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AVAILABILITY OF REFINED FUEL WITHIN THE INDO-PACIFIC AREA OF RESPONSIBILITY

December 2018

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This project will give Department of Defense (DoD) procurement and area planners an assessment on the availability of energy within the U.S. Indo-Pacific Command (INDOPACOM) area of responsibility (AOR). The assessment will help make future decisions on sourcing energy purchases and may be expanded on with assumptions for risk potentials within the energy supply chain. This project includes market research on refined oil shipping and Military Sealift Command's capacity to move fuel to the warfighter. It includes research on tanker contracting procurement by Military Sealift Command, worldwide commercial tanker characteristics, and shipping activity within Asia.

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ABSTRACT

This project will give Department of Defense (DoD) procurement and area planners an assessment on the availability of energy within the U.S. Indo-Pacific Command (INDOPACOM) area of responsibility (AOR). The assessment will help make future decisions on sourcing energy purchases and may be expanded on with assumptions for risk potentials within the energy supply chain. This project includes market research on refined oil shipping and Military Sealift Command's capacity to move fuel to the warfighter. It includes research on tanker contracting procurement by Military Sealift Command, worldwide commercial tanker characteristics, and shipping activity within Asia.

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LIST OF ACRONYMS AND ABBREVIATIONS

AIS	Automated Identification System
ADU	atmospheric distillation unit
AOR	area of responsibility
API	American Petroleum Institute
BBL	barrel of oil
BFSCM	Bulk Fuel Supply Chain Model
BPA	blanket purchase agreement
C4ISR	command and control, communication, computers, intelligence, surveillance, and reconnaissance
CCMD	Combatant Command
CDB	Chinese Development Bank
CI	Nelson Complexity Index
CNPC	China National Petroleum Corporation
COMSERVPAC	Commander, Service Pacific
DFSP	defense fuel supply points
DISA	Defense Information Systems Agency
DLA	Defense Logistics Agency
DLA-E	Defense Logistics Agency–Energy
DoD	Department of Defense
DOE	design of experiments
DORRA	DLA Office of Operations Research and Resource Analysis
DOS	days of supply
DWT	deadweight tonnage
E&P	exploration and production companies
ESPO	East Siberia Pacific Ocean Pipeline
ETA	estimated time of arrival
FAME	fatty acid methyl esters
FBO	Fedbizopps.gov
FOC	flag of convenience
frac	fracking

GCSS-J	Global Combat Support System–Joint
GDP	gross domestic product
GPE	government-wide point of entry
IEA	International Energy Agency
IHS	Information Handling Services
IMO	International Maritime Organization
INDOPACOM	Indo-Pacific Command
IOC	international oil company
IT	information technology
JLOC	Joint Logistics Operation Center
JOA	joint operating area
JP5	jet propulsion five, kerosene
JP8	jet propulsion eight, kerosene
JPO	Joint Petroleum Office
KB/D	thousand barrels of oil per day
LL	lower limit
LOA	length overall
LOGCOP	logistics common operating picture
LOGSTAT	logistics status update
LR1	Long-Range One
LR2	Long-Range Two
LR3	Long-Range Three
LRC	logistics readiness center
MB/D	barrels of oil per day
MILCON	military construction
MMB/D	million barrels of oil per day
MMBBL	million barrels of oil
MMT	million metric tons
MR	medium range
MSC	Military Sealift Command
MT	metric tons
NAICS	North American Industry Classification Systems

NIPRNet	non-classified internet protocol router network
NITC	National Iranian Tanker Co.
NOC	national oil companies
OECD	Organisation for Economic Co-Operation and Development
OMB	Office of Management and Budget
OPLAN	operational plan
OPREP-5	Operational Report-Five
OR	operations research
PACFLT	Pacific Fleet
PC&S	Post, Camp, and Station
PLAN	People’s Liberation Army Navy
POS	planned operational stock
PRNG	pseudo random number generator
PRC	People’s Republic of China
PSC	port of state control
PTDM	Pacific Tanker Delivery Model
PWRR	pre-positioned war reserve requirements
RADM	rear admiral
RFP	request for proposals
ROI	return on investment
SAPO	Sub-Area Petroleum Office
SCA	supply chain analytics
SDLC	system development life cycle
SEA	Ships’ Bunkers Easy Acquisition
SIPRNet	secret internet protocol router network
SOFA	status of forces agreement
SPR	strategic petroleum reserve
TAN	total acid number
UNREP	underway replenishment
UL	upper limit
U.S.	United States
USAF	United States Air Force

USN	United States Navy
USD(AT&L)	Under Secretary of Defense for Acquisition, Technology, and Logistics
USTRANSCOM	United States Transportation Command
VDU	vacuum distillation unit
VLCC	very large crude carrier
WS	Worldscale rate
WWII	World War II

I. INTRODUCTION

This project attempts to contribute to Indo-Pacific Command’s (INDOPACOM’s) understanding of the energy market by projecting the availability of product tankers, known as clean shipping, in East Asia during a contingency. This project includes market research on clean shipping and Military Sealift Command's (MSC’s) capability to move fuel to the warfighter. Additionally, it includes research on tanker procurement by MSC, worldwide commercial tanker characteristics, and shipping activity within East Asia.

East Asia has been the focus of United States’ interest since Commodore Perry sailed into Yokosuka and forced the opening of Japanese ports and markets in 1853. American interest in East Asia increased during the Pacific War, and the region was a key focus of foreign policy during the Cold War communist containment policy when the United States fought wars in Korea and Vietnam. Although later wars in Afghanistan and Iraq shifted American foreign policy attention towards the Middle East, East Asia once again became the United States’ primary focus during the Obama administration. In 2011, President Obama declared this change in policy when he said, “The United States is turning our attention to the vast potential of the Asia Pacific region.” United States interest in the region has continued under President Trump (2017), taking a prominent place in the latest National Security Strategy. This focus on the region has led to a significant amount of literature that focuses on a potential conflict between the United States and the People’s Republic of China (PRC). A recent book, Graham Allison’s (2017) *Destined for War* drew parallels to the Athens–Sparta conflict and warned of disastrous consequences of a United States–PRC conflict. Howard French’s (2017) *Everything Under the Heavens* studied China’s cultural history to put the PRC’s geopolitical ambitions into context. Unlike Russia, which is one of the world’s largest producers of crude oil and natural gas, the PRC imports most of its energy requirements. The PRC’s rapid growth has made it a player in the world energy market, and it has aggressively made international agreements to ensure its energy supply remains undisrupted. At times, these policies have run counter to strategic U.S. geopolitical goals in East Asia (French, 2017).

East Asia resides within the INDOPACOM area of responsibility (AOR)—the largest of the six geographic combatant commands. It is comprised of 36 countries, more than 50% of the world's population, 3,000 different languages, and 7 of the world's 10 largest militaries (United States Indo-Pacific Command Area of Responsibility, n.d). As a maritime region, it is home to nine of the world's 10 largest ports and includes the world's busiest international sea lanes (INDOPACOM, n.d.). The size of this AOR presents a tyranny of distance problem for logisticians in the area who have limited assets to provide fuel, provisions, ammunition, and stores to forces in the area. It is highly likely that fuel will be a deciding factor in a modern-day contingency just as it was during the Pacific War. The importance of fuel to INDOPACOM was prominently exhibited in Admiral Harris's U.S. Pacific Command 2018 Posture Statement:

> Fuel is the lifeblood of operations, and without resilient resupply capability, our operational effectiveness is severely degraded. Crucial to our ability to operate in increasingly contested and austere locations is the velocity of fuels support from source of supply to the point of use. Strategic positioning is a key pillar of our logistics posture. Ensuring we have the right fuel, in the right amount, at the right location, at the right time, is vital to USPACOM's ability to project power throughout the Indo-Pacific under combat conditions. USPACOM is closely integrated with the Defense Logistics Agency and the Services, and I am encouraged by the progress being made. In fiscal year 2018, investments are planned to increase fuels supply/operations infrastructure, storage, and resiliency in Guam, Japan, and Australia. I remain committed to building the capacity of our prepositioned war reserve stocks of fuel, including resiliency of the facilities, infrastructure, and distribution capabilities on which these stocks depend. (p. 23)

The initial research question proposed by INDOPACOM's Joint Petroleum Office (JPO) was, "What are the challenges or issues pertaining to the reliability of global markets to provide energy during a military conflict in the INDOPACOM AOR?" The proposed question is one where researchers could approach it from many different ways by looking at the multi-tiered supply chain, the elasticity of pricing of crude and refined oil markets, the shipping market transportation suppliers and elasticity, and the refinery capability in the region, among a multitude of other energy-related subjects.

