RISK ASSESSMENT IN THE UPSTREAM CRUDE OIL SUPPLY CHAIN:

LEVERAGING ANALYTIC HIERARCHY PROCESS

A Dissertation
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Sciences

By

Charles Awoala Briggs

In Partial Fulfillment of the Requirements
for the Degree of
DOCTOR OF PHILOSOPHY

Major Program:
Transportation and Logistics

April 2010

Fargo, North Dakota

North Dakota State University
Graduate School

Title

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

DOCTOR OF PHILOSOPHY

ABSTRACT

Briggs, Charles Awoala, Ph.D., Transportation and Logistics Program, College of Graduate and Interdisciplinary Studies, North Dakota State University, April 2010. Risk Assessment in the Upstream Crude Oil Supply Chain: Leveraging Analytic Hierarchy Process. Major Professor: Dr. Denver Tolliver.

For an organization to be successful, an effective strategy is required, and if implemented appropriately the strategy will result in a sustainable competitive advantage. The importance of decision making in the oil industry is reflected in the magnitude and nature of the industry. Specific features of the oil industry supply chain, such as its longer chain, the complexity of its transportation system, its complex production and storage processes, etc., pose challenges to its effective management. Hence, understanding the risks, the risk sources, and their potential impacts on the oil industry's operations will be helpful in proposing a risk management model for the upstream oil supply chain.

The risk-based model in this research uses a three-level analytic hierarchy process (AHP), a multiple-attribute decision-making technique, to underline the importance of risk analysis and risk management in the upstream crude oil supply chain. Level 1 represents the overall goal of risk management; Level 2 is comprised of the various risk factors; and Level 3 represents the alternative criteria of the decision maker as indicated on the hierarchical structure of the crude oil supply chain. Several risk management experts from different oil companies around the world were surveyed, and six major types of supply chain risks were identified: 1) exploration and production, 2) environmental and regulatory compliance, 3) transportation, 4) availability of oil, 5) geopolitical, and 6) reputational. Also identified are the preferred methods of managing risks which include; 1) accept and control the risks, 2) avoid the risk by stopping the activity, or 3) transfer or share the risks to other companies or insurers. The results from the survey indicate that the most important risk to manage is transportation risk with a priority of .263, followed by exploration/production with priority of .198, with an overall inconsistency of .03.

With respect to major objectives the most preferred risk management policy option based on the result of the composite score is accept and control risk with a priority of .446, followed by transfer or share risk with a priority of .303. The least likely option is to terminate or forgo activity with a priority of .251.

ACKNOWLEDGEMENTS

I would never have been able to finish this dissertation without the support and guidance of several individuals. I am indubitably thankful to my committee chairman, Dr. Denver Tolliver, for his excellent guidance, caring, and patience; for providing me with an excellent atmosphere for completing this research; and for support throughout my doctoral program endeavor. Without his guidance and persistent help, this dissertation would not have been possible. I extend my gratitude to the committee members, Drs. Denver Tolliver, Joseph Szmerekovsky, Brian Kalk, and Peter Oduor for accepting to serve. Without your support and best suggestions, it would have been next to impossible to complete this dissertation. I thank you all for your contributions and good-natured support.

I am thankful and indebted to Dr. Denver Tolliver, Director of the Ph.D Program and Associate Director, Upper Great Plains Transportation Institute, for his inspiration and support in providing me with all available resources to enhance my doctoral program journey. Without him, it would not have been possible for me to complete the academic journey. I am grateful to many people who shared their memories and experiences, especially Ms. Jody Bohn, Academic Program Coordinator and Assistant to the Director of Education Programs, for her advice and encouragement, support and constant willingness to help and also for coordinating and overseeing the administrative concerns that made it possible for me to complete my studies. My thanks to Dr. Brian Kalk, who generously shared his meticulous ideas and work on energy and environmental issues and insight, which expanded my own work and from whom the inspiration for the choice of research topic came and also for his support throughout my doctoral program. I benefited from Dr.

Oduor's proactive thoughts and discussions, and from Dr. Szmerekovsky, who provided his perspective and constructive criticism and feedback on my papers in real-time.

Furthermore, I acknowledge the financial support from Upper Great Plains Transportation Institute. My thanks must also go to Mr. Gene Griffin, Director, Upper Great Plains Transportation Institute and other staff members for their support and for making my stay in the program a pleasant experience. My thanks also to my friend and classmate Khalid Bachkar, and many other friends, who assisted, advised, and supported my efforts over the years. Especially, I need to express my gratitude and deep appreciation to Dr. Chris Iheanyi Enyinda and Peter Ifeka, whose friendship, hospitality, knowledge, and wisdom have supported and enlightened me over many years of friendship. My gratitude to special friends, including Dr. Emeka Dunu for his guidance and constructive advice, which was invaluable while seeking approval for my study leave, and to Esther and Promise Ogwu for their kindness and care to my child Charlesbury while I was away for my doctoral program. I heartily thank Tonte Victoria Briggs and Ogechi Nwagbara for their consistent and tireless moral support throughout this academic journey.

My thanks must go also to my dearest parents Chief Rosebury Isaac Briggs and the late Mrs. Eziwayn "Whyte" Rosebury Briggs, and Grandmothers Mrs. Iwo "Sisi" Ekine Briggs "who consistently helped me keep perspective on what is important in life and shown me how to deal with reality while growing up" and the late Mrs. Daughter "Dede" Obene Whyte, for who and what I am today. I greatly appreciate every one of you. Special thanks to all my siblings, for their altruistic encouragement throughout the years. Without you, this proud and victorious moment would not have been possible. Above all I am indebted to my children, "Ethel Ayanate, Pamela Ibiso, Yvonne Tonte, Charles Jr.,

Chandler Alaiyi, and Charlesbury Awoala" for their support, encouragement, and understanding while I was away on study leave and completing this dissertation. Thanks for being wonderful, intelligent, and loving children. I love you all so dearly with all my heart.

DEDICATION

This dissertation is dedicated to my children "Ethel Ayanate, Pamela Ibiso, Yvonne Tonte, Charles Jr., Chandler Alaiyi and Charlesbury Awoala". Above all, in memory of my beloved mother, Mrs. Eziwayn "Whyte" Rosebury Briggs, whose sudden death took place during this educational endeavor. Mother, I will forever miss you.

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CHAPTER 1. INTRODUCTION

The emergence of the global corporation and the global supply chain has brought about parallel changes in today's global economy; however, supply chain management has become ever more complex. In recent years, the ever increasing technical complexity of standard consumer goods, combined with the ever increasing size and depth of the global market, indicate that the connection between vendors and consumers is usually the link in the supply chain. Supply chain is a link of resources and processes that begins with the sourcing of raw materials and extends through the delivery of end items to the final customer (Trkman, Mojca, &Jurij, 2005). In a supply chain, a company is linked to its upstream suppliers and downstream distributors as materials, information, capital, labor, technology, financial assets, and other assets that flow through the supply chain. For example, wall-mart is part of the supply chain for hardware, clothing, electronics, and various other products (Mentzer et al., 2001). However, Christopher (1992) defines supply chain as: "the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer". Traditionally, a supply chain may also be defined as an integrated process where a number of various suppliers, manufacturers, distributors, and retailers, work together to acquire raw materials which are converted into final goods that are delivered to the retailer.

Theoretically, supply chain management (SCM) emphasizes the management of the entire supply chain as one entity, and the practice of supply chain management is to extend the internal business process into the supply chain thus developing an integrated supply chain (Fox, 1999).

A supply chain at its highest level is comprised of two basic integrated processes as shown in Figure 1:

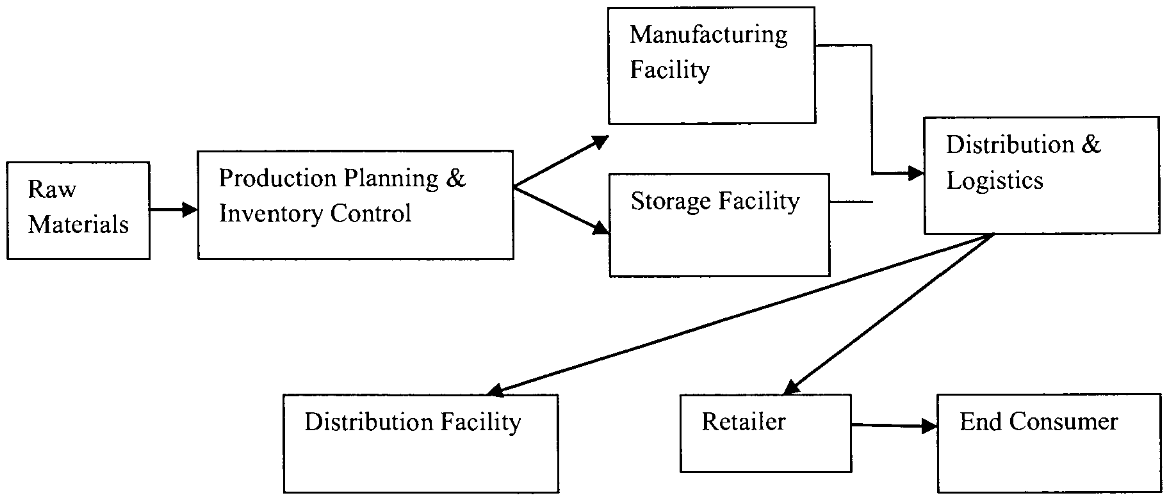


Figure 1. Supply Chain Process.

1. The production planning and inventory control process, which is comprised of the manufacturing and storage processes. This process includes the design and management of the entire manufacturing process.

2. The distribution and logistics process, which determines how products are retrieved and transported from the warehouse or storage facility to the retailer. These products may be transported to the retailer directly or through distribution facilities, which in turn transport the product to the retailer, and finally to the final consumer. These processes interact with each other to form an integrated supply chain (Beamon, 1998).

Traditionally, organizations are divided into several operating functions, namely, marketing, purchasing, production, planning, financing, etc. The purchasing function has gained great importance in supply chain management due to factors such as globalization, increased value added in supply, and accelerated technological change.

With the ever-increasing complexity in the global marketplace, a higher level of supply chain performance is being pursued in order to deliver better value to both consumers and businesses. However, in order to reach the proverbial pot of gold, a fully integrated and synchronized supply chain is required (Sewell, 1999).

In today's organizations, supply chain globalization at some level is imperative and, therefore, achieving global supply chain excellence is inevitable. Since global supply chain management seek to provide maximum customer service at the lowest possible cost, it has also been advocated that the supply-chain be managed as an integrated and coordinated system (Forrester, 1958; Forrester, 1961). Global supply chain management (GSCM) is an important part of modern business and has resulted in new logistical complexities. However, to remain competitive companies are seeking to expand global markets and increase revenues while reducing cost by outsourcing materials, parts procurement, and even manufacturing to foreign countries with lower infrastructure costs. One key traditional objective of supply chain management (SCM) is to lower the cost required to provide the necessary level of customer service to a specific segment (Houliham, 1988; Jones & Daniel, 1985; Stevens, 1989). One of the most significant paradigm shifts of modern business management is that individual businesses no longer compete as solely autonomous entities, but rather as supply chains (Lambert & Cooper, 2000). Ultimately, low cost and differentiated service help build a competitive advantage for the supply chain (Ellram & Cooper, 1990; Tyndall, Gopal, Wolfgang, & Kamauff, 1998; Cavinato, 1992; Cooper, Douglas, Lambert, & Janus, 1997; Novack, Langley, & Rinehart, 1995; Lee & Billington, 1992). In essence, supply chain management emphasizes the improvement of both efficiency (cost reduction) and effectiveness (customer service) to achieve a competitive advantage, which leads to profitability. Maximizing profits in a multi-national environment includes sourcing from locations that offer the lowest total procurement cost, manufacturing and assembling products in the least cost countries, and marketing in high potential demand centers (Al-Hashim, 1980).

To contain cost and gain a competitive advantage, multi-national corporations (MNC) across various industries pursue ambitious innovative improvement initiatives, including total quality management, global just-in-time supply chain management, lean manufacturing, lean supply chain logistics, efficient consumer response, global outsourcing/sourcing, and co-manufacturing (Enyinda, Briggs, & Ogbuehi, 2008). In addition to cost reduction, the supply chain management approach also facilitates customer service improvements. Successful implementation of supply chain management (SCM) enhances customer value and satisfaction; this in turn facilitates competitive advantage for the supply chain, and ultimately improves the profit of the supply chain.

In today's complex global supply chains, delivering products and services to markets is becoming faster and cheaper than ever before, but it also carries greater disruption risk from the source of raw materials to delivery to the consumer. As a result, managing global supply chain risk has become a critical component of supply chain management. Global supply chain management has become one of the most discussed disciplines in the popular press because of variables such as the globalization of production and market, competitive pressure, information and communication technology, consumer behavior, mass customization and supply chain network complexity, which have become increasingly uncontrollable, vulnerable, and susceptible to disruptions (Enyinda, Tolliver, & Szmerekovsky, 2007). Global supply chains (GSC) are inherently fragile with any disruption, as the supply chain failure can be costly and lead to significant delays in customer delivery. Disruption risk has received increasing attention in the last few years. In global supply chains, the potential for disruption comes in many packages, from large-scale natural disasters and terrorist attacks to plant manufacturing fires, widespread electrical blackouts, and operational contingencies such as shipping ports that are too small to handle the flow of goods coming into a country (Jianxin, 2008). In recent years, leaner just-in-time globalized supply chains are becoming increasingly vulnerable to both natural and man-made disruption. For example, the terrorist attacks on September 11, 2001, not only impacted the way goods are shipped and services delivered. More importantly, through the grave loss of life, many relationships between suppliers and customers were affected (Sheffi, 2005). The attack did not change the threat or the risk: the risk of disruption just became apparent, causing supply chain executives to become worried about supply chain disruptions as security concerns, terrorist attacks, and the transformation of supply chain into lean, complex, and globally dispersed entities has increased the risks of disruption. Firms are vulnerable not only to attacks on their own assets, but also to attacks on their suppliers, customers, transportation providers, communication lines, and other elements in their eco-system (Sheffi, 2001). The global supply-chains are becoming more vulnerable and as a result, it has become imperative for companies to monitor their supply chain partners closely keep supply chains flexible, and integrate disruption risk management into every aspect of the supply chain operation.

The upstream crude oil supply chain networks are also vulnerable and susceptible to disruption risk in drilling, pipeline operation, transportation, and distribution. All these different entities depend on the flow of information to make appropriate logistical and supply chain decisions. For example, the recent disruptions by Hurricane Rita, Hurricane Katrina, earthquakes and other natural disasters has given rise to the need for proper information infrastructure to share demand and other data between the entities in the supply chain and support various logistical and supply chain decisions. However, these vulnerabilities are just one-time events, for example, the attack on the World Trade Center, the west coast port strike in 2002, and the Northeast blackout in 2003 (Hendricks & Singhal, 2005). Since 9/11 one of the biggest risks to global supply chain is security.

The presence of oil has negative social and environmental impacts, from tanker accidents; further, routine activities such as seismic exploration and drilling have damaged the atmosphere and several ecosystems around the world. For example crude oil spills from tanker ship accidents have damaged ecosystems in Alaska, the Galapagos Islands, Spain, and many other places around the globe. There are incidences of the search for oil, the likeliness of the oil industries to act in their best interests to optimize their profits, and the environmental destruction of oil leaks, that lead to protests and revolts by affected community groups. One unfortunate aspect of the oil industry is the heightened level of displaced peoples often associated with oil extraction in developing states. Once oil is discovered, it becomes the property of that country or, in the case of sales of concessions, the property of the company that first laid claim to it. In many cases the people who inhabited the region had no claim to the oil or right to the land. A gross example of this is the case of the Niger Delta Region where the Nigerian government has openly seized land and property from its own citizens for the sole benefit of companies such as Shell and British Petroleum (Salas, 2009).

Western countries are in search of new and secure oil farther away from the Gulf countries due to geopolitical risks, especially since 9/11 and the Iraq invasion. However, attention had shifted to West African countries, Central Asia, China and India, although the focus in China and India was more dispersed. In the global environment, the strategies used by the oil importing countries to secure oil reflect their perception of economic and political vulnerability. Overall, the countries that feel threatened by possible embargos, and supply disruptions tend to lean towards bilateral and regional alliances, while those who feel less threatened remain more market oriented in their strategies to secure oil for the economy (Noronha, 2005). Today, scientists fear that the increase in oil tanker traffic and illegal tanker discharges will ultimately lead to rapid degradation of marine environments around the world. However, post 9/11, the U.S. Environmental Protection Agency's Oil Spill Program has played an important role in protecting the environment through prevention of, preparation for, and response to oil spills.

Statement of the Problem

Logistics involves the management of a physical distribution system. The more a physical distribution system is dependent upon mobility and tightly synchronized, the more vulnerable it can be (Rodrigue & Slack, 2002). The oil industry supply chain is like the supply chain of any other industry and is characterized by planning for the supply chain as a whole, sourcing raw material, marketing goods and delivering final products to consumers. The oil industry supply chain is composed of intricate entities that extend from the oil fields to the gasoline stations. The upstream crude oil supply chain has always been considered complex compared to other process industries, such as pharmaceuticals. However, the logistics function is one of the areas that affect supply chain performance in the oil industry. The current separation between the location of oil reserves and the location of oil consumption necessitates that crude oil be transported great distances to the consumer market. This has lead to the development of an increasingly complex transportation system that allows crude oil to be delivered virtually anywhere in the world. Major oil routes now stretch from the Middle East to Japan, from South America to Europe, and from Africa to the United States. Transportation of crude oil occurs via supertankers, barges, trucks, and pipelines (Burger, 1997).

These transportation systems have always been the Achilles' heel of the oil industry, but have become even more so since the emergence of global terrorism. Tankers and pipelines are very vulnerable targets; however, dealing with the issues of crude oil transportation either by maritime means or overland pipelines has become a serious domestic and international concern due to risks and challenges along the supply chain. The logistics network is highly inflexible, which arises from the production capabilities of crude oil suppliers, long transportation lead times, and the limitations of modes of transportation. Every node in the network, therefore, represents a major challenge (Jenkins & Wright, 1998). Many types of disruptions are possible. For example, the Ashland spill in January 1988, Erika in 1991, and Prestige in 2002 whether accidental or human error, put the onus on the oil industry.

The oil industry has for several years made a major impact on global, national, and local economies. Indeed, the main goal for the oil industry is production with high return. One major problem associated with the upstream sector of the oil industry is the high level of uncertainty/risk from exploration, production, to tight transportation, and the supply/delivery process.

Although much research has been conducted on issues regarding the oil industry, with the review of relevant papers and articles, it became apparent that a gap exists in the literature whereby very little was mentioned or deliberated on regarding risks specifically in the upstream sector of the oil industry. This dearth of information does not necessarily indicate there are no relevant risks in the upstream operations, but perhaps these risks are relatively unexplored, or disclosures of such uncertainties and risks may have adverse impacts on the image, credibility, and reputation of the industry. Therefore, making it clear that there is need to focus on the upstream crude oil supply chain risks and the minimization of the risks is a critical issue. Therefore this research will address the upstream crude oil supply chain to underline the importance of risk analysis and risk minimization.

Research Objectives

The boom in market demand for crude oil along with the ease of international trade and the flexibility involved in the oil industry's supply chain has made its management more complex and more challenging (Coia, 1999; Morton, 2003). Christopher (2005), stated: Global competition and outsourcing have caused the fragmentation of the supply chain, and supply chain excellence is now a prerequisite for competitive advantage. However, La Londe (1997) propose that supply chain management, (SCM) aims to deliver enhanced customer service and economic value through synchronized management of the flow of physical goods and associated information from sourcing to consumption. Today, efficient supply chain management including the oil industry has become critical to all businesses that anticipate benefits ranging from reduced lead times to increased profitability. Despite the importance of supply chain management, the growing complexities and increasing awareness among practitioners, and the concepts of supply chain vulnerability and its managerial counterpart, supply chain risk management in the oil industry is still in its infancy (Juttner, Peck, & Christopher, 2003). Therefore, understanding the risks, the risk sources, and their potential impacts on the oil industry's operations will be helpful in managing risk more efficiently and effectively and gaining a strategic advantage in the competitive global market. The objective of this research is to combine concepts from various disciplines, especially logistics and supply chain management, to propose a risk mitigation and management model for the upstream crude oil supply chain. Although there are some methodologies for supply chain vulnerability management that have been used for managing risk in the oil industry, unfortunately the vulnerabilities to the upstream crude supply chain are poorly understood and managed. As a result, the topic has received very little attention in supply chain management literature.

The most essential goal of this research is listed below:

1. Explore potential risk sources in the upstream crude oil supply chain (UCOSC).
2. Model risk management in the UCOSC.
3. Analyze and evaluate the potential impact of risks in the UCOSC.
4. Propose risk treatments (mitigation) in the UCOSC.

To investigate the above risks, the analytic hierarchy process (AHP), a decision-making technique developed in the 1970's by Thomas L. Saaty, will be ideal as it is a suitable methodology to solve decision making problems focusing not on the global oil supply chain as a whole, but on the upstream sector of the crude oil supply chain. AHP has been studied extensively and used in numerous applications for over 20 years (Ho, 2008; Cheong, Jie, Meng, & Lan, 2008). The AHP provides a framework to cope with multiple criteria situations involving intuitive, rational quantitative and qualitative aspects (Siddharth, Subhash, & Deshmukh, 2007). The AHP organizes the basic rationality by breaking down a problem into its smaller and smaller constituent's parts and then guiding decision makers through a series of pairwise comparison judgments to express relative strength or intensity of impact of the elements in the hierarchy (Saaty & Kearns, 1985). AHP is used as a decision method that decomposes a complex decision problem into a hierarchy and is also a measurement theory that prioritizes the hierarchy and consistency of judgmental data provided by a group of decision makers (Wu, Lin, & Chen, 2007). Indeed, it provides a methodology for analyzing risk in the oil industry which, when applied to specific disruption risks, will strategically mitigate the upstream crude oil supply chain risks in new and innovative ways. The exploratory study conducted and the results of the research will help in accomplishing the stated goals in risk management of the upstream sector of the crude oil supply chain.

CHAPTER 2. THE OIL INDUSTRY

The term "oil industry" means companies and persons involved in the production, refining, and marketing of oil. The petroleum-based product means gasoline, diesel fuel, home heating oil, natural gas, or other products derived from the refining of oil or petroleum.

The oil industry is a combination of the global processes of exploration, extraction, refining, transportation, and marketing of petroleum products. Global demand for oil products is the fundamental driver of the oil industry; a relevant portion of the world economy and the growing worldwide welfare still relies on oil product consumption, both for industrial production and for transportation. The evolution of the Oil industry dates back thousands of years. Oil from its discovery was used in the Middle East in paints, lighting, waterproofing of boats and baskets, and even in some cases medication. Whale oil was used as a source of domestic light, which lead to an increase in demand for whales and subsequently an increase in the price of whale oil. As a result, commercial, industrial, and domestic users started seeking an alternative source, which later became widely known as "Black Gold" (Dimitrova & López, 2005). Land oil wells were found below the seabed, which gave rise to exploration and the building of the first oil well in the open waters of the Gulf of Mexico.

In the 1920s land oil wells were found in Europe, and in the 1960s, exploration began in the North Sea, although without success until 1969 when a new field was discovered and explored west of Scotland in the Atlantic. Indeed, from 1948 to 1972, world oil consumption increased dramatically, hence this period was named "the golden age of oil". In 1960, the Organization of Petroleum Exporting Countries (OPEC) was formed, to unify the petroleum policies of the major 12 oil producing and exporting countries and began to control the oil business that benefitted its members. In 1961 the Organization for Economic Cooperation and Development (OECD) was formed which helped member countries expand in free trade and cooperate in issues of international economic importance: for example, dealing with the OPEC oil cartel.

In recent years, access to and control over oil is increasingly as important as actual ownership. As a result private companies are exerting critical control over the industry (O'Rourke & Connolly, 2003). Oil producing countries frequently exhibit some sort of nationalistic attitude towards their countries' natural resource endowments, hence the national oil companies (NOCs) are presumed to be the custodians of their countries' natural resources. A national oil company (NOC) is an oil company fully, or in the majority, owned by a national government. National oil companies that operate as an extension of the government or a government agency, including Saudi Aramco (Saudi Arabia), Pemex (Mexico), and PDVSA (Venezuela), support their government's programs either financially or strategically. The international oil companies (IOCs), including ExxonMobil, Royal Dutch Shell, and BP, are owned by their shareholders with the objective of maximizing shareholder's value. In contrast, the owners or shareholders of the national oil companies are the governments. As a result, NOCs were intended at their creation to do more than simply produce oil or gas for a nation (Marcel, 2006; McPherson, 2003; Stevens, 2008a; Van der Linde, 2000).

In 2000, six of the top ten companies were state owned and operated, while in 2006, five of the top ten companies could be classified as state owned and operated. Table 1 below shows a ranking of the top ten world oil companies.

Table 1. Comparative Ranking of the Top Ten World Oil Companies

Rank 2006	Company	Ownership	Rank 2000	Company	Ownership
1	Saudi Aramco	State	1	Saudi Aramco	State
2	ExxonMobil	Private	2	PDV	State
3	NIOC	State	3	ExxonMobil	Private
4	PDV	State	4	NIOC	State
5	BP	Private	5	Shell	Private
6	Shell	Private	6	BP	Private
7	PetroChina	90% state	7	Pemex	State
8	Chevron	Private	8	Pertamina	State
9	Total	Private	9	Total	Private
10	Pemex	State	10	KPC	State

Source: Energy Intelligence Top 100: Ranking the World's Oil Companies. (2008, December).

According to the Energy Information Administration (EIA), NOCs account for 52% of global oil production and controlled 88% of proven oil reserves in 2007 (Energy Information Administration, 2008).

In 1995, Mobil, Texaco, ARCO, Amoco, and Unocal ranked in the top 40 in the Petroleum Intelligence Weekly (PIW) "Top 50" oil companies. But in 2005, the (PIW) top 50 oil companies' annual ranking did not include ExxonMobil, Texaco, ARCO, Amoco, and Unocal. The PIW Top 50 rankings are based on six operational criteria that allow the comparison of private sector and state-owned oil companies. In contrast to national oil companies, the major oil companies and other private sector firms generally lost ground, especially in the top tiers. However, unlike other super majors, Exxon Mobil held on to its number three position.

Here are some key findings from the PIW Top 50:

1. Saudi Aramco remains No. 1, and China's CNPC surpasses BP and Shell.

2. Russia's Rosneft makes the biggest jump, from number 24 to number 16.

3. Majority state-owned national oil companies now make up 27 of 50.

4. Three new firms moved into the PIW Top 50-Uzbekneftegas, China's CNOOC and Kazmunaigas of Kazakhstan-all majority state-owned.

Recognized as the leading source of comparative assessments of oil company performance, the Energy Intelligence Top 100 provides a detailed picture of how the world's leading energy companies have performed over the past year. Below are some key results from the report:

- All three major Chinese energy firms made the Top 50 in 2009, highlighting their aggressive push to secure oil and gas resources both at home and abroad.
- CNPC jumped from #7 to #5, ahead of BP, Shell, and ConocoPhillips.
- Saudi Aramco continues its reign as number one, though NIOC gained ground in virtually all upstream categories.
- In Central Asia, Kazakhstan's Kazmunaigas and Uzbekistan's Uzbekneftegas appear in the Top 50 for the first time.
- Aggregate gas output rose 6%, while oil output remained stagnant for the Top 50. (Energy Intelligence Top 100: Ranking the World's Oil Companies, 2008, December).

In spite of the numerous actors in the global oil industry as mentioned above, there are other companies operating in the oil sector as providers of essential services, such as exploration and production to the oil companies. Examples of such service providers are: Gophysique, Schlumberger, Halliburton, Goservices, and Transocean. These companies are involved in specific technical areas: geophysical surveying and analysis, drilling, depth imaging and production equipment.

Table 2 below shows the 2009 rankings based on operational data for 2007, the most recent period available for such a wide group of firm. Oil serves a wide diversity of purposes, including transportation, heating, electricity, and industrial applications, and it is an input into over 2,000 end products (International Labor Organization, 2002). It is used as a raw material in many chemical products, such as pharmaceuticals, fertilizers, plastics, solvents, and pesticides. Overall, petroleum products derived from oil, such as motor gasoline, jet fuel, diesel fuel, and heating oil, supply nearly 40% of the energy consumed by households, businesses, and manufacturers worldwide (Grant, Ownby, & Peterson, 2006). Despite the western multinational corporations' (the seven sisters) powerful economic control of oil production, other producing countries have an objective to control the supply and to earn a greater share of the oil income. Approximately 90 countries produce oil, although a few major producers account for the bulk of world output. The Middle East remains the biggest player in oil. Saudi Arabia alone possesses 21.9% of the world's proved reserves (BBC News, 2008, July).

Oil resources play a very important role in the economic growth of every producing country; however, the reserves are not equitably distributed around the globe. According to a BP Statistical Review Report, about 61% of the world's proven oil reserves are located in the Middle East and Middle East countries are producing about 30% of the total amount of the world oil production (B.P., 2008; Energy Information Administration, 2008).

Table 2. The Petroleum Intelligence Weekly (PIW) "Top 50" Oil Companies

Rank 2007	Rank 2006	PIW Index	Company	Country	State Ownership %
1	1	30	Saudi Aramco	Saudi Arabia	100
2	2	33	NIOC	Iran	100
3	3	37	Exxon Mobil	US	
4	5	51	PDV	Venezuela	100
5	7	53	CNPC	China	100
6	4	55	BP	UK	
7	6	63	Shell	UK/Netherlands	
8	8	83	ConocoPhillips	US	
9	9	88	Chevron	US	
10	10	90	Total	France	
11	11	91	Pemex	Mexico	100
12	12	99	Sonatrach	Algeria	100
13	12	102	Gazprom	Russia	50.0023
14	14	103	KPC	Kuwait	100
15	15	111	Petrobras	Brazil	32.2
16	24	116	Rosneft	Russia	75.16
17	18	124	Petronas	Malaysia	100
18	16	126	Adnoc	UAE	100
18	17	126	Lukoil	Russia	
20	19	141	NNPC	Nigeria	100
21	19	144	Eni	Italy	30
22	21	159	QP	Qatar	100
23	23	162	Libya NOC	Libya	100
24	22	166	INOC†	Iraq	100
25	29	173	Sinopec	China	71.84
26	28	176	StatoilHydro	Norway	62.5
27	26	177	EGPC	Egypt	100
28	25	180	Repsol YPF	Spain	
29	27	187	Surgutneftegas	Russia	
30	30	215	Pertamina	Indonesia	100
31	31	223	ONGC	India	74.14
32	34	246	Marathon	US	
32	32	246	PDO	Oman	60
34	37	264	EnCana	Canada	
34	--	264	Uzbekneftegas	Uzbekistan	100
36	36	273	Socar	Azerbaijan	100
37	35	288	SPC	Syria	100
38	39	290	Ecopetrol	Colombia	89.9
39	42	291	Apache	US	
39	44	291	CNR	Canada	
41	37	294	Anadarko	US	
42	41	296	Devon Energy	US	
43	40	297	TNK-BP‡	Russia	
44	43	298	OMV	Austria	31.5
45	48	305	Hess	US	
46	44	310	Occidental	US	
47	47	312	BG	UK	
48	51	316	CNOOC	China	66.41
49	50	322	Inpex	Japan	29.35
50	52	323	Kazmunaigas	Kazakhstan	100

Source: Energy/Petroleum Intelligence Weekly Ranks World's Top 50 Oil Companies, 2009.

According to Energy Information Administration (EIA) report in 2008 depicted in Figure 2, global oil consumption grew by 1.1% in 2007 and it was expected to increase in the following years.

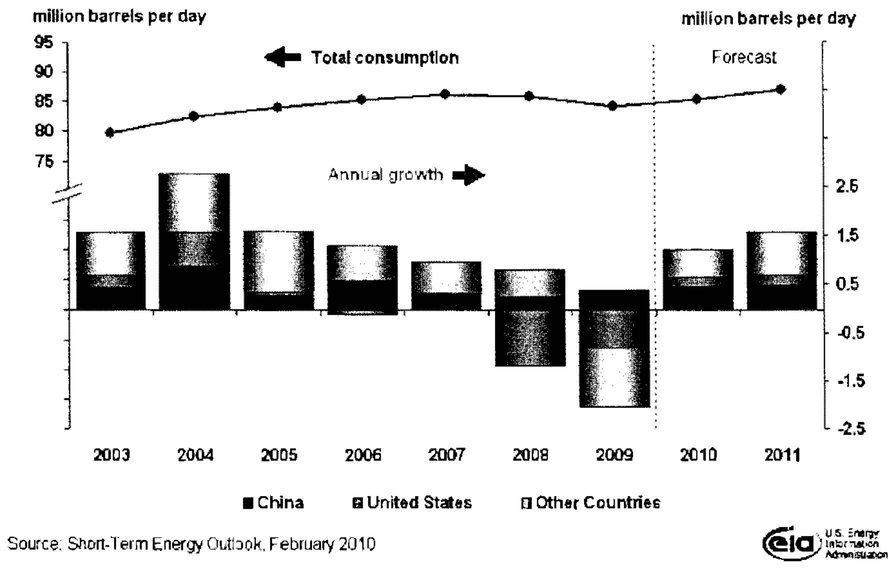


Figure 2. Global Crude Oil and Liquid Fuel Consumption.

However, Energy Information Administration (EIA) revised its projections slightly upward for global oil consumption growth as the Asian-led recovery continues. China's consumption in December 2009, increased by 0.9 million barrels per day, or 12%, above year-earlier levels, as China's economic stimulus package continued to help push up both oil usage and economic growth. Due to the increased liquid fuel consumption by China, Energy Information Administration (EIA) revised its prediction for global liquid fuels consumption to grow by 1.2 million barrels per day in 2010 and 1.6 million barrels per day in 2011 after showing annual declines in 2008 and 2009 (Energy Information Administration, 2010).

According to the U.S. Energy Information Administration (2010), U.S. liquid fuels consumption depicted in figure 3, United States Crude Oil and Liquid Fuel Consumption, declined by 820,000 barrels per day (4.2 %) to 18.7 million barrels per day in 2009, the second consecutive annual decline.

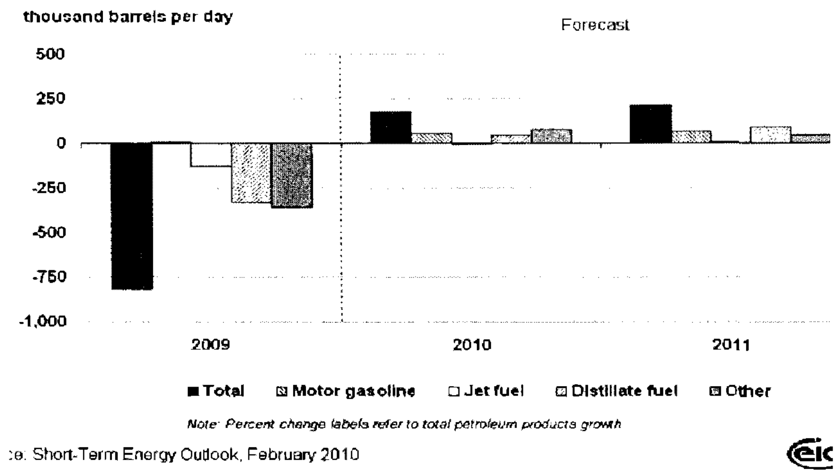


Figure 3. United States Crude Oil and Liquid Fuel Consumption.

Despite the cold weather that gripped much of the nation in late December 2009 and early January 2010, total U.S. liquid fuels consumption in those two months still fell below the levels seen in the same months a year earlier. Motor gasoline was the only major petroleum product whose annual consumption did not decline, having remained relatively unchanged. Distillate fuel consumption declined by 330,000 bbl/d (8.4 percent), in 2009, led by a sharp economy-related decline in transportation usage. Jet fuel usage fell by 130,000 bbl/d (8.6 percent). Nevertheless, EIA projects that total petroleum products consumption will rise by 180,000 barrels per day in 2010 because of the economic recovery that began in late 2009.

Among the major international oil companies, ExxonMobil ranked 14th, BP, 17th, Chevron, 19th, ConocoPhillips, 23rd, and Shell, 25th in 2006. These five firms only hold

3.8% of the world liquid reserves, which are in the United States and Canada. However, the top ten companies listed in Table 3 hold 80.6% of the total world liquid reserves (Pirog, 2007).

Table 3. World Liquid Petroleum Reserves Holdings (Millions of Barrels)

Rank 2006	Company	Reserves	Rank 2000	Company	Reserves
1	Saudi Aramco	264,200	1	Saudi Aramco	259,200
2	NIOC	137,500	2	INOC	112,500
3	INOC	115,000	3	KPC	96,500
4	KPC	101,500	4	PDV	87,993
5	PDV	79,700	5	Pemex	76,852
6	Adnoc	56,920	6	Adnoc	50,710
7	Libya NOC	33,235	7	Pemex	28,400
8	NNPC	21,540	8	Lybia NOC	23,600
9	Lukoil	16,114	9	NNPC	13,500
10	QP	15,200	10	Lukoil	11,432

Source: Energy Intelligence Research, 2003.

According to Energy Information Agency estimates shown in Figure 4, the

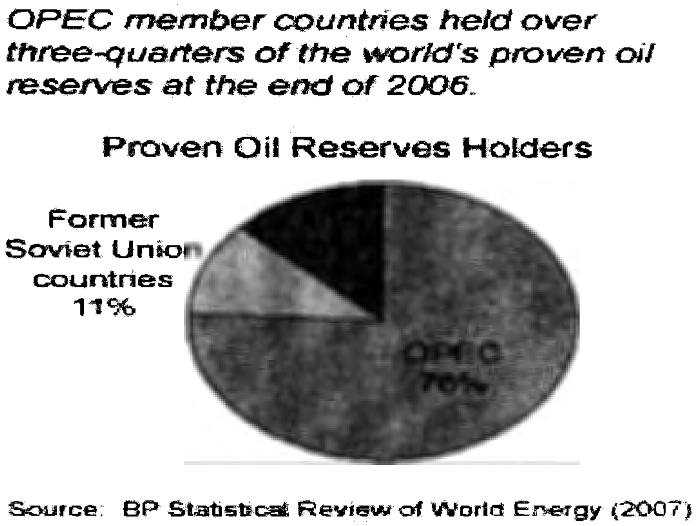


Figure 4. Proven Oil Reserve Holders.

Organization of Petroleum Exporting Countries (OPEC) members (Algeria, Indonesia, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates, and Venezuela) account for roughly 76% of the world's proven oil reserves and 40% of world production.

OPEC countries and national oil companies already hold the majority of proven (published) oil reserves, and the percentage of reserves they hold is increasing. Evidently, this concentration further establishes their future importance as major players in the world oil market and could potentially increase market tension and upward pressure on prices as world oil demand rises. This increased oil demand and unequal access to reserves has led to situations where International Oil Companies (IOCs) struggle for access to hydrocarbon reserves, controlled by National Oil Companies (NOCs) (Ruud & Jon, 2008). In the '90s, highly volatile oil prices lead to a wave of consolidations in the oil market, which brought about structural shifts in the oil industry that have continued until the present day. During this period, a top echelon of four 'Super Majors' that was created (ExxonMobil, Royal Dutch/Shell, BP-Amoco, and Total FinaElf) have preponderance in the downstream, with 32% of global product sales and 19% refining capacity. This counterbalances to a large extent the dominant upstream positions of the four large state oil companies, Saudi Aramco, Petroleos de Venezuela, Iran's NIOC, and Mexico's Penmex. (O'Rourke & Connolly, 2003).

Topology of the Oil Industry Supply Chain

The phrase "supply chain" is always used to describe the logistics activities. In an individual firm's manufacturing, transportation, distribution, or retail network, it represents an integrated view across process. It is a critical concept to drive coherent strategies and to manage an organization around common (end-to-end) performance objectives (Lasschuit &

Thijssen, 2004). Modern supply chain networks are not simple linear chains or processes; they are a set of complex networks of products and information flows that travel between the nodes of different networks. Indeed supply chains are extremely complex, and every industry's chain has its own different quirks and characteristics. For example, the oil industry is characterized as a typical supply chain with diverse preferences which effectively "pull" products through the supply chain (Nexant Chem System PERP Program, 2006). There are at least three distinct centers of manufacturing in the oil industry: the oil fields and platforms, the petrochemical plants, and the refineries. These entities are each surrounded by several logistics functions such as transportation, distribution, storage, etc. The distinction between the oil industry supply chains from traditional supply chains is that there are intermediate markets where crude and/or products can be bought or sold between upstream crude oil production and final retail delivery at service stations and other end users. The final consumer is supplied through the coordinated activities of the whole supply chain, starting from the crude exploration and production to transportation through thousands of kilometers of pipelines or in oil tankers to very capital intensive and complex refineries, to final marketable products, to distribution by pipelines, ships, rail cars, barges or road tankers to the end users.

