4.F - Cumulative Ascending Distribution for Port of Houston



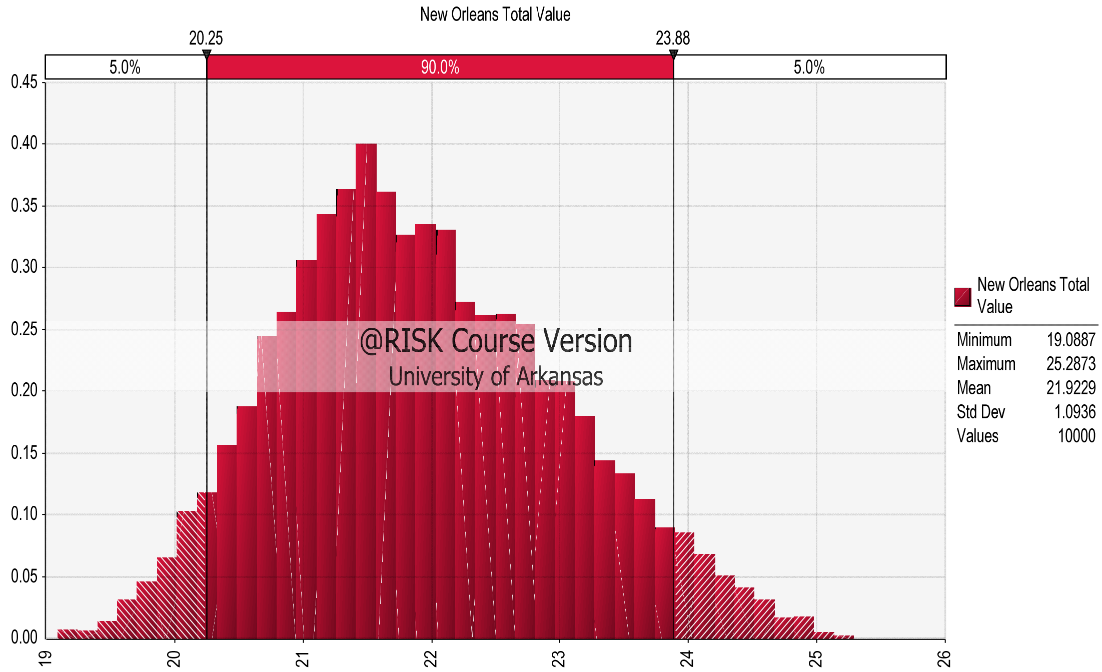
Appendix 4.G - Summary Statistics for Houston Total Value

Summary Statistics for Houston Total Value			
Statistics		**Percentile**	
Minimum	36	**5%**	37
Maximum	43	**10%**	38
Mean	39	**15%**	38
Std Dev	1	**20%**	38
Variance	1.538014331	**25%**	38
Skewness	0.359767698	**30%**	38
Kurtosis	2.601816164	**35%**	39
Median	39	**40%**	39
Mode	39	**45%**	39
Left X	37	**50%**	39
Left P	5%	**55%**	39
Right X	41	**60%**	39
Right P	95%	**65%**	40
Diff X	4	**70%**	40
Diff P	90%	**75%**	40
#Errors	0	**80%**	40
Filter Min	Off	**85%**	41
Filter Max	Off	**90%**	41
#Filtered	0	**95%**	41

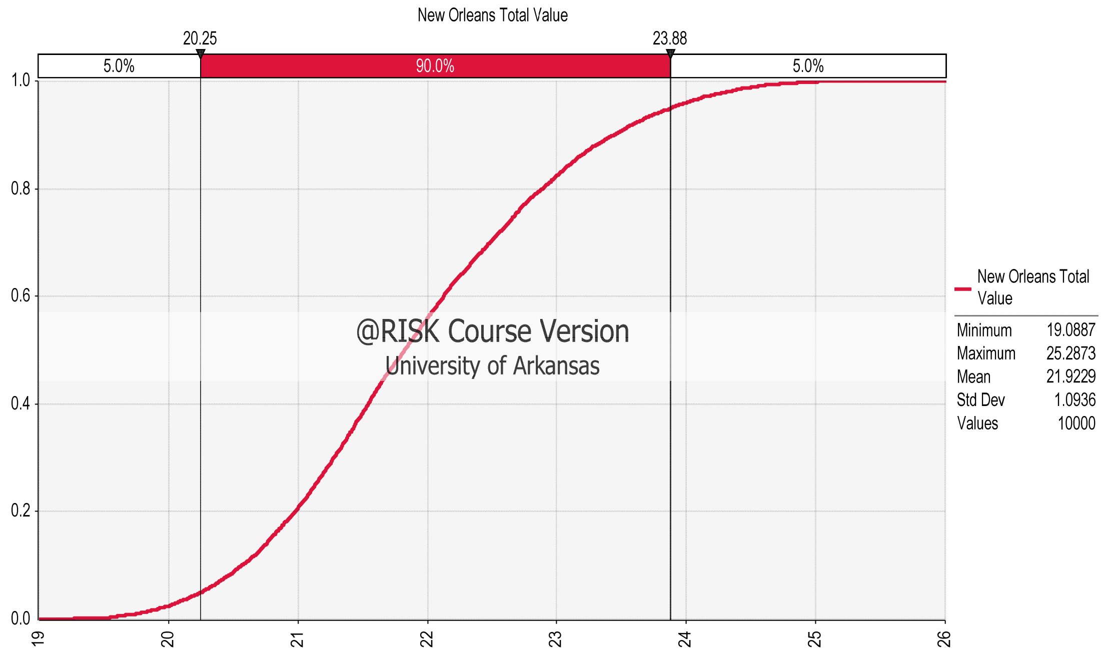
Appendix 4.H - Tornado Graph for Port of New Orleans



Appendix 4.I - Histogram for Port of New Orleans



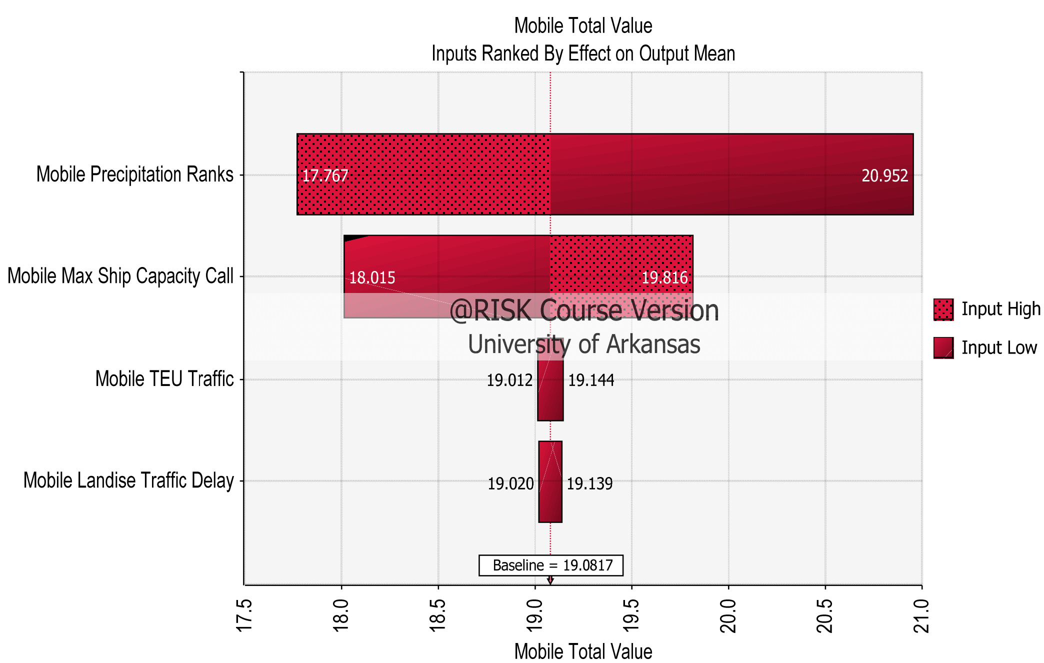
Appendix 4.J - Cumulative Ascending Distribution for Port of New Orleans



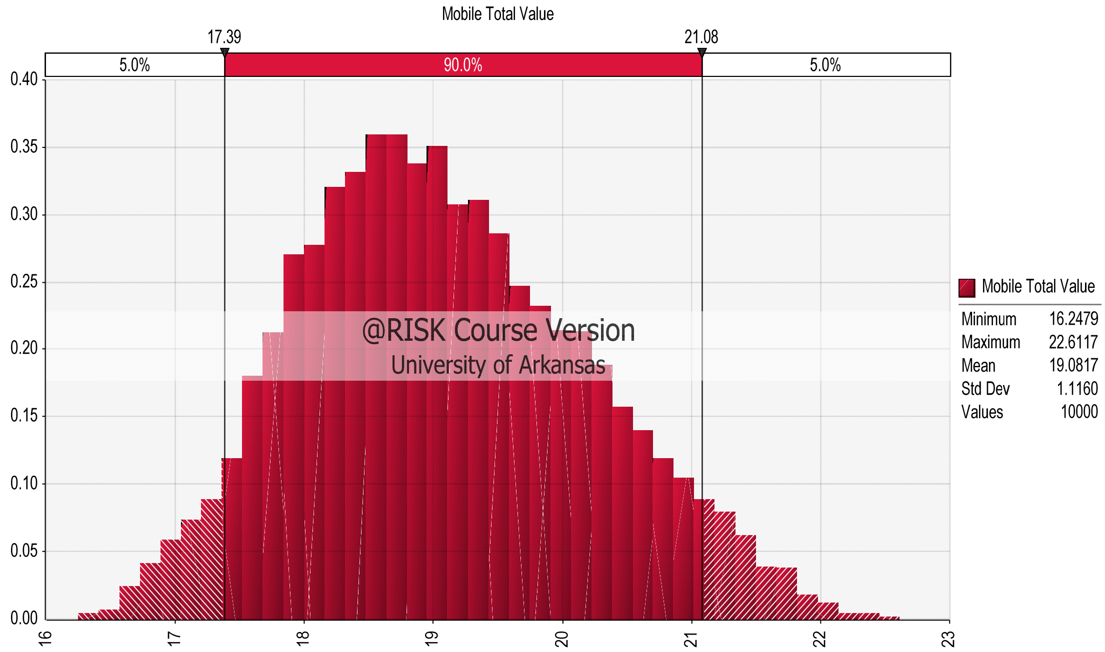
Appendix 4.K - Summary Statistics for New Orleans Total Value