The following chapters include the background, literary review, the project's methodology, and the results. The report concludes by explaining the relevance of the project's results to the question initially proposed by the JPO. The background provides the reader with a wealth of information pertaining to the many aspects of this project. The first section gives an overview of the petroleum industry, providing a synopsis of how crude oil is extracted, transported to refineries, refined into oil products, and distributed to consumers. Additionally, this section provides readers with a detailed understanding of the oil shipping industry and defines key terms used in chartering tankers. The second background section covers the PRC's strategic approach to energy security by looking at what policies were selected from the available options. This section will help planners understand how the energy policies pursued by the PRC can affect geopolitical concerns within the INDOPACOM AOR. The background's third section provides petroleum logistic lessons learned by the Navy during the Pacific War, as explained in Admiral Carter's (1953) *Beans, Bullets, and Black Oil*. The Pacific War was the last major maritime conflict fought by the U.S. military and one likely to be emulated in a INDOPACOM AOR conflict. That war employed innovative concepts such as forward sea-basing, new support ship platforms, the shuttle ship–support ship construct, and common use of replenishments at seas. The fourth section in the background explains how the Department of Defense (DoD) procures fuel through Defense Logistics Agency Energy (DLA-E) and transports fuel via sealift with MSC. This section discusses the different fuel support contracts and gives insight into how MSC charters commercial vessels. The background's final section describes how the DoD uses information systems to manage fuel.

Following the background chapter, the literature review looks at some past studies on how the DoD could achieve fuel supply chain continuity. The methodology chapter discusses how the data was extracted and used to create a standardized tanker charter profile, and how modeling and simulation were used in this study. One simulation estimated worldwide shipping availability, while the other simulation focused narrowly on shipping activity within the East Asia geographic area. The results section includes a description of the findings of the simulation and an analysis from looking at fuel requirements during the first Gulf War.

We believe this project will show INDOPACOM logistics planners, MSC, and DLA-E how publicly available data could be used to reduce supply chain risk in the advent of a contingency. Further development of the models would help INDOPACOM better understand if energy markets would be responsive to requirements during a major conflict. Strategic and operational logistics planners could use the information generated in a simulation along with the list of forces they have available for planning to develop supportable operational plans (OPLANs). This would likely reduce the risk to the supply chain by improving information flows into the commander's decision cycle.

II. BACKGROUND

In this chapter the reader will gain a general understanding of the energy industry, the geopolitical situation in East Asia, DoD's fuel procurement operations, and information technology systems used in the fuel supply chain.

A. OVERVIEW OF THE ENERGY INDUSTRY

The petroleum industry is truly a global industry where a barrel of oil can travel around the world as it moves between processes before it is ultimately used to provide energy. To illustrate this transformation, the petroleum industry uses a stream metaphor to help explain how oil flows from black goo buried underground to the final delivery to the end user, such as a vehicle's gas tank. This stream is divided into three major segments: upstream, midstream, and downstream. The upstream sector of the oil supply chain consists of locating oil, developing oil fields, and producing or extracting oil. At this point, oil has few useful qualities and it is not located near a location capable of converting the oil into useful products. The midstream sector of the petroleum industry is concerned with moving oil from the oil field to refineries where it can be transformed into final or intermediate products. The downstream sector of the petroleum industry is charged with breaking apart carbon molecules and organizing them in to useful concoctions and then distributing them to users. This overview also identifies the areas of the supply that are the most vulnerable to market disruptions.

This detailed overview of the energy supply chain revealed there is one area of the downstream segment that is more susceptible to a supply shock, and that is the fuel distribution portion. Disruptions in the fuel distribution system are normally covered by safety stock, which is supposed to smooth out short-term shortages. The expectation that stored fuel, or safety stock, will be available during a contingency is being challenged by the proliferation of standoff weapons that can target large fuel farms located anywhere in the Pacific. Compounding this challenge is the military's growing appetite for energy to power higher speeds, greater lethality, and power hungry technology. To meet these needs in a future conflict, the military's supply chain will need to be dispersed and just-in-time to ensure energy is available to the deployed units. The vast oceans and high fuel demands mean the success or failure of the fuel supply chain in the INDOPACOM AOR is dependent on the availability of clean shipping.

1. Upstream Segment

The upstream segment of the supply chain starts after oil is located and the mineral owner initiates a project to develop the field. The development of an oil field requires a large investment in time, resources, and several different types of expertise. Many of the tasks needed to bring a well into production are contracted out to various services companies (Termeer, 2013). Normally the owner or operator does not own the equipment or have the in-house expertise to drill a well (Termeer, 2013).

Exploration is done by national oil companies (NOC), integrated oil majors, and independent exploration and production companies (E&P). Typically, the large oil companies specialize in locating new sources and managing their reserves, while leaving the drilling to oil field services companies ("Upstream Oil and Gas Drilling Rig Contractors," n.d.). In the life of a well, there can be more than 30 contracted service companies filling various roles in the support of the operator ("Introduction to Upstream," n.d.). The two largest NOCs are Saudi Aramco and the Russian company Rosneft (Carpenter, n.d.). Two of the largest integrated oil majors are ExxonMobil and Chevron, and two of the larger independents are Anadarko Petroleum and Devon Energy Corporations (Dutta, 2011).

Oil field services companies allow the owner of the mineral rights and the operator to hire expertise needed to fully develop and bring an oil field into production (Termeer, 2013). As the oil services companies developed, they removed one of the largest advantages that the large integrated oil majors had in project management and drilling expertise (Bridge & Le Billon, 2017). The largest of the oil field services companies are Schlumberger Ltd., Halliburton Co., Baker Hughes Inc., and Weatherford International (Duddu, 2015).

An oil well will go through four phases to reach full development. The first phase is called *characterization* (Schlumberger, n.d.). An E&P company will utilize high powered computers and geology experts to determine what locations have the highest potential for commercially viable production (Termeer, 2013). Once a potential location shows promise the E&P company will determine the likely return on investment (ROI) and build a budget for the project (Termeer, 2013). Unfortunately, the tremendous cost of drilling a well is the only way to determine if a site is actually able to produce oil (Termeer, 2013).

After characterization, the *drilling* phase starts. The owners of the mineral rights will hire an operator to serve as the project manager. The operator is responsible for the execution and contracting of required products and services to drill the well (Termeer, 2013). The operator hires service companies to execute functions and services needed to bring a well into production. This phase ends when a viable well is established and oil is able to be brought to the surface. Some of the major services hired out include the following:

- General prepping of the wells site requires leveling the site, digging reserve pits and water wells, and creating roads to connect to transportation networks (Hilyard, 2012).

- Well preparation starts with digging a working pit called the cellar followed by drilling the initial hole and installing the conductor casing (Hilyard, 2012).

- Field services are contracted to support the crew with water tanks, trash removal, field toilets, food preparation, and any other needed services.

- The drilling rig could be leased or owned by the operator, or the drilling service could be fully contracted out to an oil field services company (Termeer, 2013). Tools, drill bits, tubing, and various other components to run the rig are rented from various contracting companies or oil services companies (Termeer, 2013).