The oil industry supply chain is a complex network of several entities consisting of upstream, midstream, and downstream. The upstream activities consist of exploration, development, and the production of crude oil to the point of transformation into final products. Historically, the upstream sector has remarkable influence on the operation of the overall supply chain since it has the ability to 'push' large quantities of crude oil through the chain. A second segment typically referred to as midstream, (although sometimes considered in the upstream sector) consists of the infrastructure used to transport crude oil and petroleum products, such as Very Large Crude Carriers (VLCCs) and Liquefied natural gas (LGN) tankers or through pipeline networks to various refineries and storage tanks around the world. The mode of transportation either by tankers or pipelines depends on the distance, the nature of the product, and the demand quantities. Trucks and rails also distribute a small fraction of the products, about four and six percent respectively, but are being increasingly utilized with the rise of biofuels such as ethanol which existing pipelines can not currently accommodate (United States Government Accountability Office, 2007).

The downstream also consists of the processing, transportation, marketing, and distribution of petroleum products, and it is usually characterized as a mature, rather competitive, and complex industry (Hackworth & Shore, 2004; Roeber, 1994). The downstream industry specifically serves two different customers: the wholesale customers that are comprised of petrochemical facilities, power plants, big fuel consumers such as the airlines, shipping companies, and other industrial customers; and the retail customers that are comprised of those who use the fuels, essentially for domestic heating and transportation.

The anatomy of the generic oil supply chain depicted in Figure 5 begins with the exploration and production of the raw materials and the transportation of the crude oil into storage tanks. The bulk crude is then sold at the commodity market and transported from the storage facility to the new owner's storage, then to the refinery. The crude is then refined into different products such as jet fuel, petrol, diesel, electricity, and petrochemicals, and transported through the product pipelines to storage terminals for distribution which is the final stage of the supply chain. The decision for optimal acquisition of crude oil depends on the grades, price, quality, timing, and distance to the refinery.

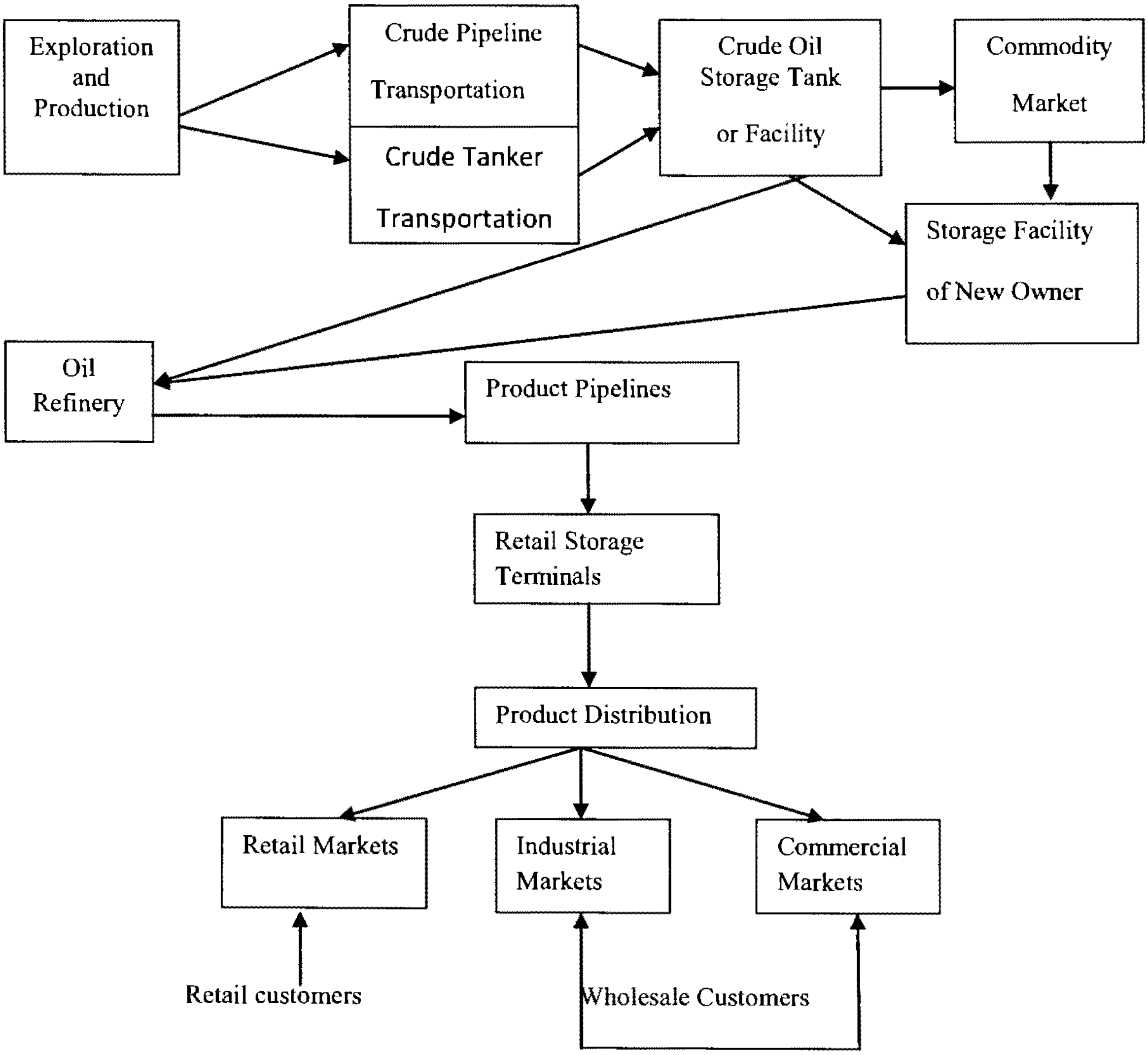


Figure 5. A Generic Oil Industry Supply Chain.

Various operations are along the links of the supply chain. For example, explorations involve seismic, geophysical and geological studies, while production operations involve drilling, production, facility engineering and reservoir. The output of the complex refining operation is the input to marketing, which is the retail sale of gasoline, engine oil, jet fuel and other refined products.

Cheng and Duran (2003) focused on crude oil world-wide transportation based on the statement that this element of the petroleum supply chain is the central logistics that links the upstream and downstream functions, playing a crucial role in global supply chain management in the oil industry, while Lee, Pinto, Grossmann, and Park (1996) concentrated on the short-term scheduling of crude oil supply for a single refinery. Forrest and Oettli (2003) posit that most of the oil industry still operates its planning, central engineering, upstream operations, refining, and supply and transportation groups as complete separate entities. Therefore, systematic methods for efficiently managing the petroleum supply chain must be exploited (Neiro & Pinto, 2004).

Oil Industry Challenges

Globalization today is drawing the oil producing nations together and increasing their interdependence, and the fates and prosperities of these nations are closely tied to the global economy. This globalization and interdependence are also creating new challenges for the oil industry; indeed, the biggest challenge is to provide significantly more oil at a reasonable cost in both a safe and environmentally friendly manner. Recent rises in oil prices have spurred many new exploration activities, yet still, the oil industry faces the challenge of developing a comprehensive strategy to change the climate of oil investment, while building more tankers, pipelines, and refineries to adequately meet the rapidly growing global oil demand. Safety and security challenges in the oil supply chain are sometimes viewed as one physical security issue, but in essence there are emergency response, process control, physical and cyber security issues along the supply chain. Like it or not, for as long as we continue to rely on petroleum as a major source of energy, our security and our economic well being will be tied to social and political developments in these unpredictable and often unfriendly producers (Klare, 2004).

The environmental regulations and compliance rules (greenhouse gas effect, soil and air pollution, etc.) are becoming severe, making the operation of the existing facilities or the construction of new ones somewhat expensive and intricate. For example, fuel specifications in regard to the quality of the final product ensure challenges and implications for the refining process along the supply chain as environmental issues are constantly receiving regulatory and legislative attention. All crudes are not equal, and therefore are not equally suited for all the outputs of the refineries. Some specific types of crude oil are listed as follows: 1) Brent Blend, a light, sweet North Sea crude with an American Petroleum Institute Gravity (APIG): a measure of how heavy or light a petroleum liquid is compared to water) of approximately 38 and a sulfur content of approximately 0.4%. Most Brent Blend is refined in northwestern Europe, but significant volumes are also shipped to the US and Mediterranean countries. 2) Russian Export Blend, the Russian benchmark crude, is a mixture of several crude grades used domestically or sent for export. Russian Export Blend is a medium, sour crude oil with an American Petroleum Institute gravity of approximately 32 and sulfur content of approximately 1.2. 3) West Texas Intermediate is the US benchmark crude oil. It is a light, sweet crude oil with an API gravity of approximately 40 and a sulfur content of approximately 0.3% (Neste Oil, 2009). The grade of crude oil termed OPEC Basket refers to oil found in Saudi Arabia, Qatar, Libya and other eastern and world nations that make up OPEC (Oil Producing and

Exporting Cartel). This classification of crude oil has many sub-grades, including Arab Light (Saudi Arabia), Fateh (Dubai), Bonny Light (Nigeria), Minas (Indonesia), Saharan Blend (Algeria), and Tijuana Light (Venezuela). This grade of crude oil is a heavier blend of crude than Brent Blend or West Texas Intermediate (Oil Job 411, 2009). In the U.S. the American Petroleum Institute (API) determines the density and sulphur content. For instance, the lightness (density) of the crude is measured by the API gravity and specified to the oil industry; the higher the API the lighter the crude. The requirement is that crude greater than 35 API gravity is considered light while crude with less than 25 API gravity is considered heavy and between 25 and 35 API gravity is generally considered medium crude grade. In terms of sulphur content crude is considered 'sweet' if the sulphur content is less than 1%, but if greater than 1% it is considered 'sour'. The lighter and sweeter the crude is, the less expensive it is to refine into usable product (Petroleum Sector Briefing, 2007). Hence, the market price of crude is based on the density and sulphur content.

According to Juhasz (2008), liabilities in environmental damages and the increasing public image vulnerabilities are becoming serious challenges to the oil industry. For example, communities that live where oil is found-from Ecuador to Nigeria to Iraq-experience human rights abuses, violence, war, environmental pollution, public health risk, and climate destruction at every stage of oil use, from exploration to production, from transporting to refining, and from consumption to disposal.

The proposition that socially responsible businesses should go beyond the boundaries of just profit maximization, to include providing solutions to society's environmental and social problems, Corporate Social Responsibility (CSR) has been greatly debated upon, and has in recent times provided the path that is embraced by business and society relationship. Regrettably, CSR has been argued by critics saying it is a distraction for businesses meeting their primary goals of making profits, an inefficient means of allocating resources, and that business lacks the legitimacy and competency to take on any such responsibility outside its primary area of expertise (Friedman, 1962; Friedman, 1970; Henderson, 2001; Levitt, 1958). In response, proponents of CSR argued that the monumental increase in business power, the widespread incidence of corporate misdemeanors, issues of ethics, and the increasing inability of governments to their basic responsibility of society as well as regulating business activity have meant that the acceptance of social responsibility by business is both inevitable and a necessity (Bowen, 1953; Bowie, 1991; Carroll, 1979; Carroll, 1991; Davis, 1960; Davis, 1967; Davis, 1973; Davis & Blomstrom, 1973; Moon, 2001).

Evidently, several incidences that occurred in the oil industry in the past few years that resulted in fatalities and major environmental damage have forced the oil companies to embed Corporate Social Responsibilities (CSR) as an essential part of their business strategies. The oil industry is at the forefront of CSR, largely because of the criticism it has taken and because of its business operations in developing and traditional countries with weak or authoritarian governments and poor records of protecting human rights or the environment. Examples, the 1989 Exxon Valdez oil spill that forced attention on environmental issues, the destructive effects on communities living close to oil industry operations in the Niger Delta and Ecuador. Also the "boycott Shell" campaigns, in response to the company's 1995 plans for disposing of decommissioned drilling rigs in the North Sea and the execution of Ken Sara Wiwa by the Nigerian military regime in November of that year, led Shell to revaluate its business conduct and communications with stakeholders and others. As a result, multinational oil companies have begun to accept social responsibility by committing to CSR and providing funds for community development.

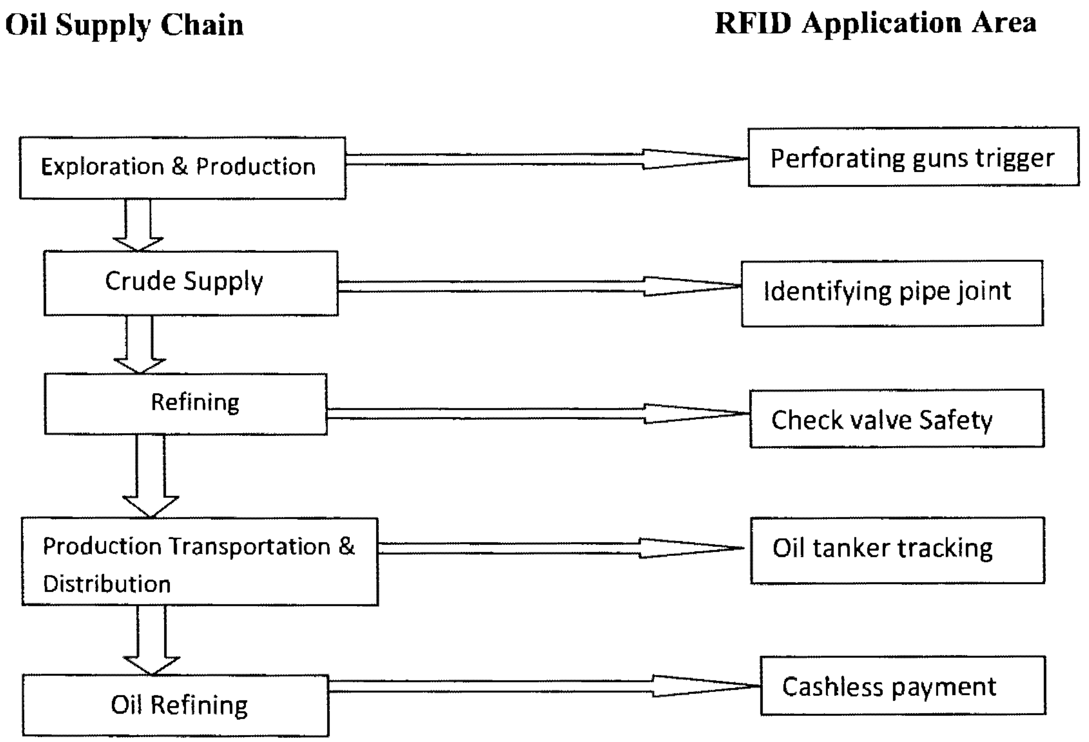
Radio Frequency Identification and Geographic Information System Application

Although RFID was originally used by the military to identify friend or foe aircraft (IFF) during the Second World War (Glidden et al., 2004; Robertson & Jalaly, 2003; Manhattan Associates, 2003), the technology was commercially applied in the 1980s and was widely accepted during the 1990s for use with keyless entry and smart tickets, document information, automatic highway and bridge toll collection, air freight tracking, and automobile manufacturing through assembly lines, etc. Even though radio frequency identification (RFID) technology has been around for some time, it has only recently become a significant enabling technology to enhance efficiency across the supply chain network. The key benefit of RFID over bar codes has been made possible by the internet, i.e. the richness and timely availability of information about the location and status of goods worldwide to manufacturers, distributors, and retailers. It is motivating retailers such as Wal-Mart and the U.S. Department of Defense to mandate the use of RFID by top suppliers (Glidden et al., 2004). RFID is increasingly becoming a highly versatile technology-and not surprising, across many industries companies are using it to increase agility, security, and visibility within their operations. In today's global supply chain management, companies focus on minute-by-minute and day-to-day supply chain optimization as a strategic advantage, and therefore perceive RFID as a vital technology for accurate, timely visibility that can also potentially enhance collaborative planning, forecasting, and replenishment. Industries such as pharmaceutical, retail, automobile, computer, and many others are now using RFID effectively to manage their assets, as it is crucial for these industries to cut costs while improving operations and customer service levels. In today's fast changing economy, Radio Frequency Identification (RFID) is a major area in which improvement in the supply chain and updating of information in real-time can boost performance without sacrificing cost effectiveness (Gupta, 2005). RFID makes it possible to transmit detailed location information wirelessly, and in fact helps the oil companies to sustain and compete or run their business more effectively and efficiently in the cut-throat market environment.

The oil industry today is also facing increasing pressure to improve operational and financial results, while they continue to meet the expected global demand for oil. RFID has been long established along the supply chain in the retail industries, but the possible uses in the oil industries have not been widely publicized (Gupta, 2005). Some key applications of RFID within the oil industry are: asset control, proactive maintenance, product lifecycle management, personnel control, drill string validation, down-hole actuation, construction management, and hazardous material disposal management.

In the exploration and production function, RFID can be used instead of lengthy gun gamma-ray positioning tool, for triggering perforating guns inside the oil wells that shoots holes in the castings that enables the oil to flow in and be pumped to the surface. For example, in the case of the North Dakota's Bakken crude oil deposit that is locked two miles underground in a narrow layer of dolomite, exploration is becoming more intense and the challenge is getting the oil out but not without improved technology such as RFID.

Figure 6 illustrates the different applications of RFID in the oil industry.



Source: Gupta, 2005.

Figure 6. RFID Applications in the Oil Industry.

However, there are other laser technologies in their infancy, such as in-situ laser perforation, first introduced by Saudi Aramco to the oil industry. The laser perforation includes facilitating hydraulic fracturing in open-hole horizontal wells (oriented fracturing), which can greatly enhance the wells' production capability. Laser technology has significant advantages over the conventional perforation technology, in that there is no compaction. A high-energy laser beam can vaporize rock formations and create a perforation with a permeable wall surface. The research and development is being undertaken in collaboration with Halliburton (Habib, Al-Ashgar, & Hazim, 2009). RFID can also be used in crude supply, to identify individual pipework joints to ensure pipework systems are correctly assembled with the correct gasket, with the correct bolts and to the correct bolt tension. By identifying each joint using auto identification technology, a database could be built to hold information specific to each joint, thus ensuring the operation is carried out with the correct procedures and the right parts during a new build or rebuild of a pipe work system. In the refinery, RFID tagging can be used to capture information on pressure safety relief valves in major vessel, pipework, and equipment. The system can be based on a tag reader suitable for use in hazardous and hostile environments typical for offshore oil and gas platforms, refineries, and petrochemical processing.

In the transportation and distribution aspect of the oil supply chain, passive RFID tags can be embedded in both the valve and the flange of the vessel or pipeline to keep records of relevant critical technical and process information. To cut costs, oil and gas companies must be able to manage trucks and shipments in real time. With instant visibility, they can streamline delivery operations, minimize costly vehicle and driver downtime, and optimize asset performance. With an RFID's fleet management system, oil companies can save time and money, tracking the delivery and movement of their crude oil/gasoline tankers. State of the art radio frequency identification technology provide retailers with automatic recognition of customers to boost revenues, to speed purchases, to personalize services, to create automated loyalty programs, and to build new marketing tools (Gupta, 2005).

There is already a considerable level of interest among oil companies surrounding the RFID technology and the deployments across various application areas as indicated above; however, many of these deployments are pilots, and those that have reached beyond this stage are truly early adopters. It has been generally suggested by several authors

(Atkinson, 2004; Giunipero & Eltantawy, 2004; Tang, 2006; Wilson, 2007), that the use of technology such as RFID and ERP will become an important facet of supply chain management. Recently, the Oil & Gas RFID Solution Group, consisting of Texas A & M University, University of Houston, Merlin Concept & Technology, Shipcom Wireless, Motorola, and Avery Dennison, is working in collaboration with other standard bodies as well as end users to define an industry wide road map for successful adoption of RFID technology (Konarski, Falsafi, & Zoghiet, 2008). To establish an RFID-oil standard, Collaborative Commerce and Data Exchange needs to allow individual up-streams, mid-streams, and down-streams to exchange information between each other seamlessly. Global oil trade has given rise to maritime oil transportation, which involves some risk that oil will accidentally spill, hence the need for mitigating or limiting the risks of contamination of the marine ecosystem. According to the American Petroleum Institute (API), in the United States, the oil industry has joined with government, universities, and other groups to conduct research and share information about advances in oil spill prevention and response. In addition to RFID technology, the emergence of complementary technologies such as global positioning system and geographic information systems (GPS/GIS) presents potentials for new innovation opportunities and supply chain optimization (Williams, 2004; Saxena, 2005). Components include navigational charts, shoreline mapping, global satellite positioning, port navigation, forecasting water levels and ocean currents (American Petroleum Institute Spill and Accidental Release, 2008). The potential vulnerability of the landscape to oil spills is an information base, critical to petroleum industry emergency response planners. In an emergency event, information on the potential risk for oil spills and the sensitivity of landscapes to oil spills is required;

therefore, tools for rapid production of response information are paramount (Miller & Onwuteaka, n.d.). The effect of oil spilled on coastal areas during transportation is governed by physical, chemical, biological (a process which depends on the oil properties), hydrodynamics, meteorological and environmental conditions. GIS technology has increased its relevance to the petroleum industry because of its use to establish appropriate responses and locate dense areas in a slick and local surveillance, to permit clean-up vessels to detect the oil.

Geographic information system (GIS) is considered one of the tools in which the benefits are not yet understood. Since its first conceptualization in the 1950's and 1960's, GIS have evolved immensely in terms of areas of application and capabilities (Mark, Chrisman, Frank, McHaffie, & Pickles, 1997). GIS is used to manage and analyze spatial data, whereas systems stimulation is used to create a representative model of the oil supply chain. Various information can be retrieved from GIS system such as the location of oil spills, the quantity of oil spills, and their distribution in the affected area, for example, location of the heaviest contamination, and the length of shoreline affected by the oil slick. This risk management system will allow new opportunities for assessment, multiple resource planning, permit viewing of the natural resources, improve the decision-making process, and provide a baseline for future assessments (Mansor & Poy, 1998). GIS-based risk management systems use the latest spatial information technology to store data required for oil spill risk assessment, response, planning, training, and risk management.

The integration of remote sensing with GIS techniques offers an effective tool for analysis of risk management. With integrated oil spill trajectory modeling, the Oil Spill Risk Management System (OSRMS) could aid the user to predict the movement of oil and assess the risk of a slick in an alert situation, and consequently, this will improve the conventional oil spill response system (Mansor & Poy, 1998). The objective of Remote Sensing Monitoring (RSM) is to inform the user about environmental emergency situations. Remote sensing data from the geographical area of interest is analyzed as the data enter the system. If a possible emergency is detected, the remotely sensed data are put into a geographical context and a map mask delineating the emergency area is generated. Then remote sensing image data are sent to the core system for further analysis (Mansor & Poy, 1998). GPS data collection is used for various applications in the oil industry. For example, it can be used for locating oil wells, buoy positions, delineating existing settlements within an oil field, and marking the extent of an oil spill. The attainable accuracy of a GPS-based system is limited by the satellite geometry and by systematic oil spills. GPS can be used also to evaluate the environmental vulnerability of landscapes to oil spills within oil fields.

Integration of GIS/GPS gives capabilities to the oil industry that did not exist years ago. For example, tracking a rig path in real time by collecting GPS points and then observing the rig within a GIS can be useful for rig positioning or determining average rig speed (Ajayi, 2007). It also provides more accurate spatial data for quality decisions in industry operations, facilitates cost effectiveness and streamlined workflow, and finally provides rapid access to current and up-to-date spatial data for mapping and analysis. Integration of GIS and systems simulation is an important yet challenging, step to address this important real life problem (Biles, Sasso, &Bilbrey, 2004). Although GIS integration into the petroleum supply chain is gaining popularity and is more mature, the use of the technology is still in its infancy.

Mergers and Acquisitions

Mergers and acquisitions are two terms used collectively to represent a union of companies. However, these two words differ in intent. A merger is a union of two firms of the same competitive size, while an acquisition is essentially a takeover by a dominant company over a small company. Mergers and acquisitions (M & A) are viable options for independent players to increase their asset bases, reduce costs, and enhance operational efficiencies. Dynamic theory predicts the use of a more complex decision-making process and stipulates that efficient industries increase their market share through internal expansion and the acquisition of other industries or sometimes a combination of both (Shapiro & Varian, 1998). While this action (acquisition) is advantageous for the buying company, the owners of the company being sold sometimes also profit from these acquisitions. For example, "USA Today" (2006, October) reported a $1.6 billion deal between Google and YouTube. Google envisioned YouTube as an emerging company with high prospect of expansion, and as a result seized the opportunity to buy YouTube. These approaches seem to confirm managerial strategies directed to expand, diversify, and allocate resources to provide more competition in the industry for long term benefits. This consolidation will ultimately enhance the quality of services that will be provided through increased competition and adoption of best practices among other providers.

Unfortunately, firms that merge usually encounter difficulties in blending cultures and implementation of programs for combining the organizations to achieve potential synergies (benefits from the combined strengths of different companies). The basic economic reason for mergers and acquisitions is the creation of economies of scale towards efficient and more productive corporations.

Oil Industry Mergers and Acquisitions

The most important mission of the upstream oil industry is to explore and produce crude oil in the most cost effective and environmentally friendly manner; however, it requires enormous capital investment, ingenuity, and agility in the exploration and production function as well as cost containment. The 1990's began a new era of oil companies in response to the severe deflation in oil price that moved the oil industry towards consolidation. M&As increased as companies in the upstream sector sought to create synergies, gain economies of scale, and increase share holders value.

According to the United States GAO's report in May 2004, over 2,600 merger transactions have taken place since the 1990's involving all three segments of the petroleum industry. About 85% of the mergers occurred in the upstream sector (exploration and production), while the downstream sector (refining and marketing of petroleum) accounted for about 13%, and the midstream sector, specifically pipelines (transportation), accounted for over 2%. The vast majority of the mergers—about 80% —involved one company's purchase of a segment or asset of another company, while about 20 percent involved the acquisition of one company's total assets by another so that the two became one company (U.S. Department of Treasury, 2008). The recent trend in the oil industry is for the companies to merge to expand their upstream levels instead of their downstream levels. For example, in 2006 ConocoPhillips acquired Burlington Resources in an effort to increase its oil reserve and also the acquisition of the upstream producer, Unocal

Corporation by Chevron, to replace its declining reserves (Corbin, Kristen, Wes, & Coreena, n.d).

Many industries today, including the oil industry, maintain rigorous programs of research and development (R&D) to expand their capabilities and lower the cost of operation, which ultimately enhances operational efficiency. For example, Exxon and Mobil did not merge in 1999 to be bigger alone, but to be better by broadening their portfolios of exploration and production, optimizing their downstream assets, while increasing competitiveness through reduced cost (Longwell, 2002). Interestingly, in today's tightly competitive oil market, mergers and acquisitions are commonplace and have become a necessary means of long-term growth and future survival. In the United States, the Federal Trade Commission refers to, ExxonMobil, Royal Dutch Shell, BP, Chevron, and ConocoPhillips, including the French firm Total as "supermajors". These are integrated firms that explore for, drill, produce, and ship crude oil and refine, distribute, and retail gasoline and other petroleum products. These Supermajors sometimes referred to as "Big oil' are individually and collectively the economic power of the largest oil and gas companies and have perceived influence on politics, particularly in the United States. Big in a sense means, 'stronger buying power' because they are capable of absorbing risk better and therefore relatively lower operating costs.

Some of the mergers include: Exxon and Mobil (1999), BP and Amoco (1998), Total and Petrofina (1999). Subsequently, Elf Aquitaine (2000), Chevron and Texaco (2001), and Conoco Inc. and Phillips Petroleum Company (2002) all merged between 1998 and 2002 (Forbes Global 2006). ExxonMobil became a world-class reference in the oil business and epitomized the search for integration, scale, and efficiency (Davies, 2000).

These mergers of the mega-giant oil companies remain the largest in corporate history. Shell also participated in the merger wave by purchasing several 'baby-standard' oil companies. The mergers allowed the oil companies to take control of the refining and selling of gasoline in the United States in the style of Standard Oil, and ultimately forged mass consolidation of these sectors, yielding rapid increases in the price of gasoline and oil company profits (Juhasz, 2008). These consolidations have essentially extended the supply chains of the oil industry both horizontally and vertically (Grainger Center for Supply Chain, 2004). An example of a series of horizontal transactions is the spate of horizontal M&As that occurred in the oil and pharmaceutical industries, although for different reasons. Horizontal mergers are consolidations between two competing firms. The merger between Pfizer and Warner Lambert is an excellent example, where the merging enabled Pfizer to acquire Lipitor as part of the consolidation (Gump, 2000). Also, according to a CNN Money Report (1998), in the oil industry the merger between Exxon and Mobil provided some advantage of economies of scale. Vertical mergers are deals between companies that have a buyer and seller relationship with each other. In a vertical transaction, a company might acquire a supplier or another company closer in the distribution chain to the customer (Gaughan, 2005). Although overall oil production is driven by global demand, the value chain is producer driven, and many of the companies are vertically integrated and have control over every level in the chain.

These integrated oil companies are the largest and most profitable companies in the industry, and outside the United States they are either publicly or nationally owned (Corbin, Kristen, Wes, & Coreena, n.d). The oil companies, both multinational (such as ExxonMobil, Royal Dutch Shell, or BP) and national (such as Petronas) often adopt a vertically integrated structure. This means they are active in the full length of the supply chain, from exploration, drilling, and extraction, to transportation and distribution to consumers. In some cases the oil companies distribute the refined products (gasoline/petrol) to their own retail station where the products are sold to final consumers (Absolute Astronomy, 2009).

Selected Oil Company Mergers and Acquisitions

In the oil industry, the so-called 'Seven Sisters' consist of three companies formed by the breakup by the U.S. government of Standard Oil, along with four other major oil companies.

They include the following:

1. Standard Oil of New Jersey (Esso) merged with Mobil to form ExxonMobil.
2. Royal Dutch Shell (Dutch 60%/ British 40%)
3. Anglo-Persian Oil Company (APOC) (British) later became Anglo-Iranian Oil Company (AIOC), then British Petroleum, and later became BP Amoco, following a merger with Amoco (which in turn was formerly Standard Oil of Indiana). It is now known by the initials BP.
4. Standard Oil Co. of New York ('Soncony') which became Mobil, and then merged with Exxon to form ExxonMobil.
5. Standard Oil of California ('Socal') became Chevron, upon merging with Texaco, became Chevron Texaco but later dropped the "Texaco" suffix returning to Chevron.

6. In 1984, most of Gulf Oil became part of Chevron, with a smaller part becoming part of BP and Cumberland Farms, in what was at the time the largest merger in world history.
7. Texaco merged with Chevron in 2001. The merged company was known for a time as ChevronTexaco, but in 2005 changed its name back to Chevron. Texaco remained a Chevron brand name.
8. Phillips acquired control of Arco's Alaska assets from BP America in April 2000 as part of the consent agreement that was part of the U.S. Federal Trade Commission's approval of BP Amoco's acquisition of Arco in April 2000.
9. Occidental acquired control of Altura Energy, a limited partnership owned by BP Amoco and Royal Dutch/Shell through Shell Oil at approximately the same time as it acquired Arco Long Beach (Tertzakian, 2005; Hoyos, 2007).

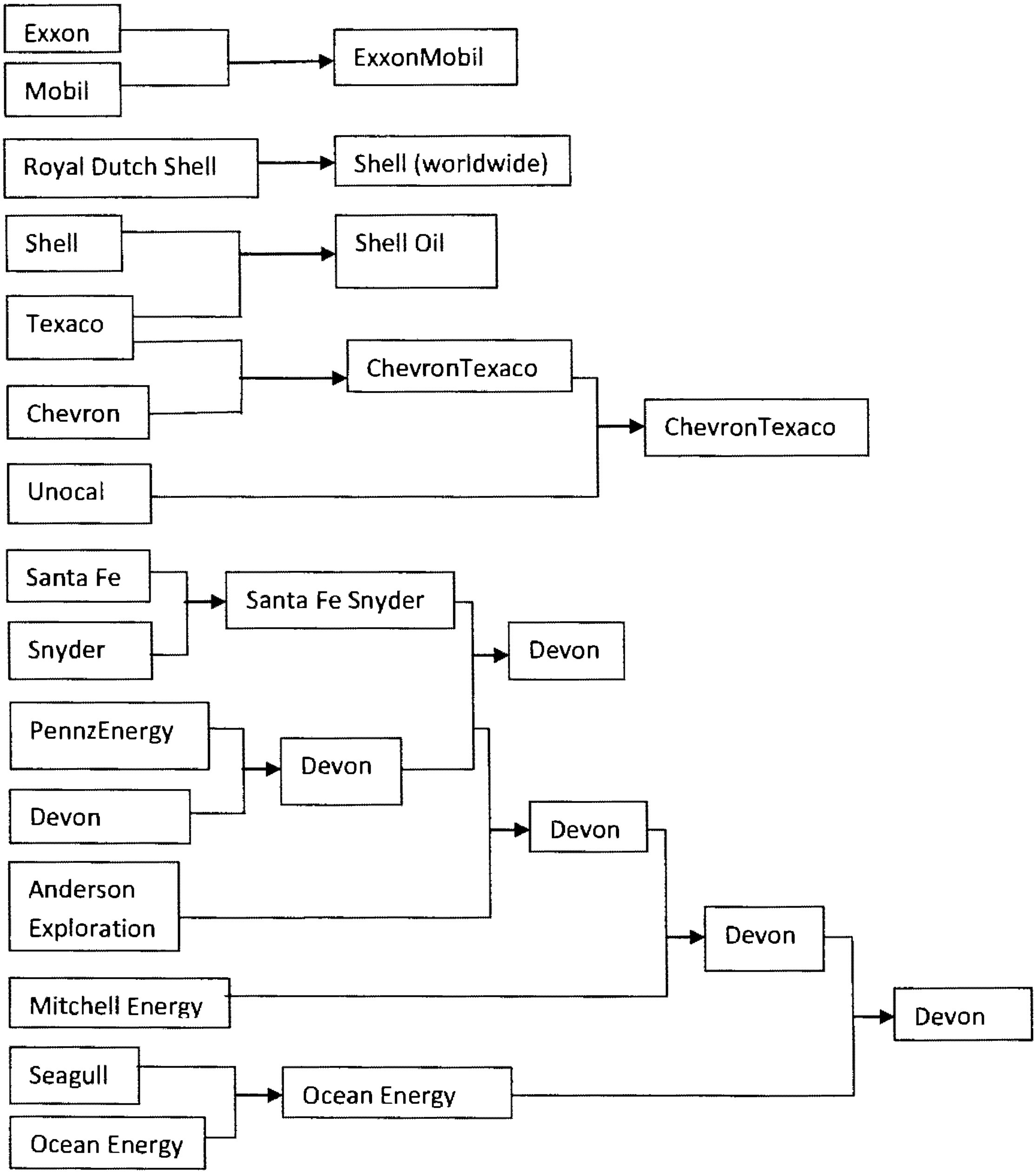
Indeed the rational between the merger of Amoco and BP is to solve specific portfolio difficulties of two separate oil companies. This merger between Amoco and BP gave rise to a series of other mergers led to the transformation and structuring of the petroleum industry. The merger facilitates cost saving by elimination of duplication as well as solving several portfolio difficulties if the companies are separate. According to America's Oil and Natural Gas Industry (2008), mergers of private oil companies have not significantly affected worldwide concentration in crude oil. These waves of oil company mergers and acquisitions shown in figures 7-A and 7-B, which include companies such as BP and Amoco, Total, Fina, Elf, Exxon and Mobil, Chevron and Texaco, might be viewed as cost minimization and strategic policies that will enhance the company's long-term competitive advantage.

In an atmosphere of continuous struggle by the oil industry to find a balance between rising global demand, depleting known resources, and management of operating costs, while mergers, acquisitions, and consolidation is on the rise, the oil industry is determining other approaches to reduce their cost. One approach is that the oil industry contracts out some of its business functions including finance, accounting, and sometimes human resources to outside service providers, which had benefited the oil industry in decreasing their operating costs.

Outsourcing: The Evolution and the Global Perspective

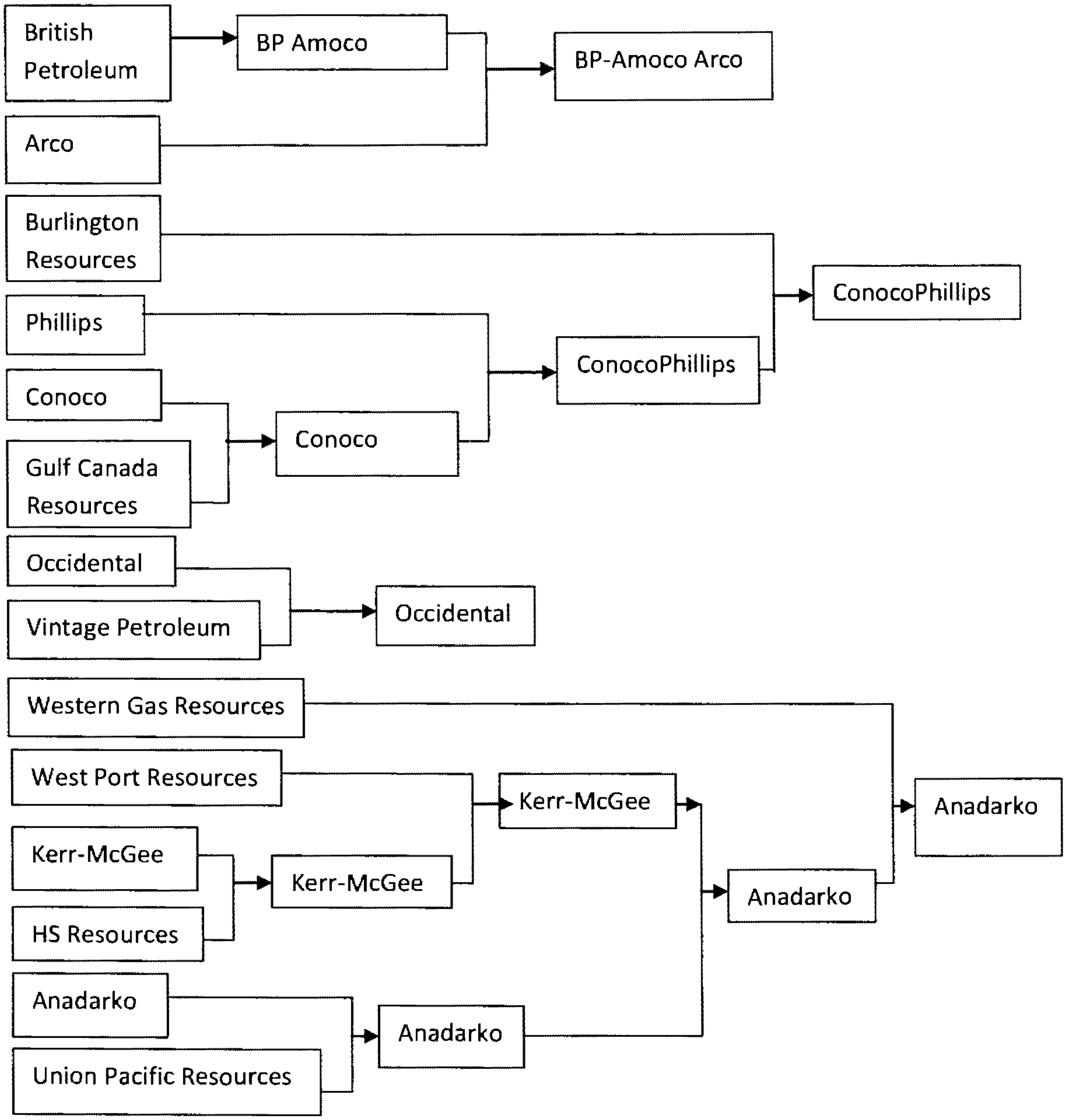
In the 1800's and 1900's, companies were vertically integrated organizations that only took care of their own manufacturing and the transportation of the finished goods to their own retail outlets. In the 1990's, Enterprise Resource Planning (ERP) was first introduced as a back-office function in human resource, accounting and/or customer service. As a result of the successful operation of the ERP systems, companies shifted their focus to the front-office functions, but ultimately outsourced their back-office functions to outside vendors. In many companies, the ERP system is perceived to be a competitive advantage, and has helped to improved accuracy in accounting data and improved decision making, which lead to cost reductions in the companies.

Typically, firms today are embracing outsourcing as a means of reducing cost, and in the process, alter their essence as competitors and their ability to exercise the same level of market power in the future as they previously did. In the General Dynamics court case, the Supreme Court recognized that current market share tells little about tomorrow's market power when a company's strength is based on advantages that are not sustainable (United States vs. General Dynamics Corporation, 1974). Unfortunately, this scenario did not seem



Adopted from America's Oil and Natural Gas Industry (2008).

Figure 7-A. Genealogy of Selected Oil Company Mergers.



Adopted from America's Oil and Natural Gas Industry (2008).

Figure 7-B. Genealogy of Selected Oil Company Mergers.

to have much impact on outsourcing phenomenon due to the fact that powerful competitors who are able to cut costs through outsourcing without losing their customers are apt to be more successful. In recent days outsourcing has expanded into the world of information technology, data transcription, and call center operations. Outsourcing can be defined as the process of transferring the responsibility for a specific business function or a set of related business functions to an external agent. Franceschini, Galetto, Pignatelli, and Varetto (2003) posit that outsourcing is a management approach that deals with delegating the operational responsibility of processes or functions that were previously delivered internally to external agents.