Summary Statistics for New Orleans Total Value			
Statistics		**Percentile**	
Minimum	19	**5%**	20
Maximum	25	**10%**	21
Mean	22	**15%**	21
Std Dev	1	**20%**	21
Variance	1.195864375	**25%**	21
Skewness	0.295762208	**30%**	21
Kurtosis	2.648188948	**35%**	21
Median	22	**40%**	22
Mode	21	**45%**	22
Left X	20	**50%**	22
Left P	5%	**55%**	22
Right X	24	**60%**	22
Right P	95%	**65%**	22
Diff X	4	**70%**	22
Diff P	90%	**75%**	23
#Errors	0	**80%**	23
Filter Min	Off	**85%**	23
Filter Max	Off	**90%**	23
#Filtered	0	**95%**	24

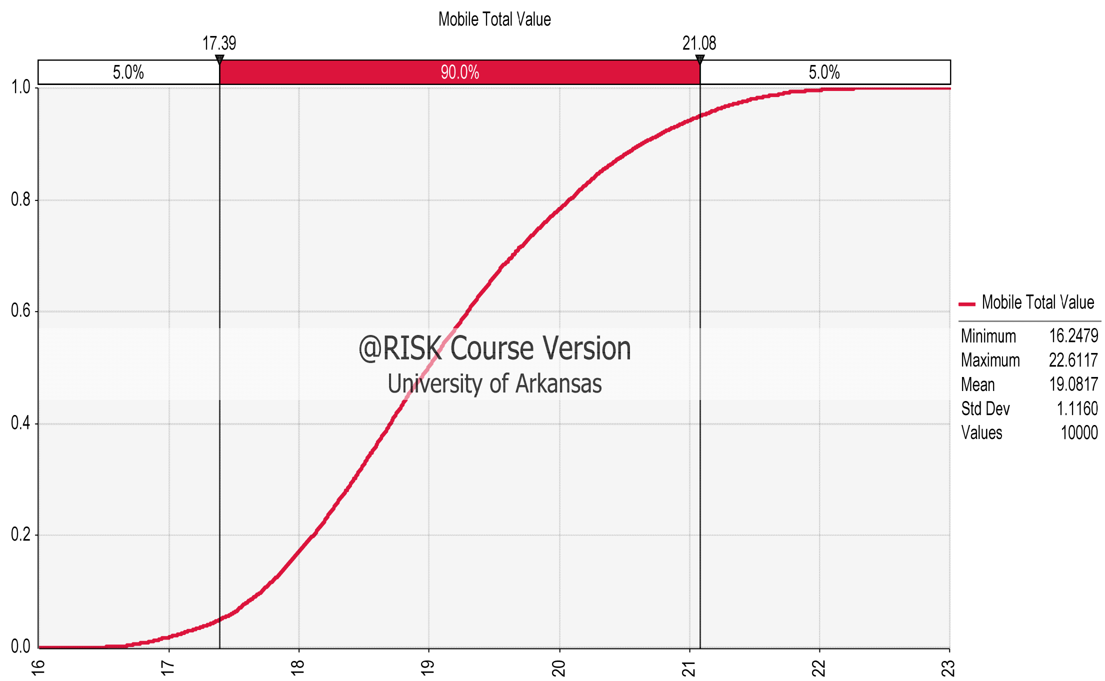
Appendix 4.L - Tornado Graph for Port of Mobile



Appendix 4.M - Histogram for Port of Mobile



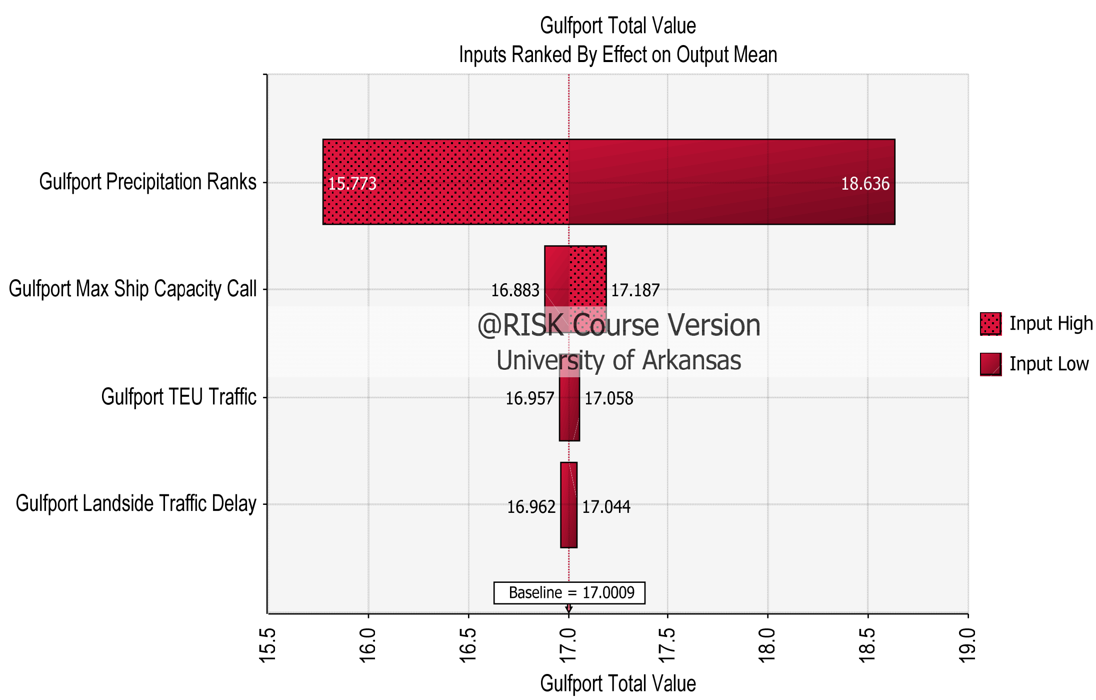
Appendix 4.N - Cumulative Ascending Distribution for port of Mobile



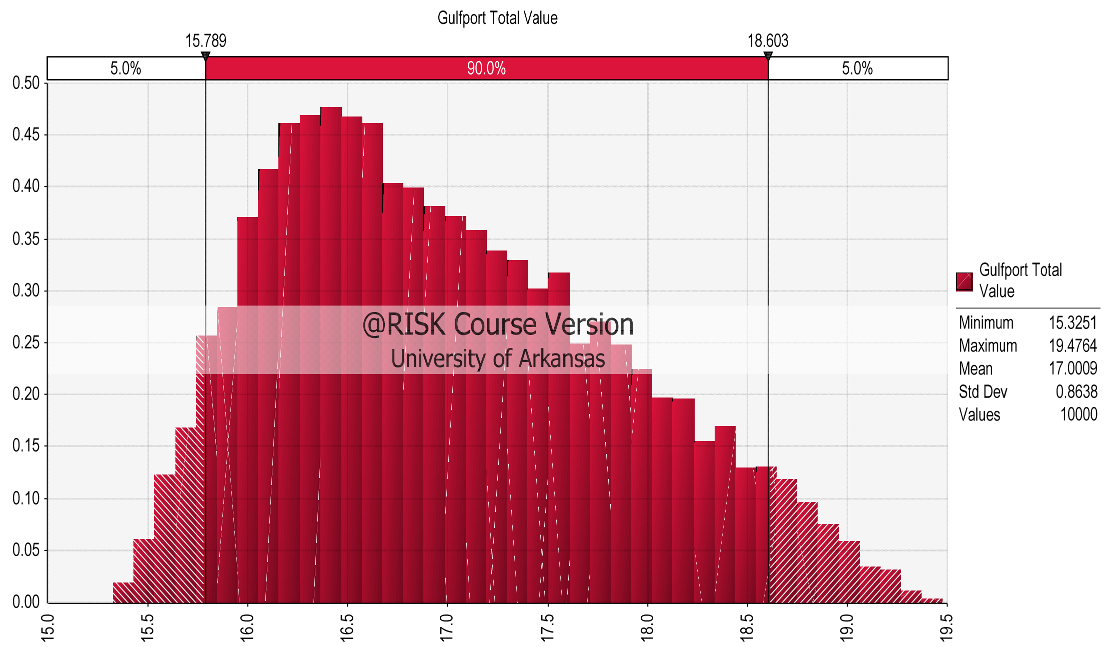
Appendix 4.O - Summary Statistics for Mobile Total Value

Summary Statistics for Mobile Total Value			
Statistics		**Percentile**	
Minimum	16	**5%**	17
Maximum	23	**10%**	18
Mean	19	**15%**	18
Std Dev	1	**20%**	18
Variance	1.245566561	**25%**	18
Skewness	0.287461542	**30%**	18
Kurtosis	2.612907964	**35%**	19
Median	19	**40%**	19
Mode	19	**45%**	19
Left X	17	**50%**	19
Left P	5%	**55%**	19
Right X	21	**60%**	19
Right P	95%	**65%**	19
Diff X	4	**70%**	20
Diff P	90%	**75%**	20
#Errors	0	**80%**	20
Filter Min	Off	**85%**	20
Filter Max	Off	**90%**	21
#Filtered	0	**95%**	21