The third step is *completion,* and it begins once the well is dug and shown to hold recoverable reserves. These process steps will prepare the well for production and are normally completed by an oil services company. The following are the required steps (DeepData, n.d.):

- Installation of casing to protect the walls of the well
- Installation of a tree to move fluids through well
- Installation of production tubing to extract oil
- Perforation of the casing at the bottom of the well
- Application of stimulation

The most often used stimulating processes are fracking (frac) and acidizing to help the oil flow to the collection point where it can be extracted to the surface. To stimulate a well using a frac process, the operator needs to source frac fluids and a proppant. Frac fluids that are sold by oil service companies and other vendors contain mostly water with propriety chemical additives to keep the viscosity of the fluids high (Hilyard, 2012). The frac fluid holds and pushes the proppant into small fractures to widen them allowing for the pooling of oil (DeepData, n.d.). The proppant is normally sand and is commonly sourced from the same suppliers that provide material for construction, agriculture, and other industrial uses (DeepData, n.d.). Acidizing a well is done to improve the flow of hydrocarbons by reducing the amount of sediment bellow the perforation or fracture (Rigzone, 2018). This is achieved by pumping acid, which is usually hydrochloric acid, at low pressure to dissolve the limestone and other material inhibiting the flow of hydrocarbons (Rigzone, 2018).

The last phase is *production*. The amount of work needed at the well head is minimal and is normally carried out by a service company who completes well head services and maintenance. Usually, other hydrocarbons, and water are present with oil requiring the use of a field separator to remove methane gas, water, and sulfur before the oil is ready to be shipped (Termeer, 2013). Storage tanks are used on site to collect both liquid hydrocarbons and gas hydrocarbons (Termeer, 2013). If the well lacks sufficient pressure to push oil to the surface, the operator will lease a pumpjack or other artificial lift to aid in recovery (Termeer, 2013). Then as the well ages and production drops an oil services company will be hired to workover the well to repair damaged tubing, casing, and removal of debris (Termeer, 2013). Additionally, the operator will utilize techniques to improve oil recovery by injecting water and gas into injection wells around the oil field to force the remaining oil to the surface (Hilyard, 2012). Throughout the life of an oil well, oil service companies remain deeply involved in the development and the production of oil. They have the critical skills and equipment all operators and owners must use.

The upstream segment operates in all countries that have recoverable oil reserves. The highly specialized nature of oil field service companies has created an industry of oil experts that are ready to drill anywhere the project is funded. New technologies and processes are changing the petroleum industry, and oil that was once not commercially recoverable is now within reach. A mature functional market allows for the efficient allocation of upstream resources to areas expected to hold the greatest rewards.

2. Midstream Segment

The midstream segment begins at the oil field where the producer of the oil needs to find the best way to move the oil from the field to the contracted delivery point. Integrated oil companies are both the producer and the refiner, but they rarely own midstream assets that deliver the oil to the refinery (Investopedia, n.d.). If the producer specializes in E&P, it must deliver the oil to the location negotiated in the contract with the buyer (Termeer, 2013). The buyer could be an energy commodity trading company that buys and sells oil to exploit discrepancies in the different dimensions of the market relating to geography, timing, and finished products (Damien, 2018). To execute complex arbitrage strategies, companies like Glencore have vast networks of investments, storage, logistics, suppliers, and customers. Commodity trading companies, like Vitol Group and Glencore, are responsible for a significant portion of the midstream market (Damien, 2018). The midstream segment is a capital-intensive portion of the supply chain and is vital to linking the buyers to the sellers of crude oil.

The main mode of transportation for oil is the marine tanker due to the flexibility and the distance oil has to move to get to the refinery (Rodrigue, 2017). Many refineries are located near major water ways to allow the use of barges and marine tankers to deliver crude oil to the refinery. Due to favorable legal provisions and international laws, many maritime carriers are located in foreign countries (HG.org, n.d.). The largest marine crude carriers include both international companies and nationalized fleets. The largest marine crude shipping companies are Teekay Group and Frontline Ltd., and the largest nationalized fleets are the National Iranian Tanker Co. (NITC) and the National Shipping Company of Saudi Arabia (Faucon, 2015; Seth, n.d). Moving oil by very large crude carrier (VLCC) not only requires paying daily rates and fuel cost, but the purchasing company must also obtain financing to purchase about two million barrels of oil (MMBBL; Plomaritou & Papadopoulos, 2018).

The second largest mode of transportation of oil is pipelines, with trucks and trains used as a stopgap (Hilyard, 2012). Crude oil pipelines are the most efficient carriers of crude but there are limitations to how they are used (Hilyard, 2012). All oil transported must meet the characteristics of the crude oil that is transported by the pipeline (Termeer, 2013). Since pipelines are an installed infrastructure, they lack the flexibility of trucks, but are far more efficient and cost less per barrel (BBL) delivered (Termeer, 2013). As oil production expands in various regions of the world, the output can outstrip the ability of the pipeline to deliver the oil. This can cause a backlog and push oil to either use more expensive modes like trucks and trains or halt production. In the United States, the Permian Basin has quickly increased production capacity faster than pipeline companies are able to add carrying capacity. This led producers to either sell their oil at a deep discount or delay production until the infrastructure catches up (Crooks, 2018).

The midstream segment of the supply chain proved to be adaptive at providing solutions to connect producers and refiners. Pipeline infrastructure that connects oil producing areas to purchasers can give them a price advantage in transporting their product to markets (Termeer, 2013). Large networks of pipelines move oil across national boundaries delivering oil thousands of miles away from where it was produced (Hilyard, 2012). In East Asia crude oil is primarily shipped via tankers through the Malacca Strait. The competition to drive down the cost of delivering a barrel of oil has led to the development of enormous ships that have been customized to be efficient as possible. The primary tanker used to deliver crude oil to Asia is the VLCC, which can deliver over two MMBBLs of crude oil from the Persian Gulf to Japan for a charted rate of less than $1 per BBL (Argus, 2018). The primary producers of oil have well-developed infrastructures giving purchasers access to a competitive global transportation network capable of moving oil over long distances for relatively low costs to purchasers. This global network of crude transportation allows purchasers to shop for the greatest value with limited regard to shipping costs.

3. Downstream Segment

The downstream segment starts when the refinery takes delivery of the crude oil and ends when useful final and intermediate products are delivered to the customer. The majority of the value added to the oil during the downstream segment occurs at the refinery. The oil or grade of oil used is dependent on the capability of the refinery and its ability to process heavy sulfur infused oil. The characteristics of oil that determine the price are density or American Petroleum Institute gravity (API), sulfur content, total acid number (TAN), salt and water amounts, and pour point (Termeer, 2013). Light sweet crude, defined as low API and sulfur content, costs less to refine and requires a less complex refinery to process it, therefore it is more valuable and goes for a higher price (Termeer, 2013). The highest margin products produced by refineries are gasoline and middle distillates like diesel, heating oil, and jet fuel (Termeer, 2013). This has led to most of the technology developed for refineries being focused on increasing yields of gasoline and middle distillates. On the right side of Figure 1 is the typical percentage of output expected from a refinery of medium complexity. All refineries have different equipment or different capacities at the different stages of the refinery, which will result in variation in output. Additionally, Figure 1 shows an overview of the processes of a typical refinery of medium complexity. The following section will discuss the three major stages a refinery uses to develop the petroleum products.