A global outsourcing strategy is the process of delegating specific non-core organization functions to specialized and efficient service providers (Elmuti & Kathawala, 2000). Global outsourcing has clearly made the structure of international competition and consequent labor market adjustments more intense. In the United States, job losses have been blamed on the increased outsourcing of jobs to other countries such as China, Philippines, and India. There are more viable cities for outsourcing, such as Chennai, Pune, Bangalore, Hyderabad, Cebu City, Manila, Mumbai, Kolkata, Delhi, and Dublin, however, of these outsourcing cities, nine are Asian cities, the exception being Dublin. Arguably, global outsourcing cannot be held solely responsible for job losses in the United States; outsourcing can only be blamed for a small portion of recent job losses. The general business cycle and rapid machine automation are essentially the causes of the sluggish job creation and concomitant job insecurities that have gripped the country. While industrial countries such as the United States, Germany, and Japan are the top outsourcers, the top insourcers, such as India, in particular but also China and Russia, are among the top twenty outsourcing countries. In other words, outsourcing is not a one-way street from developed countries (Ramkishen & Srivastava, 2007). Organizations today are increasingly relying on external partners to carry out a myriad of their business processes, and in most cases outsourcing gives the industry the opportunity to focus on what it does best. Referring to the economic theory of comparative advantage as a necessary application to analyze the question of what functions, the industry can contract out and what functions to perform in-house. The sacrifice is the alternative good that would have been produced; therefore, comparative advantage is the industry's ability to produce a good or service with lower opportunity cost than other producers.

Since comparative advantage is the ability to produce a good or service at a lower opportunity cost than someone else or other producers, Christopher (2007), concludes that using this principle, a firm will perform in-house those functions for which it incurs the minimum opportunity cost and contract out those functions in which it lacks the minimum opportunity cost. Lackow (1999), in a survey of 176 U.S firms, found that 59% indicate that the major reasons for outsourcing include cost saving, 54% improvement of services, 45% focus on core business, and 40% the ability to access outside experts. Traditionally, outsourcing is identified as a means of reducing cost of production and processes, interestingly, til date economies of scale are still presumed, as major motivation for outsourcing (Kakabadse & Kakabadse, 2005). Ramkishen and Srivastava (2007), also states that outsourcing is not a new phenomenon. Rather, it is a continuation of the process of globalization that began in the 1950's and 1960's which has led to net wealth creation globally as opposed to mere wealth transfer between countries. In some cases organizations are outsourcing globally their entire back-offices, including human resources, to offshore locations to leverage the cost and time advantages (Feeny, Lacity, & Wilcocks, 2005).

Regrettably, the increase in job losses in the United States, in recent years has been linked to increases in outsourcing; but there has not been an accurate statistics of U.S job losses to international outsourcing or an estimate of future losses. However, according to Forrester Research, 3.3 million U.S. service sector jobs will be lost to outsourcing by 2015 (Kirkegaard, 2004). Also, Cardinali (2000) predicts that by 2020, almost all the blue-collar factory worker jobs would be eradicated, though the U.S. will remain the top-manufacturing nation of the world, high use of automation and internet technology will take more jobs offshore.

Evidently, there are some success stories in outsourcing, especially in industrialized and developing countries. Outsourcing 1) opens up new export growth and employment opportunities in various tradable service activities, 2) is seen as a strategic management option instead of just a cost cutting operation, as it helps companies to achieve their business objectives through operational excellence and better market position, 3) improves professional manpower and helps companies to focus more on their core competencies, and 4) It helps companies to develop and implement cutting-edge technologies to meet their desired objectives. Other benefits of global sourcing depend heavily on parameters, such as the geographic location of the suppliers, the product purchased, or the mode of transportation. However, in comparison to sourcing from local markets, global sourcing is usually associated with increased uncertainty as well as poorer transparency and visibility (Wagner & Bode, 2006). In addition, complicating factors that must be tackled are no longer lead-times due to long routes of transportation, reliance and infrastructures (ports, communication systems), taxes, duties, and fluctuations of exchange rates (Goetschalckx, Vidal, & Dogan, 2002). In general, global sourcing contributes to the structural complexity of the supply chain (Hendricks & Singhal, 2005a). Outsourcing has become an effective tool that has been widely used to improve corporations' overall productivity and has ultimately helped in the transformation of corporations. However, outsourcing trends have been influenced by compliance requirements under the Sarbanes-Oxley Act, 2002, (compliance requires division of financial and audit reporting departments). Although many corporations had adopted the act, it was primarily passed for the public sector to improve accountability of corporate leaders. Compliance to the act by corporations means incurring additional cost; as a result organizations in the United States are circumventing the act by outsourcing their financial operations to countries such as India. Interestingly, outsourcing of non-core business functions is increasingly becoming popular in both US and European multinational companies. A survey by Pricewaterhouse Coopers of 151 American CFOs and 127 of their European counterparts estimates that 75% of the multinationals outsource their financial functions (Stowers, 2005). Essentially, outsourcing is the polar opposite of a vertical acquisition. To compete against vertically integrated incumbents, outsourcing should have the opposite effect, by allowing newcomers to enjoy cost savings that they would not soon be able to achieve on their own (Steuer, 2004). Industries that use outsourcing services are able to control costs without sacrificing reliability, as the services allow for industry best practices. As in the oil industry, best practices were shared within the limit of anti-trust laws.

The Oil Industry Outsourcing and Trends

The continuous fluctuations in oil prices are constantly pushing the oil industry to find ways to cut costs. As part of corporate strategy to lower cost, improve service, acquire expert skill, improve processes, improve focus on core activities, and gain competitive advantage, firms delegate their major non-core functions to specialized and efficient service providers. Companies in the oil industry took the outsourcing idea one step further and found that one way of outsourcing their logistics functions is to ally and collaborate with competitors (Raed, Tiravat, & Basher, 2006). This form of collaboration is often referred to as a "*systematic cooperative reciprocal barter*" (also called "swaps" or exchange) of supplies, assets, market share, or even the entire business among business competitors (O'Dwyer, 1998; Robert, 1995; Gain, 1997; Alperroicz, 2001; Sim, 2002). The source of oil is often of less importance to the ultimate consumer, as long as it meets its required specification and the date of contracted delivery. As a result, competing oil companies form alliances to improve customer service while reducing transportation and inventory costs when delivering oil to final consumers, which ultimately leads to shared transportation cost savings in the supply chain by all the participating companies. This form of collaboration is referred to as "shipment swapping". Indeed this form of collaboration with competitors creates a shared solution to common supply chain obstacles and is predicted to be the "Next Big Thing" (Morton, 2003).

For the oil industry to manage its supply chain in an effort to reduce costs, companies opt to outsource some of their logistic functions. As the trend in outsourcing has grown, these companies have become increasingly reliant on the service of third-party logistics companies for managing their supply chains (Collins, 1999). Thus, the degree of sophistication the service provider offers usually supersedes that of the in-house specialist. For example, in the oil field service industry, Schlumberger offers superior competency in drilling that oil companies have little choice but to outsource (Chung, Tim, & Tim, 2002). However, there are some functions, such as upstream applications, technical computing, engineering related applications, asset management, and work management, which reflect their core business competencies in-house. But they will outsource financial services, human resources and supporting applications.

The likely outsourcing trends in the oil industry include the following: 1) Increasing IT outsourcing of infrastructure related components. Information Technology (IT) outsourcing accounts for nearly 63% of all outsourcing revenue (Stowers, 2005). Indeed, reliable, effective, and affordable oil production has become the mission and the greatest challenge of the oil industry, therefore requiring it to be equipped with a robust, strong, secure, and flexible IT infrastructure capable of finding, analyzing, communicating, and applying specific information needed to achieve operational goals. 2) Alternative outsourcing of applications related to corporate systems, which is an imperative cost cutting tool for companies that compete on a global scale. 3) Establishing the ability to run applications from a single network as opposed to running it from multiple networks in several locations reduces cost and enables standardization and streamlining of processes and methodologies. 4) Investigating the benefits of outsourcing human resources, while delegating parts of certain core processes such as compensation, recruitment, employee retention, and benefit management to outside vendors who are experts in the field, so management can devote more time to core activities.

Outsourcing of back-office functions, such as production revenue accounting, has been greatly perceived by oil companies as a source of achieving greater synergies and cost savings. Unfortunately, the production and revenue function, which includes land management, contracts, pricing, and revenue distribution to interest and royalty owners, has been a challenging task (Gary, Deloitte, Touche, & Sam, 2007).

Oil Industry Outsourcing Risks

Transferring risk to other parties is becoming a common practice in supply chain management, such as outsourcing and sub-contracting practices where some types of supply chain risks are transferred to parties providing the service or product (Iwan, Suhaiza, & Nyoman, 2009). Since outsourcing of some of the business processes is driven by tremendous pressure to cut costs, it makes financial sense to outsource to a low-wage economy such as India, but this action can also lower the value of information of the company since people earn less. For example, since working cultures in low-wage nations are different, it increases the criminal opportunity for information to be sold out easily and for less. Beyond security risk, loss of competitive edge could be another source of risk inherent in outsourcing. Indeed, outsourcing providers, specifically those in developing nations, sometimes have the desire to climb up the value chain as they continue learning the operations of companies in developed nations. Industries or organizations that outsource most or part of their business processes also stand the risk of losing their core skills as they continuously become reliant on the outsourcing providers.

As the oil industries' rush toward outsourcing turned into a stampede and continues to grow, so does the risk. Some of the risks include the following:

- **Technical Risk:** Measures the fit between project and the skills and capabilities of the outsourcer, which can also be present if there is risk associated with the ability of the customer to deal with an outsourcer.
- **Market Risk:** Occurs when there is uncertainty surrounding the requirements and specifications. Projects with high market risk are typically not good candidates for outsourcing.

- **Project Risk:** Perhaps the biggest concern in making an outsourcing decision is the risk associated with a delay or inability to deliver the project.
- **Political and Security Risk:** Some of today's outsourcers are in developing nations without stable governments which limit the projects and activities that could be outsourced.
- **Outsourcer Risk:** The risk of the outsourcer going out of business, which may be related to political risk, but is more specifically when looking at the stability of the outsourcing company and its employee (Little, n.d.).

Some other risks of outsourcing include the following:

- **Cost Calculation:** Cost reduction is one major driver of outsourcing; therefore, the risk of outsourcing cost exceeding the expected value to the oil industry should be carefully analyzed. The cost scenarios that should be analyzed as follows:
- The current cost of managing back-office functions such as accounting and finance.
- The cost of using in-house processes with best industry standards, practices, and technology.
- The cost of back-office outsourcing includes base-line in-house expenditures, which include tangible costs such as staffing cost, infrastructure, and IT application, and intangible costs of lost focus.

Building Consensus

Since outsourcing concerns every aspect of a company's operation, it affects every level of a company, from high level corporate executives to lower level managers and employees. Due to negative reactions to outsourcing resulting from major changes, it is important to the success of an outsourcing strategy to build consensus at all companies' levels. Outsourcing must be accepted, not imposed, therefore to gain company-wide acceptance, benefit must be demonstrated and fears of losing jobs and loss of control at the front-line managers' level must be alleviated.

Difficulty in Identifying and Selecting the Right Partner for Specific Business Needs

Without extensive due diligence, the company may not be able to make the right choice of partner in an outsourcing arrangement. The risk of costly mistakes, by choosing the wrong partner and ensuring long-term mutual successful relationship, should be eliminated by considering some of the following key criteria:

- **Client References:** Conduct interviews to obtain candid and exhaustive feedback, characterizing the strength and weakness of the provider.
- **Knowledge and Experience:** Assessing the outsourcer's skill and expertise in depth reduces the risk of selecting the wrong partner.
- **Customer Service Levels:** This is the most important criteria in evaluating and choosing a potential outsourcing service provider.
- **Infrastructure:** Visiting the potential service provider's facilities helps provide a clear picture of the management expertise and physical infrastructure of the service provider.
- **Financial Health:** An ideal candidate is required to have a strong track record of cash flow, profitability and growth, substantial capital reserves, low debt, and a mixed client base.

Contract Negotiation

There is always a prolong bid and negotiation processes in finding an appropriate outsourcer; therefore, to build a flexible partnership it is necessary to develop mutual trust and respect, which will be the guiding force in the parties' relationship, rather than a rigid enforcement of contractual terms. The outsourcing agreement should contain a detailed description of services to be performed, penalties for failure of meeting service level requirements, as well as financial rewards for exceeding expectations.

Ensuring Continued Value

Risk of outsourcing may be minimized if the company invests time and effort required to effectively manage an outsourcing relationship, if not, management responsibilities could be relinquished to the outsourcer. In either case, the outsourcer will begin to operate in a vacuum, and service levels may deteriorate as the outsourcer loses touch with the company's business objectives (CGI Group, 2004).

CHAPTER 3. LITERATURE REVIEW

Global supply chains mean longer distance to travel and also more participants, which leads to more opportunities for disruptions (Sheffi, 2005). For example, when sourcing or labor moves abroad, another mode of transportation, either water or air, is often introduced to the supply chain, and the length of the supply chain is increased, introducing new potentials for disruption (Kelly, 2008). A disruption anywhere in the supply chain can have a profound effect on a corporation's performance; it erode market share, bloats cost and budget, threatens production and distribution, tarnishes credibility with investors and other stock holders, and sky rocket the cost of capital (Bostman, 2006). The increase in the complexity of the global supply chain network has also resulted in an increased disruption risk. Examples of supply chain disruptions are divided into three distinct categories: 1) intentional attacks such as terrorism, sabotage, computer hacking, labor issues, 2) natural disasters such as earthquakes and hurricanes, and 3) accidents such as fires and equipment failures (Sheffi, 2005). In addition there are some regions in the developing countries where political instabilities pose some risk to the oil industries.

These supply chain disruptions are associated with a certain probability of occurrence and characterized by severity and direct effects (Kleindorfer & Saad, 2005). They can materialize from various areas internal and external to a supply chain (Wagner and Bode. 2006). Hurricane Mitch in the Caribbean Island, 1998; the Chi-Chi, Taiwan, earthquake of September 1999 that sent shock waves through the global semiconductor market (Papadakis & Ziemba, 2001); the August 14, 2003 blackout in the northwestern U.S.; the Y2K problems, the U.S. West Coast Ports strike, 2000; the Severe Acute Respiratory Syndrome (SARS) Virus outbreak in Asia and Canada, 2003;the 2001 U.K

Mad Cow Disease that resulted in the destruction of several thousand cattle; and certainly the September 11, 2001 terrorist attacks in the U.S; and the 2004 attacks in Madrid are just a few examples that confirms that firms and their global supply chains certainly operate in an unpredictable and increasingly uncertain environment (Wagner and Bode 2006).

Supply Chain Disruption Risk

In today's globalized supply chain, managing disruption risk is increasingly an emerging issue of pivotal importance, as supply chains are becoming much more demand driven. Supply chain risk management in most cases forms the link between the organizations, customers, suppliers and the business environment. In supply chain management discipline, defining risk has always been a major concern. March and Shapiro (1987), in their classical concept, defined risk as the "variation in the distribution of possible outcome, their likelihoods, and their subjective values" or the hazard-focused interpretation, common in risk management, which is more likely to present risk in terms of : Risk = Probability (of a given event) multiplied by the Severity (negative business impact). Indeed managing risk in a demand-driven environment requires visibility along the links in the supply chain; however, Maaninen-Olsson (2005) suggests that all risk cannot be attended, as it would demand too many resources. Supply chain risk pertains to any threat of interruption to the functioning of a supply chain (Christopher, 2003).

A supply chain disruption is an unintended, untoward situation that has the potential to cause an undesirable impact to the movement of goods within the supply chains, and ultimately leads to supply chain risk. For the affected firms, it is an exceptional and anomalous situation in comparison to everyday business (Wagner & Bode, 2006). "If you are going to put all of your eggs in one basket, you'd better keep a close eye on the basket." This does not only apply to supplier relationships but virtually every level of the supply chain; from raw material sourcing to manufacturing capability to distribution services (Pickett, 2006). Logistics providers and their customers have tried to reduce waste and buffers in their various forms. Indeed the down side of this event is that lean supply chains are becoming extremely fragile and are continuously depending on exposed communication networks. As a result, they are less able to deal with shocks and disruptions that have catastrophic impacts on the firm. A disruption in supply can affect companies a long way down the supply chain, considering the fact that risk is not thought of as an eminent problem for a single company, but also for many links in the supply network (Souter, 2000). Managing risk has become a critical component of supply chain management. The implications of supply chain failures can be costly and lead to significant customer delivery delays (Wu, Blackhurst, & Chidambaram, 2006). Risk management is about being systematic and methodical; it is about discovering the "unknown unknowns" and taking action that optimizes the upside and minimizes the downside. When applied to supply chain, it restores the balance of control and strengthens each link in the global relationship (O'Brien & Gerard, 2007).

While several types of supply chain vulnerability management methodologies have been proposed for managing supply chain risk, most offer only point-based solutions that deal with a limited set of risks (Wu, Blackhurst, & Chidambaram, 2006). Therefore, understanding the risks and their potential impact on a company's operation can be helpful in managing its supply chain more effectively and therefore gaining strategic advantage in the global competitive marketplace. In today's world of increasingly complex, globally dispersed supply chains where lean is the mantra, even the slightest disruption can cripple a firm's ability to get products to market. Christopher and Lee (2004), McGillivray (2000), and Engardio (2001) suggest that the drive toward a more efficient supply chain during recent years has resulted in the supply chains becoming more vulnerable to disruption. Since the resulting detriment of supply chain disruption is a function of time, involving time pressure, it implies that the decision for mitigation must be made swiftly (Hermann, 1963).

Christopher and Peck (2004) define supply chain vulnerability as "an exposure to serious disturbance."Certainly supply chain vulnerability is a multifaceted, multidimensional construct, and a function of certain supply chain characteristics. The loss a firm incurs is a result of its supply chain vulnerability to a given supply chain disruption (Wagner & Bode, 2006). One major threat of companies today is vulnerability to unexpected supply chain disruptions; as a result, increasing attention is laid on resiliency in order to take control of the resulting consequences.

Supply Chain Security and Resiliency

In today's increasingly turbulent global business environment, it can be argued that supply chain risks and their vulnerabilities are becoming greater than ever before. Increasing global business means increased risk exposure and potential disruption within the supply chain. Since there is an increased flow of goods from one part of the globe to another, opportunities for disruption to occur become eminent. Supply chains are becoming increasingly complex as they are lengthened and leaned; indeed, several supply chains are identified to be dynamic networks (Christopher & Peck, 2004). A secured supply chain does not imply a resilient supply chain; therefore, organizations need to design supply networks for suitable levels of both security and resilience. (Rice, 2003). Supply chain security management can be defined as "the application of policies, procedures, and technology to protect supply chain assets from theft, damage, or terrorism and to prevent the production of unauthorized contraband, people, or weapons of mass destruction into the supply chains". The flip side of supply chain security is supply chain resilience, which is a supply chain's ability to withstand and recover from an incident (Closs & McGarrell, 2004).

Supply chain resiliency, the ability to avoid or reduce exposures to disruption or absorb disruptions with minimal impact to the business, has become a hot topic for corporate executives (Pickett, 2006). Christopher and Rutherford (2004) describe supply chain resilience as the ability of a system to return to its original (or) desired state after being disrupted. A resilient supply chain must also be adaptable, as the desired state may be different from the original one. Therefore action is required for the company to resume and restore its operations promptly after disruption occurs (Lee & Wolf, 2003; Rice & Caniato, 2003b, Wilding & Braithwaith, 2006). One of the most powerful ways of achieving resilience in the supply chain is to create networks that are capable of more rapid response to changed conditions (Christopher, 2003).

Global supply chains today are vulnerable to security threats and the uncertainties associated with them. As a result, governments and the private sector in collaborative efforts are launching new initiatives to create more secure and reliable supply chains (Hau, 2004), while maintaining a smooth flow of goods and services in a global supply chain (Stein, 2004). The most critical challenges facing organizations are risk and supply chain security. Preventing security breaches is indubitably the first step in improving supply chain security. While many companies have developed comprehensive security strategies they still believe in possible breaches of security systems and possible disruptions, since the protection of the entire supply chain from all sources of risk is either difficult or impossible. The United States government has already enacted a number of laws and regulations to protect people, facilities and businesses against terrorism. Most regulations deal with container transportation management in the intermodal system, since the vast majority of world trade flow utilizes containers (Iakovou, Vlachos, & Xanthopoulos, 2007). While restrictive control measures may reduce exposure to risks, they can also reduce an organization's ability to succeed (*Financial Times*, 2006; Hendricks & Singhal, 2005).

In spite of government responses to disruptions, it has been confirmed historically that such responses inadvertently pose more unthinkable impacts on supply chains other than the disruption itself. For example, the closure of U.S. airspace and delays at the borders immediately after the September 11, 2001, attack were more disruptive to the supply chain than the actual attacks (Rice & Caniato, 2003a). Primarily, stakeholders such as governments, organizations, and consumers, are demanding effective supply chain security because 1) the global economy depends on the free flow of people, goods, information, and finance, 2) businesses around the world rely on efficient supply chain operations and, 3) increased terrorist threats can have significant implications for homeland and global security (Closs & McGarrell, 2004). In addition to identifying and assessing risk, companies also need suggestions on how to protect themselves. In particular, firms are looking for ways to increase the security of their supply chains without jeopardizing their effectiveness (Sheffi, Rice, Fleck, & Caniato, 2003). In a recent study by an MIT research team headed by Sheffi it was found that companies are undertaking a series of initiatives, which are classified into three groups to protect their supply chain from disruption: physical security, information security, and freight security. These groups in turn are further segmented into two levels of response: basic and advanced. The basic levels correspond to more traditional initiatives that today have become standard practice, while the advanced level involves more forward-thinking initiatives used by a limited group of companies (Sheffi, Rice, Fleck, & Caniato, 2003). Table 4 summarizes supply chain security measures at the two levels.

Table 4. Supply Chain Security Measures

	Basic Responses	Advanced Responses
Physical Security	▪ Access control, badges. ▪ Gates, guards, camera systems etc.	▪ Extensive background checks. ▪ Vulnerability testing by outside experts
Information Security	▪ Hardware: firewalls, dedicated networks, etc. ▪ Software: Intrusion detection, antiviruses, passwords, etc.	▪ Audits of partners information security (IS) ▪ Education and training for IS security
Freight Security	▪ Inspections ▪ U.S. Government initiatives (e.g. C-TPAT, Cotainer Security Initiative, Operation Safe Commerce) ▪ Cargo seals	▪ Procedures, audits and certification ▪ Industry initiatives ▪ GPS, RFID, e-seals, biometrics, smart-cards, security sensors, etc.

Source: Sheffi, Rice, Fleck, & Caniato, 2003.

Supply chain security is achieved by not just by focusing on the individual nodes and links but by looking at the entire supply chain, since securing the supply chain entails securing all the nodes and links along the chain. In direct response to the September 11, 2001, terrorist attack, several international organizations and countries have developed or are developing programs that entail guidelines and best practices for ensuring supply chain security of cargo, processes, and personnel involved in every movement through the supply chains (Singapore Customs, 2006). Shippers and carriers that certify the use of best security practices are qualified and therefore given expedited custom processing at U.S. ports of entry.

The measures designed by the United States Department of Homeland Security to mitigate and preserve the integrity of the global supply chain are as follows: 1) The Customs-Trade Partnership Against Terrorism (C-TPAT), a voluntary government and business initiative to build cooperative relationships that strengthen and improve overall international supply chain and U.S. border security. C-TPAT is the U.S. Customs and Border Protection (CBP's) initiative that asks partners, on a voluntary basis, with members of the trade community, to provide the highest level of cargo security through close cooperation with the ultimate owners of the international supply chain, such as importers, carriers, consolidators, licensed custom brokers, and manufacturers (Bureau Veritas Services, 2007). 2) Container Security Initiative (CSI), the US and some trading partner governments are pursuing supply chain security by pushing inspections and screening upstream to originating ports. CSI focuses on the twenty ports where most of the US-bound containers originate. The goal is a series of bilateral agreements that would permit exchange of customs officers and more screening of shipments at the outbound ports. The processes involved in pick and pack, staging of outbound loads, and the final loading, are to be tightly monitored and documented (e.g., the identities of pickers, packers, loaders, checkers, and if any seals are used on the container, etc. (Hau, 2004). 3) Smart and Secure Tradelane initiative (SST) aims to enhance the safety, security, and efficiency of cargo containers and their contents moving through the international supply chain into US ports (Iakovou, Vlachos, & Xanthopoulos, 2007). Under this initiative, the world's three largest seaport operators, Hutchison-Whampoa Ltd, PSA Corporation Ltd, and P&O Ports representing over 70% of the world's container traffic, will collaborate to demonstrate and deploy automated tracking detection and security technology for containers entering US ports. Hence, containers leaving the participating ports will eventually be equipped with special electronic seals that could be used to track whether the containers have been tampered with during transit (Hau, 2004). 4) The 24-hour Advance Manifest Rule (AMR) requires that carriers submit a cargo declaration 24 hours before cargo is laden aboard a vessel, at a foreign port, for destinations in the US (Iakovou, Vlachos, & Xanthopoulos, 2007). When fully implemented, containers will only be allowed into the US if detailed contents information has been provided electronically to customs at least 24 hours prior to loading the container on the ship. The information will be useful to pre-screen questionable containers prior to arrival to the US ports and select containers for inspection at ports of entry (Hau, 2004). 5) Automated Commercial Environment (ACE) based on an automated information system enabling the collection, processing, and analysis of commercial import/export data, ACE facilitates the faster and cheaper movement of goods through ports as well as the detection of terrorist threats. 6) Automated Targeting System (ATS), is an information system that allows shipment data review against information stored in law-enforcement and commercial databases, so as to identify potentially high-risk international shipments (Iakovou, Vlachos, & Xanthopoulos, 2007). Both the CSI and C-TPAT focus on sound strategies for addressing container security, and whole-of-supply chain issues. However, these initiatives have been recognized as constituents of a framework for building a maritime security regime, and that significant gaps in security coverage will remain, despite their global adoption (Frittelli, 2003).

According to World Bank study, increased port efficiency has a significant and positive impact on the expansion of trade, as do improvements in the customs regulatory environment (Barnes & Oloruntoba, 2005). Wilson, Mann, and Otsuki (2003) argue that burdensome customs and regulatory/security measures may hinder port and maritime supply chain efficiency, which in turn leads to a contraction in trade and overall efficiency.

Supply Chain Risk Sources and Risk Management

Security and vulnerability within the supply chain have been largely overlooked or considered unimportant until the terrorist attack on the World Trade Center. The subject of supply chain security and vulnerability are finally being given needed attention as they pertain to terrorist attacks. This vulnerability can, in many cases, be described as "unwanted effects" in the supply chain. Increased vulnerability in the supply chains is a result of the drive toward more efficiency, which also in turn increases vulnerability from disruptions or disturbances (Christopher et al., 2004). To reduce this vulnerability, companies must identify their own internal risk, but also the risk derived from collaboration and linkage with other companies (Juttner, 2005). Juttner (2005) states that risk taking is generally perceived as an inevitable aspect of supply chain management. Taking risks is not the same as controlling and managing risk to an acceptable level. Taking risk is viewed as an integrated and inevitable part of management (March & Shapiro, 1987). In order words, it is decision-making under uncertainty. Braithwaite and Hall (1999) posit that in supply chain concept, the relationship between corporate strategy, risk, and the implications for supply chain management is poorly understood and needs further exploration.

In today's global business environment assessing and managing risk is becoming an important business concept; therefore, managing risk is cited as one of the primary objectives of firms that operate internationally (Ghoshal, 1987). According to Miller (1992), risk assessment and management too often focus on a particular set of uncertainties to the exclusion of other interrelated uncertainties. Since risk has become an intricate and fundamental element that is encountered in everyday operations by supply chain organizations, a firm's initial responsibility should be to understand the risks and ultimately design solutions to mitigate the impact of the risk. In the popular practitioner-oriented risk management literature (e.g., Goldberg, Davis, & Pegalis, 1999), the uses of the term "risk" can be confusing because it is perceived as a multidimensional construct (Zsidisin, 2003).

Risk is used to refer to uncertain internal or external environmental variables that reduce outcome predictability. A supply chain disruption is the situation that leads to the occurrence of risk; it is not the sole determinant of the final result, indeed the derived classes of supply chain disruptions are often labeled "supply chain risk sources" (Wagner & Bode, 2006). Supply chain risk sources are any variables that cannot be predicted with certainty and from which disruptions can emerge. According to literature reviews, supply chain relevant risk sources fall into three categories: 1) Environmental risk sources comprise any uncertainties arising from the supply chain-environment interaction that may be the result of accidents (e.g, fire), socio-political action (e.g, fuel protests or terrorist attacks) or acts of God (e.g, extreme weather or earthquakes). 2) Organizational risk sources lays within the boundaries of the supply chain parties and range from labor (e.g, strike) or production uncertainties (e.g, machine failure) to IT-system uncertainties. 3) Network related risk sources such as lack of ownership, chaos, and inertia, arise from interactions between organizations within the supply chain. (Juttner, Peck, & Christopher, 2003). Christopher and Lee (2001) also verified that a supply network brings with it risk from all related network sources, namely uncertainties due to lack of ownership, chaos, and inertia. Lack of ownership risk source in supply chains result from blurring boundaries between buying and supplying companies in the chain. This kind of risk often results in increased inventory costs due to product obsolescence, markdowns, or stock-outs, which are passed on among the organizations in the supply chain. Chaos risk, 'chaos effects' caused by the complexity of the supply chain, results from over-reactions, unnecessary interventions, second guessing, mistrust and distorted information throughout a supply chain. An example of such chaos is the well-known bullwhip effect, which describes increasing fluctuations of order patterns from downstream to upstream supply chains (Lee, Padmanabhan, & Wang, 1997).

In global supply chains, cost reduction has often been chosen over flexibility, therefore exposing the supply chain to a complete lack of responsiveness to changing environmental conditions and market signals. Network-related risk sources from an integrated part of the network design and structure can either absorb or amplify the impact of events arising from environmental or organizational risk sources (Juttner, Peck, & Christopher, 2003). Svensson (2000) classified supply chain risk sources into quantitative and qualitative, while Juttner (2005) cite three categories: supply, demand, and environmental. Chopra and Sodhi (2004) propose other sources comprised of disruptions, delays, systems, forecast, intellectual property, procurement, receivables, inventory, and capacity. Risk identification differs in various industries or organization, however some of these may include infrastructure risk, product risk, (quality, fraud, theft, counterfeiting), ethical risk, terrorism, political and pandemic, financial risk (exchange rate, interest rate, and cash flow), supplier relationship risk, Sarbanes-Oxley non-compliance risk and etc. (The Sarbanes-Oxley Act of 2002 (SOX) is a critical piece of new legislation that affects how public organizations and accounting firms deal with Corporate Governance, financial disclosure and the practice of public accounting). From Forbes Global (2006), a survey of top supply-chain executives specified that the worst supply chain risks include supplier failure (28%), strategic risk (17%), natural disaster (15%), geo-political events (11%), regulatory risk (11%), logistics failure (10%), intellectual property infringement (7%), and others (1%). The result of the survey can facilitate detailed risk treatment and help gain insight on how to prioritize and plan risk management activities; however, the likelihood of occurrence and severity of impact may be different between organizations and countries.

A supply chain is where risk becomes most probable and most damaging: "If there is a disaster looking for a place to happen, the supply chain seems an obvious candidate" (Malone, 2006). Arguably, a supply chain's risk vulnerability is determined by its risk exposure. Therefore, to manage or mitigate disruption risk firms must identify specific strategies to adopt, since managing risk efficiently for any particular firm depends on the environment for which the firm operates. A disruption that affects an entity anywhere along the supply chain can have a direct effect on a corporation's ability to continue operations, get finished goods to market, or provide critical services to customers (Juttner, Peck, & Christopher, 2003). Organizations that think they have managed risk have often overlooked the critical exposures along their supply chains. According to Braithwaite and Hall (1999), supply chains that run hundreds, if not thousands, of companies over several tiers present significant risk. Risk management strategies has been adopted for several years in diverse fields such as international management (Miller, 1992; Ting, 1988); finance (Smith, Smithson, & Wilford,1990); economics (Kahnemann & Tversky, 1979; Tversky & Kahnemann, 1992); strategic management (Bettis & Thomas, 1990; Simons, 1999); and supply chain risk management 'SCRM' (Juttner, Peck, & Christopher, 2003; Zsidisin, 2003; Ellram & Cooper 1993; Christopher, 2003).

Therefore, supply chain risk management can help an organization identify, quantify, and prioritize the risk inherent in its supply chains. Paying more attention to risk and to managing that risk is critical as new technologies, regulatory requirements, consumer demands, and potential disruptions combine to make supply chain management increasingly complex. All industries are exposed to similar risks, but not all supply chains are exposed to the same type of risk and magnitude of risk, in essence, understanding the risks and their potential impact on a company's operations can help a firm manage its supply chain more effectively and gain strategic advantage in a competitive marketplace (Lowery, 2004). Therefore, it is important to an organization's success to understand the sources of supply risk and how to best manage them (Kraljic, 2001). Indeed, adoption of appropriate risk management techniques would enable risk managers to transform potential liabilities into competitive advantages. Companies reliant on external suppliers are susceptible to vulnerabilities due to risk along the supply chain, and the oil industry in particular is no stranger to risk. Therefore, terrorism risks management in the upstream crude oil supply chain, for example, will require dealing with the real threat of terrorist acts as well as the consequences of the threat of terrorism (Magne, 2006).

The Role of Transportation in the Supply Chain

In today's global economy and deregulated environment, the contribution of transportation services is becoming increasingly important to the international supply chain structure. Transportation is an essential part in the execution of the supply chain, providing the link between nodes such as suppliers, ports, handling and distribution centers, and destinations. Without transport, certainly there would be no transaction of trade anywhere around the globe. It is the physical means by which commodities are carried from one place to the other: "what goes in comes out." Therefore, transportation capabilities must be integrated with their enabling supply chain structures (Morash & Clinton, 1997).

The logistics system consists of links and nodes, where the nodes are geographically fixed points, such as factories and terminals, while the links are elements connecting the nodes, i.e., the modes of conveyance (Ekwal, 2007). Logistics networks may be viewed abstractly in terms of flows of resources and materials across space and time. Since these flows represent physical movements within a logistics network, they depend upon externally controlled transportation systems. Important decision making in transportation includes modal selections such as truck, rail, air, or maritime, shipment size, and routing and scheduling of vehicles, which are all directly related to the location of warehouses, customers, and plants (Webster, 2008). Transportation systems are fundamental to the efficient and economical operation of a company's logistics function. They are the physical threads connecting the company's geographically dispersed operations and more specifically, add value to the company by creating time and place utility (Coyle, Bardi, & Langley, 2003). More expansively, transportation may be in an ideal position to integrate and coordinate flows throughout the supply chain (Morash &

Clinton, 1990). As trade barriers fall around the world, a new trade barrier is rising around the American continent; congestion at the nation's ports, on its highways, and along its railroads is becoming the new tariff of the 21st Century. This congestion increases travel times, disrupts tightly planned supply chains, and increases the cost of doing business with America and in America (American Association of State Highway & Transportation Officials, 2007).

Modes of transportation have in recent years undergone various technological improvements that have lead to reduced transit times. In addition, on most of the shipping routes, rates have either remained stable or have become more competitive (Lambert, 1995). Trucking is clearly the dominant mode of shipping and faces some of the largest problems. However, all the modes play a critically important role in the transportation system; rail, for example, is essential for intermodal and bulk movements across the continent, particularly for items such as automobiles, coal, and ores. Pipeline have become a proven supersonic mode of transporting commodities such as oil. Domestic water shipment is irreplaceable for high-volume, low-cost movement of chemicals, grains, ore, aggregates, and salt, particularly on the Mississippi and Ohio River systems. Air carries a tiny fraction of all freight but is critical for high value, time-sensitive cargo. Critical electronics parts, perishable gourmet foods, and even high-end clothing travel by air (American Association of State Highway & Transportation Officials, 2007).

There are different types of ships, such as tankers, barge carriers, fruit carriers, car carriers, pallet ships, liquefied natural gas (LNG) carriers, coasters, container vessels, multi-purpose general cargo ships, OBOs (ore/bulk/oil), refrigerated vessels, roll-on roll-off (Ro/Ro) vessels, as well as trains and other more specialized forms such as air transportation, land transport, and multimodal transport. The principle behind multimodal transport is the combination of the different modes in an effort to cover the portion of the route where each mode is used most efficiently in terms of cost and time to achieve a result that is almost as quick as using the more expensive mode, but is less expensive (Lambert, 1995).

Transportation service levels and costs affect supply chain costs, both directly and indirectly. The direct costs of transportation include freight charges, private trucking costs, and transfer and storage charges. In the short run, the indirect costs of transportation are the safety stock and emergency shipping cost attributable to travel time variance and uncertain performance, while the indirect effects of transportation in the long run, include spatial organization and location decisions, fixed facility cost, and output market decisions (Tolliver, 2007). To minimize total costs and maximize customer value, integration of transportation is vital in the supply chain. Specifically, the supply chain structure defines and drives the transportation capabilities of time compression, reliability, standardization, just-in-time delivery, information systems support, flexibility, and customization.

Velocity refers to how many times inventory turns per year, or the average number of days of inventory on hand. Faster transit time minimizes pipeline inventories and may allow customers to lower safety stock held in reserve (Morash & Clinton, 1990). Structural integration, such as technical operational planning and instrumental information sharing, also can foster transportation reliability, which can be defined as reduced variability of shipment times around the mean transit time (Morash, 1990). In general, lack of transportation flexibility can raise inventory carrying costs, the cost of lost sales, and production costs. Finally, customizing of transportation attributes for specific market segments or different supply chain members can further increase integration of the supply chains (Fuller, O'Conor, & Rawlinson, 1993) and (Pine, Bart, & Boynton, 1993).

Crude Oil Transportation

The refining and marketing sector of the oil industry is a high-volume, low-margin business in which efficiency is essential to survival. Nowhere is that efficiency more evident than in the transportation of crude oil. Even with the physical system, transportation is a major cost for the oil industry, and a great deal of effort is directed to improving the competitive position of individual companies through investment, trades, and supply realignment (National Petroleum Council, 1989). The oil industry made a fundamental strategic decision early in its history not to own all its tonnage needs, which opened up doors for independent businessmen to provide a shipping service to the oil companies. If oil companies had made the decision to own all their tonnage needs, there would be no tanker owners. However, making the decision that permits tanker owners to exist benefited parties, lowering transportation cost for the oil companies and providing sources of business for the tanker owners. The primary functions of an integrated oil company are to explore for oil, develop oil fields, refine crude oil, and market refined products. Transportation, be it by pipelines, ships, barges, railroad cars, or tank trucks, is not a source of profit, but a cost of doing business (Tusiani, 1996).

During World War II, the United States government separated America into five economically and geographically distinct regions for the purpose of administering oil allocation "Crude oil production and consumption." It was established by the Defense Production Act of 1950, and then abolished in 1954, with its role taken over by the U.S. Department of Interior's Oil and Gas Division. The war is long over, but the country is still divided into those segments, called Petroleum Administration for Defense Districts (PADDs), and the Department of Energy's Energy Information Administration still collects and publishes oil supply and demand data by PADD, providing a picture of regional patterns and flows. Today, as in World War II, pipelines are the primary mode for moving oil and petroleum through each of the following Petroleum Administration for Defense District regions (PADD). PADD I (east coast); is composed of the three sub-districts: Sub-district 'A' (New England); Sub-district 'B' (central Atlantic): and Sub-district 'C' (lower Atlantic). The other regions are PADD II (Midwest); PADD III (gulf coast); PADD IV (Rocky Mountain); and PADD V (west coast).

Most domestic crude oil is refined in the same region in which it is produced; however, there is a two-step process intra-PADD movement/transportation from wellhead to refineries: 1) through gathering, which is the collection of crude oil from individual properties in small-diameter pipelines or by truck for input into a large-diameter pipeline; 2) through mainline or trunkline transportation, which is the movement of the "gathered" oil to refineries. Crude oil imports are transported by pipelines, but the bulk of imported crude oil is delivered by foreign-flag tank ships. The relatively long transit times for many foreign crude oils are a significant factor in crude oil supply planning and dynamics, since it may take up to 45 days in transit after loading; therefore, for a refiner, long transit time means reduced supply flexibility and higher levels of inventory and inventory cost. In a highly volatile market, long transit times also increase the risk of adverse market changes between purchase and delivery. However, to offset these disadvantages, some producers resort to selling long-haul crude oil from transshipping terminals and price it based on the market at or near the delivery date (National Petroleum Council, 1989).

Pipeline Crude Oil Transportation

Transportation pipelines are mainly long pipes with diameters, moving products (oil, gas, and refined products) between cities, countries and even continents. Pipelines are built above or under land and also under water, and are increasingly used as a choice mode for transcontinental oil transportation. Typical examples of underwater pipe line links are the ones between North Africa and Italy and also the links from the Norwegian offshore gas field in the North Sea to European terminals. Today, oil makes up over half of the annual tonnage of all sea cargos, and there are more miles of pipelines in the world than railroads (Burger, 1997). For example, The Baku-Tbilisi-Ceyhan (BTC) pipeline, which spans 1,760 kilometers of rugged terrain with 1,500 river crossings, in 2006 began transporting oil from Azerbaijan to Turkey (B.P. Global, 2008). Also, at the end of 2008, it was noted that a total of 265,440 km of oil and natural gas pipelines exist in 37 Asian countries, out of which about 45% carry oil/refined products and condensate (Venkatesh, 2008). Roughly 170,000 miles of oil pipeline in the United States carry over 75% of the nation's crude and around 60% of its refined petroleum products. There are nearly 200 interstate oil pipelines, which account for roughly 80% of total pipeline mileage and transported volume (Rabinow, 2004). The oil industry uses several transportation modes in its operation; however, pipelines are unique due to the one-directional movement without any return payloads, but may also participate in several origins to destination markets. Most pipelines are common carriers, offering transportation services to anyone who wants them but subject to some regulations. While crude oil and petroleum products generally do not travel on the same pipelines, numerous different petroleum products are shipped back to back in batches through the same pipelines (U.S. Government Accountability Office, 2007).