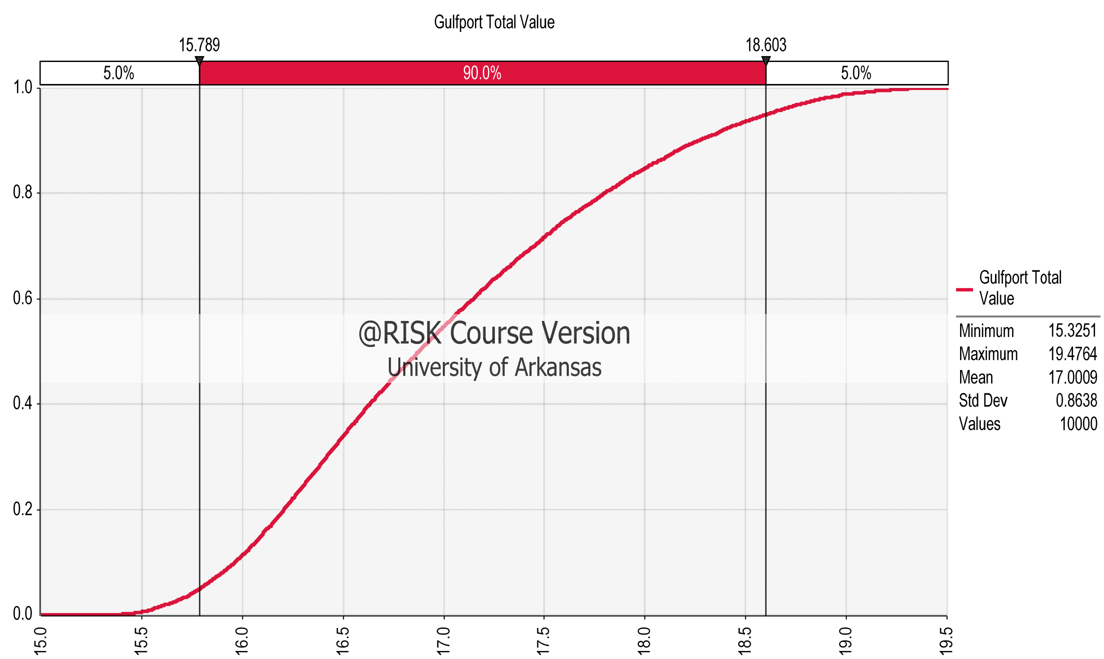
Appendix 4.P - Tornado Graph for Port of Gulfport



Appendix 4.Q - Histogram for Port of Gulfport



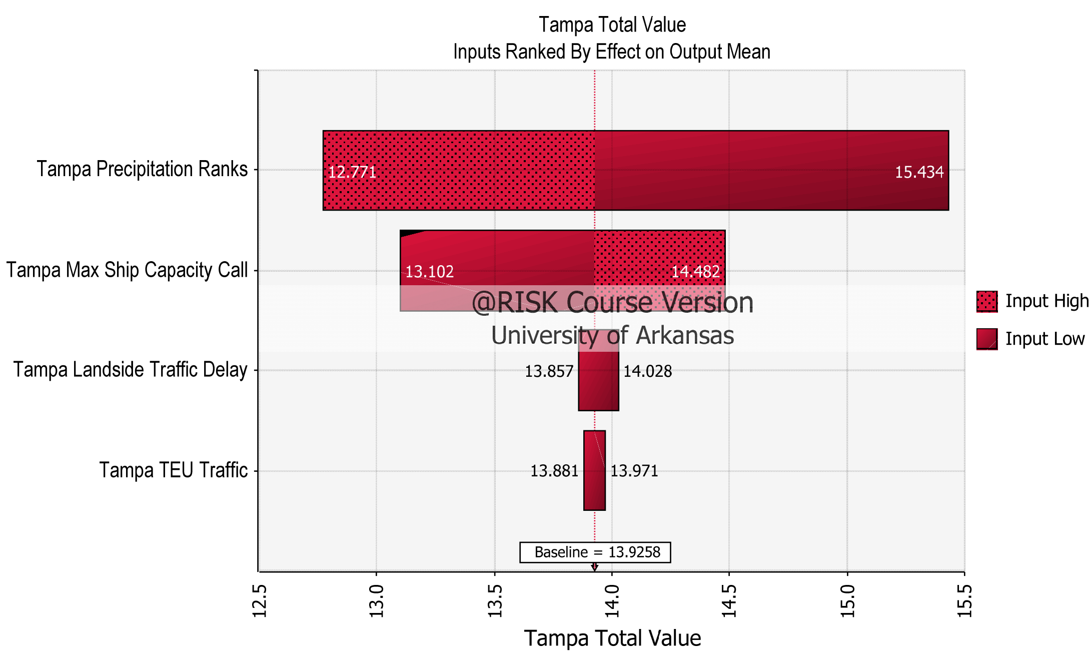
Appendix 4.R - Cumulative Ascending Distribution for Port of Gulfport



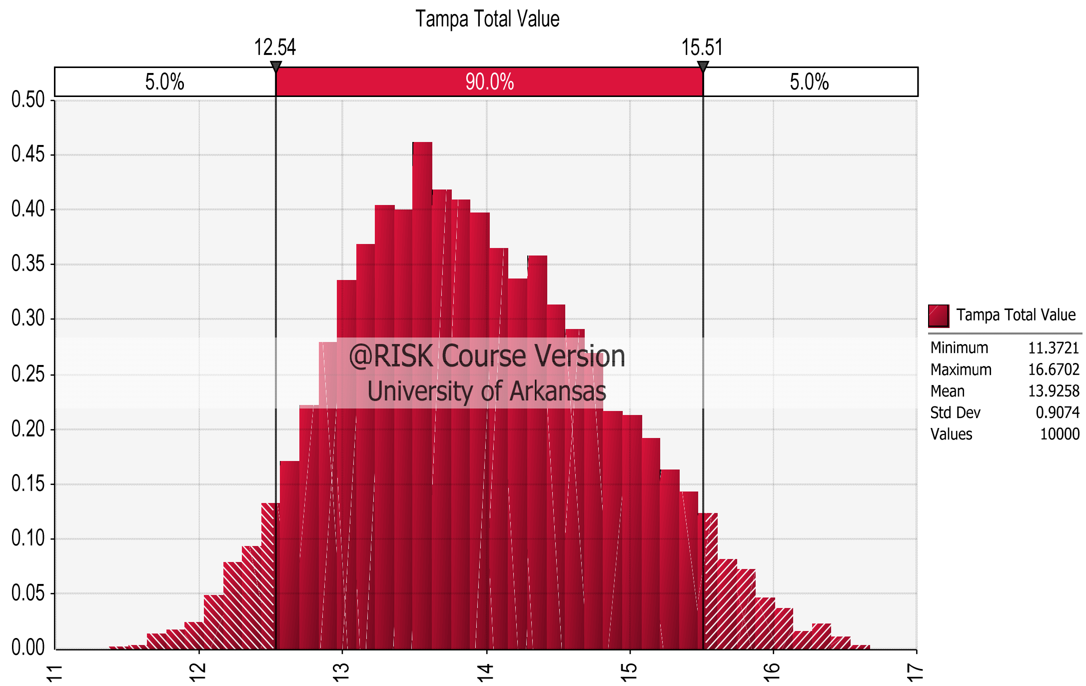
Appendix 4.S - Summary Statistics for Gulfport Total Value

Summary Statistics for Gulfport Total Value			
Statistics		**Percentile**	
Minimum	15	**5%**	16
Maximum	19	**10%**	16
Mean	17	**15%**	16
Std Dev	1	**20%**	16
Variance	0.746093503	**25%**	16
Skewness	0.455878218	**30%**	16
Kurtosis	2.410805304	**35%**	17
Median	17	**40%**	17
Mode	16	**45%**	17
Left X	16	**50%**	17
Left P	5%	**55%**	17
Right X	19	**60%**	17
Right P	95%	**65%**	17
Diff X	3	**70%**	17
Diff P	90%	**75%**	18
#Errors	0	**80%**	18
Filter Min	Off	**85%**	18
Filter Max	Off	**90%**	18
#Filtered	0	**95%**	19

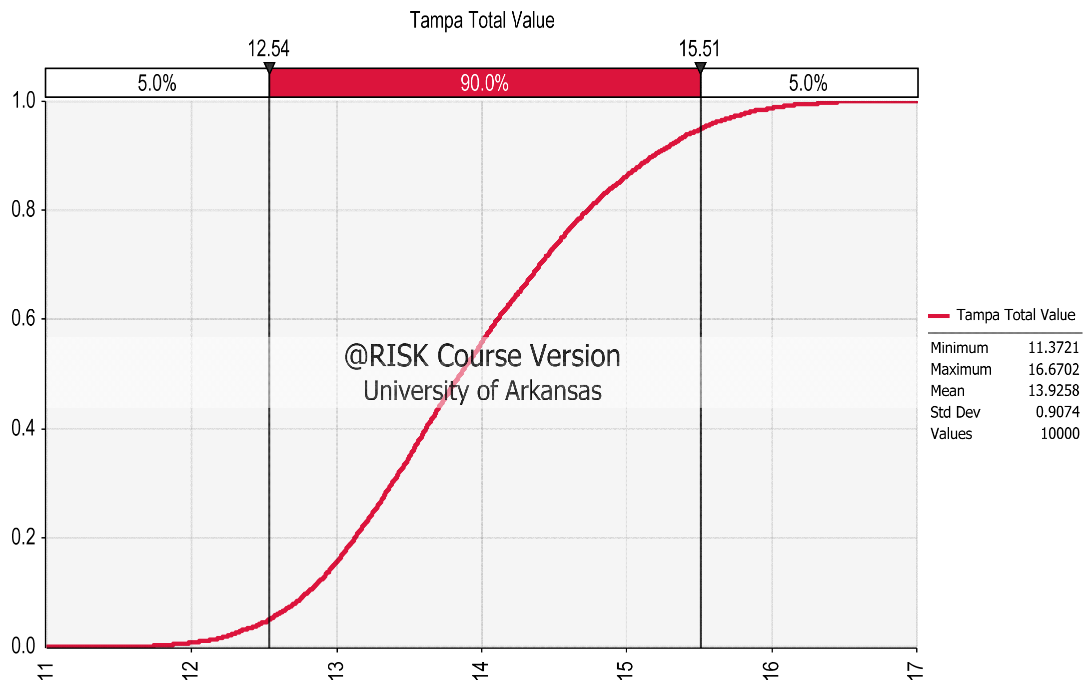
Appendix 4.T - Tornado Graph for Port of Tampa