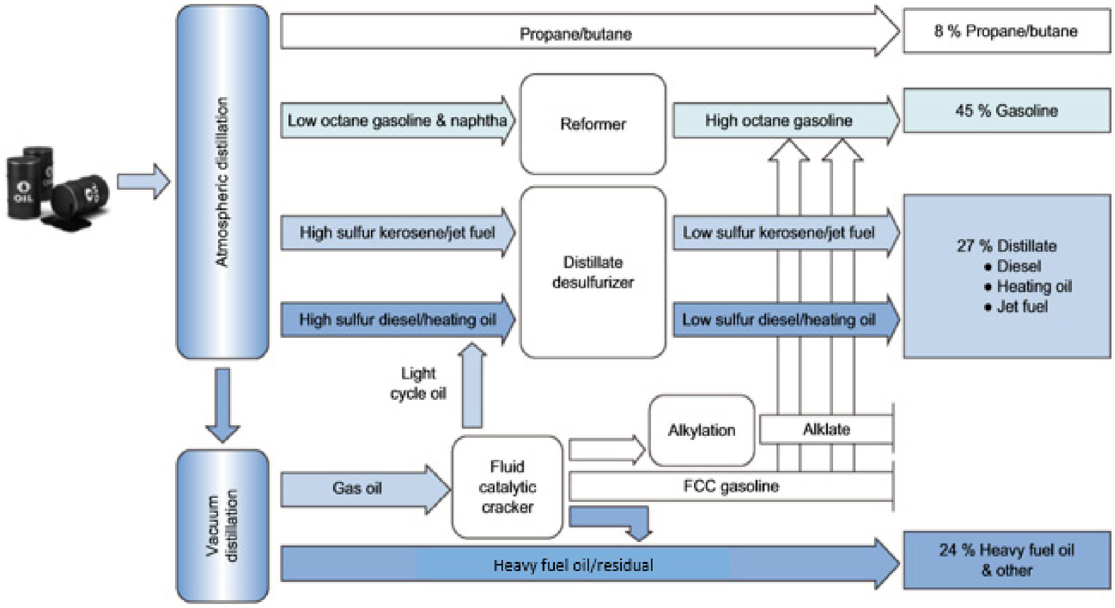

Figure 1. Processes and Products of a Refinery with Medium Complexity. Source: Kaiser (2017).

a. Three Major Stages of Refining

The first stage of refining is called *separation*, and it starts with the removal of impurities such as sulfur, contaminants, and water (Termeer, 2013). The crude then goes through a fractional distillation process that separates the oil into different components called fractions (Termeer, 2013). More advanced refineries will have both an atmospheric distillation unit (ADU) and a vacuum distillation unit (VDU; Termeer, 2013). The VDU will allow for further fractionating the raw straight run residue from the ADU into gas oil (Termeer, 2013).

The second stage is *enhanced refining or conversion* and allows the refinery to continue breaking down the straight run residue and to make new products from the fractions. Enhanced refining allows the refiner to change the yields of the feedstock into the products with the highest margins (Termeer, 2013). There are three categories of enhanced refining:

- Cracking: used to increase the output of middle and light distillates. The types of cracking processes used at a refinery are determined by the expected feedstock and the required yields (Termeer, 2013).

- Combination: used to combine smaller hydrocarbon molecules to make more desirable hydrocarbons. Combination is used to produce more middle distillates and gasoline from natural gases (Termeer, 2013).

- Re-arranging: used to alter or modify atomic configurations in to different molecules. The output of these processes are gasoline and petrochemicals (Termeer, 2013).

The third stage is *additional treatment or finishing*. It is used to develop high-quality products, remove solvents and other feedstock, and differentiate the final product (Termeer, 2013):

- Removal of unwanted elements from finished or intermediate products such as sulfur and thiol.

- Recovery of solvent for chemical feedstock or other intermediate products such as wax and lube feedstock.

- Additives are used to create high value brands or products such as rust inhibitors, extreme pressure additives, and others. Additionally, intermediate products are blended to create end products such as 87 octane gasoline (Termeer, 2013).

b. Refining Complexity

Refining complexity measures are used to compare refineries by approximating their capabilities. Two common analysis used are the *Nelson Complexity Index* (CI) and c*onversion capacity* (Kaiser, 2017). At a higher complexity, the refiner can employ more enhancements that allow greater conversion of crude oil into useful products. Two refineries at the same refinery complexity index number could have different outputs due to a variety of factors (Kaiser, 2017). The second row of Table 1 shows the simplest refinery complexity representing an operation that is able to complete basic separation using an ADU and possibly a VDU. When a refinery adds the ability to do cracking and coking it is able to convert a significant portion of a barrel of oil into gasoline and middle distillates (Termeer, 2013).

Table 1. Common Classifications and Complexity for Refineries Using the Nelson Complexity Index. Source: Kaiser (2017).

Classification	Name	Complexity range
Very simple	Topping	<2
Simple	Hydroskimming	2–5
Complex	Cracking, conversion	5–14
Very complex	Coking, deep conversion	>14
Specialty	Lube oils, asphalt	>5
Integrated	Petrochemical	>10

Figure 2 lists the world's largest refineries along with their CI and the conversion capacity. Conversion capacity is a measure of how much enhanced refining capacity a refinery has in relation to its ADU capacity as approximation of the ability of the refinery to convert to maximize gasoline and middle distolate conversion (Kaiser, 2017). Most of the largest refineries in the world are on the lower side of the complexity index, with the exception of the ExxonMobil Refinery located in Baytown, TX.

Rank	Company	Location	Capacity, Mbpd	CI	Conversion capacity, %
1	Paraguana Refining Center	Cardon/Judibana, Falcon, Venezuela	940	6.3	33
2	SK Innovation	Ulsan, South Korea	840	7.2	23
3	GS Caltex Corp.	Yeosu, South Korea	785	7.4	38
4	S-Oil Corp.	Onsan, South Korea	669	7.7	29
5	Reliance Industries Ltd.	Jamnagar, India	660	3.3	39
6	ExxonMobil Refining & Supply Co.	Jurong/Pulau Ayer Chawan, Singapore	593	5.3	10
7	Reliance Petroleum Ltd.	Jamnagar, India	580	6.7	54
8	ExxonMobil Refining & Supply Co.	Baytown, Texas	561	10.2	57
9	Saudi Arabian Oil Co.	Ras Tanura, Saudi Arabia	550	3.2	9
10	Formosa Petrochemical Co.	Mailiao, Taiwan	540	7.0	42

1998 OGJ complexity factors used in the complexity index calculation

Figure 2. World's Largest Refineries with the CI and Conversion Capacity. Source: *Oil and Gas Journal* (2014).

4. Distribution

The downstream segment also includes the transportation and distribution of finished and intermediate products. The refined products, carried in pipelines and tankers, are refered to as *clean* or *white oil* (Termeer, 2013). The destinations could be to gasoline stations, fuel storage, wholesale operations, and petrochemical refining. Commerial and government energy requirements are often filled by energy trading companies, energy wholesalers, and fuel brokages who procure petroleum products from the refiners and deliver the fuel to where it is needed at the time it is needed. These vendors play an important part in the delivery of fuel to the military bases and transhipment points around the world. Two large fuel wholesale or brokerage companies are Clipper Oil (n.d.) and World Fuel Services (n.d.).

The primary focus of this project is on chartered product tankers and how they are used to support military operations in the Pacific. This section provides a deeper look at clean shipping and how product tankers are placed on charters by looking at three main areas: overview of product tankers, flags and control of vessels, and overview of the charters.

a. Petroleum Product Tankers

Tankers that are employed in the shipment of refined petroleum products run from the very large to small coastal tankers and barges. Clean petroleum products are carried on ships that are engaged in the tramp trade. The tramp trade does not have a fixed schedule of ports of calls, instead tankers are chartered based on the cargo owner's requirements and normally move cargo between two ports. The size of tanker that is requested is based on the size of the cargo along with the limitations on the size of ship that can utilize the port. Normally product tankers that move fuel short distances are carried in smaller tankers with larger tankers used for longer voyages. The tankers that are employed in moving refined petroleum products are the following:

- Suezmax are ships categorized as Long-Range Three (LR3) with a size between 120,000 and 200,000 deadweight tonnage (DWT). These are large ships that can carry almost 1 MMBBLs of petroleum or petroleum products. Only about 3% of Suezmax tankers have tanks that are coated and able to carry highly refined fuel products (Plomaritou & Papadopoulos, 2018).

- Aframax tankers are categorized as Long-Range Two (LR2) tankers with a size between 80,000 and 120,000 DWT. These ships are named after the contracting standard they were designed to meet called the average freight rate assessment. These ships can carry about 500 MBBLs of petroleum or petroleum products. Ships in this category mostly carry crude oil, but about 30% have tanks that are coated and are able to carry clean products (Plomaritou & Papadopoulos, 2018).

- Panamax are categorized as Long-Range One (LR1) with a size between 60,000 and 80,000 DWT. These ships can carry about 350 MBBLs of petroleum or petroleum products. About 80% of these ships have coated tanks and can carry refined products (Plomaritou & Papadopoulos, 2018).