Oil as a commodity is homogeneous, and therefore pipelines running from origin to destination encounters competition with other pipelines as well as with other transportation modes from the same origin to destination. For example, if a pipeline originates from origin X to destination Y, it faces competition with other participating pipelines or marine transportation out of the same origin X. It also competes with other pipelines or marine transportation carriers into destination Y. Apparently, in both cases at origin X and destination Y, the pipeline competes with other market participants such as local oil refineries, consumers, or suppliers. For example, in the United States, the Montana and North Dakota portion of the Williston Basin crude production is estimated at about 200,000 barrels per day, North Dakota produces 110,000 barrels, Richland County in eastern Montana produces approximately 60,000 barrels, while southeastern Montana produces 30,000 barrels. Most of the crude oil produced in southwestern North Dakota and southeastern Montana is shipped by pipelines to the Guernsey, Wyoming, hub then to Colorado, Utah, and Wyoming refiners or to Wood River, Illinois, via the Platte Pipeline. Due to the growth in oil production in the entire Rocky Mountain region, existing pipelines and refineries are experiencing the effects of competition. As a result, the industry and state government are engaged in cooperative efforts to expand infrastructures in North Dakota, Montana, Wyoming, Colorado, and Utah (Ness & Helm, 2006).

In spite of the pipelines' natural monopolistic competitive character, and the apparent competition from other pipelines, growth in the market and changes in supply and demand have resulted in the construction of new pipelines that enable competition with existing pipelines (United States Federal Energy Regulatory Commission, 1992). Pipelines are critical for landlocked crudes and also complement tankers at key locations by relieving bottlenecks or providing shortcuts. They are the primary option for transcontinental transportation because they are at least an order of magnitude cheaper than alternative such as rail, barge, or road, and because political vulnerability is a small or non-existent issue within a nation's border or between neighbors such as the United States and Canada (Energy Information Administration on Trade, n.d.). Pipelines are not merely an element of trade; there are also an element of geopolitical issues and international security issues, such as the dispute that occurred early in 2009 between Russia and Ukraine, ostensibly over pricing, which led to a major political crisis.

Marine Crude Oil Transportation

Transportation of hazardous materials has been a widely discussed concept in transportation and environmental literature (Glickman, 1988; Jamei, Hobeika, & Rice, 1988; List & Abkowitz, 1986; Rothberg, 1986). According to National Research Council (NRC 1976), there seems to be a clear focus on land or rail transportation with minimal work done in marine environments. To realize the marine board's recommendation, the development of a National Marine Oil Transportation System Model (NMOTSM) that would allow quantification of oil transported within the geographic boundaries of the United States has been undertaken. Today's increasing global oil reserves are pushing exploration and production to the far ends of the earth; as a results the need for reliable transportation is becoming increasingly necessary to transport oil through the great distances from the oil field to the refineries then to the consumer markets (O'Rourke & Connolly, 2003). O'Rourke and Connolly (2003) and Devlet (2007) assert that marine transportation is the primary means of crude oil transportation and that crude oil transportation accounts for about 35% of the annual tonnage of all sea cargoes. Burgherr (2007) estimates that tankers transport almost 60% of the oil consumed in the world.

Transportation of oil is undoubtedly the link between the upstream and downstream production processes and also plays an important role in the global oil industry supply chain. Literature about the physical geography of oil production and consumption has determined a spatial differentiation between producing and consuming countries, which results in a rapidly growing imbalance in demand and supply that can only be resolved by investing in massive transportation infrastructures, such as supertankers and storage facilities, pipelines, and barges. The giant oil fields of the Middle East, for example, are thousands of kilometers from the countries of consumption in North America, Europe, and Asia; therefore; they need very large crude carriers, and ships capable of carrying 300,000 tons or more of crude oil. Marine transportation is one of the key drivers of global economic growth and competitiveness in the market it serves. In the oil market, tankers are used for the transportation of crude oil from fields in the Middle East, the North Sea, Africa, and Latin America to refineries around the globe. Oil tankers are the dominant mode of global or transcontinental oil transportation due to their extreme flexibility, low costs and efficiency; however, other complementary modes, such as trucks, and railcars are also used where the origin and destinations are land-locked. To obtain the highest value, if all other variables remain the same, the oil supplier would transport oil to the nearest market (the nearer the better syndrome) due to lower transportation costs, and hence higher netback (net revenue).

Navigation by water is usually constrained by the maximum draft of coasts, rivers, and waterways. Infrastructure constraints to port landside access are characterized by deficient bridges, freeway access ramps, railway grade crossings, and tunnels and underpasses, as well as congested or inadequate roadways serving marine terminals. Roadway access is a major problem for marine transportation because of congestion in major truck routes serving marine terminals (Transportation Research Board, 1998). In 2005, a report by Maritime Administration (MARAD) evaluated the status of U.S. ports and waterways and concluded that the domestic marine transportation supply infrastructure will become more constrained in the future.

As imports of petroleum products are projected to increase by over 80% by volume between 2004 and 2030 according to EIA, anticipated demand growth will challenge a marine transport system that is already operating, in some instances, at the limit of its capacity (U.S. Government Accountability Office, 2007). The oil industry is involved in a global supply chain that involves domestic and international transportation, value-chain strategic warehouse management, order and inventory visibility and control, materials handling, import/export facilitation, and information technology. This means, in effect, that shippers and the oil companies are jointly and mutually involved and intertwined with each other, end-to-end in transportation management from the moment an order is placed by the vendor to the day it is unloaded from the supply basket on the offshore platform (Christopher, 2007). Indeed the link in the oil industry's productive chain is the carriers transporting the hydrocarbon (Petrotecno Instituto Agentino del Petroleo y del Gas, 2004).

Petroleum and petroleum product move on tankers, but oil companies own only a small fraction and charter the remainders, which allow them to keep their own fleet completely utilized. They rely on others to supply the remainder of their needs. There are two types of charters, voyage or spot charter, when the crude owner charters or leases tankers from owners of independent tankers. When using voyage or spot charter, the crude owner leases the tanker for a specific voyage between origin and destination, and the time charter specifies duration of time, in months or years. At present, the oil tanker charter market has become two tiers, with rates for vessels used to haul oil to the U.S. being higher cost associated with potential oil spills (Wood, Barone, Murphy, & Wardlow, 2002).

Crude oil tankers are built in different sizes that fit the size of the trade route. However, because of the length of voyage, ports, and canal constraints, tanker sizes have changed over the years. For example, the closure of the Suez Canal in 1956 forced crude oil tankers to take longer routes around Cape of Good Hope. To avoid canal constraints and gain economies of scale, Very Large Crude Carriers (VLCC's) were built that carry over two million barrels of oil on every voyage from the Middle East in high volumes (more than two million barrels per ship) over long distances and to Europe and Pacific Asia. However, small tankers are used for shorter journeys, such as from Latin America to the United States. Long-haul crude creates an incentive to develop larger-size tankers to lower shipping costs through economies of scale, up to the largest tanker that could pass through the Suez Canal, the Suezmax tanker. Most tankers carrying crude oil are loaded to their deadweight, but not necessarily their volumetric, or cubic, capacity (Tusiani, 1996). Evidently, the VLCC's economies of scale outweighs the constraints imposed, although in the United States only Louisiana Offshore Oil Port (LOOP) is equipped with highly mechanized equipment with high productivity to load and unload liquid-bulk cargo, such as crude oil and petroleum products (Transportation Research Board, 1998).

Every port is unique in terms of its facility configuration, operation, cargo types, and service parameters, thus selecting a market obviously depends on transport cost and intrinsic or physical capacity. The physical capacity of a waterway might be measured in terms of the number of barges that could be locked through in the course of a year, while the capacity of ports can be measured in terms of its intrinsic or practical capacity. Indeed, the intrinsic capacity is the level of throughput that can be attained under ideal conditions of berth utilization and zero bottlenecks at various sections of the port used for cargo storage and transfer (Transportation Research Board, 1998). Marine tankers are classified into six different categories as shown in Table 5, from the modest coastal tanker to very large crude carriers (VLCC) or ultra large crude carriers (ULCC) supertankers.

Table 5. Various Classifications of Crude Oil Tankers

Size/ Classification	Deadweight Tonnage(DWT)	Average Dimension (Length, Height, Draft in feet)
Medium Range	25,000-50,000	675 / 100 / 55
Panamax	25,000-50,000	675 / 100 / 55
Aframax	75,000-120,000	810 /150 / 60
Suezmax	120,000-180,000	950 / 150 / 60
VLCC	200,000-320,000	1240 / 200 / 100
ULCC	320,000 +	1240 / 200 / 100

Source: The Robert S. Strauss Center for International Security & Law, 2008.
Note: The Medium Range and the Panamax can fit through the Panama Canal while the Aframax and the Suezmax can fit through the Suez Canal.

Most of the crude oil carriers that currently travel through the Strait of Hormuz are VLCCs carrying crude oil to markets in East Asia. A few smaller oil tankers make "quick" runs to India and other closer destinations. But, of course, tankers are flexible; nearly any ocean-going tanker can transport crude oil from the Persian Gulf to any part of the world, depending on market condition. (The Robert S. Strauss Center for International Security & Law, 2008). Oil tankers are also classified based on their carrying capacity in deadweight tons (DWT), which is the total weight of the ship (including cargo, crew, provisions, etc.) minus the weight of the ship if it were empty. Very large crude carriers (VLCC), first developed in the 1960's, have a capacity of over 200,000 DWT and can carry two million barrels of oil. Ultra large crude carriers (ULCC) can carry in excess of 320,000 DWT, roughly three million barrels of oil. Other categories of tankers include; Medium Range (MR), Panamax (the largest tankers that can fit through the Panama Canal), Aframax, and Suezmax (the largest tankers that can fit through the Suez Canal) (The Robert S. Strauss Center for International Security & Law, 2008).

As of 2007, the United States Central Intelligence Agency Statistics counted 4,295 oil tankers of 1,000 long tons deadweight (DWT) or greater. In the agency's registry, Panama was recorded as the largest flag state for oil tankers, with 528 vessels, Liberia 464, Singapore 355, China 252, Russia 250, the Marshall Islands 234, and the Bahamas 209. By comparison, the U.S. and United Kingdom only had 59 and 27 registered oil tankers, respectively. There are relatively few controls on international shipping. Each nation claims territorial control for some distance from its shores, and vessels operating within those territorial waters are subject to the nation's rules. When the owner of a vessel who lives in one nation chooses to register his vessel in a second nation and flies the second nation's flag, he is said to be flying a "flag of convenience." U.S. firms do that to avoid paying high U.S. labor cost associated with U.S. flag vessels. (Wood, Barone, Murphy, &

Wardlow, 2002). Flags of convenience have lower standards for vessels, equipment, and crews for the traditional maritime countries and often have classification societies certify and inspect the vessels in their registry, instead of by their own shipping authority. This has made it attractive for ship owners to change flags, enabling the ship to lose the economic link and the country of registry. Tables 6, 7, and 8 identify world tanker fleet ownership.

Table 6. The World Tanker Fleet Ownership/Control by Different Entities

Ownership	Numbers	M.dwt	Share of Total	Average Age
Independent	3,802	315.7	82%	9.7
Oil Company	127	14.2	4%	10.9
State Owned	390	24.5	6%	15.7
State Oil Company	260	31.0	8%	12.8
Total	**4,579**	**385.4**	**100%**	**11.5**

Source: The International Association of Independent Tanker Owners, 2007 / 2008.

Table 7. The World 10 Largest Independent Tanker Companies

Owner	NO. of tankers	M.dwt
Mitsui OSK Lines	94	12.0
Frontline/SFI	59	11.5
NYK Line	56	11.1
Teekay Shipping	80	9.1
Anangel	31	7.5
OSG Ship Management	62	6.9
Euronav	29	6.6
Dr. Peters Gmbh	23	6.4
BW Shipping	24	5.8
Dynacom	35	5.2
Total	**475**	**79.1**
Independent Fleet	**3,802**	**315.7**

Source: The International Association of Independent Tanker Owners, 2007 / 2008.

Table 8. The 10 Largest Oil Companies/State Tanker Companies

Owner	No. of Tankers	M. dwt
Petronas/AET/MISC	60	7.0
Saudi Aramco	24	6.1
NITC	28	5.8
China Shipping Group	67	3.9
Sovcomflot	41	3.9
BP	36	3.8
Novoship	50	3.8
Shipping Company of India	45	3.8
Cosco, China	29	3.4
Kuwait Petroleum Corporation	26	3.2

Source: The International Association of Independent Tanker Owners, 2007 / 2008.

Oil Spill and Legislative Regulations

One of the main objectives of this research is to evaluate the risk of oil spill incidents and legislative regulations and requirement. Although advanced technologies are used in exploration and production facilities, with multiple back-up safety systems, and even if parts of the internal or external safety precautions are taken care of, there is still that part of human-machine interaction and the environmental issues that exist as part of the total safety concept. In the process of exploration, production, transfers, and transportation, there are always the probabilities of accidental oil spills. Based on several accidents and background reasons, experts have stated that nearly 80% of tanker accidents were as a result of human error. According to PetroStrategies, Inc. (2009a), although oil spill incidents are mostly publicized, they account for only 12% of all spills, while tanker accidents contribute 5%, tanker operations 7%. Other shipping accounts for 14% and industrial waste, account for 60% which is the major source of ocean oil pollution.

These oil spillages, either accidental or caused by human error, have devastating effect on the environment: air pollution, health and safety, soil and ground water contamination and other natural ecosystem contamination. It was reported that some spill volumes are understated in the government statistics, and other spills are not reported at all, and that the actual pollution load is much greater than the annual reported average of 6.7 million gallons, possibly twice as much as the equivalent of the eleven million gallons of the Exxon Valdez spill (Nesmith & Haurwitz, 2001). The effects of these oil spillages depends on several factors including the amount of spill, exact spill location, type of oil spill, season of the spill, and strategies for subsequent clean-ups. Although there are accidental spillages, intentional spillages occur during operational dumping; for example, an oil vessel, in order to maintain stability during a return trip, takes ballast water into its cargo tank after discharging oil cargo, but on or before arrival at the loading port, dumps the dirty ballast, water-in-oil mixture into the ocean. The environmental degradation from oil tanker spill is usually difficult to predict, because of interacting factors. Two spills that took place in the same location will have different environmental consequences depending on, time of year, weather conditions, and success of clean-ups (Dick, 1998).

Oil types are classified based on various physical and chemical properties of the oil. For example oil is classified into light crude, heavy crude, and diesel. The classification is necessary because different types of equipment are used to respond to spills of different oil types. Oil spills are also categorized into four types based on the volume and type of oil spilled. The classification is based on the capability of the equipment required for the cleanup operations, such as 0-15,000 gallons, 15,000–50,000 gallons, 50,000-100,000 gallons, and 100,000-300,000 gallons. Also, different types of equipment are required for different weather/sea conditions, such as calm water, harbor, and offshore, with maximum operating significant wave heights of, 0.3m, 0.9m, and 1.8m respectively and are only applied to bays, soft bottom subtidals, seagrass beds, rocky subtidal, sandy beaches, coral reefs, mangrove forest, and salt marshes (Iakovou, Chi, Christos, & Ashutosh, 1996). The extent of contamination depends on the nature of the coastal ecosystems, for example, if the spill occurs in a period when birds and mammals are congregating and fish and shellfish are spawning (Boesch, Butler, Cacchione, Garaci, & Neff, 1987). Large oil spills further away from the coastline may not have as much environmental impact as small spills closer to the coastline. For example, the Exxon Valdez oil spill in March 1989, which led to the closing of the fisheries in Prince William Sound, Alaska, resulted in a season's loss of income for commercial fishermen and an estimated loss in revenue of about $135 million (Burger, 1997). The Exxon Valdez's 37,000 tonne spillage was ranked 34th in size among recorded tanker oil spill worldwide, but its impact was the most expensive in oil spill history (White & Baker, 1998). According to Ramseur (2007), the Exxon Valdez's spillage caused approximately $2 billion in cleanup costs and $1 billion in natural resource damages. Under the new liability limits, the responsible party is required to pay about $285 million (single-hull) or $181 million (double hull). Most of the incidental oil spill statistics collected by the International Tanker Owners Pollution Federation (ITOPF) are results from several combinations of actions and circumstances. Worldwide accidental oil spill statistics for the period from 1974 to 2008 indicate that most tanker spills are operational, such as loading, discharging, and bunkering, which usually occur at oil terminal or ports. The vast majority (91%) of the spills is relatively small spills less than seven tones. Large spills greater than seven hundred tones which are caused by collision and grounding, although rare, account for at least 84% of the spill volume (ITOPF, 2008). Table 9, complemented by figures 8, 9, and 10, analyzes oil spills in terms of the primary events or operation in progress at the time of the spill, which are grouped in different categories such as operations, accidents and others/unknown where relevant information is not available.

Table 9. Oil Spill Incidence from Tank Vessels by Cause, 1974-2008

	Spills < 7 tonnes	Spills between 7 – 700 tonnes	Spills > 700 tonnes	Total
OPERATIONS				
Loading /Discharging	2,825	334	30	3,189
Bunkering	549	26	0	575
Other Operations	1178	56	1	1235
ACCIDENTS				
Collisions	175	303	99	577
Groundings	238	226	119	583
Hull Failures	576	90	43	709
Fire & Explosions	88	16	30	134
Other /Unknown	2188	152	26	2366
Total	7817	1203	348	9368

Source: Oil Tanker Spill Statistics, 2008.

NOTE: Large spills are infrequent, but they account for a large percentage of accidental spillages by tankers.

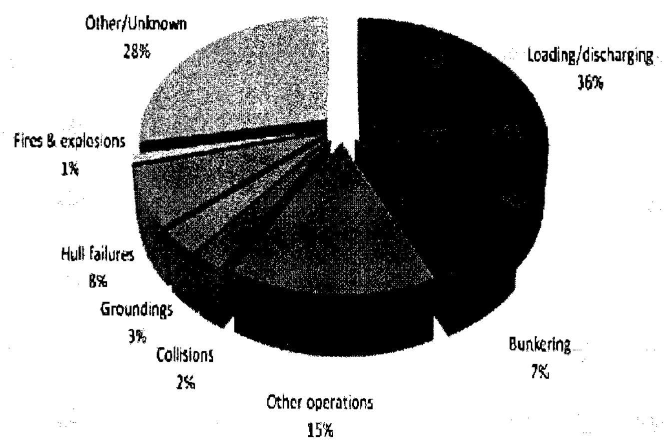


Figure 8. Percentage of Oil Spill < 7 Tonnes in Relation to the Different Causes, 1974-2008.

Noted in Table 10, and complemented by Figure 11, in 1979 the Atlantic Express tank ship off Tobago, West Indies, spilt 287,000 tonnes of oil, verifying the largest recorded vessel oil spill accident, which is about 44.8% of the yearly worldwide quantity spilt;

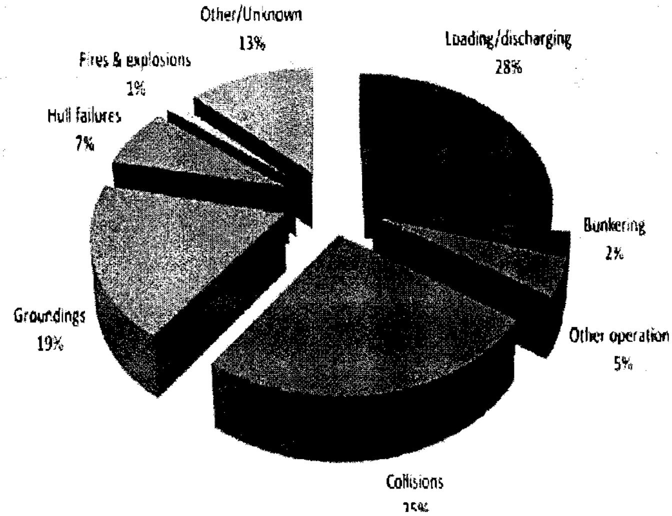


Figure 9. Percentage of Oil Spill Between 7-700 Tonnes in Relation to the Different Causes, 1974-2008.

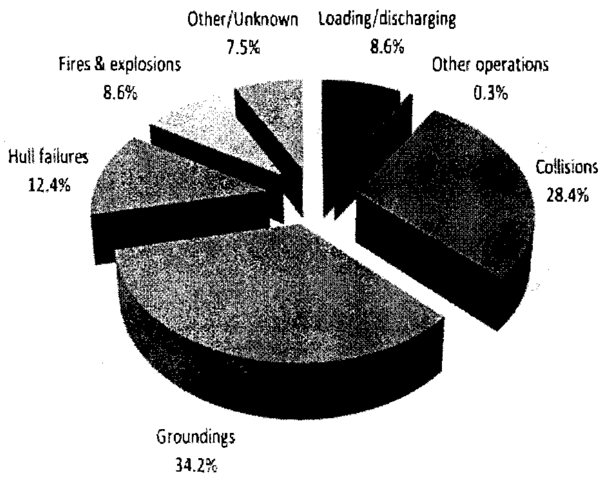


Figure 10. Percentage of Oil Spill >700 Tonnes in Relation to the Different Causes, 1974-2008.

in 1991 the ABT Summer, 700 nautical miles off Angola, spilt 260,000 tonnes, 60.5% of the yearly total. In 1983, the Castillo de Bellver spilt 252,000 tonnes, 65.6% of the worldwide total (International Tanker Owners Pollution Federation, 2008).

To date, oil spill clean-ups, remediation, and compensations are viewed as a cost to society as they result from damages to the ecosystem. It is difficult to quantify the exact damages to the national or international ecosystem; therefore, establishing the cost and making compensations to affected individuals and regions becomes more difficult, resulting in continuous damages. The marine and coastal environment were mostly impacted with the Exxon spill, which was the birth of a valuation, safety, and oil pollution legislation process for environmental damages due to oil spills.

Large spills greater than 700 tonnes tend to decrease (with some distortions) over specific periods of time, specifically 1970-1979, 1980-1989, 1990-1999 and 2000- 2008 shown in Table 11; however, approximately 5.65 million tonnes of oil were lost due to tanker accidents from 1970-2008.

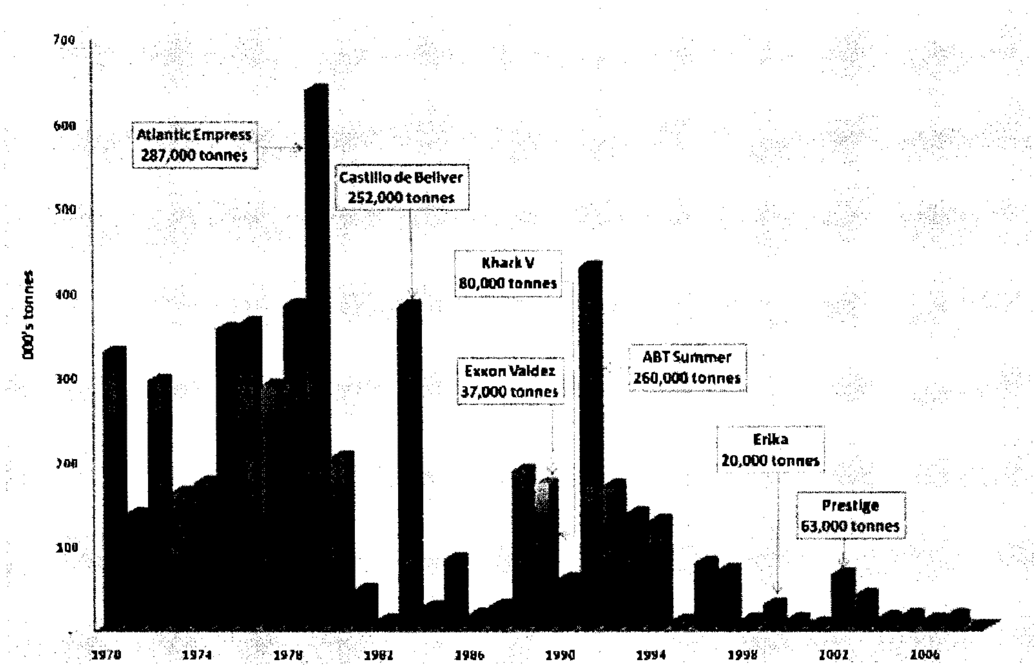
Environmental factors continue to receive vast publication and continue to assume greater importance to oil and gas activities around the globe. The major oil companies are now publicly reporting their awareness and concerns for the environment, and therefore actively monitoring their own performance targets, or those imposed through national or international legislations and regulation. Consequently, there are knock-on effects throughout the supply chain whereby suppliers and sub-contractors to the larger 'client' companies are also expected to address the shared environmental issues; meaning that companies actively engaged in the oil and gas sector must fully consider the wide range of environmental impacts that may result from either activities, therefore reducing the need to seek 'end of pipe' solutions (Envirowise, n.d.). Any high level of environmental responsibility adopted will mean that those large oil companies will place strict

Table 10. A Brief Summary of Major Oil Spill Since 1967

Posision	Ship Name	Year	Location	Spill Size (Tonnes)
1	Atlantic Empress	**1979**	Off Tobago West Indies	**287,000**
2	ABT Summer	**1991**	700 nautical miles off Angola	**260,000**
3	Castillo de Bellver	**1983**	Off Saldanha Bay, South Africa	**252,000**
4	Amoco Cadiz	1978	Off Brittany, France	223,000
5	Haven	1991	Genoa, Italy	144,000
6	Odyssey	1988	700 nautical miles off Nova Scotia, Canada	132,000
7	Terrey Canyon	1967	Scilly Isles, UK	119,000
8	Sea Star	1972	Gulf of Oman	115,000
9	Irenes Serenade	1980	Navarino Bay, Greece	100,000
10	Urquiola	1976	La Coruna, Spain	100,000
11	Hawaiian Patroit	1977	300 nautical miles off Honolulu	95,000
12	Independenta	1997	Bosphorus, Turkey	95,000
13	Jokob Maerk	1975	Oporto, Portugal	88,000
14	Brear	1993	Shetland Islands, UK	85,000
15	Khark 5	1989	120 nautical miles off Atlantic coast of Morocco	80,000
16	Aegean Sea	1992	La Coruna, Spain	74,000
17	Sea Empress	1996	Milford Haven, UK	72,000
18	Katina P	1992	Off Maputo, Mozambique	72,000
19	Nova	1985	Off Khang Island, Gulf of Iran	70,000
20	Prestige	2002	Off the Spanish Coast	63,000
35	Exxon Valdez	1989	Prince William Sound, Alaska, USA	37,000

Source: Oil Tanker Spill Statistics, 2008.

requirements on the supply chain with an aim to improving their environmental performance.



Source: Oil Tanker Spill Statistics, 2008.

Figure 11. Graphical View of Oil Spill Statistics.

There are several incidents of oil spills around the world. According to the Oil Spill Intelligence Report (OSIR), spills in the size range of at least 34 tonnes have occurred in the waters of 112 nations since 1960. Undoubtedly oil spills happen more frequently in certain parts of the world, which are identified as the 'hot spots' for oil spills from vessels: the Gulf of Mexico (267 spills); the Northeastern U.S. (140 spills); the Mediterranean Sea (127 spills); the Persian Gulf (108 spills); the North Sea (75 spills); Japan (60 spills); the Baltic Sea (52 spills); the United Kingdom and English Channel (49 spills); Malaysia and Singapore (39 spills); the west coast of France and the west coasts of Spain (33 spills); and Korea (32 spills) (Global Marine Oil Pollution Information Gateway, 2005).

Table 11. Total Annual Quantity of Oil Spill from 1970 – 2008

Year	Quantity in Tonnes	Year	Quantity in Tonnes	Year	Quantity in Tonnes	Year	Quantity in Tonnes
1970	330,000	1980	206,000	1990	61,000	2000	14,000
1971	138,000	1981	48,000	1991	430,000	2001	8,000
1972	297,000	1982	12,000	1992	172,000	2002	67,000
1973	164,000	1983	384,000	1993	139,000	2003	42,000
1974	175,000	1984	28,000	1994	130,000	2004	15,000
1975	357,000	1985	85,000	1995	12,000	2005	17,000
1976	364,000	1986	19,000	1996	80,000	2006	13,000
1977	291,000	1987	30,000	1997	72,000	2007	18,000
1978	386,000	1988	190,000	1998	13,000	2008	2000
1979	640,000	1989	174,000	1999	29,000	2009	N/A
1979s total	3,142,000	1989s total	1,176,000	1999s total	1,138,000		

Source: Oil Tanker Spill Statistics, 2008.

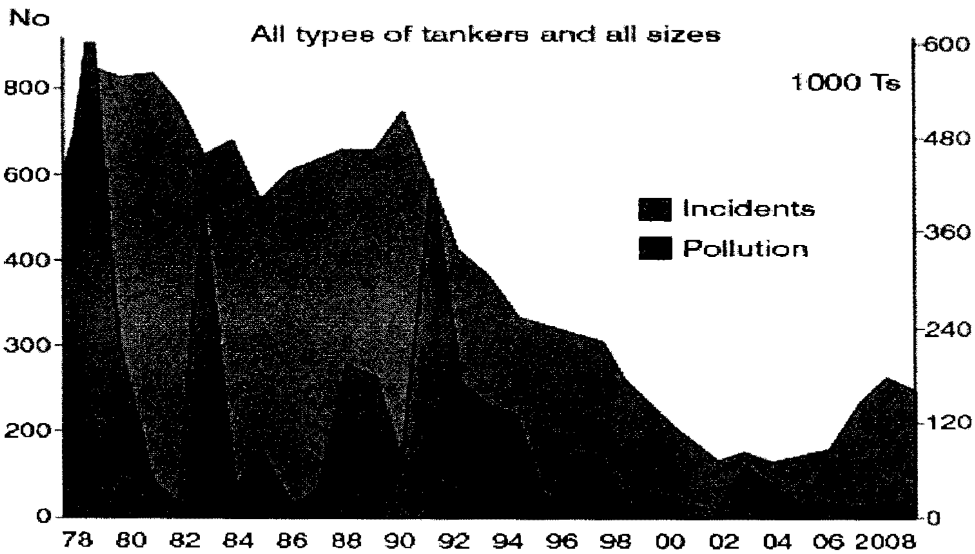
Tanker Accidents

Irreducible risks are associated with waterborne oil transportation irrespective of any policy controlling oil pollution risks. Persisting oil spills, even since the enactment of OPA-90, may imply that a certain rate of spill is an inevitable and irreducible risk under any legislation providing the internalization of oil pollution costs as long as there is waterborne oil transportation (Kim, 2002). Sarin and Scherer (1976) argue that tanker accident spillage increases with tanker size, indicating that larger tankers can handle more oil, while Meade, LaPointe, and Anderson (1998) states that smaller tankers exhibit higher accident rates than larger tankers and that the older tankers are not more prone to accidents than newer ones. Homan and Steiner (2008) argue that most accidents do not result in spills and higher accident rates do not necessarily imply higher spill rates.

Anderson and Talley (1995) posit that oil spillage from a tanker accident is larger when the tank ship is adrift and when the accident occurs in a coastal waterway, but smaller for larger and U.S. flag tankers. Tank ship accident oil spillage per vessel gross ton is smaller for a U.S. than for a non-U.S. flag tank ship, but increases with the vessel damage severity of the accident (Talley, 1999). However, Anderson and Talley (1995) also specify that oil spills from tank barge accidents are larger for collision and material/equipment failure accidents, while Talley (2000) concludes that if the accident occurs in a river, at nighttime, and with older barges, the oil spill is smaller if precipitation exists at the time of the accident. Brook (1992) notes that the cause of the vast majority of tanker accidents is human error. As a result, some have questioned the mandate for double-hull tankers and question if other approaches might be more cost-effective.

Talley, Di, and Kite-Powell (2001), in their investigation of vessel oil spill differentials for transfer and vessel-accident spills for the post OPA-90 period, uncovered that tank barges, but not tank ships, have incurred larger vessel-accident oil spills (investigated by the U.S. Coast Guard) than non-oil-cargo vessels for this period. Kim (2002) did a non-statistical review of OPA-90's effectiveness and unveiled the fact that the number and volume of oil spills in U.S. waters had fallen considerably since the passage of the act; however, the study did not control for changes in any exploratory variables. According to Burgherr and Hirschberg (2008) two-way analysis of variance (ANOVA) was used to investigate how major factors were related to oil spill volume using pre-marine pollution (pre-MARPOL) and MARPOL (the international convention for the prevention of pollution from ships) single types, since accidents with double sides/bottoms only and double hull construction rarely occur.

Tanker accidents have always raised concerns about the environment, as increased movement always signals increased risk; however, it is encouraging to learn as depicted in Figure 12 that there is a drastic downward trend in oil spill in recent times compared to the mid-1980s, primarily due to a drop in tanker accidents and the introduction of safety measures as well as the enactment of various legislative instruments through the years.



Source: The International Association of Independent Tanker Owners, 2007 / 2008.

Figure 12. Reported Tanker Incidents/Oil Pollution from 1978-2008.

The legislation may have proven to successfully serve its purpose, but there are still some irreducible risks irrespective of any policy controlling oil pollution risks. Some descriptions and prominent examples of such incidents are as follows:

The grounding of the EXXON VALDEZ in 1989, on Blight reef in Prince William Sounds Alaska, spilt 48,600,000 liters (37,000 tonnes) of crude oil into U.S. waters, the worst oil spill disaster, which led to the passage of the Oil Pollution Act of 1990 (OPA 90). The Exxon experience was an important milestone in terms of not only its visibility but also its effect on oil spill regulations and the methods around valuation of ecosystem goods and services (Sanctuary & Fejes, 2006).

The tanker Braer lost power and ran aground on January 5, 1993, on the Shetland Islands, UK, releasing 84,700 tonnes of Norwegian Gulfaks crude oil into the sea. The extreme conditions and the light nature of the crude oil, resulted in natural break up and evaporation of the spill, and a major ecological disaster avoided (Mouat, 2003).

On December 12, 1999, the Maltese-registered tanker Erika sank 40 miles off the coast of Brittany, France in the Bay of Biscay, releasing more than 10,000 tonnes of heavy fuel oil. The tanker broke into two; the bow section sank in about 100 meters of water with 6,400 tonnes of cargo, while the stern section sank 10 nautical miles away with 4,700 tonnes of cargo. The spill damaged approximately 400 km of French shoreline (Sanctuary & Fejes, 2006). The ecological disaster was far greater than that of Braer due to the heavy and persistent nature of the oil spill. The resulting intense press coverage and public outrage lead to two packages of measures being developed, Erika I and Erika II. However, unlike the US OPA 90, the packages were not rapidly transposed into national law. By July 23, 2003, only five EU Countries had transposed both the directives relating to the Erika I package (Mouat, 2003).

On November 13, 2002, the Prestige under a Bahamian flag, owned by a Greek shipping company and chartered by Anglo-Swiss carrying Russian oil from Latvia to

Singapore, sprung a leak 50 km off the coast of Finisterre, Galicia, in Spain, releasing 63,000 tonnes of heavy fuel oil when the ship broke into two and sank.

Pipeline Accidents

Pipelines also are sources of spills, leaks, and fires. Some pipelines are used beyond their estimated 15 years of engineering life span (Epstein & Selber, 2002). Environmental pollution caused by pipeline spill could result from human factors to material defects: pipe corrosion, ground erosion, tectonic movements on the bottom, and encountering ship anchors and bottom trawls. Indeed pipeline defects could be the source of small but gradual to long-term leakage or leakage that might lead to an abrupt explosion. In the last decade, the reported numbers of leaks and their impact on the environment have been steadily decreasing in the United States (U.S. Office of Pipeline Safety, 1999). The U.S. office of pipeline safety (OPS) database shows that 67 million gallons of crude oil, gasoline, and other petroleum products dripped and poured from holes in the nation's pipelines during the 1990s. Despite the indisputable successes achieved by modern technology of pipeline construction and exploitation under different natural conditions, including the extreme ones, pipeline oil transportation does not eliminate the possibility of serious accidents and consequences. In the U.S for example, over the past 30 years, according to the Office of Pipeline Safety, pipelines have spilt approximately 316 million gallons of crude oil and petroleum products. Pipelines can leak continuously for a long period of time which is bad enough, but when ruptured can cause large spills. In thousands of communities around the globe, oil pipeline accidents such as those shown in Table 12, have caused huge property damage, tragic injuries and deaths, and lasting environmental damages. It is therefore necessary to identify some of the oil spill accidents and explosions on pipelines that have damaging impacts to the marine environment and also to the public in general.

According to World War 4 Report (2009), Ecuador's trans-Andean Heavy Crude Pipeline (OPC) ruptured on February 24, 2009, near the rainforest community of Santa Rosa, Napo Province, and spilt 14,000 barrels of oil in the Amazon region. The OPC carries crude from oilfields in the Amazon region to Ecuador's coast for several foreign companies, including China's Andes Petroleum, Spain's Repsol-YPF, Brazil's Parastatl Petrobras, and the French Perenco. It was reported that 47 communities were affected, and the spill paralyzed fishing and normal activities of the community. Also in 2000, at the Guanabara Bay off the Brazilian coast, about 1,300 tonnes of oil were released into the sea (Global Marine Oil Pollution Information Gateway, 2005). Stealing from pipelines (locally known as bunkering) in Nigeria has developed an integrated supply chain in which petroleum can be stolen from the wellhead, distilled, and sold at gas stations around the country. The increasing scope and ingenuity of the oil thieves has triggered severe explosions and oil spills that resulted in personal injuries (even to the oil thieves), environmental damage in some Niger Delta areas, and financing and escalation of violence. In 2008, the number of barrels spilt from Shell Nigeria operation rose to about 40,000 barrels compared with about 15,000 barrels in 2007 (Donovan, 2009).

It was is reported that the largest spill on record, along 800 miles of the Trans-Alaska Pipeline, occurred shortly after it opened in 1978 when vandals blew up a section, causing about 700,000 gallons to escape. And, in 2001 a man fired his hunting rifle into the pipeline, creating a leak that forced about 285,000 gallons into the tundra which led to a

$7 million cleanup. It was also reported that in Northern Alaska, 20,000 gallons of crude spilt from a corroded pipeline near Prudhoe Bay in 2006 (Verhovek, 2006).

Table 12. Additional Examples of Serious Pipeline Accidents in Recent Years

Company	Date	Location	Gallons Released	Comments
Shell Pipeline Corporation	April 1998	St. James, LA	748,000	A Crude oil release at a tank farm was caused by operational problems
All American Pipeline Company	December 1997	CA (city not reported to OPS' database)	540,000	Corrosion failure in pipeline.
Williams Pipeline Company	March 1997	Des Moines, IA	1.26 million	Gasoline leak(s) from corrosion at a pipeline-related tank farm caused extensive property damage.
Colonial, Exxon, Texaco, Valero	October 1996	Houston, TX	1.47 million	Pipelines broke under pressure from severe flooding, spilled oil into the San Jacinto River.
Koch Pipeline	August 1996	Lively, TX	Gaseous release from a liquid pipeline	Pressurized liquid butane escaped from a corroded section of the pipeline, killing two teenagers.
Colonial Pipeline	June 1996	Greenville, SC	957,600	Diesel fuel spilled into the Reedy River, killing 35,000 fish. Rupture caused by inadequate management controls and training.
Colonial Pipeline	March 1993	Reston, VA	408,000	Fuel spilled into Sugarland Run, a tributary of the Potomac River. Water supplies in the area were shut down for several days, accompanied by air pollution.

Source: U.S. Office of Pipeline Safety, 1999.

Oil Pollution Legislation

The disaster of the Exxon Valdez oil spill led Congress to pass the Oil Pollution Act of 1990, which provides a comprehensive system of liability and compensation for damage resulting from oil spills. The provisions include the following: 1) Establishing civil and criminal penalties for oil spill violations, 2) Developing national contingency plan for oil spill cleanup, 3) Establishing procedures to claims for the Oil Spill Liability Trust Fund, 4) Setting certain construction specifications for oil tankers, 4) Setting financial responsibility and insurance requirements, 5) Establishing procedures for natural resource damage assessment and cleanup (Bode & Grenier, L.L.P., n.d.).

The Exxon experience was an important milestone in terms of not only its visibility, but also its effect on oil spill regulations. The spill triggered huge public outcry demanding immediate review of U.S government legislation on maritime safety and oil pollution, which resulted in the passing of the Oil Pollution Act of 1990 (OPA-90). The Act established accountability for vessel oil spills in United States' waters, upholding 'the polluter pays' principle by making vessel owners liable for oil pollution response and compensation whilst issuing tough penalties to those who fail to comply (U.S. Environmental Protection Agency, n.d.). The financial liabilities imposed by the act to vessel owners could be as high as $1,200 per gross ton or $10 million for vessels larger than 3,000 gross tons, whichever is greater (Talley, Di, & Kite-Powell, 2001). Responsible parties at onshore facilities and deepwater ports are liable for up to $350 million per spill; holders of leases or permits for offshore facilities, except deepwater ports, are liable for up to $75 million per spill, plus removal costs. The federal government has the authority to adjust, by regulation, the $350 million liability limit established for onshore facilities. Also the OPA-90 provides that the responsible party for a vessel or facility from which oil is discharged, or which poses a substantial threat of a discharge, is liable for:1) certain specified damages resulting from the discharged oil; and 2) removal costs incurred in a manner consistent with the National Contingency Plan (NCP). Also, if a responsible party can establish that the removal costs and damages resulting from an incident were caused solely by an act or omission by a third party, the third party will be held liable for such costs and damages. In addition, offshore facilities are required to maintain evidence of financial responsibility of $150 million, and vessels and deepwater ports must provide evidence of financial responsibility up to the maximum applicable liability amount. Claims for removal costs and damages may be asserted directly against the guarantor providing evidence of financial responsibility.