Appendix 4.U - Histogram for Port of Tampa



Appendix 4.V - Cumulative ascending for port of Tampa



Appendix 4.W - Summary Statistics for Tampa Total Value

Summary Statistics for Tampa Total Value			
Statistics		**Percentile**	
Minimum	11	**5%**	13
Maximum	17	**10%**	13
Mean	14	**15%**	13
Std Dev	1	**20%**	13
Variance	0.823347305	**25%**	13
Skewness	0.23945557	**30%**	13
Kurtosis	2.596914403	**35%**	14
Median	14	**40%**	14
Mode	14	**45%**	14
Left X	13	**50%**	14
Left P	5%	**55%**	14
Right X	16	**60%**	14
Right P	95%	**65%**	14
Diff X	3	**70%**	14
Diff P	90%	**75%**	15
#Errors	0	**80%**	15
Filter Min	Off	**85%**	15
Filter Max	Off	**90%**	15
#Filtered	0	**95%**	16

Appendix 4.X - Probability Distribution Data for the Monte Carlo Simulation of the Cost Model

Vessel Size

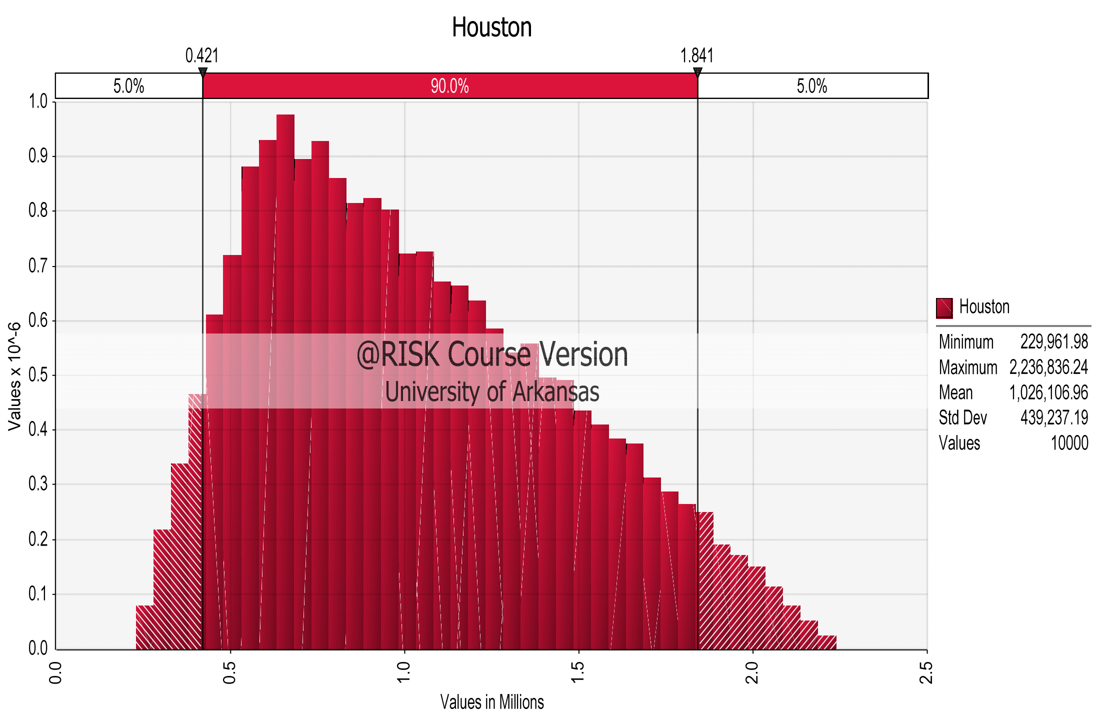
	Min	Base	Max
# of containers	1,078	3,306	13,000
LOA (feet)	476	964.93	1,200
Draft (feet)	26	36	50
Breadth Extreme (Feet)	82	105.64	157
Gross Tonnage (ton)	13,764	53,675	141,716

Appendix 4.X (Cont.)

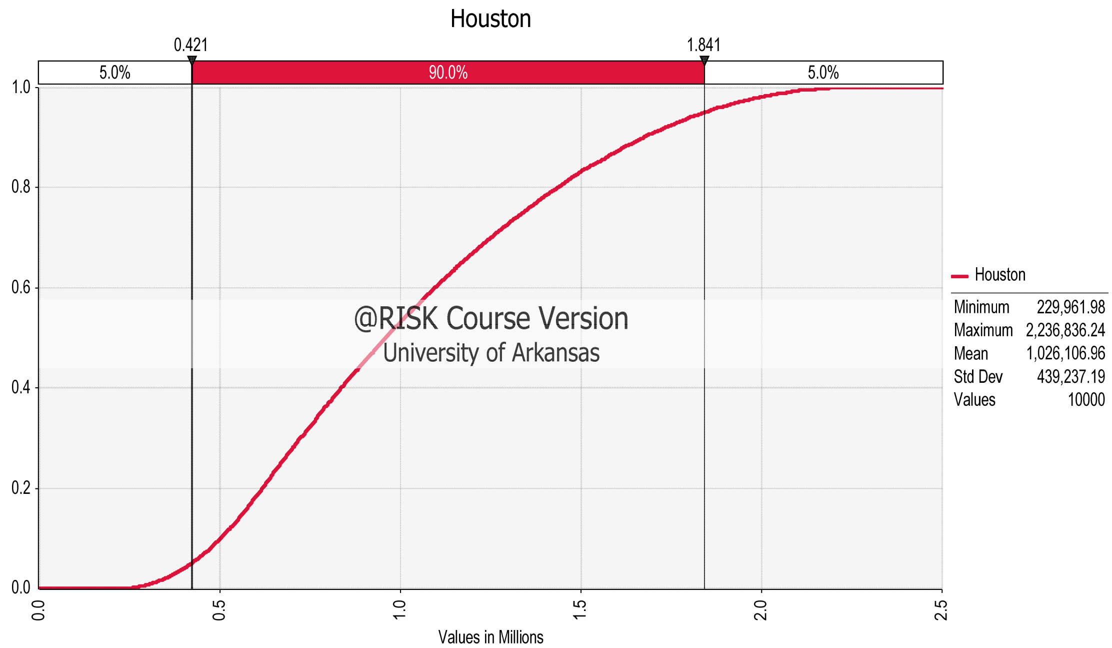
Supply Chain Disruption

	Min	Base	Max
Duration of Port Call (days)	1	2	5
Days of containers in yard	1	3	40

Appendix 4.Y - Histogram for Port of Houston – Cost Model



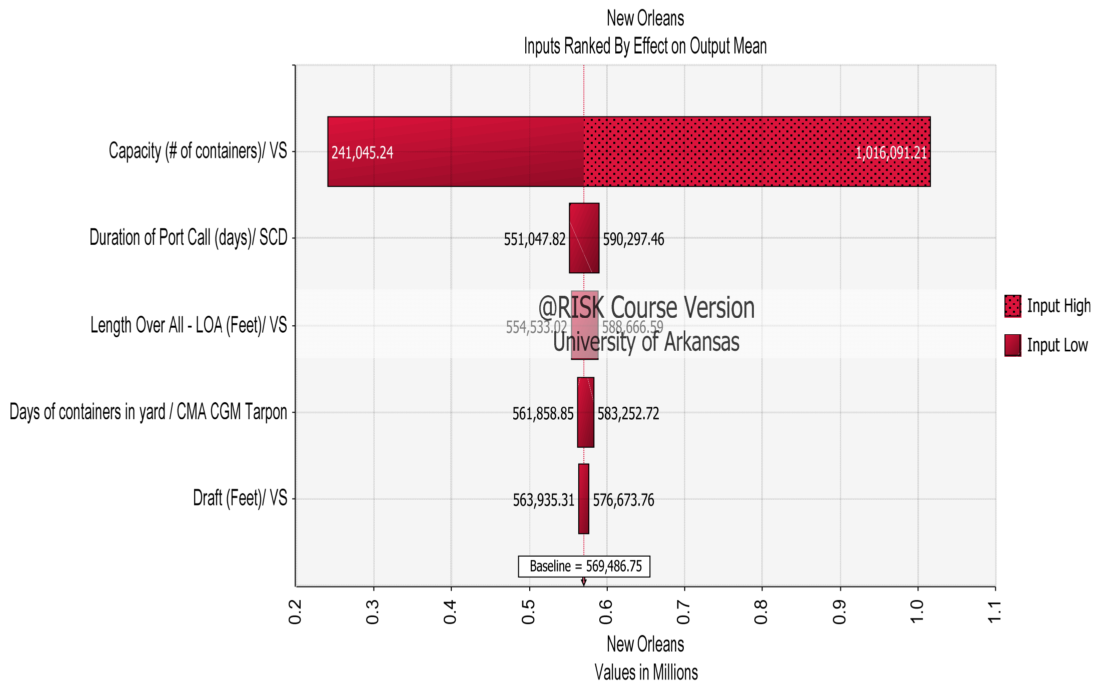
Appendix 4.Z - Cumulative Ascending Distribution for Port of Houston – Cost Model