- Handymax tankers are employed in the shorter range and coastal trade of refined petroleum products, with these ships being common in the intra-Asia fuel trade (Kendall, 1986). Tankers between 45,000 and 60,000 DWT are normally classified as medium range (MR) with tankers smaller than 45,000 DWT called Handy size. About 96% of the tankers in this category have coated tanks and can carry refined petroleum products (Plomaritou & Papadopoulos, 2018). Many of the tankers below 45,000 DWT are called chemical tankers and have stainless steel tanks allowing them to carry high value chemicals and other products (Plomaritou & Papadopoulos, 2018).

Tankers are divided into two main categories that specify the types of cargo they carry. Dirty tankers are ships employed to carry crude oil, whereas clean tankers are the ships that carry highly refined petroleum products (Plomaritou & Papadopoulos, 2018). To carry highly refined petroleum products, tankers have to meet strict specifications put in place to ensure that embarked cargo will be the same quality at the port of debarkation (Plomaritou & Papadopoulos, 2018). Fuels, such as gas oil or diesel, do not have strict requirements and can be carried in dirty tankers that also carry crude oil (Plomaritou & Papadopoulos, 2018). Clean tankers must have tanks that are coated in inorganic, nonferrous compounds, with epoxy being the most common (Plomaritou & Papadopoulos, 2018). Clean petroleum products are carried in tankers that have either been cleaned or had carried clean refined products during the last voyage (The Energy Institute, London, 2017). Additionally, tankers that carry jet fuels, such as jet propulsion eight (JP8) and jet propulsion five (JP5), have specific limits on what previous loads the tanker could have been carrying (The Energy Institute, London, 2017). The tanks must be completely dry and must not have carried any leaded products or products with more than 5% fatty acid methyl esters (FAME; The Energy Institute, 2017). Carrying different grades of fuel or switching from crude can require time consuming and expensive conversion costs, which normally keep tankers from switching to cleaner products (Kendall, 1986).

b. Flags, Control, and Management of Tankers

Ships can be flagged or registered in almost any country around the world, and in some countries the entity does not need to have a presence established. If the vessel is registered in a country that is different than the owner's legal domicile, it is referred to as a *flag of convenience* (FOC; HG.org, n.d.). The United Nations created the International Maritime Organization (IMO) to ensure international standards in safety, security, and pollution reduction in the maritime domain are developed and followed by shippers engaged in international trade (International Maritime Organization [IMO], 2018). The agreements developed by the IMO require the states where the vessels are registered to ensure they the minimum standards. Some nations that allow FOC have lax enforcement of IMO standards, which led to several accidents and spills, causing damage in foreign ports (Paris Memorandum of Understanding on Port State Control [Paris MoU], 2018). To ensure that the ships that operate with a FOC are in compliance with the IMO requirements, nations or groups of nations have established port of state control (PSC) areas that require visiting ships be inspected. The PSC can cite the ships that are deficient or in some instances they will detain ships that are not in compliance and hold them until the owners make corrections. If ships are detained multiples times they can be banned and no longer allowed to use any port that has signed the PSC agreement (Paris MoU, 2018). Additionally, ships flagged by a blacklisted nation will be under increased inspections and quicker bans if ships are detained (Paris MoU, 2018). Due to the use of FOC the and the international aspect of the shipping industry the location of the flag or ship registry provides only limited information on the owner, management, and operation of a vessel.

Control over tankers is exercised primarily through the use of three methods. The first method is through industrial shipping, where the owner of the cargo is also the owner of the vessel (Plomaritou & Papadopoulos, 2018). This is used by some nationalized petroleum companies and some integrated oil majors to carry crude oil to refineries. Entities that are engaged in industrial shipping may also supplement their fleets through the use of charters. The second way the use of a tanker is secured is with a time charter. A charterer is the person who has a contract with a vessel owner (Kendall, 1986). The charterer that has a time charter, is able to control the schedule and request ports of call but is not responsible for navigation and operation of the ship. At the end of the time charter, the ship must be returned to a location specified in the charterparty (Plomaritou & Papadopoulos, 2018). A charterparty is a contract between the charterer and the vessel owner that stipulates how the ship will be operated. The last way to secure use of a tanker is through the spot or voyage market (Plomaritou & Papadopoulos, 2018). A voyage charterparty covers cargo movement from a specified port to another specified port or area. A voyage charterparty may specify multiple ports of embarkation and debarkation but limits the charterer's ability to deviate from the specified areas in the charterparty (Plomaritou & Papadopoulos, 2018). Additionally, a voyage charterparty limits the flexibility of the cargo owner and is normally only used for emergent requirements that charterer's current assets are not able to meet (Kendall, 1986). In a voyage charter, the charterer only pays the daily rate and the ship owner is responsible for all costs of operation to include port fees. Industrial shipping in the tanker market has been in decline with large for-hire tanker fleets emerging to support the energy supply chain operations (Plomaritou & Papadopoulos, 2018).

Management of tankers and ships can take several forms, from the owner being the manager, to management being contracted to a maritime management firm (Plomaritou & Papadopoulos, 2018). Management of tanker assets has three major functions, of which any or all can be contracted to a third-party management company. The first function is called *technical management*, which is responsible for the cost of operations, tracking performance, and ensures tankers are safe to operate (Plomaritou & Papadopoulos, 2018). The second element is *crew management,* where all elements of human resource management are accomplished. The third function is *commercial management,* where tasks associated with the finding and fixing of contracts is accomplished. In commercial management the tasks that must be accomplished are the marketing of shipping services, charterparty negotiation, and the payment of all costs along with the collection of income from the charterer (Plomaritou & Papadopoulos, 2018). Shipping is a global industry where owners, management, vessels, customers, and agents can all be located in several different counties.

c. Chartering Tankers

The charterparty is a contracted agreement that outlines the required performance of the ship as it relates to the carriage or movement of cargo. All charter agreements start with the standard tanker charterparty and requests for deviations are made to the entities on each side of the deal (Kendall, 1986). The charterparty defines basic requirements such as pump rates, loss of cargo, and condition of cargo at delivery. It will also specify what allowances are allowed to be incurred on behalf of the charterer, and when arbitraries are to be paid for non-routine request that increase risk to the vessel (Kendall, 1986). The charterparty will also define the amount of working days the vessel is allowed in port to load and also to unload without incurring demurrage fees that will be paid by the charterer (Kendall, 1986).

The cost of chartering a tanker is calculated primarily two different ways depending on the type of charter used (Plomaritou & Papadopoulos, 2018). The charterparty will either state the *freight rate* if it is a voyage charter, or the *hire rate* if it is a time charter (Plomaritou & Papadopoulos, 2018). Freight rates for tankers are calculated by using a rate calculated for a standardized ship on a well-traveled route that is published in an index called the Worldscale (WS; Plomaritou & Papadopoulos, 2018). The standard ship the WS uses specifies characteristics of the ship in regards to DWT, fuel burn rates, speed, and time in port when calculating the rates (Worldscale, 2018). The standardization of the ship and route allows for cargo owners and ship owners to compare various routes and make better decisions. The rate published in the index is all-inclusive covering bunkering, port costs, cost of operation, and is quoted in dollars per tonne and updated annually (Worldscale, 2018). The WS's indexed rates are for round-trip voyages covering several common routes such as Persian Gulf to Japan. To account for short-term market variation, freight rates are published and quoted as a percentage of the WS; for example, WS70 would be 70% of WS indexed rate. The rate calculation for time charters require the owner to forecast the costs of the crew, financing, maintenance, and depreciation for the duration of the contract before agreeing to a hire rate. All bunkering costs and fees associated with port calls are normally the responsibility of the charterer (Plomaritou & Papadopoulos, 2018).