States have the authority to enforce, on the navigable waters of the state, OPA requirements for evidence of financial responsibility. States are also given access to federal funds (up to $250,000 per incident) for immediate removal, mitigation, or prevention of a discharge, and may be reimbursed by the Trust fund for removal and monitoring costs incurred during oil spill response and cleanup efforts that are consistent with the National Contingency Plan (NCP). The fund's primary purpose is to pay cleanup costs for a spill where there is no responsible party, or when the responsible party is protected by a limit on liability and the cost of the spill exceeds the maximum liability, or after the responsible party becomes insolvent (Tusiani, 1996). Civil penalties are authorized at $25,000 for each day of violation or $1,000 per barrel of oil discharged. Failure to comply with a federal removal order can result in civil penalties of up to $25,000 for each day of violation (U.S. Environmental Protection Agency, n.d.). There are several criticisms about the shortcomings of the liability limits relating to whether the current liability limits are sufficient to support the fundamental polluter pay principle to OPA-90 and whether the risk is properly divided between the responsible party and the oil spill liability trust fund (OSLTF) (Hearing, 2006). There were concerns about the maximum amount OSLTF might pay for any single incident, which cannot exceed $1 billion; however, at the end of FY2006, OSLTF had only approximately $604 million, while the fund was projected to have more than $1 billion by the end of the 2008 (Ramseur, 2008). This indicates that any major oil spill could easily deplete the Fund.

A new wrinkle in phasing out the existing fleet in an effort to prevent pollution is the mandatory requirement for double hulls on existing tankers contained in both the IMO Marpol Regulation 13G and the U.S OPA (Oil Pollution Act) of 1990. For VLCCs under Marpol Regulation 13G, phase-out occurs when single hull VLCCs and Suezmax tankers reach an approximate age of 25 years. But there is a loophole whereby Marpol protocols permit installing segregated ballast tanks that postpone the requirement for double hulls by another five years, which extends vessel life to about thirty years (Tusiani, 1996). The U.S. proposal to the International Maritime Organization (IMO) for the establishment of an international requirement for double-hull tank vessel was adopted in MARPOL (National Research Council, 1998 and Resolution MEPC.52 (32) 1992). This provision also require that existing single hull tanks be retrofitted with double hull or, beginning 1995, be phased out of operation by 2015. The phasing out is applicable to tankers above 5000 gross tons; however, the Coast Guard's rule did not require any structural measures for existing single-hull tank vessels (Kim, 2002).

Unequivocally, the double hull requirements became the highest enforcement and compliance cost incurred by the oil industry (Murat, 2009). Indisputably, the industry standard now is the adoption of a double hull by 2020 by all maritime oil transportation fleets around the globe (National Research Council, 1998). However, on March 24, 2009, US Senator Frank Lautenberg introduced a bill that would require the use of double hulls in nontank vessels, such as offshore supply boats, passenger ships, fishing boats, and containerized cargo vessels (Snow, 2009).

Each nation has its own regulation. It is therefore impossible to cite an overall or global set of oil industry regulations and environmental policies. The focus, therefore, is on the United States regulatory framework and legislations. For example, tankers calling on Caribbean transshipment ports are outside the jurisdiction of OPA-90 (Tusiani, 1996). However, in conjunction with OPA-90's regulation, the international regulation effective July, 1993, is applicable to oil tankers around the world (Percival, Schroeder, Leape, & Miller, 1996).

The waterborne industry has had difficulties with a lack of consistent regulations among various government agencies. In spite of the fact that oil spills has decreased substantially since the enactment of the OPA-90, some large oil spills still occur, inducing state governments to regulate and monitor oil spills in the states' waters. However, state-imposed environmental regulations may be in direct conflict with those established at the federal level (National Petroleum Council, 1989). In 1991 Washington State adopted a Vessel Oil Spill Prevention and Response Act. The act established the Office of Marine Safety to promulgate standards and regulations for oil tankers moving in and through state waters, requiring training for the crew, such as English language proficiency for members of the crew, navigation watch procedures, and casualty reporting measures for any vessel that ultimately reaches Washington's seacoast. Following the enactment of Washington's standards, the International Association of Independent Tanker Owners (Intertanko), brought suit seeking relief against the state officials charged with enforcing the new standards. Intertanko contends the best achievable protection (BAP) standards invade an area long pre-empted by the federal government and are inconsistent with several international treaties. Washington argues that these measures are necessary to protect the coastal waters from the serious dangers of oil spills, and they do not conflict with federal regulations. However, it was concluded that in the area of maritime commerce and shipping, the comprehensive federal regulatory scheme and the national and international effort to maintain uniformity in shipping standards leaves the individual states with few alternatives in fashioning laws to protect important and vulnerable coastal waters.

The court determined that it is for Congress and the Coast Guard to determine the sufficiency of federal regulations to deal with prevention of environmental harm. While states may regulate in matters peculiar to state waters, a state may not attempt to supplement existing federal statutes without compromising the uniformity of the federal scheme. In spite of the individual states' significant interests in preventing oil spills, in matters of federal preemption, it is not the sufficiency of the regulations that is an issue but the question of political responsibility between federal and state governments (US vs. Locke, 2000).

Harmonizing U.S law with existing international convention seems to be unlikely in the near future, since international regime does not acknowledge the replacement or acquisition of the equivalent of damaged resources and the diminution in value of the resource pending restoration that are a fundamental concept to OPA (Resolution MEPC.52 (32) of the Marine Environment Protection Committee of IMO, 1992). Recent developments, however, suggest that international and US laws are converging. In the 1996 regulations implementing the natural resource liability provisions of the U.S Oil Pollution Act (OPA-90), natural resource damages are quantified as the costs of a restoration plan designed to return resources to baseline and to compensate for interim losses. The 1992 International Convention Protocols, which entered into force in May 1996, include the costs of resource "reinstatement" measures, though a clear definition of the scope of reinstatement, consistent with the restoration concepts in the OPA regulations, could provide an inclusive measure of damages for environmental harm (Jones, 1999).

Several United States agencies regulate and monitor the upstream, midstream, and downstream sector of the oil industry, but under a dispersed, fragmented, and sometimes overlapping set of statutes (U.S. Environmental Protection Agency Office of Compliance Assurance, 2000), which includes the following: 1) The Federal Energy Regulatory Commission (FERC), an independent agency that regulates the transmission of oil through interstate pipelines by setting and enforcing pipeline 'tariffs' i.e., the price and terms under which shippers send their products through the pipelines and the rules governing access to those pipelines. FERC also collects administrative, financial, and operational information on crude oil and petroleum product pipeline companies. 2) Department Of Transportation's (DOTs) Pipeline and Hazardous Materials Safety Administration (PHMSA) regulates safety for oil pipelines that transport oil and petroleum products. Among other things, it oversees oil pipelines' design, maintenance, and operating procedures. 3) The DOT's Maritime Administration (MARAD) reports to Congress on the status of a public port's supply infrastructure needs. 4) The Environmental Protection Agency (EPA) develops and enforces regulations that implement environmental laws including the Clean Water Act and the Oil Pollution Act, which aims to control the discharge of pollutants into the environment by refiners and other industries. EPA also administers the National Environmental Policy Act, which requires federal agencies to consider environmental impacts of proposed actions (United States Government Accountability Office, 2007).

In spite of federal regulatory agencies, states also implement their own regulations to enforce or implement environmental standards. For example, the state of California implemented an air quality maintenance plan in an effort to reduce emissions from stationary sources like refineries, and comprehensive leak identification, maintenance, and inspection programs (California Air Resource Board, 2002). Also, foreign countries, either through individual or collective actions, play regulatory roles that affect trade conditions for products. For example, the International Energy Agency (IEA) is an organization established by a treaty of 26 oil importing Organization for Economic Co-operation and Development (OECD) countries to cope with oil supply disruptions and coordinate an international response, in the case of disruption, to the global oil supply. It is agreed that member countries should keep significant strategic stocks of crude oil and /or petroleum products to be available in the event of a severe supply disruption (United States Government Accountability Office, 2007).

Upstream Crude Oil Supply Chain Risk Sources

The credibility of the oil industry is dependent partly on responsibility for health, safety, and the environment, which are taken seriously by the organizations along the supply chain. Indeed, the oil industry for several years has been confronted with challenges of compliance to health, safety, and environmental standards set in the production and transportation of crude oil. However, it is also critical to protect the other components along the supply network. Large quantities of crude oil freight are moved around the globe, and selection of transport mode and route as well as general security management are not necessarily at the optimum level. Some of the potential threats to oil facilities and their transportation systems are due to deliberate actions by terrorists and others (Bajpal & Gupta, 2006).

The FBI defines terrorism as "the unlawful use of force or violence against persons or property to intimidate or coerce a government, the civilian population, or any segment thereof, in furtherance of political or social objectives." The number of international terrorist incidents has increased in recent years, and the potential threat posed by terrorists has increased (Hudson, Majeska, Savada, & Metz, 1999). Post 9/11, the biggest risk in the oil industry remains security threat that ranges from exploration and development security to pipeline security, maritime transport security, to protection of product distribution and the retailing sector. Due to rising security threats, offshore platforms are subject to increased physical protection as part of the framework of critical infrastructure in the United States and other countries. Based on this, large offshore facilities operating on the Outer Continental Shelf (OCS) of the United States are required to meet strict security regulations established by the United States Coast Guard and Department of Homeland Security. The Maritime Regulations, 33 CFR part 106.105 requirements were developed under the authority of the Maritime Transportation Security Act (MTSA), which among other things requires the development of security plans designed to deter, to the maximum extent practicable, transportation security incidents resulting in a significant loss of life, environmental damage, transportation system disruption, or economic disruption in a particular area (Honeywell International Inc. 2008). Reports from the Department of Homeland Security (DHS), the U.S. Department of State, and the Federal Bureau of Investigation (FBI) have indicated that the petroleum industry may be a target of terrorism due to the inherent nature of the products used and its importance to the national infrastructure (American Petroleum Institute 2005). Attacks on oil installations have become the weapon of choice for the international terrorism, irrespective of the political system and social-financial boundary conditions of the society under attack (Steinhausler, Furthner, Heidegger, Ryndell, & Zaitseva, 2008).

Terrorist attacks, though not so often, can cause damages and disruption along the crude oil supply network. Specifically the petroleum industry may be a target for terrorism due to the following characteristics: 1) the physical and chemical properties of the products handled at petroleum sites, 2) the importance of petroleum to the national economy, 3) the importance of petroleum to national security, and 4) the symbolism of the industry as a cornerstone of capitalism and western culture (American Petroleum Institute, 2005). Regrettably, prominent terrorist leaders have consistently made it clear that the petroleum industry is one of their principal strategic targets. They have for several years denounced the West's "theft" of oil and resources from the Middle East and Africa; therefore, the strategy to attack oil interests is part of an overall "bleed-until-bankruptcy" plan against the West and nations that are cooperating with the West and its corporate sector. The goal is to cut supplies or reduce them through any means (Goslin, 2008). Terrorist attacks that have been carried out to date on oil infrastructure have caught oil producers unprepared. For example, al-Qaeda's February 24, 2005, attack on the Aramco facility in Abqaiq and Saudi Arabia sent shock waves through the world's financial markets. On the same day, the price of oil on international markets jumped nearly $2.00 per barrel, despite the attack's complete failure (Cohen, 2007). Most analysts agree that the February attack, an additional attempt on March 28, 2005, and a 9/11-style assault in April 2007, all of which were successfully averted, were merely trial runs in a much longer campaign designed to disrupt the global economy in general, and the oil industry in particular (Stratfor Global Intelligence, 2006).

Since global economic survival depends on a continuous reliable supply of petroleum products, it is therefore imperative to mitigate security threats in this industry worldwide. The identified upstream crude oil supply chain risks includes 1) exploration and production risk, 2) environmental and regulatory compliance risk, 3) transportation risk, 4) availability of resource risk, 5) geopolitical risk, and 6) reputational risk.

Exploration and Production Risk

The critical environmental risks during exploration and production are the associated disturbance to the natural ecosystem, which could lead to unplanned occurrences such as leaks and spillages with permanent devastating effects. Norrman and Lindroth (2004) classify risk into different categories: operational accidents, operational catastrophes, and strategic uncertainty. Operational accidents are those affecting the operational process or resources related to logistics and supply chain, such as fires, truck accidents, machine failure, labor strike, etc. For example, the impact of natural hazards such as Hurricanes Katrina and Rita damaged over one hundred oil production platforms and approximately 150 pipelines that gather and transport oil from offshore wells. In total they spilled nine million gallons of oil, mostly from damaged coastal facilities that supported offshore Gulf oil production (Levy & Gopalakrishnan, 2009). These operational catastrophes are rare and difficult to predict, but could occur with severe impact at the upstream sector of the oil supply chain. Recently, operational catastrophes are happening with an increasing rate, making it a necessity for companies to have well prepared mitigation strategies for this type of risks (Iwan, Suhiza, & Nyoman, 2009). Scientists have long blamed increases in average global temperatures on the burning of petroleum-based fuel and emission of carbon dioxide and other greenhouse gases. Climate change is one of the most challenging problems facing the oil industry, affecting everything from the performance of submarines in coastal waters to the integrity of socio-ecological systems. Climate change could also exacerbate impacts on the ocean ecosystem, compounding the impact of drilling offshore (Levy & Gopalakrishnan, 2009).

Exploration and production areas are located in remote and isolated areas characterized by poor transport structures (distribution hubs for moving the crude to market worldwide) and communication to authorities and the associated security infrastructure, therefore making them more attractive targets for terrorists (Honeywell International, 2008). The attackers could sometimes be members of neighboring or surrounding communities. For example, in June, 2008, a Royal Dutch Shell oil platform operating 120 kilometers off the Nigerian coast's Delta region was assaulted by terrorists using speed boats (Goslin, 2008). Also in 2006, gunmen using speedboats invaded the Benisede oil platform operated by SHELL in the Niger Delta (BBC News, 2006). Because of the interconnectedness of about 6000 offshore platforms and several onshore around the globe, a problem at one key platform may restrict an entire country's crude oil source by several percent, which makes platforms such as the one at Bombay High oil field a strategic asset in the supply chain (Urso, Colpo, & Sheble, 2006). Incidents such as this explain the probable safety and security threats facing the global oil supply network and the potential consequences of loss of life, lost production, and destruction of equipments.

Environmental and Regulatory Compliance Risk

Environmental risk during production could create negative impacts in the air, in water, and onland. Proponents of offshore drilling argue that domestic oil drilling can stimulate the domestic economy therefore enhance energy independence. On the flip-side environmental advocates continue to argue that the potentially catastrophic risk to the environment and coastal communities from oil exploration and production outweighs the economic benefits, and each activity relating to offshore oil production (exploration, extraction, and transportation and storage) would pose unacceptable environmental risks (Levy & Gopalakrishnan, 2009). Regulatory compliance risk, reefers to legislative requirements on oil spills that lacks legal clarity. For example, OPA states that tankers should "carry appropriate removal equipment that employs the best technology economically feasible and that is compatible with the safe operation of a vessel." The act does not spell out the precise requirements, which are to be determined by the designated rule maker, the Coast Guard (Tusiani, 1996).

Transportation Risks

The crude oil supply chain involves thousands of miles along water and land. As a result, separate entities assume responsibilities for securing different links, which makes the entire supply chain extremely difficult to secure. The extraction points are often in remote and isolated rural areas, making crude oil transportation to worldwide markets difficult and, therefore contributing to infrastructure vulnerability. Transportation risks therefore include, terrorist attacks on crude oil pipelines, terrorist attacks on maritime transportation (piracy). Unfortunately, there are increasing signs of collaboration between terrorism and piracy (Luft & Korin, 2003).

Terrorist Attacks on Pipelines

Pipelines are a unique feature of the crude oil supply chain that are built either above ground, making them conspicuously visible, or buried underground with location identifications above ground. Regrettably, the locations of these pipelines through isolated terrain add to their vandalism and vulnerabilities to terrorist attacks. Pipelines are prone to vandalism and terrorist attacks with firearms and explosives, or by other physical means. Some pipelines may also be vulnerable to "cyber-attacks" on computer control systems or attacks on electricity grids or telecommunications networks (Parfomack, 2008).

Crude oil pipeline networks are valuable national assets. Therefore, governments around the globe, particularly in developing nations are increasingly recognizing that threats to national interest/security are more likely to stem from internal than external sources. Regardless of whether the attack is perpetrated by the nation's indigenes, foreign nationals or terrorist groups, sabotage on crude oil pipelines is regarded as a serious threat to a country's national security and may disrupt oil supply chains, cripple the company's operations, and slow down the country's economic growth, especially if the country's major source of revenue depends on crude export. Examples of some terrorists attacks are as follows: In Columbia, the terrorist groups the Revolutionary Armed Forces of Columbia known by its Spanish acronym FARC, and the National Liberation Army (ENL) have attacked the national pipeline Cano Limon-Covenas so many times that it become known as "the flute" (AIGS Energy Security Brief, August 2003). In December 2005, the Movement for the Emancipation of the Niger Delta (MEND) blew up Shell's Opobo Pipeline in Delta State (Ibinabo, 2007). In 2006, the Indian terrorist group the United Liberation Front of Asom (ULFA) staged several pipeline attacks in the oil-rich region of Assam (AIGS Energy Security Brief, March 2005). In June 2007, the U.S. Department of Justice arrested members of a terrorist group planning to attack a jet fuel pipeline and storage tanks at John. F. Kennedy (JFK) International Airport in New York (U.S. Department of Justice, 2007). In 2001, a vandal's attack on Trans Alaska Pipeline System

(TAPS) with a high-powered rifle forced a two-day shutdown and caused extensive economic and ecological damage (Congressional Research Service, 2008). In January 2006, federal authorities acknowledged the discovery of a detailed posting on a website supposedly linked to Al-Qaeda that reportedly encouraged attacks on U.S. pipelines, especially TAPS, using weapons or hidden explosives (Congressional Research Service, 2008; Loy, 2006). A slew of other attacks have succeeded or been thwarted in several countries around the globe including Saudi Arabia, Russia, Sudan, and Yemen.

Interestingly, pipelines have proven to be a safe and fundamentally efficient means of crude oil transmission, but they are also vulnerable to accident and terrorist attacks with the potential to cause public injury and environmental damage. As a result, in the United States, for example, the 109th Congress passed the Pipeline Safety Improvement Act of 2006 (P.L. 109-468) to improve pipeline safety and security practices and to reauthorize the Federal Office of Pipeline Safety. Also, the 110th Congress passed the Implementing Recommendation of the 9/11 Commission Act of 2007 (P.L. 110-53), signed on August 3, 2007 by President Bush, which mandates pipeline security inspections and potential enforcements (section 1557) and requires federal plans for critical pipeline security and incident recovery (section 1558) (Parfomak, 2008). The Office of Pipeline Safety (OPS), within the Department of Transportation (DOT), is the lead federal regulator of pipeline safety. The OPS uses a variety of strategies to promote compliance with its safety regulations, including inspections, investigation of safety incidents, and maintaining a dialog with pipeline operators. For example, in 2002, the OPS conducted a vulnerability assessment to identify critical pipeline facilities and worked with industry groups and state pipeline safety organizations "to assess the industry's readiness to prepare for, withstand and respond to a terrorist attack" (Congressional Research Service, 2008).

Terrorist Attacks During Maritime Transportation

Global transportation of crude oil links both upstream and downstream activities, and plays an important role in global oil industry supply chain management. It is increasingly evident that crude oil tankers plying unpoliced waters around the globe have become a favorite target for terrorist attacks. The attack in 2000 on the USS Cole in Yemen was a clear indication that, although it was swift as a battle ship, with enhanced weapon and operational capabilities to defend itself and fend off enemy vessels and assaults, it has been vulnerable to terrorist boat attack. Due to this indefensible nature of vessels on high seas, terrorists/pirates have found it relatively easy to attack crude oil tankers. On today's globalized planet, the vast oceans and crowded littoral waters present a dichotomy of essential personal and economic sustenance on the one hand, and on the other, the very real security challenge of immense areas of ungoverned or weakly controlled space. For both dimensions of the challenge, maritime security is essential (Fallon, 2005). The United Nations' Convention on the Law of the Sea (UNCLOS) places focus upon acts of piracy that occur on high seas, "areas which are outside the primary jurisdiction of any one nation." Article 101 of UNCLOS defines piracy as a) " any illegal act of violence or detention, or any act of depredation, committed for private ends by the crew or the passengers of a private ship or a private aircraft, and directed: (i) on the high seas, against another ship or aircraft, or against persons or property on board such ship or aircraft; (ii) against a ship, aircraft, persons, or property in a place outside the jurisdiction of any State; (b) any act of voluntary participation in the operation of a ship or of an aircraft with knowledge of fact making it a pirate ship or aircraft; (c) any act of inciting or of intentionally facilitating an act described in subparagraph (a) or (b)" (United Nations' Convention on the Law of the Sea, 1982). Soon after UNCLOS was adopted, it became clear that its conception of piracy did not cover many of the violent crimes committed on the seas.

On October 7, 1985, four armed stowaways onboard the Italian cruise liner *Achille Lauro* hijacked the ship and killed one American passenger. The apparent political motivations for the attack, the location of the attack in Egyptian waters, and the fact that the attack originated from the target ship rather than from a separate ship, placed the attack outside the UNCLOS definition of piracy and, presumably, beyond the purview of universal jurisdiction. The United States, and other states that may have had an interest in prosecuting the attackers, were apparently left without the authority under international law to do so (Barrios, 2003). After the Achille Lauro attack, the international community, through the UN and its International Maritime Organization (IMO), promulgated the Rome Convention, which established a legal basis for prosecuting maritime violence that did not fall within the UNCLOS piracy framework. The Rome Convention made it unlawful to seize or take control of a ship by force or the threat of force, to perform an act of violence against a person on board a ship if it is likely to endanger safe navigation of that ship, to destroy or damage a ship or its cargo if it is likely to endanger safe navigation, to place devices or substances on a ship that are likely to destroy that ship, to knowingly communicate false information to a ship that would endanger safe navigation, and to injure or kill any person in connection with any of the above acts. The Rome Convention authorizes and, under certain circumstances, requires party states to establish jurisdiction over the perpetrators, either extraditing the perpetrators to another interested signatory state or prosecuting the alleged offenders themselves (Barrios, 2003). Over the years, piracy has remained a security challenge and threat to international commerce specifically, in the Southeastern part of Asia and Africa where commercial ships in these areas are susceptible to attacks by pirates due to narrow water ways. In spite of the intense counter terrorist measures, oil terrorism is increasingly becoming a matter of routine.

World oil transit chokepoints are a critical part of global energy security due to the high volume of crude oil traded through their narrow straits (Energy Information Administration, 2008). The world's two most strategic chokepoints are the Strait of Hormuz leading out of the Persian Gulf and the Strait of Malacca linking the Indian and Pacific Oceans. Other important passages include Bab el-Mandab, which connects the Arabian Sea with the Red Sea; the Panama Canal and the Panama Pipeline connecting the Pacific and the Atlantic Oceans; the Suez Canal and the Sumed Pipeline linking the Red Sea and the Turkish/Bosporus Straits joining the Black Sea and the Caspian Sea region to the Mediterranean Sea (Energy Information Administration, 2008).

Most of these critical chokepoints are located in areas where Islamic fundamentalism is prevalent. For example, the Strait of Hormuz and its three tiny islands of Abu Musa, Greater Tunb Island, and Lesser Tunb Island are controlled by Iran; Bab el-Mandab is controlled by Yemen, the ancestral home of bin Ladin. Part of the 500-miles long Strait of Malacca courses through Indonesia's oil rich province Aceh, inhibited by one of the world's most radical Muslim populations (Energy Information Administration, 2008). Terrorist attacks on supertankers in any of these chokepoints may result in explosion and spreading stain and burning crude oil that could shut down the channel for several weeks, resulting in a profound impact on global markets and the maritime insurance industry (Luft & Korin, 2003). In Nigeria for example, the July 2009 incident forced Royal Dutch Shell, (RDSa.L), U.S. oil company, Chevron (CVX.N) and Italy's Agip (ENI.MI) to shut down around 300,000 barrels per day production for seven weeks following the attack, lifting global oil prices (Hannington & Tume, 2009).

The International Maritime Bureau (IMB) reports the emergence in Southeast Asia of a 'new brand of piracy' in which the attacks are motivated by political agendas rather than a traditional motive to rob. Actual attacks by terrorists have thus far been limited to temporary seizures of vessels and crewmen, but officials express concern over the case in which large crude oil tankers could be hijacked and used as weapons with which to block commercial waterways (Barrios, 2003). Crude oil tankers are high investments to the tanker industry as well as the oil industry; therefore, any emergency arising from activities such as deliberate threats from terrorists is considered a critical security and safety risk that must be properly addressed.

The trend of some attacks and concerns are as follows:

- October, 2002: Boat crashed into oil tanker off Yemen coast. (BBC News, 2002).
- October 6, 2002: Boat bomb attack against French oil tanker MV Limburg off Ash Shahir port (Number 10.gov.uk, 2005).
- April, 2008: Seoul, South Korea, a Japanese oil tanker was damaged in an attack in the Middle Eastern waters off the coast of Yemen (Fackler, 2008).
- April, 2008: Armed pirates attacked and damaged a huge oil tanker off the Somali coast (Agence France Presse, 2008).

- November, 2008: Somalia terrorist-linked pirates seized the Sirius Star, a Saudi owned crude oil super-tanker 450 miles South East of Mombasa, Kenya. (Kimery, 2008).
- July 17, 2009: Militants launched two attacks on oil tankers in Northwest Pakistan carrying fuel supplies to NATO forces in neighboring Afghanistan. (Saukvally.com, 2009).
- January, 2009: The tanker MT Meredith, loaded with 4,000 tonnes of diesel, was badly damaged in a terrorist attack by the Movement for the Emancipation of the Niger Delta (MEND). (Al-Jazeera English News, 2009).
- July, 2009: Nigerian main rebel group sabotaged an oil tanker at the Lagos depot outside the Niger Delta (Hannington &Tume, 2009).
- July 2009: Somali pirates hijacked an Indian ship and used it to launch an unsuccessful attack on very large crude carrier (VLCC) 'The Elephant' (NASDAQ, 2009).

These terrorist attacks have devastating effects on national security, disrupt domestic oil supply, increase crude oil price, increase fears of environmental disaster, and subsequent possible increase in insurance premiums on tankers going through places such as the Gulf of Aden. Premiums were tripled for ships calling at ports in Yemen after the 2002 terrorist attack on French oil tanker Limburg off the Yemen coast, forcing many vessels to cancel Yemen from their schedules or divert to ports in neighboring states (Richardson, 2004b). Concerns about global terrorism on crude oil transportation have exacerbated the ambitions for security needs on a global scale; areas with major security problems in the near term are located in the Middle East, Africa, Central Asia and Asia

(Steinhausler, Furthner, Heidegger, Ryndell, & Zaitseva, 2008). Despite increased but varying degrees of security measures taken by different nations to protect oil infrastructure, global terrorists and regional/local insurgencies, in the quest to advance their agendas have continued to target oil infrastructures around the globe. Such disruptions in the supply chain would profoundly affect business confidence (Richardson, 2004b), the price of oil, and the global economy, specifically among newly industrializing nations (Anderson, 2008).

Availability of Crude Oil Resource Risk

Exploration and production of crude oil is dependent on availability and access to reserves to enable a continued supply to satisfy the growing global demand for oil. Although oil is a depletable asset, it is a commodity that is highly irreplaceable with alternative sources such as natural gas and nuclear energy; therefore, there is the probability that in years to come people would live in a world without oil. Although many other oil producing nations have reserves, the Middle East seems to be more concentrated with oil reserves. The importance of oil has lead oil consuming nations to be concerned about the security of oil supplies from the major oil producing (OPEC) countries. Hussain (2006) stipulate that under the right conditions, OPEC nations can meet the expected growth in the world oil demand by expanding its oil production if the oil industry will remain profitable, considering the fact that OPEC is not the only supplier of oil in the international market, and as a result, cannot guarantee stable price and availability of supplies to all consumers at all times. Further, Hussain (2006), also contends that to enable OPEC provide enough investments to increase capacity to meet the expected growth in oil demand it must be able to obtain reasonable oil prices in real terms, i.e, taking account of imported inflation and changes in the U.S dollar exchange rate; and a reduction of taxes in the major oil consuming countries that limits the growth in oil demand and thus reduces the income of oil producing countries. This ultimately limits the producing county's ability to invest in their respective productive capabilities, such as exploration and development, and consequently they are unable to match significant increases in global oil demand. Given the global dependency on oil, an inadequate supply to meet the increasing global demand will be very devastating.

Cohen (2007) argues that the main problem of oil shortages today is not a lack of reserves in the ground, but a lack of access above ground. In the 1980's and early 1990's, several articles were written about ownership of oil resources. Thereafter, however, the industry received limited attention: oil prices were low, supply seemed secure, and the fall of communism opened new opportunities for the international oil majors (Wolf, 2008).

The risk of oil supply has been a major security policy issue since in the 1970's, as most of the OECD economies' dependency on imported oil from the Middle East increased with the growth in political instability of the major oil exporting nations, OPEC's rising influence, the 1973-1974 Arab oil embargo (U.S. Department of State, 1976), and the nationalization of the upstream oil supply chain. Regrettably, all these could lead to, or give rise to erratic oil supply risk.

The threat of security of oil supply can be analyzed either in terms of demand for the producing country or supply for the consuming country. For the producing country oil security means security of demand, while for the consuming country it means security of supply (Opoku, 2009). Khatib (2000) also defines oil security as the continuous availability of oil in different forms, in sufficient quantities and at affordable price levels. Yergin

(2006) defines energy security as the "availability of sufficient supplies at affordable prices." Kalicki and Goldwin (2005) similarly define energy security in terms of "provision of affordable, reliable, diverse and ample supplies of oil and gas and their future equivalents and adequate infrastructure to deliver these supplies to market."

Apparently, oil security issues are not a new concern; they have since become a matter of both national and international concern (Opoku, 2009). For example, oil producing nations, such as OPEC, also need security of demand from their oil, since the economic survival of such nations depends on revenues from oil exports in foreign currencies that are used in reverse to import goods and services required for development. Therefore, any unexpected reduction in the demand for oil exports and hence oil revenue, will have economic and political impact on these countries. Regrettably, under such conditions the world could face a shortage in oil supplies, which would have negative effects on the global economy (Hussain, 2006). According to documented literature (Karl, 1997; Gary & Karl, 2003; Moody-Stuart, 2003; Christian, 2003; Kleveman, 2003; Stevens, 2003; Katz et al. 2004; Shaxson, 2005), oil can have increasingly negative impacts on low-income producing countries. These negative effects include low and sometimes negative economic growth for the country, poor provision of basic public services, weak governance, widespread poverty and insecurity (Keith, 2005). Ross (2001) confirms that these poor countries that are dependent on oil revenue often experience slower economic growth, high levels of corruption, higher military expenditure, and incredibly worse performance on child malnutrition reduction as well as adult illiteracy, and are more vulnerable to economic shock. Poor nations that are dependent on oil sales for key revenues are often adversely affected by the ownership of the resource (Karl, 1997).

Global demand for oil is increasing, but supplies of this key energy source are limited, so availability will be constrained and its price will rise with serious implications for prosperity and stability worldwide, creating a worsening security challenge. The Saudi spare capacity has deteriorated over the past decade, by one-half, from 3-4 million barrels per day to 1-1.5 million barrels per day. The loss of spare capacity will have strong implications for both the functioning of the oil market and the energy security agenda (Fattouh, 2006). To make matters worse, some experts question reserve estimates provided by national oil companies in the gulf and elsewhere, as the numbers are not independently audited. Without a clear understanding of how much oil is available, the world may be up for more nasty surprises (Cohen, 2007).

Geopolitical Risk

The 1973 and 1979-1980 oil shocks made "geopolitics of oil" the byword to describe the sources of uncertainty surrounding oil supplies and prices. Today, while geopolitics is not absent from the current oil shock, it is global economics that drive oil prices. In a world oil economy highly influenced by national oil companies, there are inevitable boundary issues, and in that sense, geopolitics still has a role to play (Munk, 2005). The stability of oil exporting nations is of paramount importance to the world oil market. For example, the strike in Venezuela, the war in Iraq, and the ongoing disruptions of Angola and Nigeria oil were examples of what could happen if such incidents occur in other countries such as Saudi Arabia and Iran. Another OPEC oil embargo is very unlikely; however, if oil is ever used as a weapon to combat the United States or western foreign policy, or if sanctions were imposed on Iran, it will have devastating effects on the global economy.

Conflicts occur over control of oil, such as civil unrest or war that uses disruption of oil operations as a tactic, conflict with indigenous groups over oil development and even superpower geopolitics, e.g. control over Middle East oil reserves (O'Rourke & Connolly, 2003). Unfortunately, disagreement over control of oil revenue by ethnic groups has always destabilized countries and disrupted the flow of oil.

Research has shown that the price of oil accurately tracks geopolitical risk factors, with greater weights given to the politics of the Middle East. The greater the geopolitical risk at any time, the greater the price of oil and vice-versa (Shaunak, 2007). The issue of access to countries with oil resources is also mired in geopolitics. For both China and India, the Caspian Sea is a major attraction for its oil and gas resources. But the region is still difficult to access, given the geopolitics of the region and Russia's strategic interest to make it a part of its security system, the lack of a clear international legal regime on resource ownership centered around the issue of whether it is a sea or a lake, and the absence of institutions to ensure that oil development is smooth and instills confidence in international investors.

Moreover, even as the newly independent states of Azerbaijan, Kazakhstan, and Turkmenistan are eager to develop their resources and create international linkages, the region needs access routes to global markets for its energy resources. Since the existing transportation routes are mostly through Russia, attempts are being made to diversify these routes through other neighboring countries, both to increase geographical access to East and South Asia, and to reduce dependence on Russia. Until these issues – strategic, security, economic and legal – are resolved, the Caspian Sea energy resources will remain a potential source of great conflict as the scramble for resources increases. In the case of

Venezuela on the other hand, China and India may benefit, as President Chavez sees oil as a 'geopolitical weapon' to contain the US. (Noronha, 2005).

Reputational Risk

The "reputation" of any company provides an aggregate impression of performance. Reputational issues for any company relate to public perception of their record on a number of issues, ranging from managerial style and environmental issues, to human rights. Amid the growing concern of "ethical" investors worldwide, these later dimensions are becoming ever more important (Stevens, 2008). According to the Committee of European Insurance and Occupational Pension Supervisors (CEIOPS), reputational risk is defined as the risk of potential damage to an undertaking through deterioration of its reputation or standing due to a negative perception of the undertaking's image among customers, counterparties, shareholders, and/or regulatory authorities (Mathias, 2008). Oil companies can gain back their reputation and win public goodwill and improve the value of their brands if they commit to fiscal discipline and corporate social responsibility. The public is demanding greater social responsibility; therefore, companies in the oil industry that are able to understand its exposure to reputational risk through quantification and being capable to deal with the risk through reputational risk management have a clear competitive advantage, and oil companies that cannot take the heat are beginning to feel the consequences (Mathias, 2008).

CHAPTER 4. RESEARCH METHODOLOGY

Risk and uncertainty are a widely discussed issue in supply chain management literature and are often use synonymously. However, they are distinct concepts. Risk is often identified to be the consequence of uncertainty (Lalwani, Disney, & Naim, 2006). One of the most pressing areas for companies in today's global business environment is the assessment and management of risk. Managing risk is cited as one of the primary objectives of firms operating internationally (Ghoshal, 1987). In a modern complex decision-making environment, to mitigate risk, an organization must recognize the extent, likelihood, and consequence of the risk to the organization. Miller (1992) adopts the term 'uncertainties' to refer to the unpredictable nature of the operating environment in which companies operate, and then categorizes these uncertainties according to their source. Iwan, Suhaiza, and Nyoman (2009) argue that although supply chain management has always had a strong emphasis on risk, the notion of supply chain risk management has gained an increasing popularity in recent years due to increasing supply chain complexity.

However, Faisal, Banwet, and Shankar (2006b) and Tang (2006) believe that effective supply chain risk management (SCRM) is an imperative for companies. For example, companies like Ericsson (Norrman & Jansson, 2004) and Nokia, (Li, Ragu-Nathan, Ragu-Nathan, & Rao, 2006) developed a supply chain management model after a fire at its sub-supplier. This is one of the mostly discussed cases in supply chain risk literature. Both companies, Ericsson and Nokia have since realized the need for an effective risk management in their supply chain operations. Srividhya and Raj (2007) suggest that global corporations therefore need to develop and follow an all-encompassing and holistic risk management model – one that looks at all the uncertainties and their degrees of influence on the various segments of the global supply chain.

For the oil industry, the upstream sector is characterized as a "high-risk" industry due to the sizeable investment level, geological uncertainties, and other risks related to fiscal and political uncertainties with host countries. Therefore, the risks encountered in the upstream sector need to be addressed to ensure commercial viability of an oil project (Al-Thani, 2008). Risk management involves identifying the supply chain risk events, assessing the probabilities and the severity of impacts, prioritizing the risk event, and developing actions for mitigating the risk. It also involves the course of actions to consider in reducing the risks. According to (Iwan, Suhaiza, & Nyoman, 2009), risk management involves such options as transferring it to or sharing it with other parties, accepting it as it is, or avoiding the risk. Many studies exist in international literatures that identify specific risk in the oil supply chain. A proposed energy supply risk categorization falls into source dependence, facility dependence, transit dependence and structural risk, which includes natural disasters, political blackmail, terrorism, war, civil unrest, and etc (Weisser, 2005).

However, Stern (2002) categorizes risk in the energy supply to include import dependence, source dependence, transit dependence, facility dependence and security dependence. Fattouh (2007) categorizes risk in the energy supply to include war and civil conflicts, political instability, regime change, revolutions, successful terrorist attacks on oil facilities, export restriction, closure of trade routes, and sanctions. Mitchell (2002) stipulates that oil supply risk can be categorized according to the time period: 1) Short term (12–18 months): disruptions of international supplies, 2) medium term (3–5 years):

export cartel issues, medium term: political issues, 3) long term (10–15 years): resource shock, medium to long term: 'Real climate policy' shock.

This section of the dissertation is devoted to the categorization of risk that is taken into consideration in the risk assessment of the upstream crude oil supply chain. The risks identified are exploration and production risk, environmental and regulatory compliance risk, transportation risk, availability of oil resource risk, geopolitical risk (political instability of exporting nations), and reputational risk. It is therefore important to provide a methodology for identifying, analyzing, evaluating, and selecting a risk treatment (mitigation) to manage these risks. To evaluate and prioritize these risks, the techniques such as the Multi-Criteria Analysis Method and the Analytic Hierarchy Process would be ideal, as they are suitable methodologies to solve decision making problems, while focusing on the upstream crude oil supply chain.

Multi-Criteria Analysis

Management decision- making problems often involve multiple criteria/objectives/attributes. Multi-Criteria Analysis is a decision-making tool developed for complex multi-criteria problems. Those include qualitative and/or quantitative aspects of the problem in the decision-making process. Multiple-Criteria Analysis (MCA) is a collection of methodologies to compare, select, or rank multiple alternatives that involve incommensurate attributes (Levy & Gopalakrishnan, 2009). In a situation where multiple criteria are involved, confusion can arise if a logical well-structured decision-making process is not followed. MCA is a tool that can help evaluate the relative importance of all criteria involved, and reflect their importance in the final decision-making process. Another difficulty in decision making is that reaching a general consensus in a multidisciplinary team can be very difficult to achieve. Therefore, by using MCA, the members don't have to agree on the relative importance of the criteria or the rankings of the alternatives. Each member enters his or her own judgments and makes a distinct, identifiable contribution to a jointly reached conclusion (Mendoza et al., 1999). Two problems exist in MCDM models: 1) an evaluation problem concerned with the evaluation of, and the probable choice of discretely defined alternatives, and 2) a design problem concerned with identifying the preferred alternative from a potentially infinite set of alternatives implicitly defined by a set of constraints (Kamal & Al-Harbi, 1999).

For several years different quantitative methods have been adopted to enhance rational decision making that involves multiple criteria, such as outranking method, judgmental modeling, weighted sum model, weighted product model, fuzzy sets, and AHP. Since AHP has been considered as one well-known and most- used decision making models in situations where the decision criteria are based on multiple attributes, it is therefore well suited for eliciting and modeling the risk management preferences in the upstream crude oil supply chain.