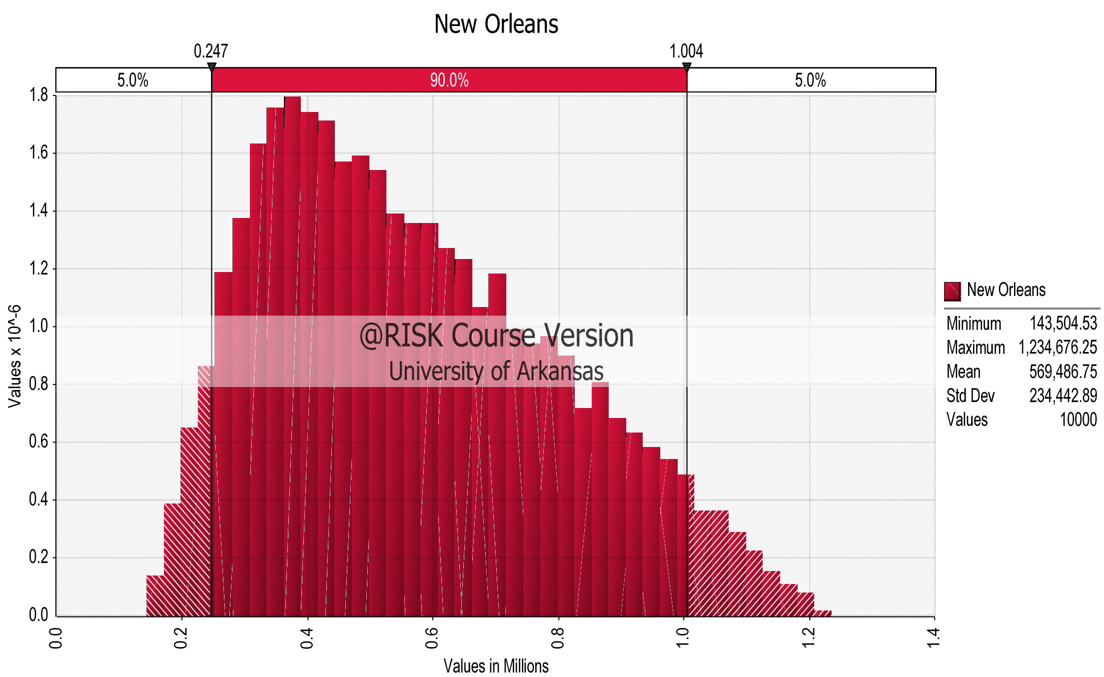
Appendix 4.AA - Summary Statistics for Houston Total Cost

Summary Statistics for Houston			
Statistics		**Percentile**	
Minimum	221,682	**1.0%**	310,245
Maximum	2,238,036	**2.5%**	361,738
Mean	1,026,131	**5.0%**	423,004
Std Dev	439,114	**10.0%**	501,785
Variance	1.92821E+11	**20.0%**	617,689
Skewness	0.485352661	**25.0%**	668,139
Kurtosis	2.40328663	**50.0%**	959,156
Median	959,156	**75.0%**	1,336,154
Mode	631,504	**80.0%**	1,431,068
Left X	423,004	**90.0%**	1,670,173
Left P	5%	**95.0%**	1,839,957
Right X	1,839,957	**97.5%**	1,960,133
Right P	95%	**99.0%**	2,064,314
#Errors	0		

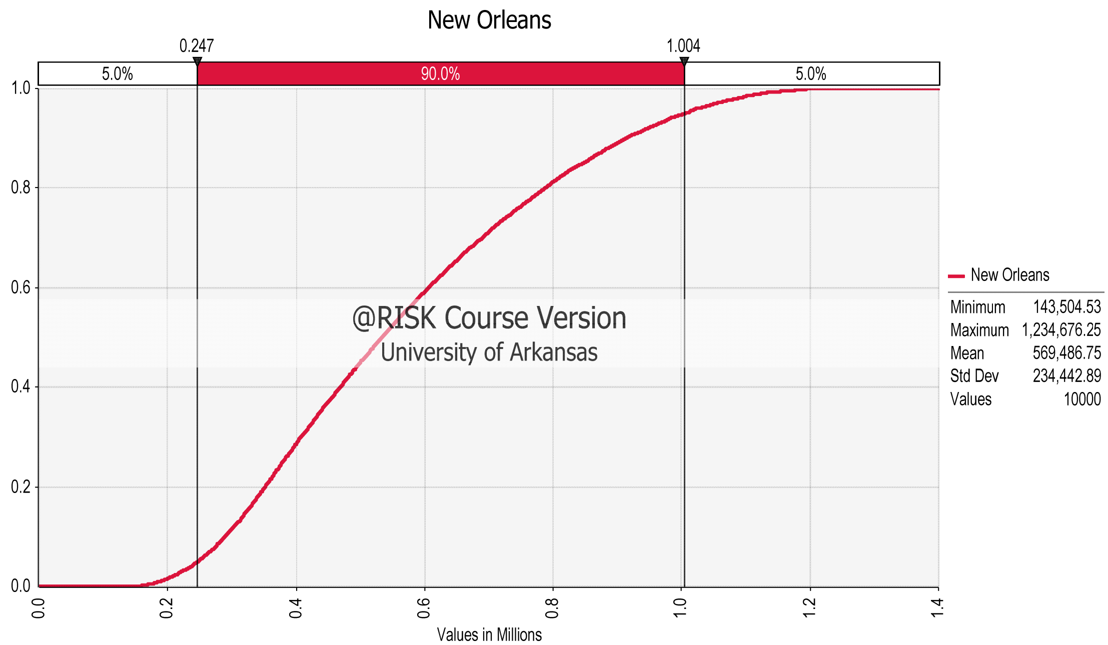
Appendix 4.BB - Tornado Graph for Port of New Orleans – Cost Model



Appendix 4.CC - Histogram for port of New Orleans – Cost Model



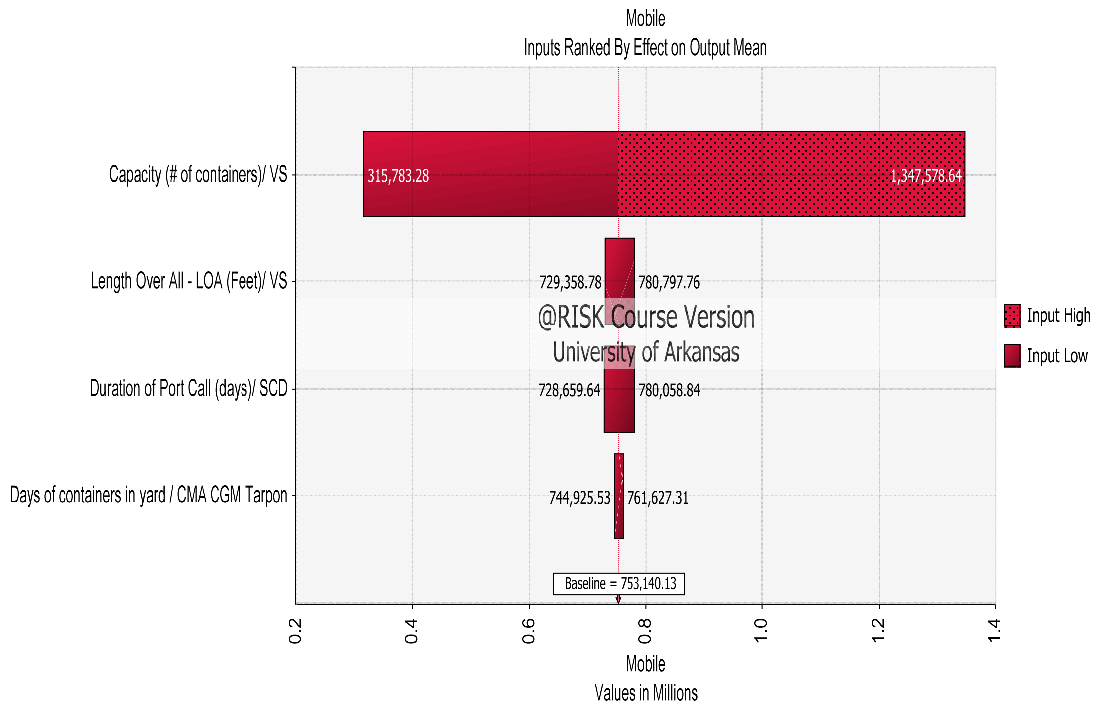
Appendix 4.DD - Cumulative Ascending Distribution for Port of New Orleans – Cost Model



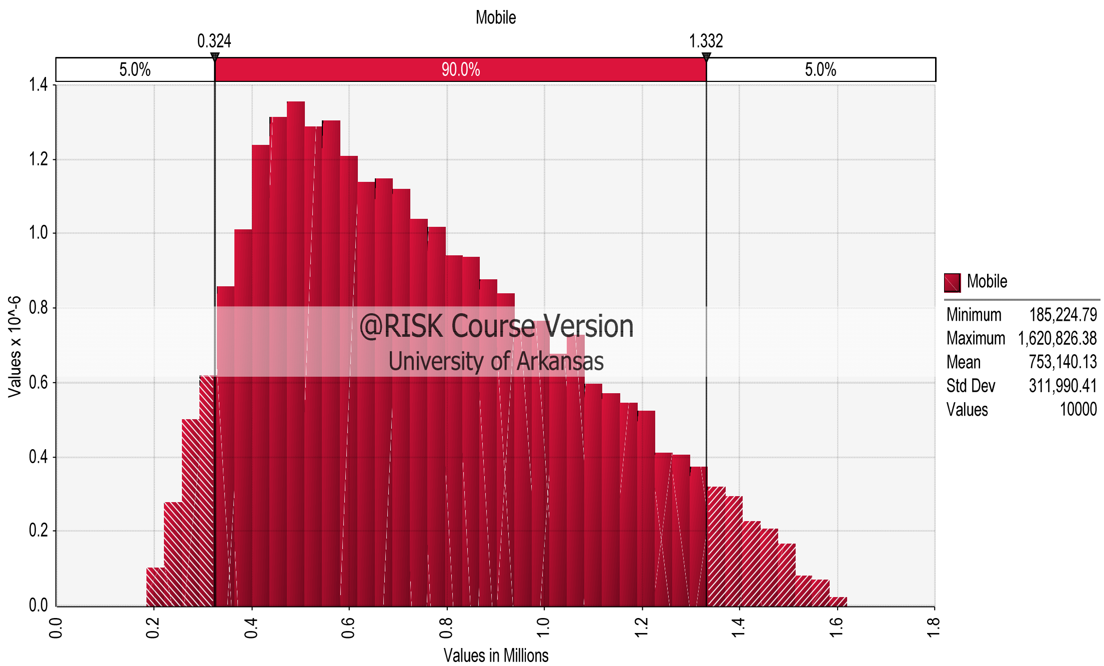
Appendix 4.EE - Summary Statistics for New Orleans Total Cost