Petroleum products are normally carried by tankers that are on time charters, with voyage charters used for emergent requirements (Kendall, 1986).

d. Chartering Process

The chartering process consists of three major phases that ships owners and cargo owners use to reach an agreement. At the beginning of negotiations, both entities start with the standard charterparty and request deviations or relief from clauses (Plomaritou & Papadopoulos, 2018). The negotiations will consist of offers and counter-offers until there is agreement on the various clauses, schedules, and other issues to ensure the requirements are clearly defined. The chartering process also has to account for government regulations and required limitations on operations. An important limitation on who is able to carry cargo is called *cabatage*, and it concerns the transportation of cargo from port to port within a nation's boundaries. Many nations, including the United States, have cabatage regulations that limit the movement between domestic ports to only United States flagged vessels. A description of the three major chartering phases is as follows:

1. The *investigation phase* starts when the cargo owner advertises the carriage requirements using a *cargo order* (Plomaritou & Papadopoulos, 2018). These requirements include size of cargo, holding conditions, dates, locations, and other specifications. The ship owner responds back with a *position list* that includes information on the ship (Plomaritou & Papadopoulos, 2018).

2. In the *negotiation phase*, the cargo owner instructs the broker to collect *indications* or *freight ideas*, which are requests for proposals that are nonbinding, from the vessels that match the cargo order's initial requirements (Plomaritou & Papadopoulos, 2018). The ship owner and cargo owner can negotiate freight indications with multiple entities simultaneously, until the cargo owner has a freight idea that best matches the requirement. At this point, the cargo owner's broker will then ask the ship owner for a firm offer (Plomaritou & Papadopoulos, 2018).

Provisions of the charterparty are negotiated until all portions are in agreement to include freight rate or hire amount, or the offer is rescinded.

3. The focus of the *follow-up phase* is to finalize and sign the charterparty. The charterer's broker draws it up and sends it to the ship owner's broker to ensure it is in agreement with parameters of the negotiation phase (Plomaritou & Papadopoulos, 2018). If everything is in agreement, then the document will be signed and the ship put *on fixture*. When a ship is on fixture it is under contract with a charterer.

5. Tankers Are the Primary Constraint

All segments of the fuel supply chain have multiple sources that are dispersed around the world, except the distribution of fuel. A conflict in the Pacific will have to overcome forces separated from the supply chain by large stretches of the Pacific Ocean. Product tankers will need to serve as the life line to the dispersed forces in the Pacific. The United States military is primarily dependent on jet fuel to power everything from aircraft to tanks and wheeled vehicles. The reliance on jet fuel requires strict adherence to storage conditions to keep the fuel from being contaminated. Exploring product tankers and their availability is critical to better understanding the United States' ability face a contingency in the Pacific.

B. THE PEOPLE'S REPUBLIC OF CHINA'S STRATEGIC APPROACH TO ENERGY SECURITY

The PRC has overtaken the United States as the world's largest consumer of energy, and its vast demand for energy has a large effect on the global energy trade. The PRC experienced 10% annual gross domestic product (GDP) growth throughout the early-to-mid 2000s (Yergin, 2011). This economic growth was aided by the use of energy to power its massive manufacturing arm. From 2002 to 2007, China's energy consumption increased by 84% (BP, 2018) and its energy grid capacity doubled (Yergin, 2011). This climb in Chinese energy consumption was a major driver of world consumption, which saw more than 3% annual consumption growth during that time. Although China's energy usage is highly dependent on coal, it has become a major player in the oil market. Its current share of global oil demand is more than 13%, up from 6% in 2000 (BP, 2018).

China's growth was not without disruption. It started the period with an energy shock in 2003 when energy consumption growth more than doubled from previous years. China's red-hot growth in production rapidly increased its need for electricity. Suddenly, domestically-produced coal could not meet energy demands, forcing China into the international energy markets. Energy shortages resulted in brownouts and blackouts across the country, causing people to ration their electricity usage. Factories worked shortened work-days. Some hotels even required their thermostats to stay above 79 degrees and for their staff to take stairways rather than use elevators. (Yergin, 2011). The situation stabilized but this experience helped shape Chinese opinion of energy security, making it a hot topic. *People's Daily*, the Chinese Communist Party's official newspaper, published 476 articles from 2009 to 2011 containing the term "energy security" (*nengyuan anquan*), compared to 2000, when the term was only used once (Kennedy, 2015).

China has pursued several policies to secure its energy requirements. Its strategic direction can be understood using the lenses of general energy security policy. This chapter explores disruptions of supply and the ways a country can prevent or mitigate the disruptive impacts of energy shortages. Continuing forward, this chapter provides an in-depth look at China's energy security vulnerabilities and its strategic approach to energy. These strategies include the international expansion of its NOCs, its loan-for-oil deals, its transnational pipeline projects, the expansion of the People's Liberation Army Navy (PLAN), and the construction of its strategic petroleum reserve (SPR).

Oil is the energy source primarily focused on in this chapter for several reasons. First, the oil trade is the most developed of all energy commodities as it is widely traded across the globe. Most countries obtain their coal from indigenous sources (International Energy Agency [IEA], 2007) and natural gas is largely restricted to regional markets (O'Sullivan, 2017). Second, China has become increasingly reliant on oil imports, more so when compared to its other sources of hydrocarbon energy. The PRC imports only 6% of its coal requirements, and although the PRC has increased its natural gas production in recent years, the relative size of natural gas within the PRC's energy mix is only at 7%. In contrast to coal and natural gas, the PRC imports 69% of its oil requirements which satisfies 16% of the PRC's total hydrocarbon requirements (BP, 2018). Finally, there are few substitutes for oil as an energy source within the transportation sector. The large amount of the PRC's oil imports and the global integration of oil trade makes the PRC a major player in the global oil market.

1. Energy Security

The International Energy Association (IEA) defines *energy security* as having access to "adequate, affordable, and reliable sources of supply" (IEA, 2007, p. 160). Energy powers our electricity, fuels our transportation, and lubricates our economy. Energy usage is tied to industrial economies, where the more industrialized countries use higher amounts of energy per person. Due to its economic importance, energy security is also seen as a high priority in national security. Without energy, economies cannot function, militaries cannot transport its equipment, and the state loses its ability to project power. The ability of the United States to secure access to energy was critical to becoming a world power. This access of energy is equally important to the PRC for its economy and military growth, thus as the PRC grows, its need for energy grows. In order to understand the PRC's energy policy, we turn to disruptions of supply and discuss how a consumer country can prevent or mitigate their impacts.

a. Disruptions of Supply

There are three general sources of supply disruption: technical, human, and natural. Technical disruptions are caused by malfunctions in energy infrastructure such as pipelines, heating, or pumping equipment. Human disruptions include strategic withholding, underinvestment of capital, sabotage, terrorism, and political instability. Natural disruptions could come from resource depletion and natural disasters, such as earthquakes or hurricanes and typhoons (Winzer, 2012). These disruptions can be further categorized into short-term disruptions and long-term disruptions. Short-term disruptions often arrive unexpectedly and can occur from technical failures, strikes, political intervention, sabotage, accidents, and natural disasters. Long-term disruptions include underinvestment in crude oil, refining, or transportation capacity. Long-term disruptions could also come from political inefficiencies and market failures. It is important to understand that short-term and long-term disruptions are not mutually exclusive and are often related to one another. For example, underinvestment could limit options for shifting to other resources, causing vulnerability in the event of a short-term supply disruption (IEA, 2007).

The severity of supply disruption depends on a number of factors for the consuming country including the nature and size of the disruption, the type of fuel, how long the disruption is expected to last, and how much fuel the country imports. The disruption's impact also has to do with the resiliency of the country's economy (IEA, 2007). If a country has a competitive, well-functioning market, its economy will reallocate supplies according to ability to pay. In the long-term an increase in prices will encourage investment, which will eventually drive down prices. However, a country may have price controls or market inefficiencies that could prevent the market from adjusting prices to a new equilibrium based on supply and demand. Furthermore, a country could have insufficient infrastructure to shift the allocation of other resources or a regulatory environment that discourages investment. In short, disruptions come from various sources and the impact of a disruption has to do with its nature and the flexibility of a country's economy.

b. Responses to Disruptions

Governments have an interest in maintaining a healthy market since energy security is a public good in which everyone benefits. They use various policies in an attempt to either prevent energy disruptions or to mitigate the effects of a disruption. Preventive policies include developing strategic stockpiles, fuel switching capacities, subsidies to immature energy technology, and encouraging production in order to reduce dependence on foreign sources of energy. Mitigation policies might include reducing consumption, promoting substitution, rationing, and setting price ceilings. Governments can also use external policies such as making trade agreements with producing countries, forming economic cooperative agreements with other consuming countries, ensuring access to existing energy supplies and supply routes, and diversifying foreign energy supplies and supply routes (Duffield, 2015). As described in the upcoming section, the PRC has opted for a number of these approaches in its energy security strategy.