Analytic Hierarchy Process

The analytic hierarchy process (AHP) has found widespread application in decision-making problems involving multiple criteria in systems of many levels (Liu & Hai 2005). Tam and Tummala (2001) also identify its usefulness when several decision makers with different conflicting objectives are involved. The analytical hierarchy process (AHP) provides a framework to cope with multiple criteria situations involving intuitive, rational, quantitative and qualitative, aspects (Alberto, 2000). Hierarchical representation of a system can be used to describe how changes in priorities at upper levels affect the priority of criteria in lower levels (Chan, 2003). It organizes the basic rationality by breaking down a problem into its smaller constituent part and then guides the decision maker through a series of pairwise comparison judgments to express relative strength or intensity of impact of the elements of the hierarchy (Saaty & Kearns, 1985). The AHP methodology is a flexible tool that can be applied to any hierarchy of performance measure (Rangone, 1996).

In this research, the decision relates to the choice of one of the alternatives. The three components identified in the problem solving are 1) system decomposition, 2) comparative assessment, and 3) synthesis of priorities. System decomposing refers to the formation of the hierarchical structure with the basic objective that is with its goal, criteria and objectives, and alternatives. The mathematical model is the second component of the process where the priorities (weights) of the elements are placed at the same level of the hierarchical structure and calculated. The mathematical model is the basis for generating the ranking scale. The third component of the model means that the generated local priorities of the criteria and alternatives are synthesized into the total criteria alternative priorities.

The application of this method begins with the necessary definition of the hierarchy model and its elements with the goal at the top, criteria as sublevels in the middle and, finally, alternatives at the bottom. The next step is to generate a mathematical model. This model is based on mutual pairwise comparison, i.e., at each level of a hierarchy structure its elements are subjected to pairwise comparison. Decision makers' preferences are presented by a scale (Saaty's Scale), which is defined as the ratio scale and is assumed that the intensity of preferences between each two alternatives can be represented using the scale that verbally describe intensities and their respective numerical values in the range of 1-9.

On the basis of the mathematical model, and from the assessment of the relative importance of the elements of the corresponding level in the hierarchy structure, local priorities, that is, weights of criteria as well as alternatives, are derived, and then synthesized in the total alternative priorities. In the end, the ranking list of the ranking values of the alternatives is obtained, so that the sensitivity analysis can be conducted.

AHP has been successfully used to solve several transportation problems (Vreeker, Nijkamp, & Welle, 2002; Lirn, Thanopoutou, Beynon, & Beresford, 2004; Chang & Yeh 2001; Poh & Ang, 1999; Tzeng & Wang, 1994). The AHP has also been a helpful methodology used in solving decision problems in studies such as supplier selection, forecasting, risk opportunities modeling, plan and product design, etc. (Siddharth, Subhash, & Deshmukh, 2007), and has been universally used in solving multi-attribute decision-making problems (Saaty, 1980). The AHP methodology has been usefully demonstrated in several studies around the globe (Song & Yeo, 2004; Dey, 2004a) and has been used in several industries (Beynon, 2002; Chwolka & Raith, 2001; Lirn, Thanopoutou, Beynon, & Beresford, 2004). Partovi, Burton, and Banerjee (1990) used it for operation management decision-making. Dey, Tabucanon, and Ogulana (1994) used it in managing the risk of project. Korpela and Tuominen (1996) and Dey (1996) used AHP for benchmarking logististic operations and project management respectively. Main and Christine (1999) used AHP for evaluation and selection of a private sector project. Dey (2001) described AHP as an effective tool for project selection. Dey, Tabucanon, Ogulana, and Gupta (2001) used AHP for cross country petroleum pipeline selection. Dey (2004b) used AHP in a decision support system for inspection and maintenance, a case study of oil pipelines. Nataraj (2005) used AHP as a decision-support system in the petroleum pipeline industry. Mustafa and Ryan (1990) used AHP for bid evaluation.

Despite the positive attributes, popularity, and simplified concepts of AHP that is widely reported in the literature, it is continuously being criticized for its inability to adequately handle the inherent uncertainty and impression associated with the mapping of the decision maker's perception to exact numbers. In the traditional formulation of the AHP, human judgments are represented as exact numbers. However, in many practical cases the human preference model is uncertain and decision makers might be reluctant or unable to assign exact numerical values to the comparison judgments (Felix & Niraj, 2005). For example, Watson and Freeling (1982) stipulate that AHP, in order to elicit the weights of the criteria by means of ratio scale, asks decision-makers questions that seem to be vague or meaningless, such as "which of these two criteria is more important in relation to the set goal and by how much?"

Although Belton and Gear (1985) and Dyer and Wendel (1985) criticize the AHP saying it lacks theoretical basis, Harker and Vargas (1987) and Perez (1995) counter the criticisms and contend that the AHP in fact, is based on a firm theoretical foundation.

AHP Application in Crude Oil Supply Chain Risk Management

Risk assessment is most powerful when historical data or subjective expert opinions are available; however, in a situation of uncertainty, potential outcomes cannot be described in terms of objectively known probability distributions, nor be estimated by subjective probabilities (Haimes, 1998).

The application of AHP to the upstream crude oil supply chain risk assessment decision problem entails three broad phases:

1) Structuring the complex decision problem as a hierarchy, displaying the ultimate objective or the overall goal of risk management, the various risk factors and the alternative criteria of the decision maker. This hierarchical structure enables the decision-maker in structuring the complex system into manageable sub-system.

2) The prioritization process, accomplished by assigning numbers from a scale developed by Saaty to represent the importance of the criteria. A matrix with pairwise comparisons with these attributes provides the means for calculation. The decision maker evaluates each criterion against all others and can express a preference between each pair as equal, moderate, strong, very strong, and extremely preferable (important). These judgments can be translated into numerical values on a scale of 1 to 9, with 1 being equal importance and 9 being very strongly important (Saaty, 2000). The decision maker evaluates each criterion against all others, and value of relative importance is assigned to more important criteria and the reciprocal to the lesser important. Elements at each level of the hierarchy are compared with each other in pairs, with their respective "parents' at the next higher level. With the hierarchy used here, matrices of judgments are formed.

3) After assigning all the relative comparisons, the principal eigenvector of the effects table is calculated for each criterion, which is normalized across all the criteria to equal 1 (Levy & Gopalakrishnan, 2009). With regard to the recommended steps by Saaty (2006), the hierarchy structure to model the upstream crude oil supply chain risk is shown in figure 13. The procedure is as follows:

1. Define the problem and determine the overall goal.

2. Identify the criteria and attributes that must be satisfied to fulfill the overall objective.
3. Identify the decision alternatives or outcome.
4. The structure of the hierarchy is organized by placing the objective at the first level, criteria at the second level, and decision alternatives at the third level. The identified decision criteria are exploration and production risk; environmental and regulatory compliance risk; transportation risk; availability of oil resource risk; geopolitical risk, and reputational risk. As a result, the final crude oil supply chain

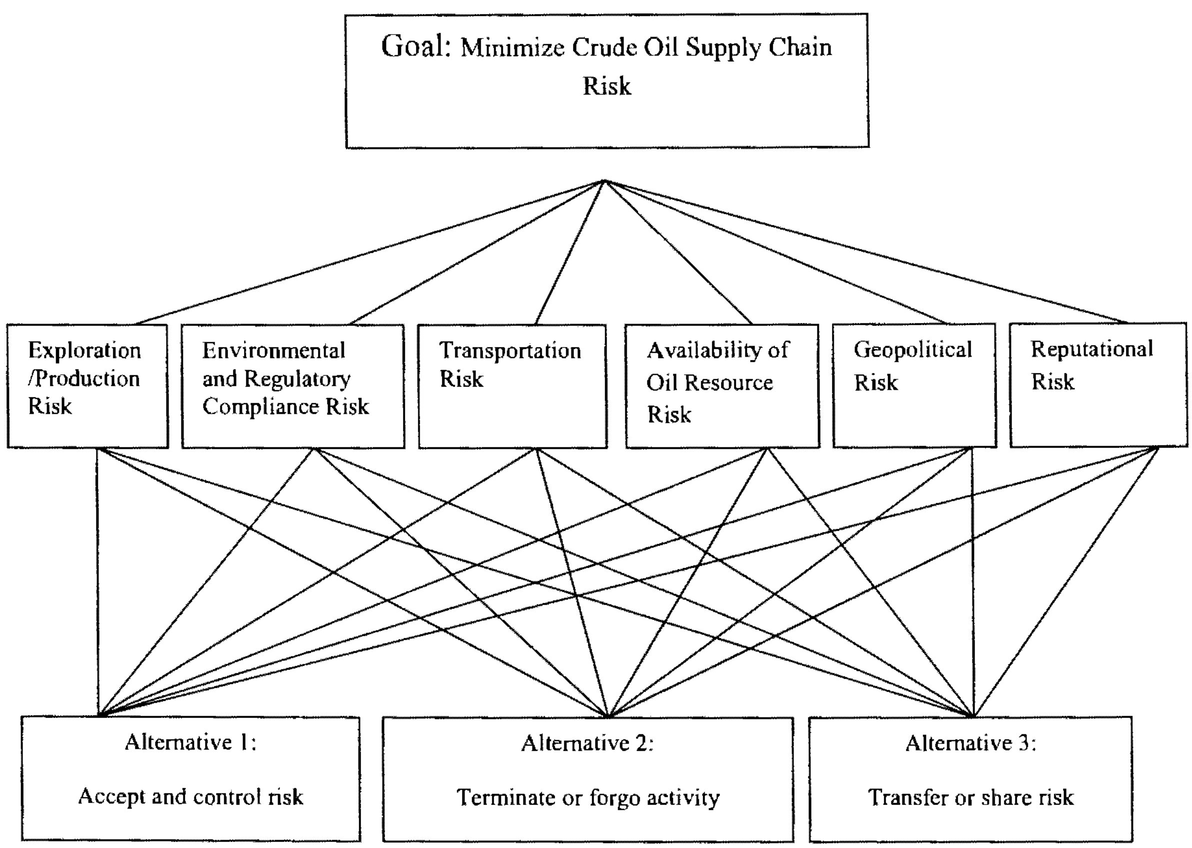


Figure 13. The Hierarchy Structure of the Crude Oil Supply Chain Risk.

risk assessment hierarchy consists of three levels with nine nodes, which include the criteria and the alternatives.

5. The alternative options proposed to manage the upstream crude oil supply chain risk specified at level three are:

Risk Acceptance

Some supply chain risks are simply infeasible to intervene with preventive measures such as avoiding, transferring, or reducing. Risk is always present and depending upon the uncertainties and their potential consequences, it can be accepted and measures taken to minimize it. The acceptability of each risk involves an assessment of the residual level of risk compared with the amount of risk that risk managers are willing to accept. The management of the risk needs major improvement before the risk can be regarded as acceptable. Risks are retained and managed when an organization is capable of managing the risks more efficiently than others and is sufficiently rewarded for that. However, it is imperative not to confuse acceptability of risk with impact; a risk with high impact and a high likelihood can be acceptable if adequate actions are already being taken to manage the risk.

Terminate or forgo activity

Risk avoidance in general entails avoiding an activity to avoid the identified supply chain risk involved. The avoidance strategy eliminates the supply chain risk. The disadvantage of using risk avoidance as a form of risk management is that it prevents the upstream sector from taking actions that increase exposure to earning opportunities. Although the aim of avoiding risk is to completely evade the activities that involve unacceptable risk, mitigating risk involves the planning of future actions and activities to prevent or reduce the consequence of the risk occurring.

Transfer or Share Risk

Risk transfer does not mean total elimination of risk; it entails transferring the consequence of a risk to a third party. Risk transfer strategies generate risk that still requires proactive management, but reduce the risk to an acceptable level. Examples of risk transfer include insurance, using external agents with renowned knowledge, purchasing a solution as opposed to building it, and outsourcing expensive projects and risky projects. For example, the upstream sector of the oil industry is classified as "high-risk" industry due to the sizeable investment level, geological uncertainties, and other risks that are related to physical uncertainties with host countries. Therefore, transferring risk may reduce some of the adverse consequences of the industry.

Construction of the Pairwise Comparison Matrix A

Typically in AHP, a decision situation is presented where several alternative choices are assessed relative to each other with respect to multiple criteria. The criteria likewise are assessed relative to each other with respect to an overall goal (Thomas & Srinivas, 2008). AHP is a decision method that enables the decomposition of complex decision problem into a hierarchy, as well as a measurement theory for prioritization of the hierarchy and consistency of judgmental data provided by a group of decision makers (Wu, Lin, & Chen, 2007). AHP combines all the decision makers' evaluations into one final decision by pairwise comparison of alternatives (Saaty, 1980). There have been positive attributes to the successful applications of AHP in several complex decision problems. In the upstream crude oil industry supply chain risk analysis, the AHP is a useful technique to accommodate the multiple dimensions and conditions that constitute supply chain risk. Establishing the pairwise comparison matrix A is as follows: Let $C_1, C_2, \ldots, C_n$ represent the set of elements, and a_{ij} represents the quantified judgment on a pair of elements C_i and C_j. Here, the element a_{ij} of the matrix refers to the relative importance of the i^{th} factor in response to the j^{th} factor yielding an $n^x n$ matrix A as follows:

$$A = [a_{ij}] = \begin{matrix} C_1 \\ C_2 \\ C_n \end{matrix} \begin{bmatrix} 1 & a_{12} & \ldots & a_{1n} \\ \frac{1}{a_{12}} & 1 & & a_{2n} \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \ldots & 1 \end{bmatrix} \qquad \text{(Eq.1)}$$

$$1 \leq i, j \leq n$$

Here, $a_{ii} = 1$ and $a_{ij} = 1/a_{ji}$; for all $i,j = 1, 2, 3 \ldots n$. Therefore assigning the elements $C_1, C_2 \ldots C_n$ to the numerical weights $W_1, W_2, \ldots Wn$, reflects the recorded respondent judgments obtained. For example, from the Saaty's scale value of 1-9 in Table 13, if a respondent compares two elements, exploration/production risk (C_1) to environmental and regulatory compliances risk (C_2) and specified that C_1 is very strongly more important than C_2 then the numerical weight assigned to this pairwise comparison, $a_{12} = 7$, indicating that C_1 is 7 times more important than C_2, for all $a_{ij} = 1$. However, if $a_{ij} = \alpha$ then for consistency, it is required that $a_{ji} = 1/\alpha$. Therefore if $a_{12} = 7$, then $a_{21} = 1/7$ must hold.

In reference to Saaty's, the pairwise comparison matrix should possess the following properties:

Reciprocity. With the application of the AHP, if $a_{ij} = \alpha$, while, $a_{ji} = 1/\alpha$, with $1/9 \leq \alpha \leq 9$. Since the matrices of the pairwise comparisons of an element at one level determine the achievement of the preceding level's objectives, the pairwise comparisons of the attributes at level 2 with one another in relation to their importance to the objective at level 1 in the hierarchy will require only n (n-1)/2 comparisons to build the matrix with a dimension n × n. Therefore in this case, at level 2, the pairwise comparisons of the six attributes (risk factors) will result in a 6 × 6 pairwise comparison matrix. Then at level 3, for each of the 6 attributes, the same procedure when used for pairwise comparison of the three alternatives will result in six matrices of size 3 × 3.

Table 13. Saaty's 1-9 Scale of Relative Importance for Pairwise Comparison

Identity of Importance (values of a_{ij})	Definition	Explanation
$a_{ij} = 1$	If the two objectives *ij* are equal importance	Two activities contribute equally to the objective.
$a_{ij}=3$	If objective *i* is moderately more important than objective *j*	Experience and judgment slightly favor one activity over another.
$a_{ij=5}$	If objective *i* is strongly more important than objective *j*	Experience and judgment strongly favor one activity over another.
$a_{ij=7}$	If objective *i* is very strongly more important than objective *j*	An activity strongly favors one over another; its dominance demonstrated in practice.
$a_{ij=9}$	If objective *i* is absolutely more important than objective *j*	Importance of one over another affirmed on the highest possible order.
$a_{ij=2,4,6,8}$	Intermediate Values	Used when compromise between the priorities are needed.

Homogeneity. For this research, referring to equation 1, when the input matrices of the respondent's judgments are compared to themselves, the principal diagonal elements are all at unity, confirming that each element has equal importance. Therefore, if the elements *i* and *j* are judged to be equally important, then $a_{ij} = a_{ji}$ and $a_{ii}=1$. These indicate that the lower triangle elements of the matrix are now the reciprocals of the upper triangle elements.

Consistency. Considering A as a consistency matrix, the relations between weight W_i and judgments a_{ij} are represented as $W_i/W_j = a_{ij}$ (*for all i, j* = 1, 2 . . . n) with assigned relative weight entering the matrix as an element a_{ij}, with a reciprocal entry $1/a_{ij}$ at the opposite side of the main diagonal will present the matrix of the pairwise comparison as follows:

$$A = [a_{ij}] = \begin{bmatrix} w_1/w_1 & w_1/w_2 & . & . & w_1/w_n \\ w_2/w_1 & w_2/w_2 & . & . & w_2/w_n \\ w_n/w_1 & w_n/w_2 & . & & w_n/w_n \end{bmatrix} \qquad \text{(Eq. 2)}$$

AHP stipulates that since the evaluators do not necessarily know the vector of the actual relative weights, it is difficult to accurately construct the pairwise comparison of the relative weights of matrix A, rendering this observed matrix A to have inconsistencies. Admittedly, several estimations made by evaluators may have created series of inconsistencies that need to be checked. Therefore the weight W can be estimated from the following equation:

$$\Delta A * \Delta W = \lambda_{max} * \Delta W \qquad \text{(Eq.3)}$$

Where ΔA denotes the observed matrix of pairwise comparisons, λ_{max} is the maximum or principal eigenvalue of ΔA and ΔW is the vector estimator of W. According to Saaty (1980) since the maximum eigevenvalue λ_{max} is always greater than or equal to *n* (the number of elements) it should be an acceptable estimator of *n*. Conversely, when the observed value of ΔA is consistent, the value of the maximum eigevenvalue λ_{max} is always greater than or very close to *n,* allowing for the construction of the consistency index CI, and consistency ratio CR as follows:

$$C I = (\lambda_{max} - n)/(n - 1) \qquad \text{(Eq.4)}$$

$$C R = (CI / ACI) * 100. \qquad \text{(Eq.5)}$$

Here ACI represent the average index of randomly generated weights.

The AHP measures how consistent the evaluator's judgment is by utilizing the consistency ratio (CR), which is the ratio of the consistency index over the random index (RI) using equations 4 and 5 and the approximated random indices from Table 14.

Table 14. Approximated Saaty's AHP Random Indices (RI)

Size of matrix (n)	1	2	3	4	5	6	7	8	9	10
Random Indices(RI)	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

A consistency ratio (CR) that estimates the extent of inconsistency in each pairwise comparison matrix must be bèlow a specific threshold. According to Saaty (1980), a deviation in consistency ratio of less than .10 or 10% is acceptable without adverse effect on the result, but considered to be inconsistent if greater than .10 or 10%, and therefore the judgment is expected to be revised. Here, Expert Choice software will be used to check the consistency ratio.

Aggregating the expert judgments. Aggregating the individual expert's opinion is an important aspect of group decision-making process. As a result, the geometric mean method (GMM) is considered an appropriate method. The justification is that if the individual decision makers have an acceptable inconsistency, it results in an acceptable aggregated value as group decision making (Mohammed & Ali, 2008). When the GMM is employed as a prioritization procedure, the group inconsistency is at least as good as a worst individual inconsistency for aggregation approaches (Xu, 2000). Therefore, to aggregate the combined judgment of several experts into one major opinion to estimate the priority of crude oil supply chain risk, the geometric mean method (GMM) will be applicable.

CHAPTER 5. PROBLEM FORMULATION AND RESULT ANALYSIS

The upstream oil industry decision-making problem is divided into different segments: the major objectives and alternative policy options that are selected from relevant literature review. The major objectives and alternative policy options are constructed in the form of hierarchy specifying the objective at level 2 to be of high value. The level 2 objectives in the model are exploration/production risk, environmental and regulatory compliance risk, transportation risk, availability of oil resource risk, geopolitical risk, and reputational risk. The objective of the hierarchy is to select the best alternative that satisfies the goal of minimizing upstream crude oil supply chain risk. The proposed alternatives that the supply chain risk manager intends to evaluate are shown at level three of the model in Figure 13 chapter 4. In spite of the fact that the model has three levels, it adequately covers the parameters on which the upstream crude oil supply chain is supposed to perform. In fact by limiting the number of levels to only three, the model has become easy to use and can find practical utility. From a practitioner's judgment and point of view, this model is more suitable than one which would incorporate more levels in the hierarchy.

The judgments of risk management experts from the oil industry were sought in comparison of the relative importance of the criteria, and the information of the pairwise comparison matrices will be used in the AHP model. The result of the six decision objectives will be used in computing the upstream crude oil supply chain risk management composite score.

Data Source and Description

The criteria for determining the upstream crude oil supply chain performance have been determined from the strategic objectives of the oil industry. The strategic objective is mapped to the perspective of the AHP. To model the upstream crude oil supply chain risk, a questionnaire is developed based on the hierarchy tree to enable pairwise comparisons between all the factors at the different level in the hierarchy of the AHP based on the recommended nine-point scale by Saaty for making pairwise comparisons. The structure of the hierarchy is comprised of three levels. Level 1 describes the major objective of the decision problem i.e., minimizing the upstream crude oil supply chain risk. At level 2, the major objective is further broken down into six decision criteria (exploration/production risk, environmental and regulatory compliance risk, transportation risk, availability of oil resource risk, geopolitical risk, and reputational risk), while level 3 defines the three alternative risk management policy options.

To achieve the objectives of the research, a survey questionnaire technique approach was used to collect data to specify the order of importance of the upstream crude oil supply chain risks. The questionnaire was designed to collect the opinions of subject matter experts (risk managers) in the oil industry. The result of the survey questionnaire was used as input to the AHP. The questionnaire has 33 questions classified into two sections, according to the different risk factors identified. The AHP model helps in determining relative importance of the criteria in the shape of weights taking into account the views of different experts. This is done by asking experts to do pairwise comparisons with reference to the major goal and taking the geometric means of such comparisons in order to arrive at a single figure for the pairwise comparisons. In section 2, the questions are also designed to seek the expert's preferences of alternative strategies for mitigating risk with respect to each of the six major criteria. Risk management experts from the oil industry were required to respond to several pairwise comparisons where two categories at a time are compared with respect to the major goal.

Several comparisons were performed to enable the development of the relative importance of major objectives needed to obtain the stated crude oil supply chain goal. The survey questionnaires were mailed to several oil industry risk management experts (SMEs: subject matter expert) to complete the analysis. Owing to the extremely sensitive nature of the oil industry's operations and specific target segment of respondents, it became difficult to collect opinions from a huge number of subject matter experts. Certain oil companies expressed their apologies for being unable to respond to the questionnaires, whilst others did not reply at all, i.e., there was no excuse or letter of explanation. Responses of 10 subject matter experts were collected out of 50 questionnaires that were mailed out. Statistically a sample size of 30 is considered large; therefore 50 questionnaires represent a large sample to conduct my analysis. The subject matter experts who were contacted were limited to publicly own national and international oil companies located in different demographic regions around the globe such as; the United States, United Kingdom, Saudi Arabia, Nigeria, Oman and Canada. Even within these target segments of the oil industry only those experts who have sufficient understanding of supply chain risk in the oil industry were eligible to fill in the questionnaire. Most respondents carried the designation of managers, executive vice president for risk assurance, director for compliance and enterprise risk management, director for transportation and logistics, team leader for production and pipeline team, VP for operation risk management, executive director for exploration and production, etc. The detailed survey questionnaire is reported in Appendix B.

Derivation of the Relative Priorities of Major Objectives and Alternatives

The geometric mean scores associated with the major goal and the alternative risk management policy options reported in Tables 15-22 were derived using a Microsoft Excel spreadsheet. The geometric mean scores are computed from the individual expert scores on Saaty's 1-9 scale provided by the 10 experts elicited. The Expert Choice 11.5 software package (2000-2004) based on AHP is used to assist in estimating the weights of the importance of the six major risk elements (exploration/production, environmental and regulatory compliance, transportation, availability of oil resource, geopolitical, and reputational) and also test the inconsistency among the individual expert's preferences. Expert Choice Software is also used in estimating the rankings of the three alternatives.

Table 15 below is the geometric mean score of the pairwise comparisons matrix of the risk criteria given by the subject matter experts.

Table 15. Combined Experts' Judgment Pairwise Comparison Matrix of Major Risk Objectives with Respect to the Goal

	Exploration / Production Risk	Environmental and Regulatory Compliance Risk	Transportati on Risk	Availability of Oil Resource Risk	Geopolitical Risk	Reputational Risk
Exploration/ Production Risk	1	1.231144	1.048122	1.490182	2.085348	1.799592
Environmental and Regulatory Compliance Risk	.812252	1	.0581811	.933033	1.334188	1.474768
Transportation Risk	.954087	1.718772	1	2.724154	2.839053	1.987134
Availability of Oil Resource Risk	.671059	1.071773	.51186	1	1.533675	1.533675
Geopolitical Risk	.479536	.686201	.35223	.652029	1	.797577
Reputational Risk	.691503	.835959	.578068	.698827	1.253797	1

These judgments are entered employing Saaty's pairwise comparison scale in Table 13. The decision makers evaluates each criterion against all others and values of relative importance is assigned to more important criteria and the reciprocal to the lesser important. For example, comparing the geometric mean values of geopolitical risk to all other risk criteria, it shows the lowest value, indicating less important risk for the oil industry to manage.

Alternative Risk Management Options Evaluation

A Pairwise comparison was performed for the relative effect of each of the alternative policy options, which include accept and control risk, terminate or forgo activity and transfer or share risk are shown in Table 16 through Table 21.

Table 16. Combined Pairwise Comparison Matrix for Alternatives with Respect to Exploration/ Production Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk	Priorities
Accept & Control Risk	1	3.396163	1.523808	.550
Terminate or Forgo Activity	.121297	1	.423598	.210
Transfer or Share Risk	.65625	2.360728	1	.240

Table 17. Combined Pairwise Comparison Matrix for Alternatives with Respect to Environmental and Regulatory Compliance Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk	Priorities
Accept & Control Risk	1	2.010677	.812252	.413
Terminate or Forgo Activity	.497345	1	.360222	.260
Transfer or Share Risk	1.231144	1.987134	1	.327

Table 18. Combined Pairwise Comparison Matrix for Alternatives with Respect to Transportation Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk	Priorities
Accept & Control Risk	1	2.531293	.551321	.413
Terminate or Forgo Activity	.395055	1	.430179	.260
Transfer or Share Risk	1.354802	2.324616	1	.327

Table 19. Combined Pairwise Comparison Matrix for Alternatives with Respect to Availability of Oil Resource Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk	Priorities
Accept & Control Risk	1	2.01635	1.655132	.500
Terminate or Forgo Activity	.495946	1	.555098	.250
Transfer or Share Risk	.079683	1.801483	1	.250

Table 20. Combined Pairwise Comparison Matrix for Alternatives with Respect to Geopolitical Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk	Priorities
Accept & Control Risk	1	1.888175	.779977	.413
Terminate or Forgo Activity	.529612	1	.633538	.260
Transfer or Share Risk	1.282089	1.578437	1	.327

Table 21. Combined Pairwise Comparison Matrix for Alternatives with Respect to Reputational Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk	Priorities
Accept & Control Risk	1	1.732051	1.011848	.413
Terminate or Forgo Activity	.57735	1	.707107	.260
Transfer or Share Risk	.988291	1.414214	1	.327

Empirical Results: The AHP Application to the Upstream Crude Oil Supply Chain Risk Management Using Expert Choice

This section presents the estimated results of the crude oil supply chain risk management interpretations using the AHP methodology. The AHP methodology used here in modeling the risk management is analyzed using the Expert Choice Software.

The empirical results are discussed in three distinct sections. Section 1 reports on the oil industry hierarchy, including the local priorities and global priorities associated with major decision criteria and pairwise comparisons of the major decision criteria. Section 2 discusses the synthesis results, including ideal synthesis, synthesis details of all the priorities or weights, and alternative policies with respect to the goal – minimizing crude oil supply chain risk. Section 3 reports on the sensitivity analysis, including performance, dynamic, gradient, head-to-head, and two-dimensional plot.

Major Decision Objectives

The pair-wise comparison of all the risk criteria generates a priority matrix as given in Table 22 and Figure 14 shows that transportation risk, (.263), exploration/production Risk (.198) and environmental/regulatory compliance risk (.161) are the top three major risk areas in the upstream crude oil supply network, followed by availability of oil resource risk (.150), reputational risk (.124) and geopolitical risk (.105).

Table 22. Priority Matrix for the Major Objectives

Objective	Priority	Rank
Transportation Risk	.263	1
Exploration /Production Risk	.198	2
Environmental and Regulatory Compliance Risk	.161	3
Availability of Oil Resource Risk	.150	4
Reputational Risk	.124	5
Geopolitical Risk	.105	6
Inconsistency Ratio	0.03	

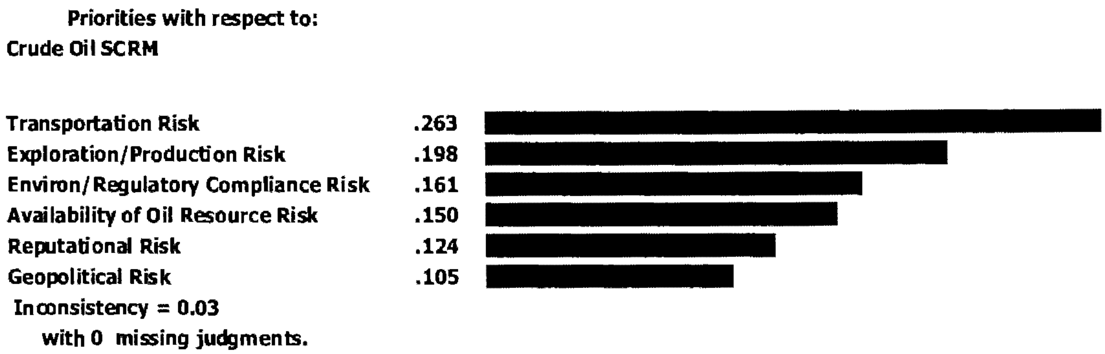


Figure 14. Comparing the Priority Matrix for Major Objectives.

This indicates that transportation risk is the most important risk to mitigate in the upstream crude oil industry with a priority of .263 (26.3%). This result confirms the drastic changes, challenges, and uncertainties along the supply chain, followed by exploration and production risk .198 (19.8%), environmental and regulatory compliance risk .161 (16.3%), availability of oil resource risk .150 (15.0%), while reputational risk is .124 (12.4%) and geopolitical risk is .105 (10.5%), indicating that the latter two are less important priorities to be considered.

However, the normalized priorities associated with Figure 14 are indicated below .

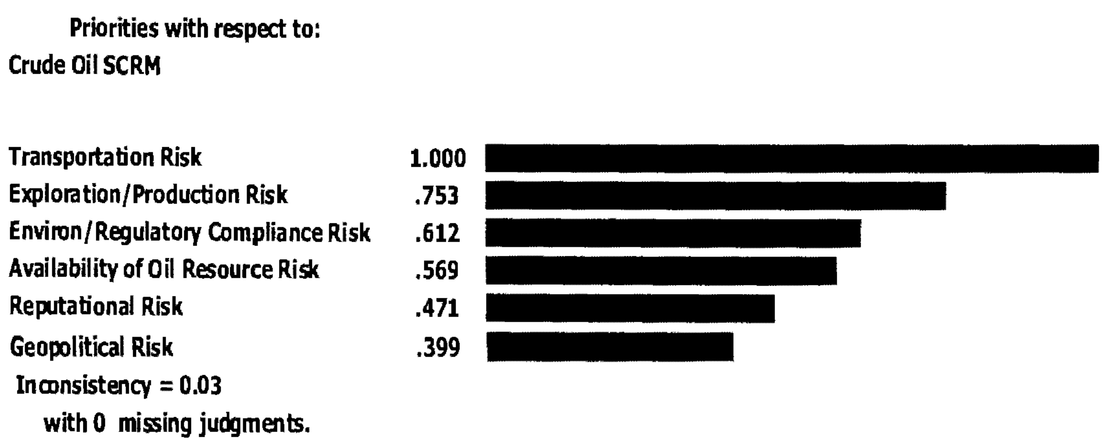


Figure 15. Normalized Priorities.

It can be seen here that transportation risk still shows the highest priority. Approaches to manage oil industry transportation risk specify some man-made incidences which are due to malicious intent; therefore it is important that, the assessment of transportation risk in the oil industry must include terrorism scenario on the different transportation modes. To manage transportation risk in the oil industry the individual national government should among others: develop risk management control strategies (prevention deterrence; preparedness; response recovery; stringent international and U.S. regulations) on oil transportation.

Table 23 shows the results of the composite scores that are associated with the alternative priorities: accept and control risk, transfer or share risk, and terminate or forgo activities.

Table 23. Priority of Objectives with Respect to Alternative Options

Objective Priority	Alternative Priority			
		Accept & Control Risk	Transfer or Share Risk	Terminate or Forgo Activity
Transportation Risk	.263	.413	.327	.260
Exploration and Production Risk	.198	.550	.240	.210
Environmental & Regulatory Compliance Risk	.161	.413	.327	.260
Availability of Oil Resource Risk	.150	.500	.250	.250
Reputational Risk	.124	.413	.327	.260
Geopolitical Risk	.105	.413	.327	.260
Composite Score		.446	.303	.251

Synthesis Results

To determine the overall preferences for the risk management policy options for the crude oil industry risk model, the priorities are synthesized. The global or overall priorities for the alternative policies are ranked as follows: accept and control risk (.446), transfer or share risk (.303), and terminate or forgo risk (.251). When normalized, the priorities for the alternative policies add up to 1.00 shown in Figure 16 (the ideal synthesis with respect to the goal), which indicate that accepting and controlling risk is the most important risk management policy option among the three policy options, with an overall priority score of .446. However, Figures 16-A to16 -F still verify the fact that accept and control risk still ranks number one in the alternative policy option in respect to managing the upstream crude oil supply chain risk.

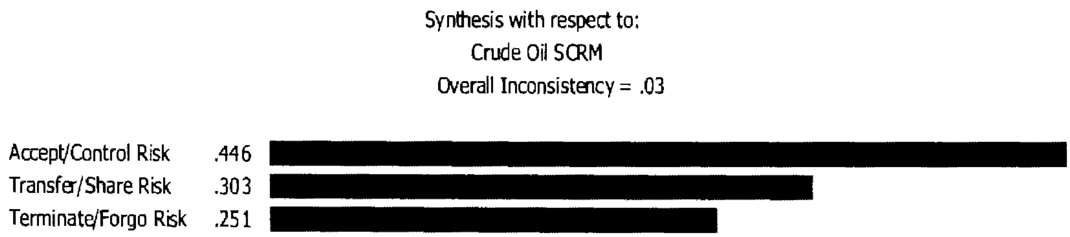


Figure 16. Ideal Synthesis with Respect to the Goal.

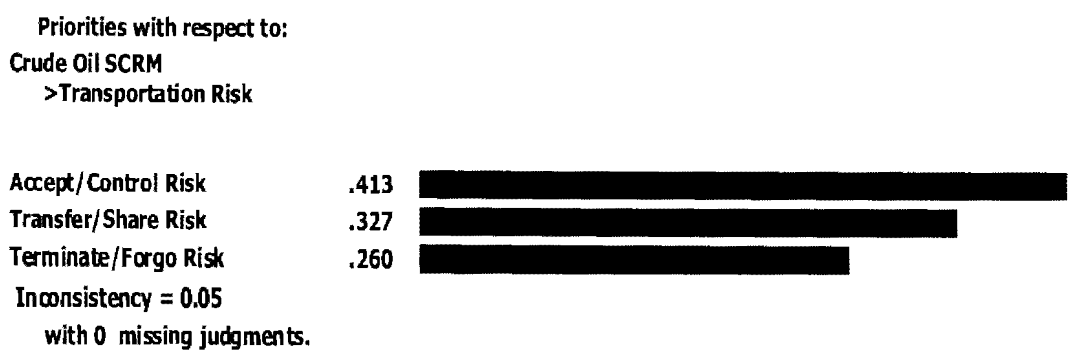


Figure 16-A. Ideal Synthesis with Respect to Transportation Risk.

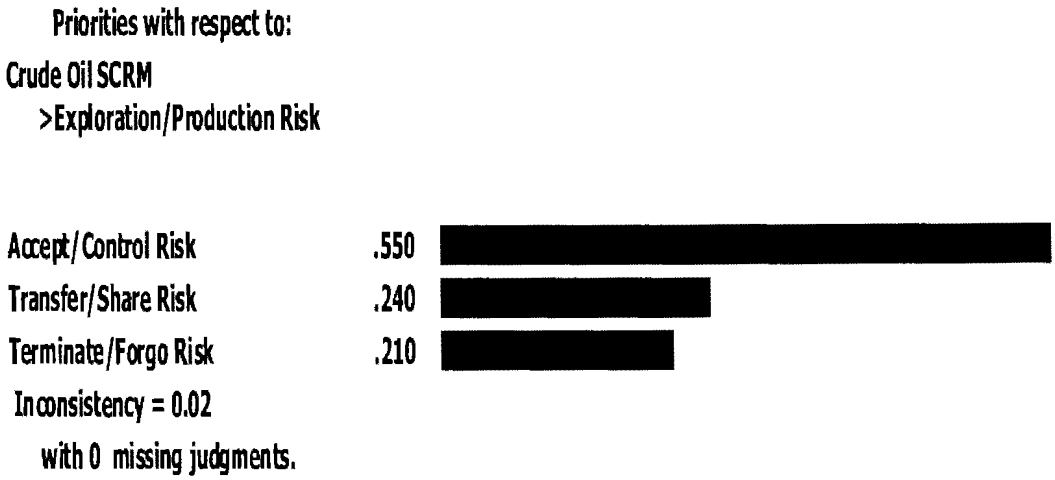


Figure 16-B. Ideal Synthesis with Respect to Exploration/Production Risk.

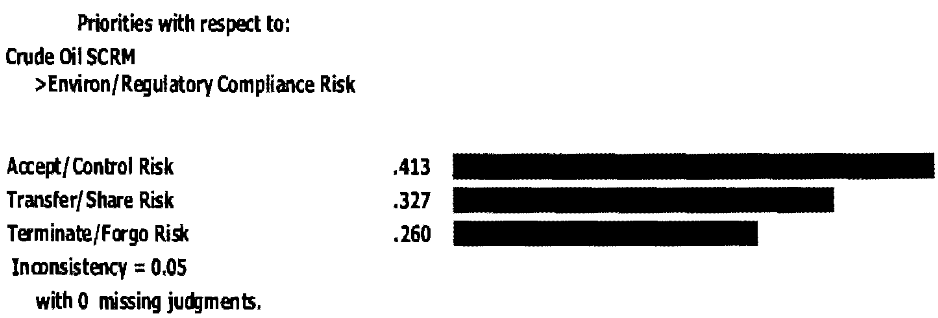


Figure 16-C. Ideal Synthesis with Respect to Environmental/Regulatory Compliance Risk.

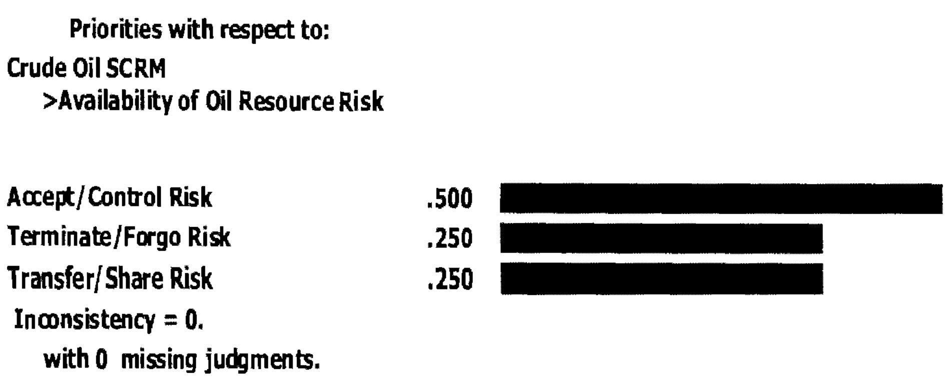


Figure 16-D. Ideal Synthesis with Respect to Availability Oil Resource Risk.

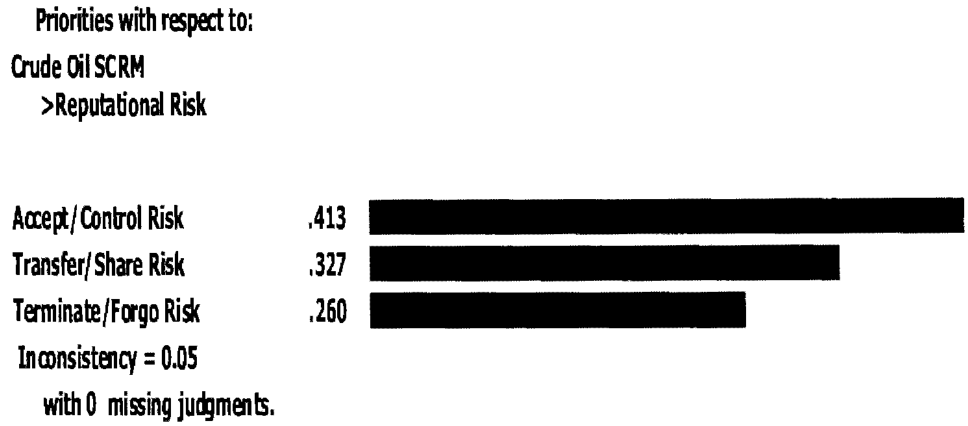


Figure 16-E. Ideal Synthesis with Respect to Reputational Risk.