Summary Statistics for New Orleans			
Statistics		**Percentile**	
Minimum	138,127	**1.0%**	187,729
Maximum	1,227,280	**2.5%**	215,094
Mean	569,494	**5.0%**	246,985
Std Dev	234,315	**10.0%**	290,108
Variance	54903391875	**20.0%**	351,103
Skewness	0.486848141	**25.0%**	378,500
Kurtosis	2.409129518	**50.0%**	533,723
Median	533,723	**75.0%**	735,455
Mode	422,694	**80.0%**	785,696
Left X	246,985	**90.0%**	912,187
Left P	5%	**95.0%**	1,002,882
Right X	1,002,882	**97.5%**	1,068,203
Right P	95%	**99.0%**	1,124,310
#Errors	0		

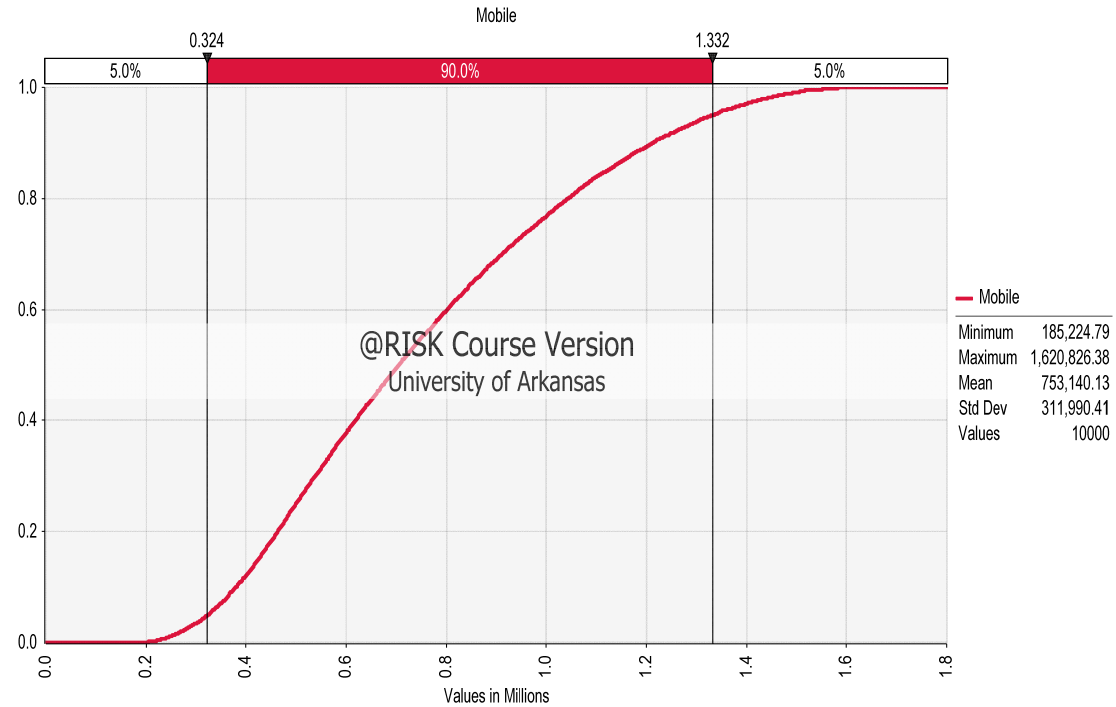
Appendix 4.FF - Tornado Graph for Port of Mobile – Cost Model



Appendix 4.GG - Histogram for Port of Mobile – Cost Model



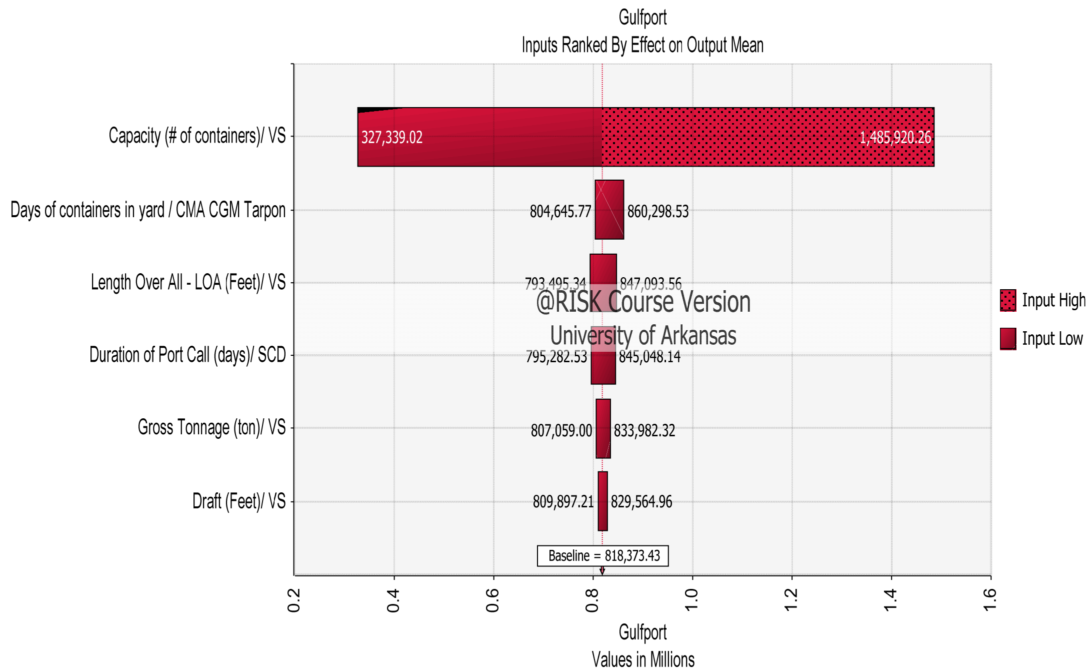
Appendix 4.HH - Cumulative Ascending Distribution for Port of Mobile – Cost Model



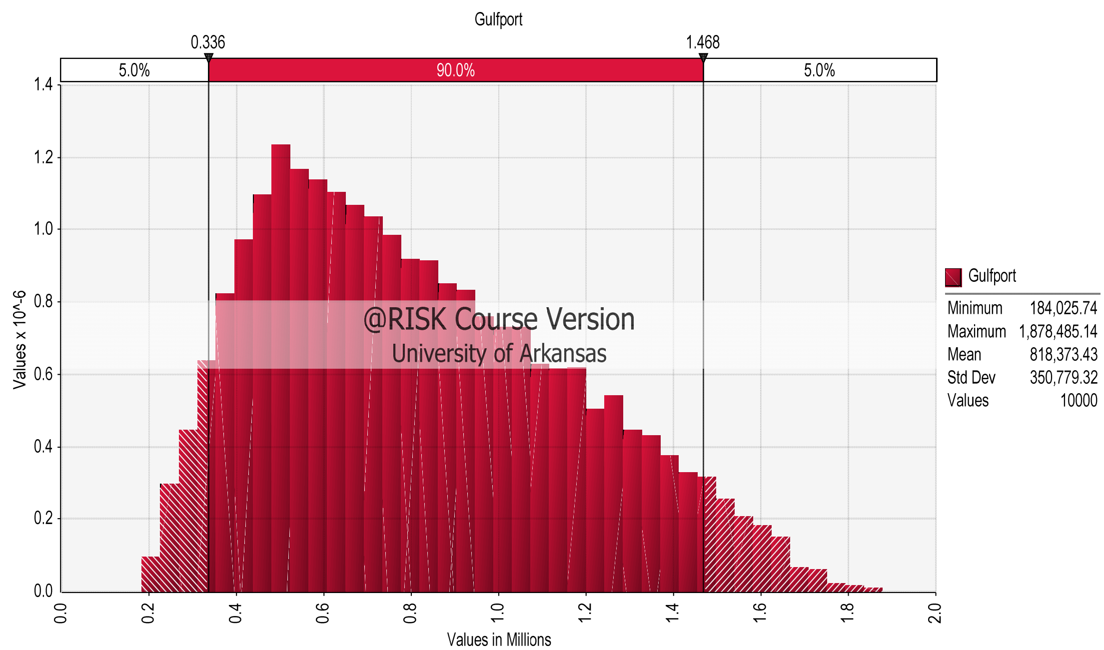
Appendix 4.II - Summary Statistics for Mobile Total Cost

Summary Statistics for Mobile			
Statistics		**Percentile**	
Minimum	177,448	**1.0%**	244,718
Maximum	1,617,266	**2.5%**	280,847
Mean	753,151	**5.0%**	323,342
Std Dev	311,846	**10.0%**	380,881
Variance	97248046230	**20.0%**	463,549
Skewness	0.484053567	**25.0%**	498,725
Kurtosis	2.404930103	**50.0%**	706,413
Median	706,413	**75.0%**	973,796
Mode	472,856	**80.0%**	1,041,191
Left X	323,342	**90.0%**	1,208,947
Left P	5%	**95.0%**	1,330,200
Right X	1,330,200	**97.5%**	1,416,081
Right P	95%	**99.0%**	1,491,670
#Errors	0		