2. Chinese Energy Security Policies

The PRC's strategic objective has been to secure the energy it needed to power its rapidly growing economy. It has implemented policies to expand foreign sources of energy, diversify and secure energy shipment routes, and create a strategic stockpile.

a. Strategic Vulnerabilities

The PRC's oil fields are thought to have reached their peak, with their production starting to decline (Jiang & Sinton, 2011). This decline in production has not diminished China's appetite for oil. Demand will continue to grow, but not as drastically as it did in the early 2000s. To meet demand future demand requirements, China will continue to import more oil. The IEA predicts that China will import 83% of its oil by 2040 (IEA, 2017b). This growing reliance on imports leaves the PRC vulnerable to political instability within producer countries and to supply disruptions.

The vast majority of Chinese crude oil imports goes through two main chokepoints—the Strait of Hormuz and the Strait of Malacca. The Strait of Hormuz is the body of water through which 30% of all seaborne-traded crude oil passes, 80% of which flows to Asian markets, making it the world's busiest chokepoint for oil shipments (Energy Information Administration [EIA], 2017). Much of that oil continues through the Strait of Malacca, the world's second busiest oil shipment chokepoint. Figure 3 shows the percentage of oil that passes through the world's chokepoints each day. The PRC's unfavorable reliance on the Malacca Strait was called the "Malacca Dilemma" by former president Hu Jintao (O'Sullivan, 2017). Any disruption to that checkpoint would result in diversions through the Indonesian archipelago, adding extra days to deliveries and costs to shipments. The PRC's vulnerability to the Malacca Strait has encouraged it to diversify its shipment routes.

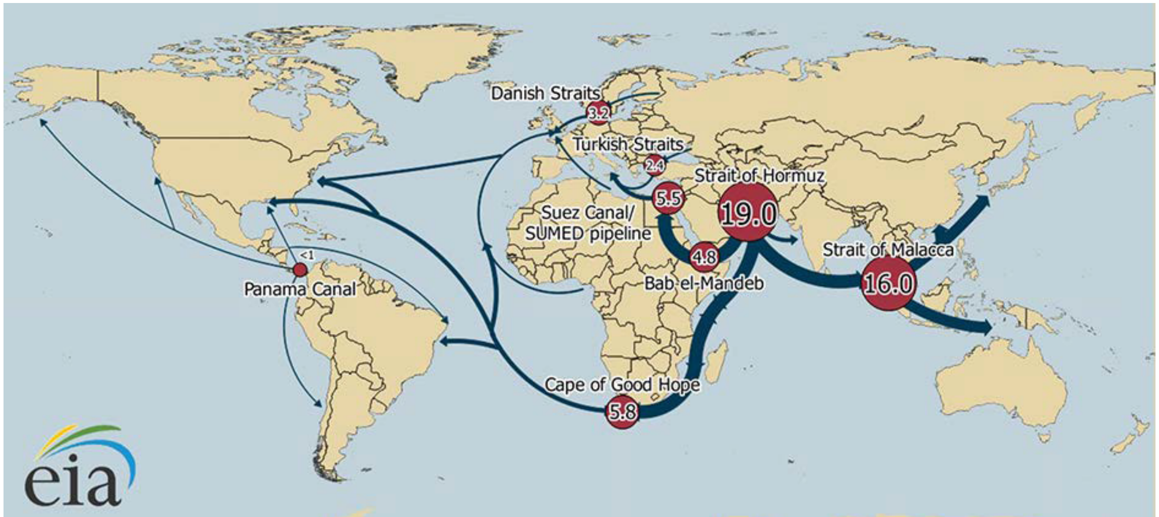

Figure 3. MMB/D Transit Volumes through World Maritime Oil Chokepoints, 2016. Source: EIA (2017).

As of 2013, 75% of Chinese oil imports came from the Middle East and Africa (Kennedy, 2015) whose shipments largely travel through the Indian Ocean and the Strait of Malacca. Sea routes along the Straits of Hormuz and Malacca, and the East and South China Seas are currently patrolled by the U.S. Navy and its allies. These patrols help provide stability to trade but leaves the PRC with a perceived vulnerability that the United States can easily shut down the same trade routes and chokepoints that it patrols. Outside of coastal areas, the PRC would not be able to protect its long energy supply chains.

b. Go Out Strategy

The PRC has encouraged the international expansion of its NOCs through the "Go Out" strategy. The expansion satisfies both national objectives and commercial opportunities. This expansion's national objectives include increasing oil and natural gas reserves, expanding production, and diversifying its sources of oil. Commercial opportunities for the NOCs include becoming into fully international companies, developing an integrated supply chain, partnering with other international oil companies (IOCs) to build relationships and diversify risks, and to gain technical expertise.

Large trade surpluses allowed the NOCs to seek energy sources outside of its country totaling $270 billion and included $90 billion in loans between 1992 and 2015

(IEA, 2017a). Overseas activity by NOCs have enabled 2.1 million barrels per day (MMB/D) in 2013 in overseas production (Jiang & Ding, 2014), up from 1.1 MMB/D in 2009 (Jiang & Sinton, 2011), and more than half of the 3.8 MMB/D domestically produced in 2017 (BP, 2018). The main targets of investment have been Kazakhstan, Angola, Russia, Canada, and Iraq. The NOCs are active in more than 40 countries.

Chinese NOC overseas production and equity in oil and natural gas allows the PRC to have a secure source of energy. However, it has been estimated that only 10% of NOC's upstream activities are shipped back to the PRC (Meidan, 2015). The locations of NOC upstream production have determined where the oil was sold. For example, in 2007, the majority of oil produced in Sudan and Indonesia was sold in the PRC, while the majority of oil produced in Ecuador was sold to the United States. In the case of Ecuadorean oil, it was more cost-effective to sell oil to the United States than to ship it back to the PRC (Downs, 2010).

c. Loan-for-Oil Deals

The NOCs have also been associated with the PRC's loan-for-oil and loan-for-gas deals. These agreements allowed the PRC to further diversify its sources. Notable deals have been made with Russia, Brazil, Venezuela, and Turkenistan. The first deal was between the Chinese Development Bank (CDB) and Russia in 2009. In this deal, Russia received $25 billion to help finance the East Siberia-Pacific Ocean Pipeline (ESPO) to the PRC. Russian energy company, Rosneft agreed to repay the loan to China National Petroleum Corporation (CNPC) by guaranteeing the NOC access to 300,000 barrels per day (MB/D) for 20 years. CNPC was to buy the oil at market prices and then transfer the payment through an account set up by CDB (Jiang & Sinton, 2011). Figure 4 illustrates this set up in detail and is an example of a typical loan-for-oil deal.