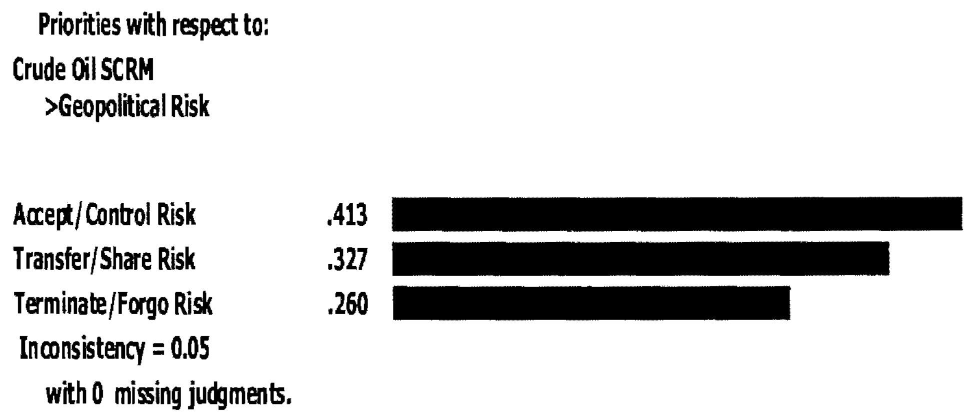


Figure 16-F. Ideal Synthesis with Respect to Geopolitical Risk.

Sensitivity Analysis for Major Decision Objectives

The sensitivity analysis option of Expert Choice Software enables the decision maker to graphically explore the response of the overall alternative policy options and changes in the relative importance (weight) of each attribute or criterion. This is an important aspect of using AHP in analyzing problems, since results are based on subjective expert assessments. A series of sensitivity analyses were conducted using Expert Choice

Software includes 1) performance, 2) gradient, 3) dynamic, 4) head to head, and 5) two-dimensional plots. Each of these five graphical modes expresses different viewpoint to a sensitivity analysis, enabling the user to easily manipulate the criterion priorities and instantly observe the impact of the change that is reflected in the ranking of alternative.

Performance Sensitivity Analysis

The performance sensitivity analysis depicted in Figure 17 represents the variation of the alternative policies' rankings to changes in each criterion. It shows the ratio of each alternative's weight percentage to criteria weights.

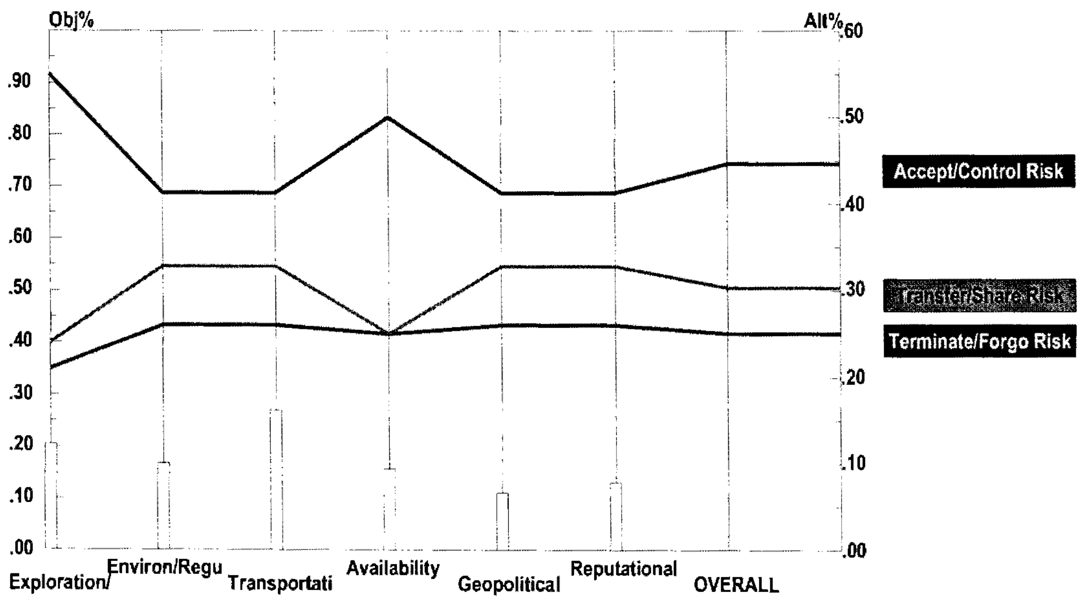


Figure 17. Performance Sensitivity Analysis.

Determining the best risk mitigating strategy, the decision maker will read the overall priority from the observation of the right "y"-axis and the overall priority for each alternative risk management strategy. The right "y" axis represents the overall priority of each alternative (with the OVERALL axis showing the overall priority of each criterion).

The result shows that accept and control risk is about .45 (45%), transfer or share risk is about .31 (31%), and terminate or forgo risk is about .25 (25%). The vertical bars represent the derived relative priorities of each criterion. The left "y" axis represents the relative priority of each criterion as synthesized from the expert's pairwise comparisons. Based on the result, exploration and production risk is about .20 (20%), environmental and regulatory compliance risk is about .18 (18%), transportation risk is about .28 (28%), availability of oil resource risk is about .16 (16%), geopolitical risk is about .10(10%), while reputational risks is about .11(11%). In reference to alternative policy priorities with respect to each major objective while reading from the right "y" axis, with respect to exploration and production risk, accept and control risk is about .91 (91%), transfer or share risk is approximately .40 (40%), and terminate or forgo activity is about .35 (35%). For environmental and regulatory compliance risk, accept and control risk is about .70(70%), transfer or share risk is approximately .55(55%), while terminate or forgo activity is about .42 (42%). Regarding transportation risk, accept and control risk is about .70 (70%), transfer or share risk is about .55 (55%), and terminate and forgo activity is about .40 (40%). With respect to availability of oil resource risk, accept and control risk is about .85 (85%), transfer or share risk is about .40 (40%), and terminate or forgo activity is about .40 (40%). For geopolitical risk, accept and control risk is about .70 (70%), transfer and share risk is about .55 (55%), while terminate or forgo activity is about .41(41%). With respect to reputational risk, accept and control and transfer is about .71 (71%), transfer and share risk is about .55(55%), while terminate and forgo is about .40 (40%). Finally, for the overall, accept and control risk is about .75 (75%), which is still the best risk mitigation strategy followed by transfer or share risk which is about .30 (30%), and then terminate or forgo activity at about .25 (25%). It can be seen in Figure 17-A scenario 1 that changing the criterion value with respect to environmental and regulatory compliance risk from .18 to .30 does not change the ranking of the alternatives, and that accept and control risk still remain the number one alternatives.

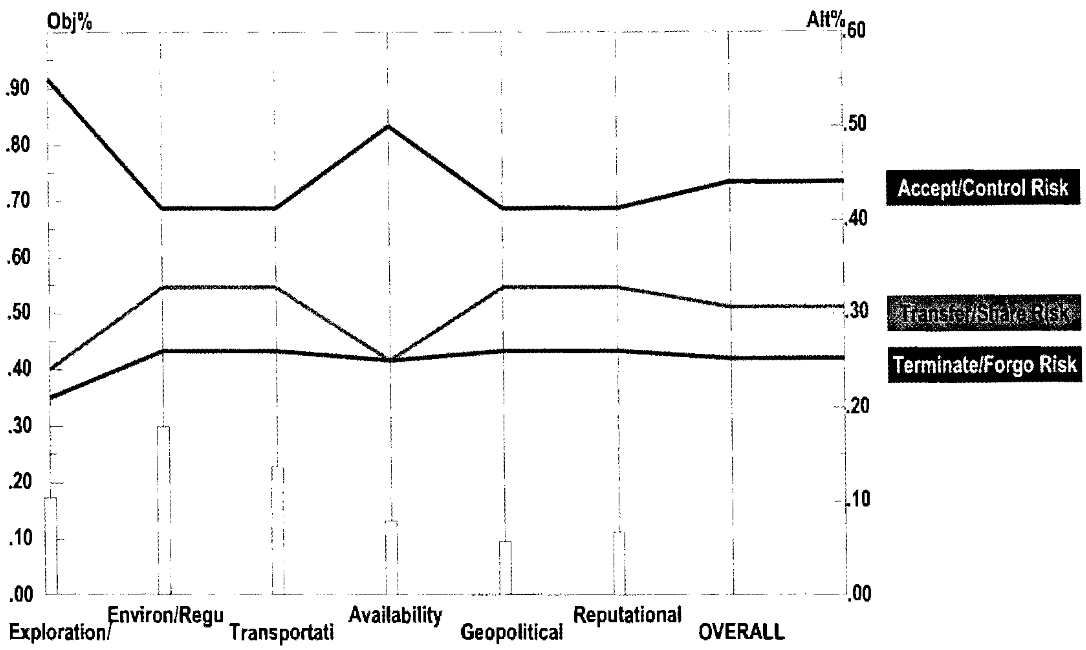


Figure 17-A. Performance Sensitivity Analysis: Scenario 1. With Respect to Environmental and Regulatory Compliance Risk.

It can be seen in Figure 17-B scenario 2, that changing the criterion value with respect to transportation risk from .28 to .35 did not change the ranking of the alternatives and that accept and control risks still remain the number one alternative. However, upon conducting the sensitivity analysis for the rest of the decision criterion, the rankings still remain insensitive.

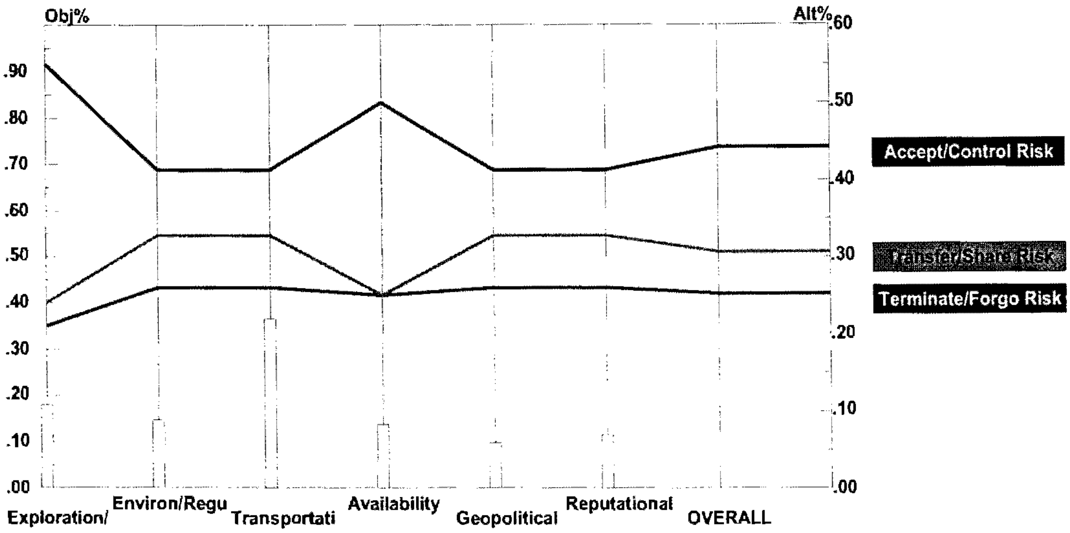


Figure 17-B. Performance Sensitivity Analysis: Scenario 2. With Respect to Transportation Risk.

Dynamic Sensitivity Analysis

The dynamic sensitivity analysis is a horizontal bar graph that is used to increase or decrease the priority of any criterion to observe the change in the priorities of the alternative policy options. Changing the weights of the criteria depends on the direction in which the criterion is expected to change according to the decision maker in the case of the upstream oil industry. For example, if the decision maker changes the weight of transportation risk while all other criteria remain the same, this may or may not change the risk management policy options, that is if increasing or decreasing the criterion priorities on the left column will change the priorities on the right column as depicted in Figure 18.

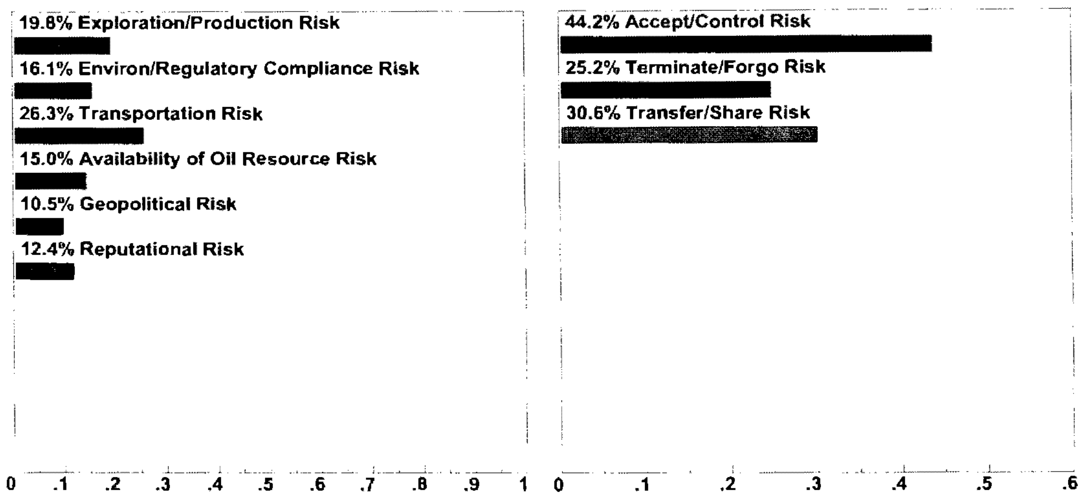


Figure 18. Dynamic Sensitivity Analysis.

In scenario 1, increasing the criterion weight with respect to geopolitical risk from 10.5 in Figure 18 to 20.5 in Figure 18-A, did not change the ranking of the alternatives and that accept and control risk still remain the number one alternative.

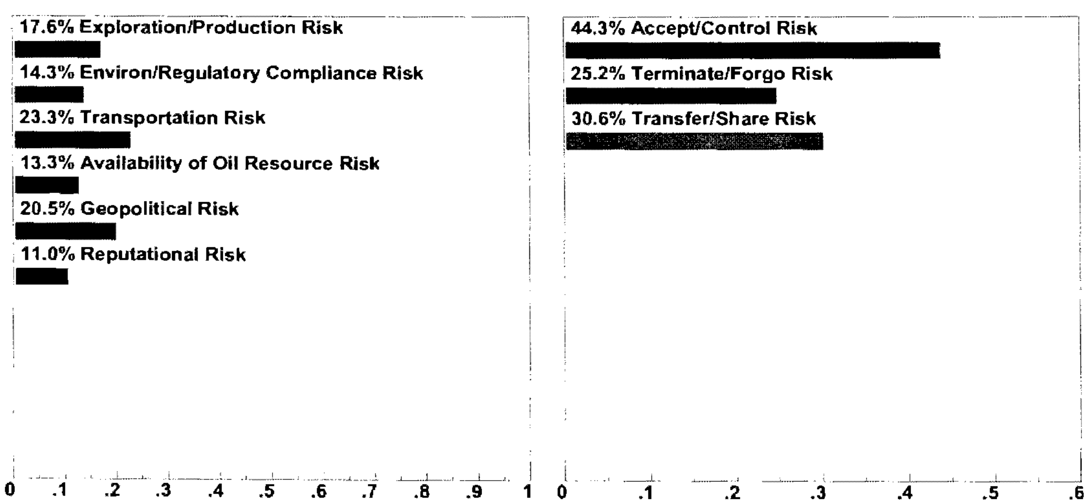


Figure 18-A. Dynamic Sensitivity Analysis: Scenario 1.With Respect to Geopolitical Risk.

Also in scenario 2, Figure 18-B decreasing the criterion weight from 10.5 in Figure 18 to 5.0 in Figure 18-B, still renders the ranking of the alternative insensitive.

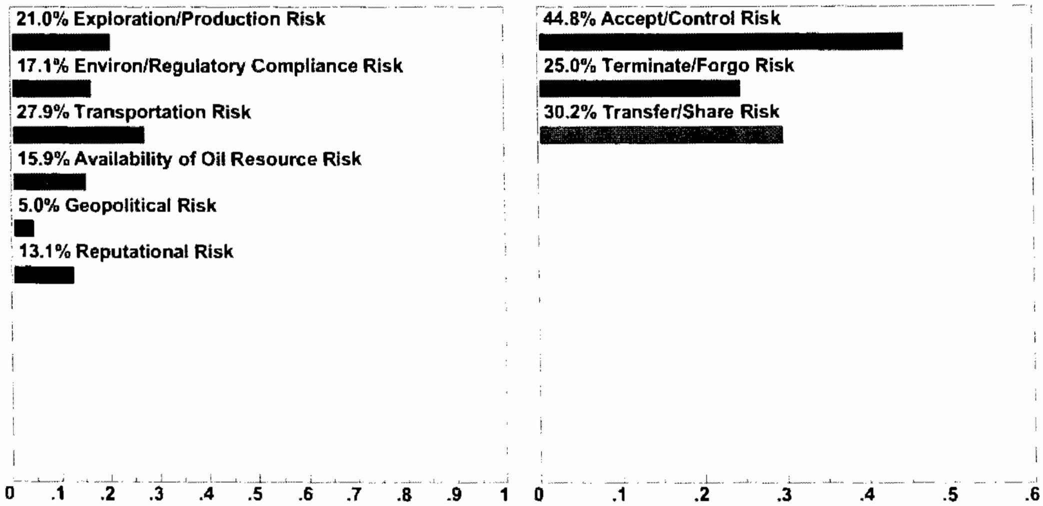


Figure 18-B. Dynamic Sensitivity Analysis: Scenario 2.With Respect to Geopolitical Risk.

In scenario 3, increasing the criterion weight with respect to reputational risk from 12.4 in Figure 18 to 22.5 in Figure 18-C, did not change the ranking of the alternatives and that accept and control risk still remain the number one alternative.

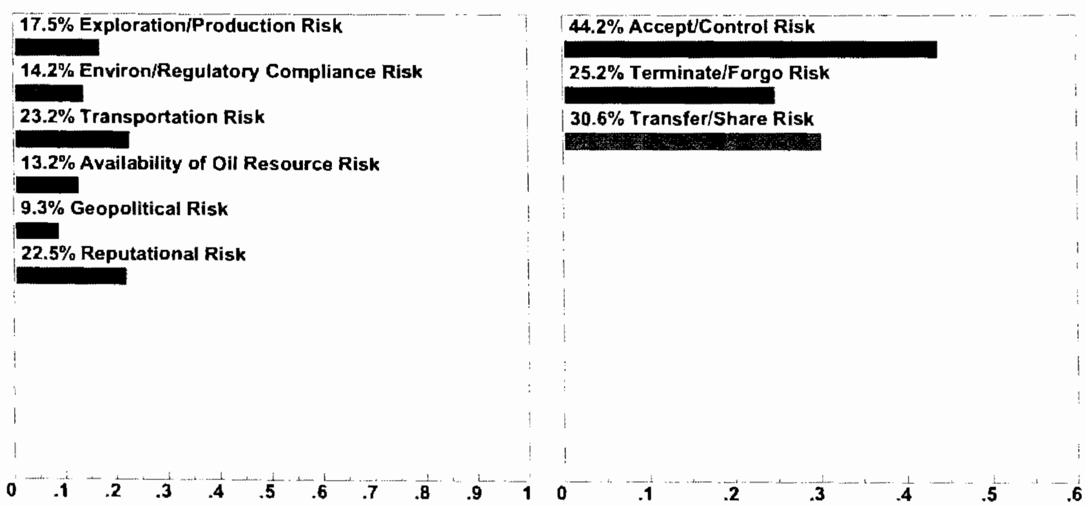


Figure 18-C. Dynamic Sensitivity Analysis: Scenario 3.With Respect to Reputational Risk.

Also in scenario 4, Figure 18-D, decreasing the criterion weight from 12.4 in Figure 18 to 9.8 in Figure 18-D still renders the ranking of the alternative insensitive.

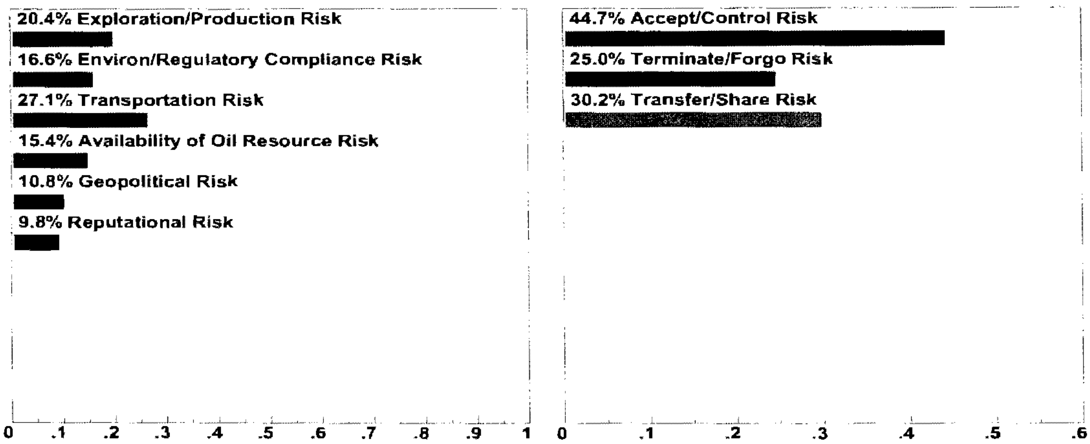


Figure 18-D. Dynamic Sensitivity Analysis: Scenario 4. With Respect to Reputational Risk.

Gradient Sensitivity Analysis

The gradient sensitivity analysis graph shown in Figure 19 represents the variation of the alternative policy option ranking to changes in one objective or criterion at a time, such as exploration and production risk. The X-axis represents the criterion weight, while the Y-axis represents the overall weights of alternative. This graph helps to determine if the decision is sensitive to the change of the criterion weight. The decision is sensitive to a given criterion if a small change in the weight of that criterion results in changes in the preferred alternative. The vertical line on the graph illustrates the current priority of the selected criterion, which is exploration and production risk. The current priority of an alternative is where the alternative line intersects the vertical criterion line. This graph illustrates the fact that for exploration and production risk criterion, the weight is about .20 (20%).

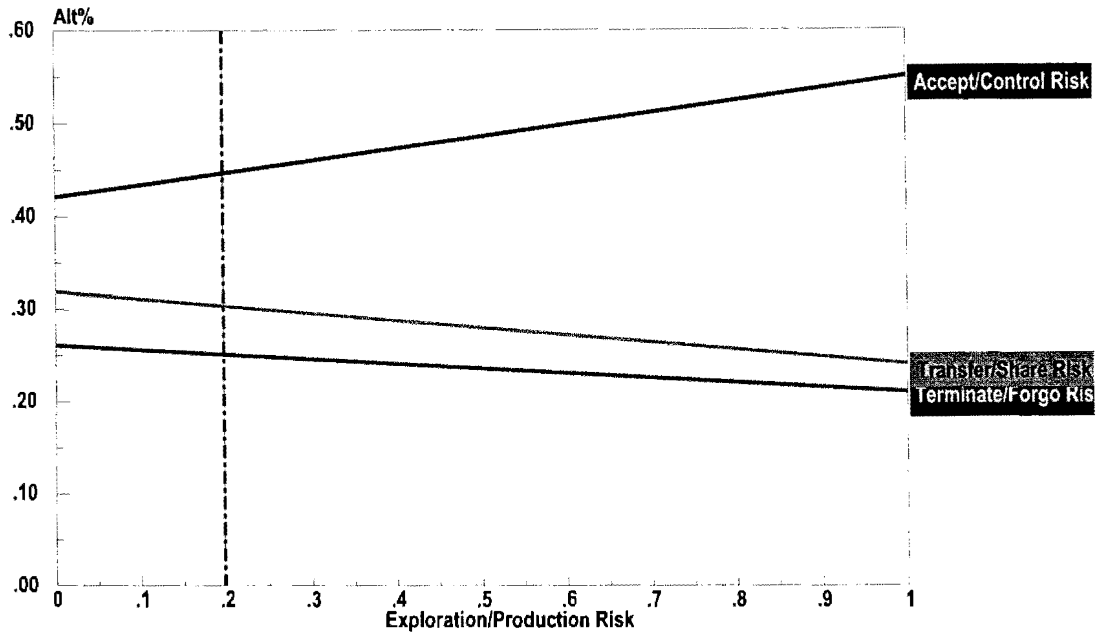


Figure 19. Gradient Sensitivity Analysis: With Respect to Exploration and Production Risk.

If the criterion weights increases or decreases, and the preferred alternative changes, the preferred alternative is sensitive to either the increase or decrease in the criterion weight. However, when the criterion weight increases, for example from .20 (20%) in Figure 19 to .30 (30%) in figure 19-A, the ranking of the preferred alternative does not change indicating that the decision is not sensitive to the increase in weight of the exploration and production risk criterion. Further, decreasing the weight from .20 (20%) in Figure 19 to.10 (10%) in Figure 19-B did not change the ranking of the alternative, indicates that the decision criterion still remain insensitive.

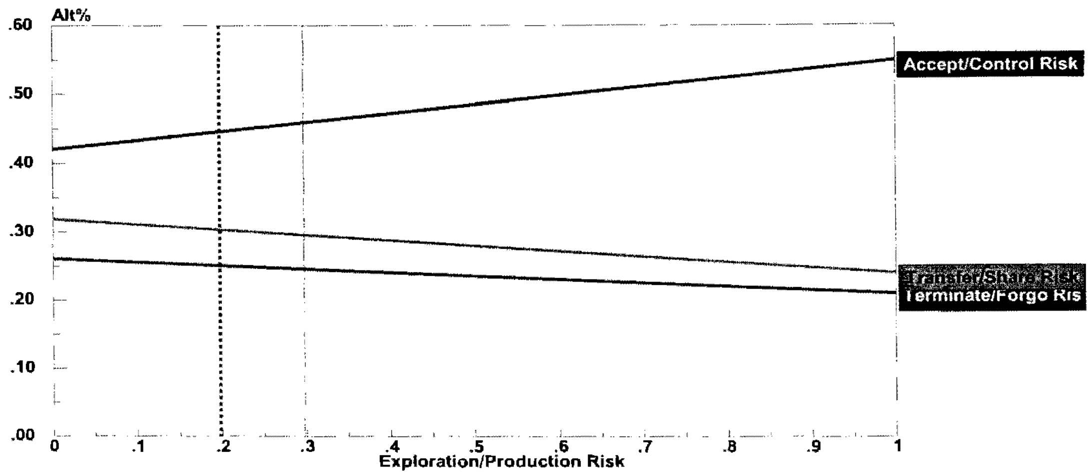


Figure 19-A. Gradient Sensitivity Analysis: Scenario 1. With Respect to Exploration and Production Risk.

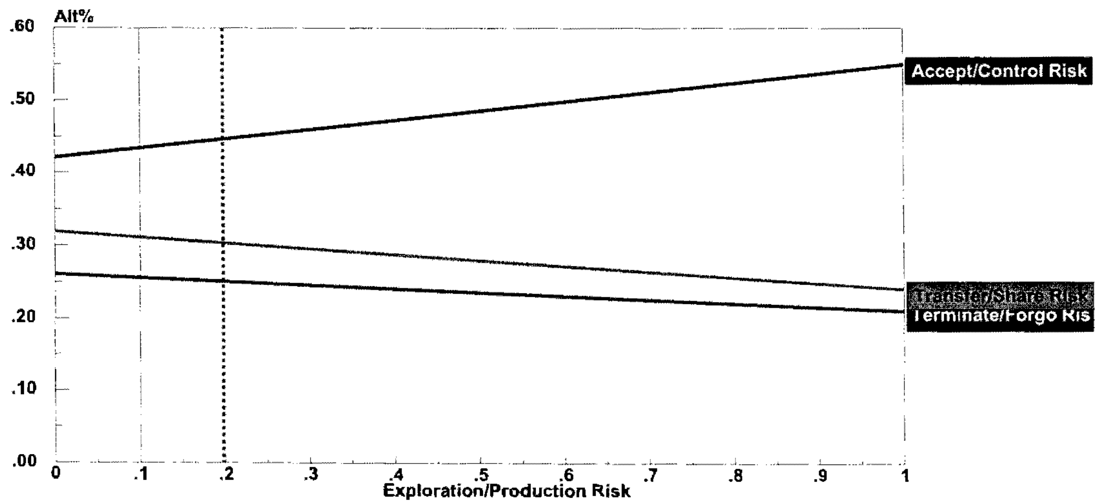


Figure 19-B. Gradient Sensitivity Analysis: Scenario 2. With Respect to Exploration and Production Risk.

Weighted Head-to-Head Sensitivity Analysis

The head-to-head sensitivity analysis graph shows the differences between the priorities of the alternatives, taking two at a time for all of the criteria. The head-to- head sensitivity analysis could be either weighted or unweighted to show differences in either manner. When unweighted, the criteria are treated as though they have equal priorities, but when weighted, the criteria show both priorities and differences. The head-to-head sensitivity analysis depicted in Figure 20 compares accept and control alternative policy to terminate or forgo activity against the major decision criteria.

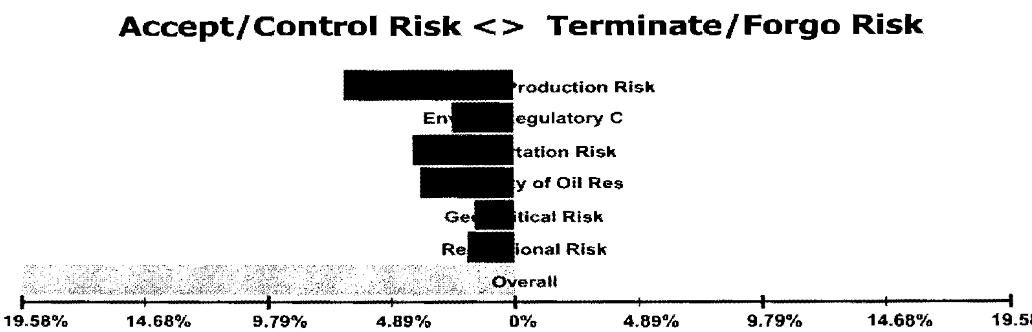


Figure 20. Weighted Head-to-Head Sensitivity Analysis Between Accept and Control Risk and Terminate or Forgo Activity.

The result here indicates that the risk manager prefers accept and control risk about 7.5% more to terminate or forgo activities with respect to exploration and production risk. However, the overall result shown at the bottom of the graph indicates that accept and control risk is 19% better than terminate or forgo activity with respect to exploration/production risk. Therefore it is important for decision makers in the upstream oil industry to accept the risk and put in place appropriate controls (preventive and detective) to manage the risk to maximum value. Also Figure 20-A, comparing transfer and share risk to accept and control risk, indicate that accept and control risk is 5.2% more important to transfer and share risk, with an overall result that accept and control risk is 14.68%.

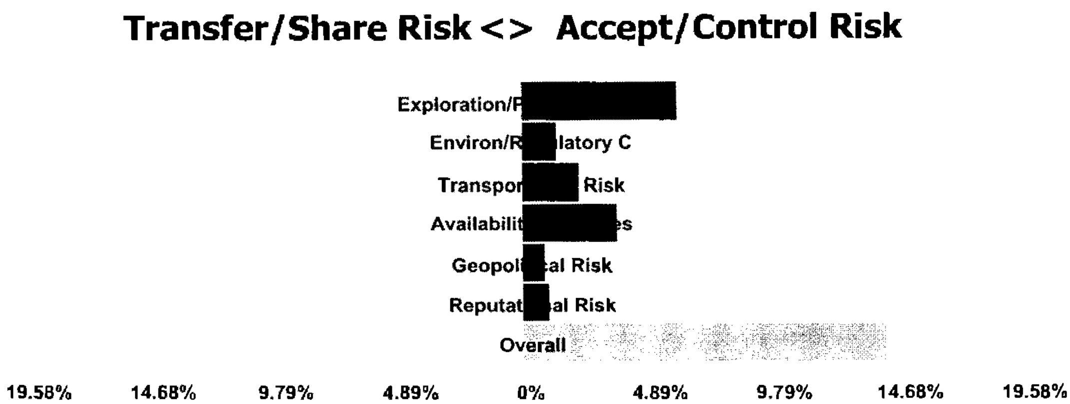


Figure 20-A. Weighted Head-to-Head Sensitivity Analysis between Transfer/Share Risk/Accept and Control Risk.

Two Dimensional Plot (2D) Sensitivity Analysis

The two-dimensional plot sensitivity analysis shown in Figure 21 indicates how well the alternatives perform with respect to any two criteria, in this case environmental and regulatory compliance risk compared to exploration and production risk.

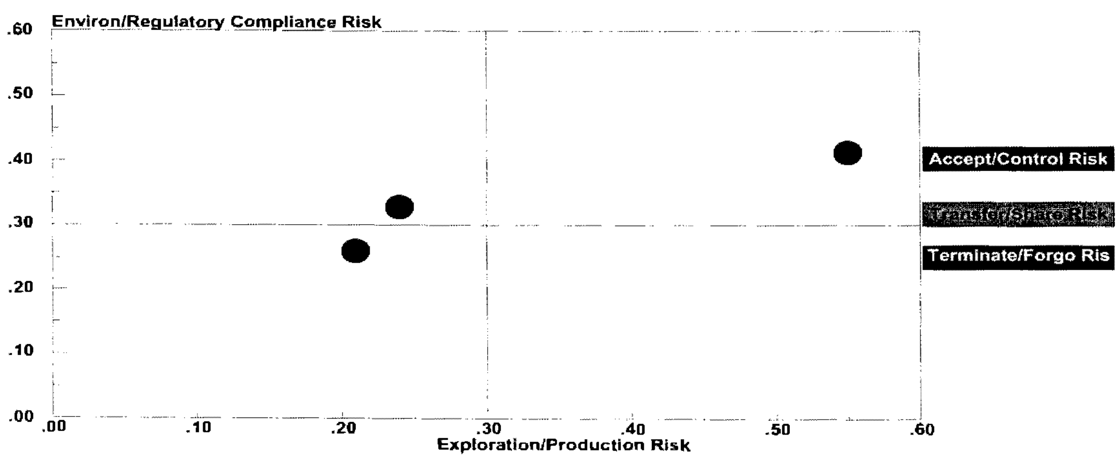


Figure 21. Two Dimensional Plot (2D) Sensitivity Analysis.

The result indicate that the upper right-hand corner shows that accept and control risk shows a more favorable alternative policy in relation to exploration and production risk with about .55 (55%), and environmental and regulatory compliance risk is approximately .44 (44%) while transfer or share risk in relation to exploration and production risk is about .24 (24%), and environmental and regulatory compliance risk is .34 (34%). Terminate and forgo on the lower left hand corner is the least favorable alternative policy with respect to environmental and regulatory compliance risk decision criterion which is about .25 (25%) and exploration and production risk about .20 (20%).

CHAPTER 6. SUMMARY, CONCERNS AND THOUGHT FOR FUTURE RESEARCH

Summary

Risk is defined as a potential future event that may influence the achievement of objectives; that includes upside and downside risks. Effective risk management increases the value of business decisions because conscious choices are made in relation to risks that have an impact on, or result from, these business decisions. The objective of risk management is not, therefore, arbitrarily to reduce or eliminate risk. In general, many people are involved in managing risk, and risk management, which is an integral part of the group's management activities (strategy, planning, execution, operation, monitoring, and appraisal); it is not a separate activity. Risk management is the responsibility of those who are accountable to deliver the associated objective; therefore, the identification of the risk can only have value or meaning when explicitly linked to the objective.

This research involves the evaluation of the actual oil industry to identify and select an appropriate upstream crude oil supply chain risk management model leveraging analytic hierarchy process (AHP). The AHP provides a framework to cope with multiple criteria situations involving intuitive, rational, quantitative, and qualitative aspects. This study shows that the AHP is appropriate for developing such a model. It organizes the basic rationality by breaking down a problem into its smaller constituent parts, and then guides the decision maker through a series of pairwise comparison judgments to express relative strength or intensity of impact of the elements of the hierarchy. The AHP methodology is a flexible tool that can be applied to any hierarchy of performance measure; in addition, the AHP model is effective in decision making. The most essential goal of this research is to identify the potential risk sources, model the risk management, analyze and evaluate the potential impact of risks, and propose risk treatment in terms of the most important risk to manage and finally select the appropriate alternative options to minimize, such as accept and control risk, terminate or forgo activity, and transfer or share risk.

To achieve the objectives of the research, a survey questionnaire approach was used to collect data to specify the order of importance of the upstream crude oil supply chain risks. The questionnaire was designed to collect opinion of subject matter expert (risk managers) in the oil industry. The result of the survey questionnaire was used as input to the AHP, and the result of the pairwise comparison of the major objective indicates that the most important risk to minimize and manage in the oil industry is transportation risk with priority of .263 (26.3%). This verifies the fact that transportation in the petroleum supply chain is the central logistic that links the upstream and downstream functions, playing a crucial role in the global supply chain management in the oil industry.

Exploration/production and environmental and regulatory compliance risk are also identified as major risk factors with priorities of .198 (19.8%) and .161 (16.1%) respectively. With respect to major objectives or goals, the most preferable risk management policy option based on the result of the composite score is accept and control risk with a score of .446 (44.6%) followed by transfer or share risk at .303 (30.3%). The least likely is terminate or forgo activity .251 (25.1%). Results from the dynamic sensitivity analysis, Figure 18, with respect to the major goal, also verifies that accept and control risk with a priority of 44.2% is the most preferred risk management policy option, followed by transfer or share at 30.6% ,and terminate or forgo at 25.2%. In most comparison processes it is obvious that some inconsistencies would occur. However, Saaty (1980) specify that an inconsistency ratio of about .10 (10%) or less may be considered acceptable without adverse effect on the result. The overall inconsistency ratio for the aggregate response is .03 which is below the Saaty's recommended threshold for an acceptable inconsistency. However, the results also indicate inconsistency ratios for the different decision alternatives. With respect to; transportation risk inconsistency is .o5, exploration and production risk is .02, environmental and regulatory compliance risk is 05, availability of oil resource risk is 0.0, reputational risk is .05 while geopolitical risk is .05. Overall, the respondent judgments indicate reliable expert judgment.

To gain more in-depth insight of the problem and result, sensitivity analysis options of the Expert Choice Software was performed to further study the effect of changing the weights of criteria on the overall weight of the alternatives. The results of such analyses also indicate that transportation risk is most prominent while accepting and controlling risk is also the most prominent alternative risk management option. In the oil industry, accepting and controlling risk for example; reputational risk became an issue as a result oil spill. Companies in the oil industry have a long history of neglecting environmental issues but consequently as a result of public outcry, accepted the risk of oil spill and put in place some appropriate controls to reduce their reputational risk as much as possible. Transportation risk in the oil industry could be managed to an acceptable level. However, these companies in the industry today deal with several issues such as; globalization, regulatory compliance, increased environmental pressures, mergers and acquisitions that combine make operational risk management a complex and difficult task for the oil industry. Recent events have suggested that greater clarity is needed in terms of who is responsible for managing risks, especially transportation and exploration/production.

Concerns and Thought for Future Research

Different approaches can be taken to identify risks and the approach taken might depend on the complexity of the industry and the volatility of the risk environment. However, the identification of the risks may result in a long list that may not be monitored or managed by risk managers. Admittedly, some of the risks may simply be monitored or managed as part of daily management routine. Some may be combined, since they address the same underlying issues, or may be managed at a different organizational level. Risk assessment assists in allocating resources and prioritization of actions based on a comprehensive picture of all significant risks in the context of the objectives of the relevant entity. Approaches to manage oil industry transportation risk specify some man-made incidences which are due to malicious intent; therefore it is important that, the assessment of transportation risk in the oil industry must include terrorism scenario on the different transportation modes. To manage transportation risk in the oil industry the individual national government should among others: develop risk management control strategies (prevention deterrence; preparedness; response recovery; stringent international and U.S. regulations) on oil transportation. Although simple in concept, implementing these processes in the oil industry transportation sector could also be challenging.

Collaborative interest can also mean collective security and corporative protection of the flow of oil, which benefits both producing and consuming nations. A shortfall or slack in this endeavor may play into the hands of insurgents and international terrorists that seek to alienate, divide, and defeat national interests, especially industrialized western nations. Considering the importance of the oil supply risk issue, a number of future potential research areas can be recognized to achieve an integral examination of the subject area. In fact the quantification and assessment of each risk's probabilities might be an important and demanding task that probably has never been attempted. This might also be true for the impact of each of the risks as well. This study has opened the door for further studies to be conducted and to investigate the risk impact on other sectors of the oil industry.