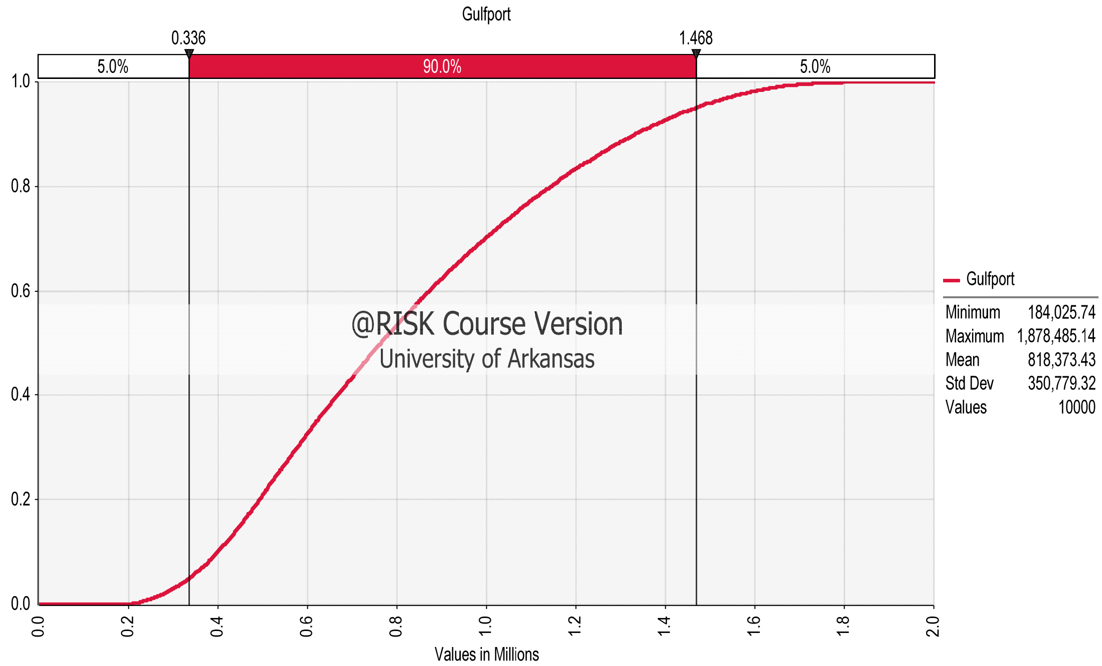
Appendix 4.JJ - Tornado Graph for Port of Gulfport – Cost Model



Appendix 4.KK - Histogram for Port of Gulfport – Cost Model



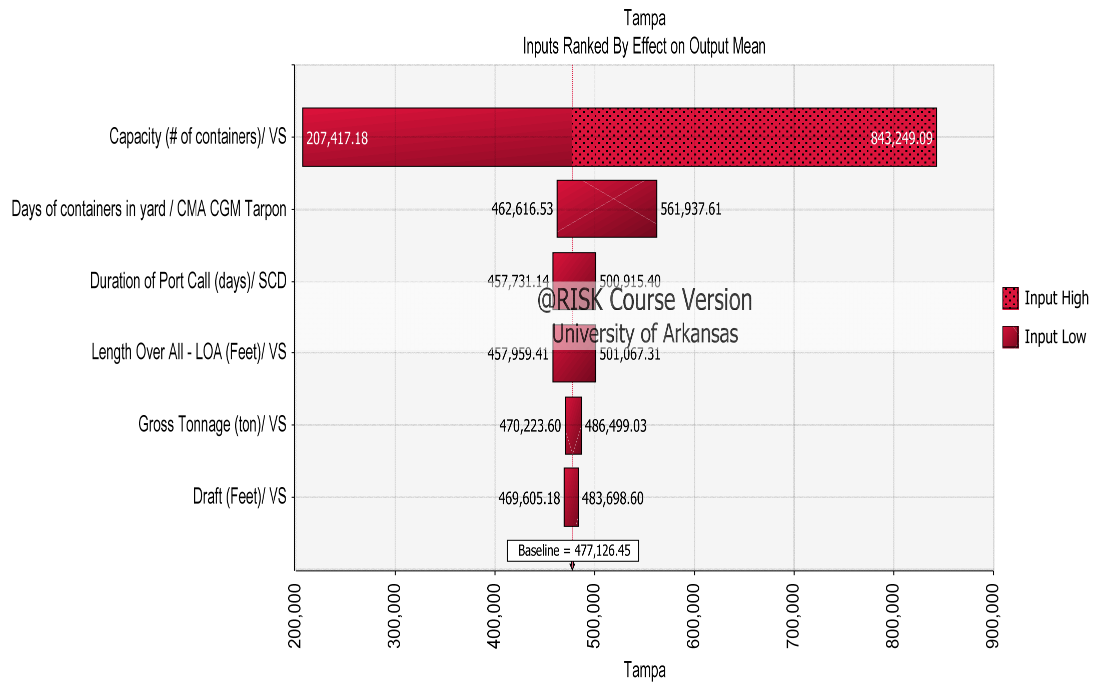
Appendix 4.LL - Cumulative Ascending Distribution for port of Gulfport – Cost Model



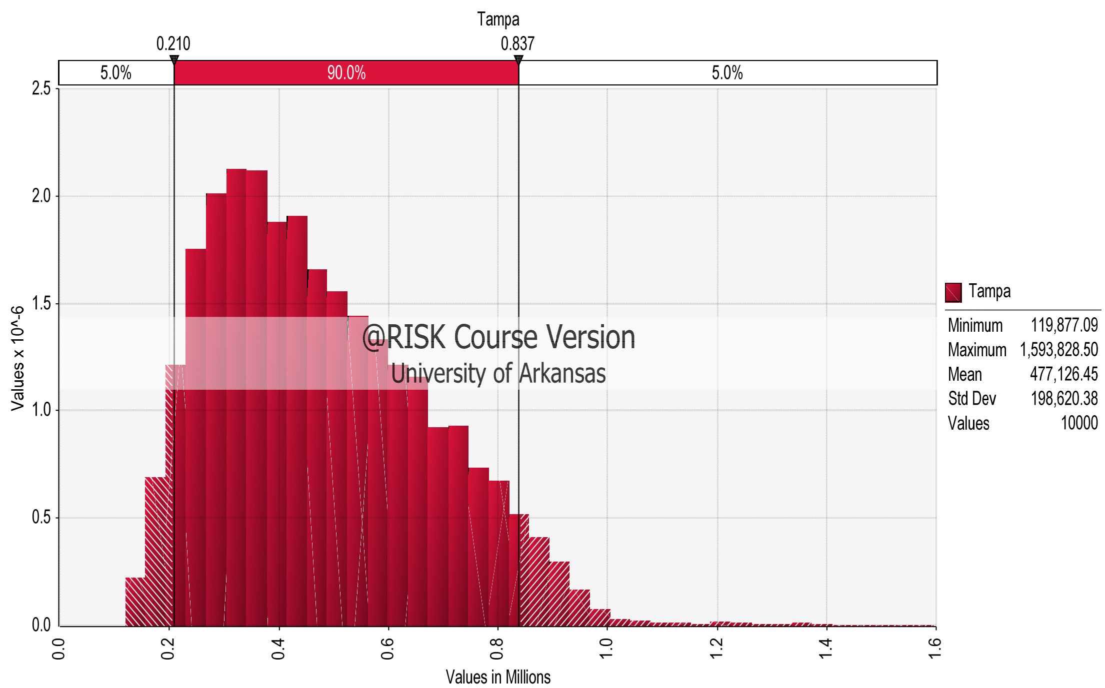
Appendix 4.MM - Summary Statistics for Gulfport Total Cost

Summary Statistics for Gulfport			
Statistics		**Percentile**	
Minimum	176,980	**1.0%**	247,103
Maximum	1,868,164	**2.5%**	288,100
Mean	818,377	**5.0%**	335,723
Std Dev	350,642	**10.0%**	401,042
Variance	1.2295E+11	**20.0%**	491,504
Skewness	0.493561334	**25.0%**	532,855
Kurtosis	2.42308316	**50.0%**	765,060
Median	765,060	**75.0%**	1,066,049
Mode	502,771	**80.0%**	1,140,286
Left X	335,723	**90.0%**	1,332,980
Left P	5%	**95.0%**	1,466,462
Right X	1,466,462	**97.5%**	1,564,210
Right P	95%	**99.0%**	1,652,739
#Errors	0		

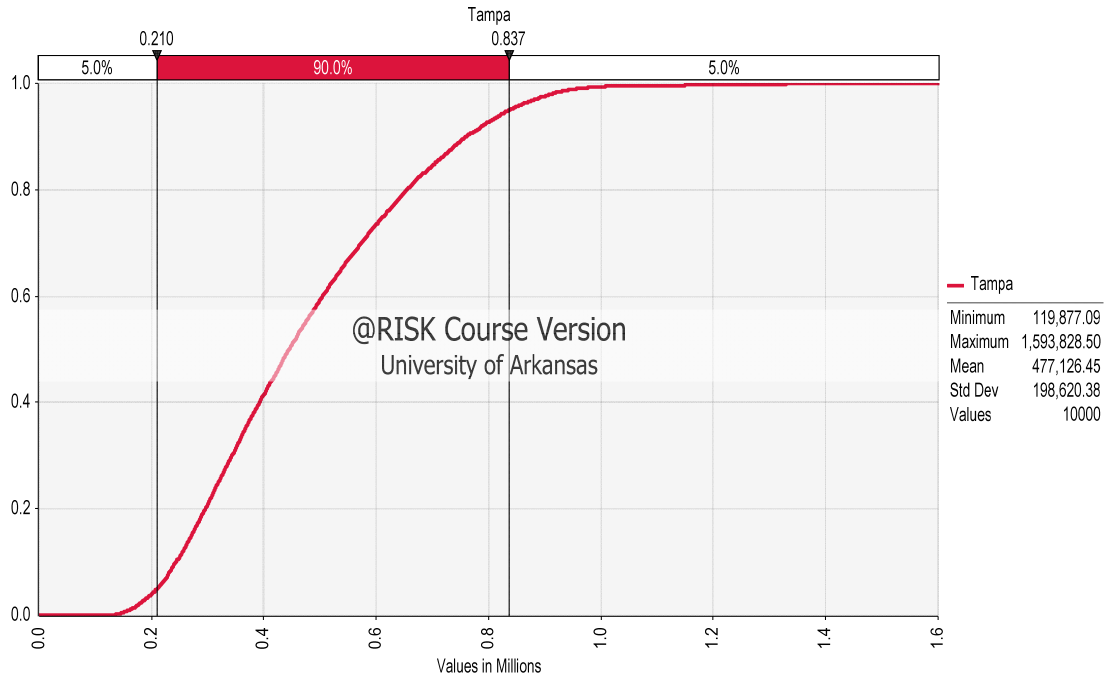
Appendix 4.NN - Tornado Graph for Port of Tampa – Cost Model