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APPENDIX A. EXPERT JUDGMENT PAIRWISE COMPARISON MATRIX

Table A-1. Expert #1 Judgment-Pairwise Comparison Matrix of Major Risk Objectives with Relation to the Goal

	Exploration/ Production Risk	Environmental and Regulatory Compliance Risk	Transportation Risk	Availability of Oil Resource Risk	Geopolitical Risk	Reputational Risk
Exploration/ Production Risk	1	1	1	3	3	1
Environmental and Regulatory Compliance Risk	1/1	1	1	3	3	1
Transportation Risk	1/1	1/1	1	1	2	1
Availability of Oil Resource Risk	1/3	1/3	1/1	1	1	1/2
Geopolitical Risk	1/3	1/3	1/2	1/1	1	1/2
Reputational Risk	1/1	1/1	1/1	2	2	1

Table A-2. Expert #2 Judgment-Pairwise Comparison Matrix of Major Risk Objectives with Relation to the Goal

	Exploration/ Production Risk	Environmental and Regulatory Compliance Risk	Transportation Risk	Availability of Oil Resource Risk	Geopolitical Risk	Reputational Risk
Exploration/ Production Risk	1	1/5	2	2	1/5	1
Environmental and Regulatory Compliance Risk	5	1	1/5	1/5	2	1
Transportation Risk	1/2	5	1	3	3	1
Availability of Oil Resource Risk	1/2	5	1/3	1	3	3
Geopolitical Risk	5	5	1/3	1/3	1	3
Reputational Risk	1/1	1/1	1/1	1/3	1/3	1

Table A-3. Expert #3 Judgment-Pairwise Comparison Matrix of Major Risk Objectives with Relation to the Goal

	Exploration/ Production Risk	Environmental and Regulatory Compliance Risk	Transportation Risk	Availability of Oil Resource Risk	Geopolitical Risk	Reputational Risk
Exploration/ Production Risk	1	1/3	4	6	6	1
Environmental and Regulatory Compliance Risk	3	1	1	5	3	1
Transportation Risk	1/4	1/6	1	6	5	6
Availability of Oil Resource Risk	1/6	1/5	1/6	1	1	1
Geopolitical Risk	1/6	1/3	1/5	1/1	1	1
Reputational Risk	1/1	1/1	1/6	1/1	1/1	1

Table A-4. Expert #4 Judgment-Pairwise Comparison Matrix of Major Risk Objectives with Relation to the Goal

	Exploration/ Production Risk	Environmental and Regulatory Compliance Risk	Transportation Risk	Availability of Oil Resource Risk	Geopolitical Risk	Reputational Risk
Exploration/ Production Risk	1	5	1	6	4	5
Environmental and Regulatory Compliance Risk	1/5	1	1	5	1	1
Transportation Risk	1/1	1/1	1	5	7	4
Availability of Oil Resource Risk	1/6	1/5	1/5	1	1	1
Geopolitical Risk	1/4	1/1	1/7	1/1	1	1
Reputational Risk	1/5	1/1	1/1	1/1	1/1	1

Table A-5. Expert #5 Judgment-Pairwise Comparison Matrix of Major Risk Objectives with Relation to the Goal

	Exploration/ Production Risk	Environmental and Regulatory Compliance Risk	Transportation Risk	Availability of Oil Resource Risk	Geopolitical Risk	Reputational Risk
Exploration/ Production Risk	1	1/2	1/5	1	1/3	1
Environmental and Regulatory Compliance Risk	2	1	1/5	1/5	1/4	1
Transportation Risk	5	5	1	1	1/2	5
Availability of Oil Resource Risk	1/1	5	1/1	1	1	4
Geopolitical Risk	3	4	2	1/1	1	5
Reputational Risk	1/1	1/1	1/5	1/4	1/5	1

Table A-6. Expert #6 Judgment-Pairwise Comparison Matrix of Major Risk Objectives with Relation to the Goal

	Exploration/ Production Risk	Environmental and Regulatory Compliance Risk	Transportation Risk	Availability of Oil Resource Risk	Geopolitical Risk	Reputational Risk
Exploration/ Production Risk	1	1	1	3	3	1
Environmental and Regulatory Compliance Risk	1/1	1	1	3	3	3
Transportation Risk	1/1	1/1	1	3	3	1
Availability of Oil Resource Risk	1/3	1/3	1/3	1	1	1/3
Geopolitical Risk	1/3	1/3	1/3	1/1	1	1/3
Reputational Risk	1/3	1/3	1/1	3	3	1

Table A-7. Expert #7 Judgment-Pairwise Comparison Matrix of Major Risk Objectives with Relation to the Goal

	Exploration/ Production Risk	Environmental and Regulatory Compliance Risk	Transportation Risk	Availability of Oil Resource Risk	Geopolitical Risk	Reputational Risk
Exploration/ Production Risk	1	4	1	1/4	4	2
Environmental and Regulatory Compliance Risk	1/4	1	1	1/3	4	1
Transportation Risk	1/1	1/1	1	1	3	1
Availability of Oil Resource Risk	4	3	1/1	1	6	3
Geopolitical Risk	1/4	1/4	1/3	1/6	1	1/3
Reputational Risk	1/2	1/1	1/1	1/3	3	1

Table A-8. Expert #8 Judgment-Pairwise Comparison Matrix of Major Risk Objectives with Relation to the Goal

	Exploration/ Production Risk	Environmental and Regulatory Compliance Risk	Transportation Risk	Availability of Oil Resource Risk	Geopolitical Risk	Reputational Risk
Exploration/ Production Risk	1	4	1	1/3	3	2
Environmental and Regulatory Compliance Risk	1/4	1	1/3	1/3	2	1
Transportation Risk	1/1	3	1	1	4	4
Availability of Oil Resource Risk	3	3	1/1	1	2	3
Geopolitical Risk	1/3	1/2	1/4	1/2	1	1/2
Reputational Risk	1/2	1/1	1/4	1/3	2	1

Table A-9. Expert #9 Judgment-Pairwise Comparison Matrix of Major Risk Objectives with Relation to the Goal

	Exploration/ Production Risk	Environmental and Regulatory Compliance Risk	Transportation Risk	Availability of Oil Resource Risk	Geopolitical Risk	Reputational Risk
Exploration/ Production Risk	1	1	1	1	3	1
Environmental and Regulatory Compliance Risk	1/1	1	1	1	2	1
Transportation Risk	1/1	1/1	1	1	3	1
Availability of Oil Resource Risk	1/1	1/1	1/1	1	1	2
Geopolitical Risk	1/3	1/2	1/3	1/1	1	1/2
Reputational Risk	1/1	1/1	1/1	1/1	2	1

Table A-10. Expert #10 Judgment-Pairwise Comparison Matrix of Major Risk Objectives with Relation to the Goal

	Exploration/ Production Risk	Environmental and Regulatory Compliance Risk	Transportation Risk	Availability of Oil Resource Risk	Geopolitical Risk	Reputational Risk
Exploration/ Production Risk	1	3	1	1	3	2
Environmental and Regulatory Compliance Risk	1/3	1	1/3	1/2	2	1
Transportation Risk	1/1	3	1	3	3	2
Availability of Oil Resource Risk	1/1	2	1/3	1	2	2
Geopolitical Risk	1/3	1/2	1/3	1/2	1	1/2
Reputational Risk	1/2	1/2	1/2	1/2	2	1

Alternative Risk Management Options Evaluation

A pairwise comparison was performed for the relative effect of each of the alternative policy options which include: accept and control risk, Terminate or forgo activity and transfer or share risk.

Table A-11. Expert #1 Pairwise Comparison Matrix for Alternatives with Respect to Exploration/ Production Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	7	2
Terminate or Forgo Activity	1/7	1	1/7
Transfer or Share Risk	1/2	7	1

Table A-12. Expert #1 Pairwise Comparison Matrix for Alternatives with Respect to Environmental and Regulatory Compliance Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	3	1
Terminate or Forgo Activity	1/3	1	1/4
Transfer or Share Risk	1/1	4	1

Table A-13. Expert #1 Pairwise Comparison Matrix for Alternatives with Respect to Transportation Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	3	1
Terminate or Forgo Activity	1/3	1	1/3
Transfer or Share Risk	1/1	3	1

Table A-14. Expert #1 Pairwise Comparison Matrix for Alternatives with Respect to Availability of Oil Resource Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	9	5
Terminate or Forgo Activity	1/9	1	1/5
Transfer or Share Risk	1/1	5	1

Table A-15. Expert #1 Pairwise Comparison Matrix for Alternatives with Respect to Geopolitical Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	2	1
Terminate or Forgo Activity	1/2	1	1/2
Transfer or Share Risk	1/1	2	1

Table A-16. Expert #1 Pairwise Comparison Matrix for Alternatives with Respect to Reputational Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	6	1
Terminate or Forgo Activity	1/6	1	1/2
Transfer or Share Risk	1/1	2	1

Table A-17. Expert #2 Pairwise Comparison Matrix for Alternatives with Respect to Exploration/ Production Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	1/8	1/8
Terminate or Forgo Activity	8	1	1
Transfer or Share Risk	8	1/1	1

Table A-18. Expert #2 Pairwise Comparison Matrix for Alternatives with Respect to Environmental and Regulatory Compliance Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	1/9	1/6
Terminate or Forgo Activity	9	1	1
Transfer or Share Risk	6	1/1	1

Table A-19. Expert #2 Pairwise Comparison Matrix for Alternatives with Respect to Transportation Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	1/5	1
Terminate or Forgo Activity	5	1	1/2
Transfer or Share Risk	1/1	2	1

Table A-20. Expert #2 Pairwise Comparison Matrix for Alternatives with Respect to Availability of Oil Resource Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	1/7	1/7
Terminate or Forgo Activity	7	1	1/3
Transfer or Share Risk	7	3	1

Table A-21. Expert #2 Pairwise Comparison Matrix for Alternatives with Respect to Geopolitical Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	3	1/3
Terminate or Forgo Activity	1/3	1	1
Transfer or Share Risk	1/3	1/1	1

Table A-22. Expert #2 Pairwise Comparison Matrix for Alternatives with Respect to Reputational Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	1/8	1/8
Terminate or Forgo Activity	8	1	1/2
Transfer or Share Risk	8	2	1

Table A-23. Expert #3 Pairwise Comparison Matrix for Alternatives with Respect to Exploration/ Production Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	6	1
Terminate or Forgo Activity	1/6	1	1/4
Transfer or Share Risk	1/1	4	1

Table A-24. Expert #3 Pairwise Comparison Matrix for Alternatives with Respect to Environmental and Regulatory Compliance Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	1	1
Terminate or Forgo Activity	1/1	1	1
Transfer or Share Risk	1/1	1/1	1

Table A-25. Expert #3 Pairwise Comparison Matrix for Alternatives with Respect to Transportation Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	5	1/5
Terminate or Forgo Activity	1/5	1	1/2
Transfer or Share Risk	5	2	1

Table A-26. Expert #3 Pairwise Comparison Matrix for Alternatives with Respect to Availability of Oil Resource Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	1	2
Terminate or Forgo Activity	1/1	1	1
Transfer or Share Risk	1/2	1/1	1

Table A-27. Expert #3 Pairwise Comparison Matrix for Alternatives with Respect to Geopolitical Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	2	1/2
Terminate or Forgo Activity	1/2	1	1
Transfer or Share Risk	2	1/1	1

Table A-28. Expert #3 Pairwise Comparison Matrix for Alternatives with Respect to Reputational Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	1	1
Terminate or Forgo Activity	1/1	1	1
Transfer or Share Risk	1/1	1/1	1

Table A-29. Expert #4 Pairwise Comparison Matrix for Alternatives with Respect to Exploration/ Production Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	6	5
Terminate or Forgo Activity	1/6	1	1/4
Transfer or Share Risk	1/5	4	1

Table A-30. Expert #4 Pairwise Comparison Matrix for Alternatives with Respect to Environmental and Regulatory Compliance Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	1	1/2
Terminate or Forgo Activity	1/1	1	2
Transfer or Share Risk	2	1/2	1

Table A-31. Expert #4 Pairwise Comparison Matrix for Alternatives with Respect to Transportation Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	5	1/5
Terminate or Forgo Activity	1/5	1	1/3
Transfer or Share Risk	5	3	1

Table A-32. Expert #4 Pairwise Comparison Matrix for Alternatives with Respect to Availability of Oil Resource Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	1	1
Terminate or Forgo Activity	1/1	1	1
Transfer or Share Risk	1/1	1/1	1

Table A-33. Expert #4 Pairwise Comparison Matrix for Alternatives with Respect to Geopolitical Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	3	1/2
Terminate or Forgo Activity	1/3	1	1
Transfer or Share Risk	2	1/1	1

Table A-34. Expert #4 Pairwise Comparison Matrix for Alternatives with Respect to Reputational Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	1	1
Terminate or Forgo Activity	1/1	1	2
Transfer or Share Risk	1/1	1/2	1

Table A-35. Expert #5 Pairwise Comparison Matrix for Alternatives with Respect to Exploration/ Production Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	9	6
Terminate or Forgo Activity	1/9	1	1
Transfer or Share Risk	1/6	1/1	1

Table A-36. Expert #5 Pairwise Comparison Matrix for Alternatives with Respect to Environmental and Regulatory Compliance Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	6	3
Terminate or Forgo Activity	1/6	1	1/5
Transfer or Share Risk	1/3	5	1

Table A-37. Expert #5 Pairwise Comparison Matrix for Alternatives with Respect to Transportation Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	1/3	1/2
Terminate or Forgo Activity	3	1	1
Transfer or Share Risk	2	1/1	1

Table A-38. Expert #5 Pairwise Comparison Matrix for Alternatives with Respect to Availability of Oil Resource Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	9	9
Terminate or Forgo Activity	1/9	1	1
Transfer or Share Risk	1/9	1/1	1

Table A-39. Expert #5 Pairwise Comparison Matrix for Alternatives with Respect to Geopolitical Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	1	1
Terminate or Forgo Activity	1/1	1	1
Transfer or Share Risk	1/1	1/1	1

Table A-40. Expert #5 Pairwise Comparison Matrix for Alternatives with Respect to Reputational Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	1	1
Terminate or Forgo Activity	1/1	1	1
Transfer or Share Risk	1/1	1/1	1

Table A-41. Expert #6 Pairwise Comparison Matrix for Alternatives with Respect to Exploration/ Production Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	4	3
Terminate or Forgo Activity	1/4	1	1/2
Transfer or Share Risk	1/3	2	1

Table A-42. Expert #6 Pairwise Comparison Matrix for Alternatives with Respect to Environmental and Regulatory Compliance Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	3	1
Terminate or Forgo Activity	1/3	1	1/3
Transfer or Share Risk	1/1	3	1

Table A-43. Expert #6 Pairwise Comparison Matrix for Alternatives with Respect to Transportation Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	3	1
Terminate or Forgo Activity	1/3	1	1
Transfer or Share Risk	1/1	1/1	1

Table A-44. Expert #6 Pairwise Comparison Matrix for Alternatives with Respect to Availability of Oil Resource Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	1	1
Terminate or Forgo Activity	1/1	1	1
Transfer or Share Risk	1/1	1/1	1

Table A-45. Expert #6 Pairwise Comparison Matrix for Alternatives with Respect to Geopolitical Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	1	1
Terminate or Forgo Activity	1/1	1	1
Transfer or Share Risk	1/1	1/1	1

Table A-46. Expert #6 Pairwise Comparison Matrix for Alternatives with Respect to Reputational Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	3	3
Terminate or Forgo Activity	1/3	1	1
Transfer or Share Risk	1/3	1/1	1

Table A-47. Expert #7 Pairwise Comparison Matrix for Alternatives with Respect to Exploration/ Production Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	4	1
Terminate or Forgo Activity	1/4	1	1/4
Transfer or Share Risk	1/1	4	1

Table A-48. Expert #7 Pairwise Comparison Matrix for Alternatives with Respect to Environmental and Regulatory Compliance Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	4	1
Terminate or Forgo Activity	1/4	1	1/4
Transfer or Share Risk	1/4	1/4	1

Table A-49. Expert #7 Pairwise Comparison Matrix for Alternatives with Respect to Transportation Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	4	1
Terminate or Forgo Activity	1/4	1	1/4
Transfer or Share Risk	1/1	4	1

Table A-50. Expert #7 Pairwise Comparison Matrix for Alternatives with Respect to Availability of Oil Resource Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	4	1
Terminate or Forgo Activity	1/4	1	1/4
Transfer or Share Risk	1/1	4	1

Table A-51. Expert #7 Pairwise Comparison Matrix for Alternatives with Respect to Geopolitical Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	4	1
Terminate or Forgo Activity	1/4	1	1/4
Transfer or Share Risk	1/1	4	1

Table A-52. Expert #7 Pairwise Comparison Matrix for Alternatives with Respect to Reputational Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	4	1
Terminate or Forgo Activity	1/4	1	1/4
Transfer or Share Risk	1/1	4	1

Table A-53. Expert #8 Pairwise Comparison Matrix for Alternatives with Respect to Exploration/ Production Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	5	3
Terminate or Forgo Activity	1/5	1	1
Transfer or Share Risk	1/3	1/1	1

Table A-54. Expert #8 Pairwise Comparison Matrix for Alternatives with Respect to Environmental and Regulatory Compliance Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	5	1/2
Terminate or Forgo Activity	1/5	1	1/2
Transfer or Share Risk	2	2	1

Table A-55. Expert #8 Pairwise Comparison Matrix for Alternatives with Respect to Transportation Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	6	3
Terminate or Forgo Activity	1/6	1	1/4
Transfer or Share Risk	1/3	3	1

Table A-56. Expert #8 Pairwise Comparison Matrix for Alternatives with Respect to Availability of Oil Resource Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	6	3
Terminate or Forgo Activity	1/6	1	1/3
Transfer or Share Risk	1/3	3	1

Table A-57. Expert #8 Pairwise Comparison Matrix for Alternatives with Respect to Geopolitical Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	2	1
Terminate or Forgo Activity	1/2	1	1/2
Transfer or Share Risk	1/1	2	1

Table A-58. Expert #8 Pairwise Comparison Matrix for Alternatives with Respect to Reputational Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	3	3
Terminate or Forgo Activity	1/3	1	1/2
Transfer or Share Risk	1/3	2	1

Table A-59. Expert #9 Pairwise Comparison Matrix for Alternatives with Respect to Exploration/ Production Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	3	1
Terminate or Forgo Activity	1/3	1	1/3
Transfer or Share Risk	1/1	3	1

Table A-60. Expert #9 Pairwise Comparison Matrix for Alternatives with Respect to Environmental and Regulatory Compliance Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	3	1
Terminate or Forgo Activity	1/3	1	1/2
Transfer or Share Risk	1/1	2	1

Table A-61. Expert #9 Pairwise Comparison Matrix for Alternatives with Respect to Transportation Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	5	1/5
Terminate or Forgo Activity	1/5	1	1/4
Transfer or Share Risk	5	4	1

Table A-62. Expert #9 Pairwise Comparison Matrix for Alternatives with Respect to Availability of Oil Resource Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	2	1
Terminate or Forgo Activity	1/2	1	1/2
Transfer or Share Risk	1/1	2	1

Table A-63. Expert #9 Pairwise Comparison Matrix for Alternatives with Respect to Geopolitical Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	1	1
Terminate or Forgo Activity	1/1	1	1/2
Transfer or Share Risk	1/1	2	1

Table A-64. Expert #9 Pairwise Comparison Matrix for Alternatives with Respect to Reputational Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	3	1
Terminate or Forgo Activity	1/3	1	1/2
Transfer or Share Risk	1/1	2	1

Table A-65. Expert #10 Pairwise Comparison Matrix for Alternatives with Respect to Exploration/ Production Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	3	1
Terminate or Forgo Activity	1/3	1	1/2
Transfer or Share Risk	1/1	2	1

Table A-66. Expert #10 Pairwise Comparison Matrix for Alternatives with Respect to Environmental and Regulatory Compliance Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	3	1
Terminate or Forgo Activity	1/3	1	1/2
Transfer or Share Risk	1/1	2	1

Table A-67. Expert #10 Pairwise Comparison Matrix for Alternatives with Respect to Transportation Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	6	4
Terminate or Forgo Activity	1/6	1	1/2
Transfer or Share Risk	1/4	2	1

Table A-68. Expert #10 Pairwise Comparison Matrix for Alternatives with Respect to Availability of Oil Resource Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	2	4
Terminate or Forgo Activity	1/2	1	1
Transfer or Share Risk	1/4	1/1	1

Table A-69. Expert #10 Pairwise Comparison Matrix for Alternatives with Respect to Geopolitical Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	2	1
Terminate or Forgo Activity	1/1	1	1/3
Transfer or Share Risk	1/3	1/3	1

Table A-70. Expert #10 Pairwise Comparison Matrix for Alternatives with Respect to Reputational Risk

	Accept & Control Risk	Terminate or Forgo Activity	Transfer or Share Risk
Accept & Control Risk	1	3	1
Terminate or Forgo Activity	1/1	1	1
Transfer or Share Risk	1/1	1/1	1

APPENDIX B. UPSTREAM CRUDE OIL SUPPLY CHAIN RISK ANALYSIS SURVEY QUESTIONNAIRE

Dear Sir:

My name is Charles Awoala Briggs. I am a Ph.D. candidate in Transportation and Logistics with emphasis in Logistics and Supply Chain Management, Department of Transportation and Logistics, Upper Great Plains Transportation Institute, North Dakota State University of Agriculture and Applied Science, Fargo, ND 58102. My dissertation topic is "Risk Assessment in the Upstream Crude Oil Supply Chain, Using AHP Model Approach."

You are invited to participate in this research. The survey is anonymous and your participation is voluntary and that participants may choose not to participate or quit participating at any time without penalty or loss of benefits to which they are already entitle. I am writing to elicit your opinion as an executive in the oil industry with expert knowledge on risk management. I am investigating the opinions of experts by means of a survey questionnaire that should take about 10 – 15 minutes to complete.

To complete the survey, please mark or circle the criteria number (code) that you assess to be of equal importance or more important than the other, with respect to the goal: "**minimizing risk**" and express on the verbal scale the importance of the more or equal important criteria over the other. Please see the example described in pages 3&4 of the questionnaire.

Your identity will not be linked to your survey responses and will not be identified in the written analysis, and you will not be identified by the company which you work. Experts do not have to agree on the relative importance of the criteria, or the rankings of the alternative. This questionnaire uses Analytic Hierarchy Process (AHP) to model risk management in the upstream crude oil supply chain. As an expert on risk management and/or enterprise risk management, your opinion will be significantly invaluable to my research.

I enclosed a stamped self addressed envelope for your survey response, and if you have any question about this research please contact me at (701)-231-5763 (office) or (701)-367-3602 (cell phone), or Charles.Briggs@ndsu.edu or my advisor, Dr. Denver Tolliver, at (701)-231-7190 or Denver.Tolliver@ndsu.edu. If you have questions about the rights of human participants in research, or to report a problem, contact the NDSU Institutional Review Board (IRB) Office, at (701) 231-8908, or ndsu.irb@ndsu.edu.

Thank you for your participation in this research. If you wish to receive a copy of the research results, please email me at Charles.Briggs@ndsu.edu

INTRODUCTION:

The upstream crude oil supply chain has always been considered to be complex due to the separation between the location of oil reserves and the consumer market which has lead to the development of complex transportation system that facilitate the delivery of crude oil virtually anywhere in the world. There is fast growing importance to today's global energy market of the national oil companies. Indeed 14 of the world's top 20 upstream oil and gas companies are national oil companies. These companies control the majority of the world's carbon resources and have the ability than ever before to shape the global market in ways that have worldwide impact.

One major problem associated with the upstream sector of the oil industry is the high level of uncertainty/risk from exploration and production, to tight transportation and supply/delivery process. Regrettably, some of the risks that these companies face are risks that energy consumers ultimately face as well. The objective of this research is to propose a risk mitigation and management model for the upstream crude oil supply chain using analytic hierarchy process: a decision making technique developed in the 1970's by Thomas L. Saaty to solve decision making problems that involves multiple objective. To evaluate and prioritize these risks the analytic hierarchy process (AHP) which provides a framework to cope with multiple criteria situations involving intuitive, rational, quantitative and qualitative aspects will be used.

Risk assessment enables resource allocation and the prioritization of actions contingent on an overall picture of the significant risks in the context of the objectives of the specific industry. The identified decision criteria or risks are; exploration and production risk; environmental and regulatory compliance risk; transportation risk, availability of oil resource risk, geopolitical risk and reputational risk.

1. Exploration and production risk; the exploration and production phase is the first phase, known to the oil industry as the upstream phase in the oil life circle. Typically the oil industry encounters greater risk such as disturbance to the natural

ecosystem such as leaks and spillages, operational accidents, operational catastrophes and strategic uncertainty.

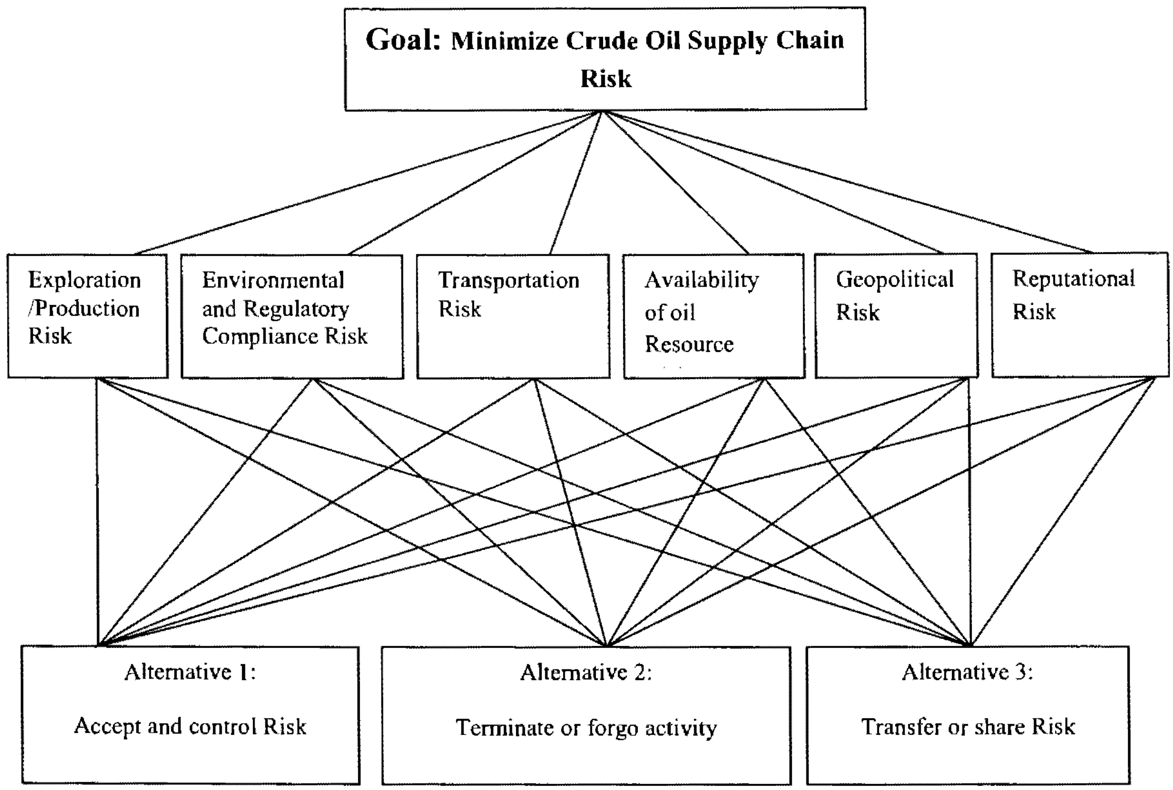
2. Environmental and regulatory compliance risk; the impact of operation on the environment and legislative requirement on oil spill and lack of legal clarity.
3. Transportation risk: include terrorist attacks on crude oil pipelines, and on maritime transportation (piracy).
4. Availability of oil resource risk; assess to and availability of reserves to ensure continuity of supply to meet the growing world demand for oil.
5. Geopolitical risk: the potentially adverse impact of decisions driven by constituent political groups.
6. Reputational risk. Reputational issues for any company relate to public perception of their record on a number of issues, ranging from managerial style and environmental issues, to human right. The risk of potential damage to an undertaking through deterioration of its reputation or standing due to negative perception of the undertaking's image among customers, counterparties, shareholders and/or regulatory authorities.

The alternative options propose to manage the upstream crude oil supply chain risks, specified at level three of the hierarchy are:

1. Accept and control the risk: Accept the risk and put in place appropriate controls (preventive measures) to manage the risk to minimize the value.
2. Terminate or forgo activity: Risks are avoided, for example by stopping an activity. Although the aim of avoiding risk is to completely evade the activities that involve unacceptable risk, mitigating risk involves the planning of future actions and activities to prevent or reduce the consequence of the risk occurring.
3. Transfer and / or share risk: Some risks are transferred. Risk transfer does not mean total elimination of risk, it entails transferring the consequence of a risk to a third party. Risk transfer strategies generate risk that still requires proactive

management, but reduce the risk to an acceptable level. Risk transfer include, insurance, using external agents with renowned knowledge, purchasing a solution as opposed to building it, and outsourcing expensive projects and risky projects.

The Hierarchy Structure of the Crude Oil Supply Chain Risk



Level 1 (Goal): To Minimize Crude Oil Supply Chain Risk (COSCR); **Level 2 (Criteria):** Major Supply Chain Risk Factors; **Level 3 (Alternative):** Risk Mitigation Strategies or policies.

For your opinion as an expert, the pair-wise comparison scale by Saaty, reported in Table 14, can be used to assess or express the importance of one element over another.

Saaty's 1-9 scale of Relative Importance for Pair-Wise Comparison (Saaty, 2006)

Identity of Importance	Definition of Verbal Scale	Explanation
1	If the two objectives are equal importance	Two activities contribute equally to the objective
3	If one objective is moderately more important than the other	Experience and judgment slightly favor one activity over another
5	If one objective is strongly more important than the other	Experience and judgment strongly favor one activity over another
7	If one objective is very strongly more important than the other	An activity strongly favor one over another; its dominance demonstrated in practice
9	If one objective is absolutely more important than the other objective	Importance of one over another affirmed on the highest possible order
2,4,6,8	Intermediate Values	Used when compromise between the priorities are needed
Reciprocals of above	In comparing elements *i* and *j* if *i* is 3 compared to *j*; then *j* is 1/3 compared to *i*	

PLEASE SEE EXAMPLES BELOW

Please mark or circle the criteria number (code) that you assess to be of equal importance or more important than the other, with respect to the **goal: "minimizing risk".**

If you mark or circle **"3"on the right side of "1"** in the following question, it means that **Environmental and Regulatory Compliance Risk."** is **3 times** more important in your expert opinion than **"Exploratory/Production Risk".**

1	Exploratory/Production Risk	9	8	7	6	5	4	3	2	1	2	**3**	4	5	6	7	8	9	Environmental and Regulatory Compliance Risk.

Conversely, marking or circling the number **"1"** in the following question, means that **"Exploratory/Production Risk"** is as important as **"Transportation Risk"**

2	Exploratory/Production Risk	9	8	7	6	5	4	3	2	***1***	2	3	4	5	6	7	8	9	Transportation Risk

Moreover, marking or circling **"5" on the left side of "1"** in the following question, means that **"Exploratory/Production Risk"** is **5 times** more important than the **"Availability of Oil Resource Risk".**

3	Exploratory/Production Risk	9	8	7	6	**5**	4	3	2	1	2	3	4	5	6	7	8	9	Availability of oil Resource Risk

I believe that the above examples will provide helpful insight to the questionnaire. Please contribute your expert opinion by **marking (X) or cycling (O)** your choice of number for the comparison.

Section I: Criteria (Major Risk Factors or Categories)

Question A. Please mark or circle the criteria number (code) that you assess to be of equal importance or more than the other, with respect to the **goal: "Minimizing Upstream Crude Oil Supply Chain Risk"**.

1	Exploration/Production Risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environmental and Regulatory Compliance Risk
2	Exploration /Production Risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Transportation Risk
3	Exploration /Production Risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Availability of Oil Resource Risk
4	Exploration /Production Risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Geopolitical Risk
5	Exploration /Production Risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Reputational Risk
6	Environmental and Regulatory Compliance Risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Transportation Risk
7	Environmental and Regulatory Compliance Risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Availability of Oil Resource Risk
8	Environmental and Regulatory Compliance Risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Geopolitical Risk
9	Environmental and Regulatory Compliance Risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Reputational Risk
10	Transportation Risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Availability of oil Resource Risk
11	Transportation Risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Geopolitical Risk
12	Transportation Risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Reputational Risk
13	Availability of Resource Risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Geopolitical Risk

14	Availability of Resources Risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Reputational Risk
15	Geopolitical Risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Reputational Risk

Section 2: Risk Management: The Alternatives Strategies

Question B. Please mark or circle the alternative number (code) that you assess to be of equal importance or more important than the other, with respect to **"Exploration/Production Risk".**

1	Accept and control Risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Terminate and forgo activities
2	Accept and control Risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Transfer or share Risk
3	Terminate and forgo activities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Transfer or share Risk

Question C. Please mark or circle the alternative number (code) that you assess to be of equal importance or more important than the other, with respect to **"Environmental and Regulatory Compliance Risk".**

1	Accept and control Risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Terminate and forgo activities
2	Accept and control Risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Transfer or share Risk
3	Terminate and forgo activities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Transfer or share Risk

Question D. Please mark or circle the alternative number (code) that you assess to be of equal importance or more important than the other, with respect to **"Transportation Risk".**

1	Accept and control Risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Terminate and forgo activities
2	Accept and control Risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Transfer or share Risk
3	Terminate and forgo activities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Transfer or share Risk

Question E. Please mark or circle the alternative number (code) that you assess to be of equal importance or more important than the other, with respect to **"Availability of Oil Resource Risk".**

1	Accept and control Risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Terminate and forgo

																		activities
2	Accept and control Risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Transfer or share Risk
3	Terminate and forgo activities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Transfer or share Risk

Question F. Please mark or circle the alternative number (code) that you assess to be of equal importance or more important than the other, with respect to **"Geopolitical Risk"**.

1	Accept and control Risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Terminate and forgo activities
2	Accept and control Risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Transfer or share Risk
3	Terminate and forgo activities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Transfer or share Risk

Question G. Please mark or circle the alternative number (code) that you assess to be of equal importance or more important than the other, with respect to **"Reputational Risk".**

1	Accept and control Risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Terminate and forgo activities
2	Accept and control Risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Transfer or share Risk
3	Terminate and forgo activities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Transfer or share Risk

Once again I appreciate your kind help and thank you for your time in offering your expert opinion.

APPENDIX C. CURRICULUM VITAE

ACADEMIC BACKGROUND

Ph.D. (ABD) in Transportation and Logistics. North Dakota State University, Fargo, ND (*Expected Graduation – Spring, 2010*).

Major Concentration Area: Logistics and Supply Chain Management.

Dissertation Topic: ***"Risk Assessment in the Upstream Crude Oil Supply Chain: Leveraging Analytic Hierarchy Process"***

MS. - Alabama A & M University, Normal, AL. May, 1986.

Major Area: Economics

Supporting Area: Finance.

B.BA. – Schiller International University, London England, July 1982.

Major: International Business

Minor: Finance

HONORS/AWARDS/LEADERSHIP POSITIONS

Best Paper Award for 2009: Best Paper in Supply Chain Management Track, 16th Annual

American Society of Business and Behavioral Science to held in Las Vegas, February 21-23, 2009.

Best Paper Award for 2009: Best Paper in Supply Chain Management Track, International Academy of Business and Public Administration Disciplines, April 24-26, 2009.

Best Paper Award for 2008: Best Paper in Supply Chain Management Track, Global Academy of Business and Economic Research International Conference, Orlando, Florida, September 17-19. 2008.

American Educational Inc.1999: Who is Who Among American Teachers.

Wiley's Publishing Company 1993: Listed in the Wiley Guide to Finance Faculty.

Alabama A & M University, School of Business Student Body 1993: Certificate of Appreciation for Superior Guidance.

History of Full Time Employment/Teaching Experience

Instructor, 1988-2006

Department of Economics and Finance School of Business Alabama A & M University Normal, AL.

TEACHING RESPONSIBILITIES

MS. Program: Graduate Courses Taught (1989-1994)

Survey of Economic Theory, Urban Economics, International Economics, Public Finance/ Public Sector Economics, Research Method in Economics.

Undergraduate Course (1986-2006)

Basic Economics, Business Statistics I/II, Principles of Microeconomics, Principles of Macroeconomics, Intermediate Microeconomics, Intermediate Macroeconomics, Principles of Finance, Public Finance/Public Sector Economics, Money and Capital Market, Bank Administration, Investment Analysis and Portfolio Management, International Economics.

HISTORY OF PART-TIME EMPLOYMENT/TEACHING EXPERIENCE

Adjunct Instructor. (1986-1988).

Department of Economics and Finance School of Business Alabama A & M University, Normal, AL.

Adjunct Instructor. (1997-1999). Oakwood College, Huntsville, AL

Adjunct Instructor. (1992-2003). Calhoun Community College, Huntsville, AL.

Adjunct Instructor. (1992-1993). Chrysler United Auto Worker.

Courses Taught: Business Statistics I/II, Principles of Microeconomics, Principles of Macroeconomics.

TEACHING METHODS USE.

Discussion of contemporary and/or emerging issues in global economic issues; Case Method; News Reports, Ethical & Social Issues in Global Business/Economic Reports; Documentary firms/Videos; Guest Speakers; Experiential Exercises; Role Playing; Power-point Presentations.

TEACHING INTERESTS

Transportation Management, Global Supply Chain Management, Logistics and Supply Chain Risk Management, Purchasing and Supply Chain Management, Advanced Logistics & Supply Chain Management, International logistics and Supply Chain Management, International Business and Statistics.

RESEARCH INTERESTS

Oil Industry Supply Chain Logistics; Oil Transportation and Supply Chain Security; Supply Chain Risks; Corporate Social Responsibility and Environmental Issues, International Logistics and Supply Chain, Risk on Oil Security, Sense and Respond Supply Chain, Applications of RFID in Oil Supply Chain, Global Oil Trade.

TEACHING EFFECTIVENESS

Student teaching evaluations range from very good to excellent; Innovative teaching methods often used.

REFEREED JOURNAL PUBLICATIONS

Enyinda, C. I., **Briggs, C A.** and Koo, W. (2008). "The Role of Competitive Intelligence Leverage in Supply Chain Risk Management Strategy." Global Review of Business and Economic Research.

Enyinda, C. I., **Briggs, C.A.** and Hawkins, A. (2009). "Multi-criteria Decision Making Approach for Improved Strategic Risk Management within Pharmaceutical Supply Chain." International Journal of Business, Marketing, and Decision Sciences.

Enyinda, C. I., **Briggs, C.A.** and Bachkar, K. (2009). "Applying Analytic Hierarchy Process Framework for Assessing Risk in Pharmaceutical Supply Chain Outsourcing." The Journal of Business and Accounting.

REFEREED PROCEEDINGS PUBLICATIONS.

Enyinda, C. I., **Briggs, C.A.** and Bachkar, K. (2009). "Managing Risk in Pharmaceutical Global Supply Chain Outsourcing: Applying Analytic Hierarchy Process Model." In Proceedings of American Society of Business and Behavioral Sciences.

Enyinda, C. I., **Briggs, C.A**, and Koo, W. (2008). "The Role of Competitive Intelligence Leverage in Supply Chain Risk Management Strategy." In Proceedings of Global Academy of Business and Economic Research.

Enyinda, C. I., **Briggs, C.A**, Tolliver, D., and Mbah, C. (2008). "Lean Supply Chain Implementation: Transforming Nigerian Military Supply Chain Value Stream into a Lean Sustainment Enterprise for the 21st Century." In Proceedings of 2008 the International Academy of African Business and Development.

Enyinda, C. I., Ogbuehi, A. and **Briggs, C.A.** (2008). "Global Supply Chain Risks Management: A New Battleground for Gaining Competitive Advantage." In Proceedings of American Society of Business and Behavioral Sciences, Volume 15 No 1, pp. 278-292.

Briggs, C.A. (2002). "Poverty and Homelessness"; In Proceedings of 2002, Industry and Economic Track; Alabama Academy of Science

Briggs, C. A. (1999). "Discrimination in Employment in the Labor Market": In Proceedings of 1999, Industry and Economic Track; Alabama Academy of Science.

Briggs, C.A., Eric Rahimian. (1999). "Plunging Oil Price since 1970 and the Impact on Trade and Income"; In Proceedings of 1999, Industry and Economic Track; Alabama Academy of Science.

SERVICE TO THE UNIVERSITY/SCHOOL OF BUSINESS/DEPARTMENT

Academic Advisor: AAMU Bull Dog Football Team, 2001-2003.

Academic Advisor: AAMU School of Business Economics Department, 1990-2006.

Faculty Senator: Alabama A & M University, 1999 – 2006.

Service Award: Alabama A & M University, 1999/ 2004/2009.

School of Business Representative: Alabama A&M University Grievance Committee 2005 – 2006.

School of Business Representative: SACS on-site interview participant, general education faculty, 2004.

School of Business Representative: Alabama A & M University, Operation Jump Start for Freshmen Students, 1988-2005.

School of Business Representative: Alabama A & M University, High School Senior Day, 1988-2005.

School of Business Representative: Alabama A & M University, Youth Motivational Task force, 1988-2005.

School of Business Representative: Alabama A & M University, Student Recruitment, 1998-2004.

Alabama A & M University, School of Business AACSB Student Affairs Committee, 1999-2000.

Alabama A & M University, School of Business AACSB Faculty Development Committee, 2000-2003.

Alabama A & M University, School of Business AACSB Curriculum Committee, 2004-2006.

Alabama A & M University, School of Business, Department of Economics and Finance Faculty Search Committee Member (2000).

Alabama A & M University, School of Business Honor Day Committee Member, 1995-2001.

PROFESSIONAL AFFILIATIONS

Council of Supply Chain Management Professionals, American Society of Business and Behavioral Sciences, The International Academy of Business and Public Administration Disciplines, International Academy of African Business and Development, Global Academy of Business and Economic Research.