Appendix 4.OO - Histogram for the Port of Tampa – Cost Model



Appendix 4.PP - Cumulative Ascending for Port of Tampa – Cost Model



Appendix 4.QQ - Summary Statistics for Tampa Total Cost

Summary Statistics for Tampa			
Statistics		**Percentile**	
Minimum	109,249	**1.0%**	159,717
Maximum	1,678,376	**2.5%**	183,252
Mean	477,311	**5.0%**	207,009
Std Dev	199,372	**10.0%**	246,207
Variance	39749147097	**20.0%**	295,765
Skewness	0.703389739	**25.0%**	318,365
Kurtosis	3.399005167	**50.0%**	446,301
Median	446,301	**75.0%**	610,406
Mode	340,652	**80.0%**	652,226
Left X	207,009	**90.0%**	758,663
Left P	5%	**95.0%**	838,975
Right X	838,975	**97.5%**	898,204
Right P	95%	**99.0%**	964,572
#Errors	0		

Appendix 4.RR - Certification of Student Work

UNIVERSITY OF ARKANSAS

College of Engineering
Department of Industrial Engineering

Kim LaScola Needy, PhD
Dean of Graduate School and International Education
University of Arkansas

March 7, 2017

I am writing to verify that Rivelino R. De Icaza H. completed more than 51% of the work for the chapter titled "Port Selection Decision Support System: The Influence of Panama Canal Expansion in Gulf Coast Ports" in his dissertation. He is also the first author of this article.

Sincerely,

G. S. Parnell
DR. GREGORY S. PARNELL
Research Professor and Director, M.S. in Operations Management

4207 Bell Engineering Center • Fayetteville, Arkansas 72701 • 479-575-3156 • 479-575-8431 Fax
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Appendix 4.SS - Institutional Review Board (IRB) Approval

UNIVERSITY OF ARKANSAS

Office of Research Compliance
Institutional Review Board

November 2, 2016

MEMORANDUM

TO:	Rivelino De Icaza Gregory Parnell
FROM:	Ro Windwalker IRB Coordinator
RE:	New Protocol Approval
IRB Protocol #:	16-10-151
Protocol Title:	*Multiobjective Decision Analysis for Port Selection using a Decision Support System: The Influence of Panama Canal Expansion*
Review Type:	☒ EXEMPT ☐ EXPEDITED ☐ FULL IRB
Approved Project Period:	Start Date: 11/02/2016 Expiration Date: 11/01/2017

Your protocol has been approved by the IRB. Protocols are approved for a maximum period of one year. If you wish to continue the project past the approved project period (see above), you must submit a request, using the form *Continuing Review for IRB Approved Projects*, prior to the expiration date. This form is available from the IRB Coordinator or on the Research Compliance website (https://vpred.uark.edu/units/rscp/index.php). As a courtesy, you will be sent a reminder two months in advance of that date. However, failure to receive a reminder does not negate your obligation to make the request in sufficient time for review and approval. Federal regulations prohibit retroactive approval of continuation. Failure to receive approval to continue the project prior to the expiration date will result in Termination of the protocol approval. The IRB Coordinator can give you guidance on submission times.

This protocol has been approved for 10 participants. If you wish to make *any* modifications in the approved protocol, including enrolling more than this number, you must seek approval *prior to* implementing those changes. All modifications should be requested in writing (email is acceptable) and must provide sufficient detail to assess the impact of the change.

If you have questions or need any assistance from the IRB, please contact me at 109 MLKG Building, 5-2208, or irb@uark.edu.

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Appendix 4.TT - Institutional Review Board (IRB) Protocol

Attached Sheet as per Item #9 of IRB Form

Title: Multiobjective Decision Analysis for Port Selection using a Decision Support System: The influence of Panama Canal Expansion

Investigator(s): Rivelino De Icaza, Ph.D. Candidate
Gregory Parnell, Ph.D., Faculty Advisor
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College of Engineering
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Description:
You are being asked to participate in my research project to evaluate the port selection of the principal trade route that could be affected by the Panama Canal expansion: the Northeast Asian Transpacific route to the US Gulf Coast. If you agree, you will participate in a video conference interview at your convenience for around 1 hour. You will be asked to review the list of attributes used to measure the port selection decision in order to add or eliminate attributes in the model. In addition, using your expertise in the topic, you will be asked to provide weights and uncertainties percentages for each of the attribute of the port selection model.

You are welcome to ask any questions you may have about the study before you agree to take part. Participation in this research is completely voluntary, and you are free to choose not to be interviewed, or even to change your mind at any point during the interview. There are no anticipated risks to participating in the study.

All information will be recorded anonymously and your name will not be attached to your answers in my records.

Please keep this page for your records. If you have any questions about the research at any time, please feel free to contact the research or his Faculty Advisor at the contact information listed above. If you have any concerns or questions about your rights as a research participant, you can contact the University of Arkansas' Compliance Coordinator, Ro Windwalker, at 479-575-2208 or irb@uark.edu.

Your participation in the interview indicates your consent to use your responses in my research.
Thank you for your help!

IRB #16-10-151
Approved: 11/02/2016
Expires: 11/01/2017

5. Conclusion and Future Work

This chapter presents the findings of the dissertation research and proposes future research related to the port selection decision problem. First, a port selection literature review was analyzed by timeline, journals, geographical location, and focus of studies. In addition, it summarized the multiple criteria and the models used for the port selection literature. With the port traffic increase trend and the constant changes in the maritime industry over recent years, the port selection topic has become an active area of research. The port selection articles are concentrated in the maritime and transportation journals. In addition, few articles have focused on the global perspectives of supply chains or regional areas; instead the focus has been on specific regions within a country. Most of the port selection studies have been focused on shipping lines, shippers and freight forwarders. In addition, multiple and conflicting criteria are found in the port selection literature, with a variation of the criteria used through the studies depending on the characteristics being analyzed in the research. Many models have been used in the port selection literature, with the AHP decision analysis technique being the most popular among researchers.

The next chapter demonstrated the application of the multi-attribute value theory (MAVT) with the valued-focused thinking (VFT) approach using the criteria and port alternatives of a published port selection study for West Africa. The study used the AHP methodology. In addition, the research also applied the traditional Alternative-Focused Thinking (AFT) approach in order to emphasize that more insights can be obtained using the VFT approach. It was demonstrated in the research that quantitative port data is available and can be used to score port alternatives, rather than using data from surveys and questionnaires.

Finally, chapter 4 presented the port selection decision support system for shipping lines using the main container ports in the Gulf Coast of the United States of America. The research presented the case of the influence of the Panama Canal Expansion in the port selection decision, which enables that bigger containerships to use the ports located in the Gulf Coast. The decision support system used the MODA with VFT approach, and it was demonstrated that quantitative port data is available on the internet and can be used to score alternatives in the model. In addition, input from an industry expert was used for the development of the value hierarchy and the swing weight matrix. For the development of the cost model, data such as tariff documents, were obtained from port websites. Also a probabilistic model was included in the research, detailing the uncertainties that impact the port selection decision. The Monte Carlo Simulation was used to determine the risks presented by each port alternative, as well as their probabilities. The development of the decision support system demonstrated that important elements mentioned above are considered in the port selection decision. Therefore, it represents a practical tool for shipping lines' decision makers to select the best port that will add the most value to the global supply chains of their customers. In addition the model used in this research not only provides a ranking of the port alternatives according to their objectives, but also offers shipping lines opportunities to achieve the best possible service for their customers.

5.1 Future Work

Potential future research could involve port selection studies with different scopes and techniques. Studies of greater scope could focus on incorporating transshipments into port selection decisions for shipping lines and adding a second set of ports to offer more route network alternatives for shipping lines. Studies using different technique could employ an optimization model and a comparison of two methodologies such as MODA vs Net Present Value.

First, a study could assess the impact of transshipments on port selection. Transshipments could gain more importance due to the current maritime transportation trend of ordering larger container vessels. Within the global fleet, the average ship size has displayed a cumulative annual growth of 18.2 per cent for the period 2010-2015. For 2016, the average size of vessels ordered was 8,508 TEUs, which represents more than double the current average size operating in the market (UNCTAD, 2016). Many ports have not increased their capacity, and others are working on adapting their facilities to meet the new demands. Therefore, transshipments could play an important role for some ports and shipping lines. Second, a study could be conducted that adds more U.S. port alternatives so that decision makers could expand their options for their shipping network. Two different sets of ports, located in different regions such as the Gulf Coast and the East Coast, could be compared to provide more insights to the decision makers. In addition both regions can be the destination of vessels that crossed through the Panama Canal. Moreover, the proposed methodology could be used by researchers to study the port selection problem in other regions of the world. Third, a possible study could compare different approaches such as MODA vs Net Present Value, or any other decision analysis technique. For the MODA approach, the weight elicitation process for each value measure could include the participation of more industry experts, so that a consensus could be achieve for the weights. This could minimize biases that can arise from an opinion of only one expert. It can also contribute to the literature and the industry to illustrate the approach that offers the most advantages and reliable results to decision makers.

Fourth, a future study could develop an optimization model that maximizes the value of the port subject to constraints of availability on container capacity, depth, budget, supply chain services, connectivity, etc. Decision makers evaluating the use of a significant number of route alternatives and constraints will find the optimization approach useful.

Bibliography

UNCTAD. (2016). *Review of Maritime Transport.* Geneva: United Nations.