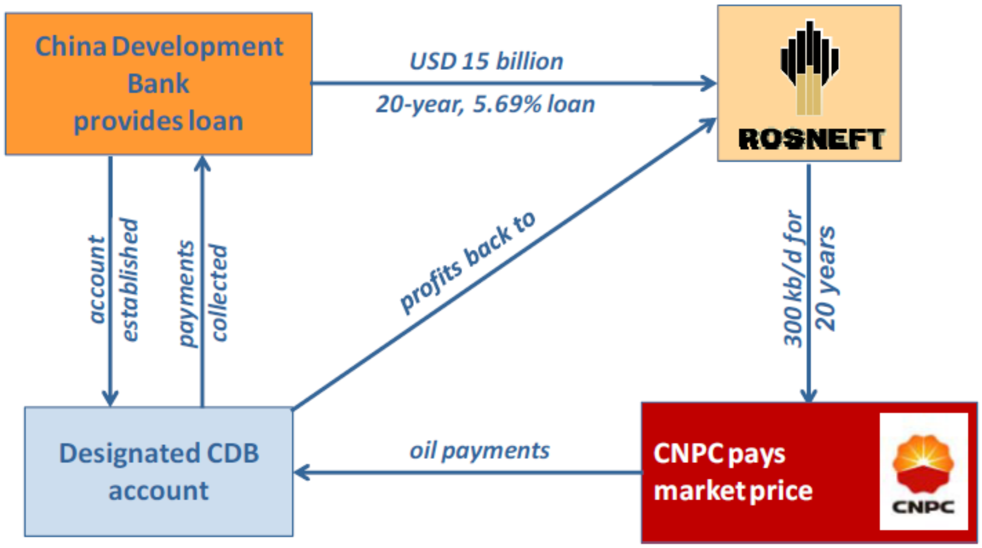

Figure 4. Sino-Russian Loan-for-Oil Structure. Source: Jiang and Sinton (2011).

d. Transnational Pipeline Projects

The PRC has sought to lessen its exposure to the Malacca Dilemma by financing pipeline projects that carry oil over land instead of by sea. These projects have occurred in all directions—China's west, north, and south. From the west, the PRC's first transnational oil pipeline came from Kazakhstan in 2006. It brought more than 200 thousand barrels of oil per day (KB/D) and has been doubled to 400 KB/D. From the north is Russia's ESPO pipeline, which came online in 2012. It sends oil from Tayshet to the port of Kozmino, where fuel can be sent to East Asia by sea. Russia can send 300 KB/D through the ESPO and plans to expand capacity to 1.6 MMB/D by 2020, including augmenting its pipeline to Skovorodino, on the Russo-Sino border. From the south, is an oil pipeline with a 440 KB/D from Myanmar. This supply from Myanmar will bypass the Malacca Strait (EIA, 2015). Figure 5 provides a map of oil and natural gas pipeline projects as of 2011. Another project the PRC has undertaken is a pipeline from Pakistan. This will run from Gwadar, Pakistan to Kashgar, in the Xinjiang region of the PRC.

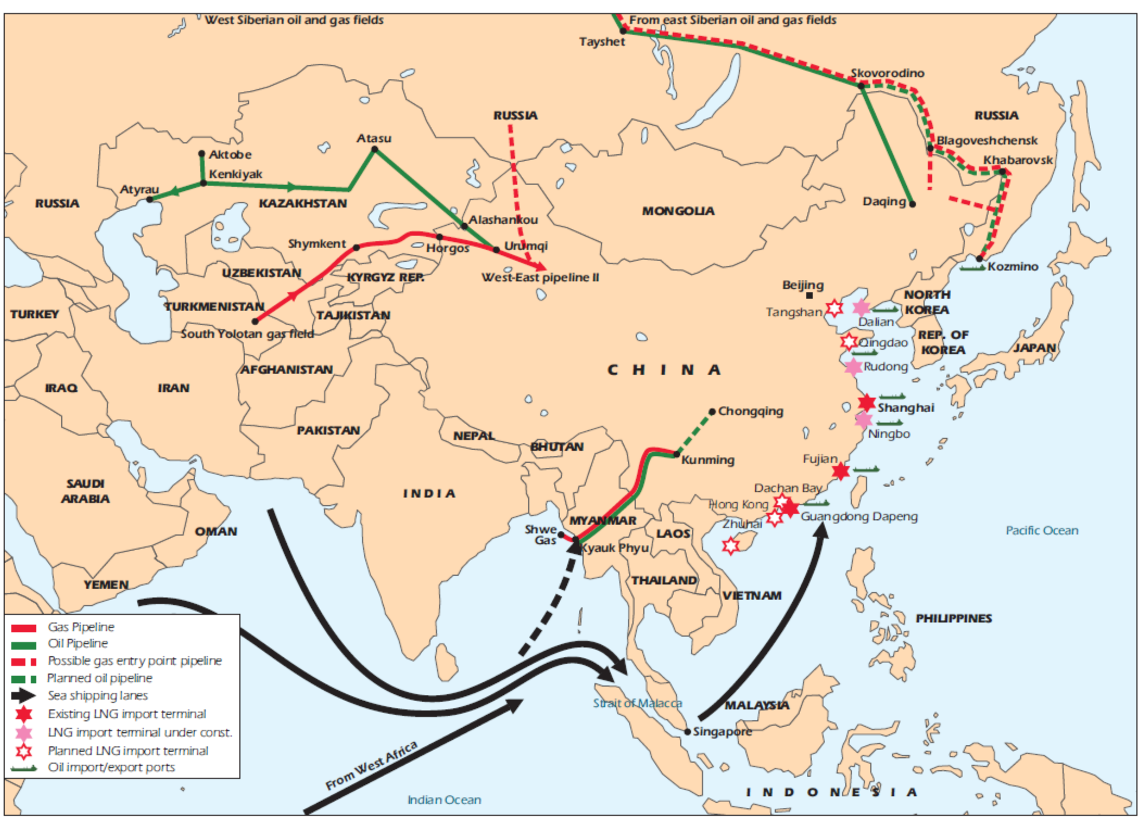

Figure 5. Routes for the PRC's Oil and Natural Gas Imports. Source: IEA (2011).

e. Expansion of People's Liberation Army Navy

Although the PRC has worked to diversify its crude oil suppliers and supply routes, it was estimated to still rely on the Strait of Malacca for 54% of 2015-level crude oil imports (Jiang & Sinton, 2011). These shipments will need protection at sea which helps explain why the PRC has focused on expanding its blue water navy. The PRC's naval modernization strategy has involved heavy spending in weapons acquisitions. These programs include submarines, fighter jets, surface combatant ships, and supporting command and control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) systems (O'Rouke, 2018). In 2012, the PRC commissioned the *Lionang*, a refurbished Soviet Union carrier bought from Ukraine. The PRC has increased its submarine force, cyber forces, anti-access/access denial abilities, and bought a refurbished carrier from Ukraine. Recently, it launched its first domestically built carrier for sea trials. This carrier, temporarily named Type 001A is expected to be fully operational by 2020 (Westcott & Lendon, 2018).

f. Strategic Petroleum Reserve

Similar to the IEA, whose countries agreed on creating SPRs to limit disruptions in oil supplies following the 1973 oil embargo, the PRC has decided to build its own SPR. An SPR would give the PRC an emergency source of oil that could alleviate domestic issues that result from short-term reductions of foreign oil imports. An SPR can be structured as either government-owned reserves, obligations imposed on domestic companies to hold reserves, or a combination of both.

The PRC's SPR is in the final phase of production. The National Bureau of Statistics placed the PRC's SPR at 233 million barrels in 2015 (IEA, 2017a). This volume is about one third of the United States' SPR and holds 28 days of imports at 2017 levels. This reserve amount may last longer as the PRC has taken advantage of low oil prices to help build its SPRs and the reported number of imports captures this buildup. When the SPR is completed it will hold 386 million barrels. The PRC was given an active IEA association status in 2015 but is not a member. To be eligible for membership in the IEA, one must be part of open-market, democratic state in the Organisation for Economic Co-Operation and Development (OECD), and subject to its economic cooperation policies. The PRC has not coordinated its SPR into oil sharing agreements with the IEA. Various energy experts have advocated Chinese cooperation with the IEA (Kennedy, 2015). Figure 6 displays the three phases along with each step's capacity on completion date. The IEA expects the SPR's phase three to be completed in 2020 (IEA, 2017a).

	Operator	Location	Capacity (mb)	Status	Completion	Type
Phase 1	Sinopec	Zhenhai	32.7	Filled	3Q06	Above ground
	Sinochem	Zhoushan 1	31.4	Filled	4Q07	Above ground
	Sinopec	Huangdao 1	20.1	Filled	4Q07	Above ground
	CNPC	Dalian	18.9	Filled	4Q08	Above ground
Phase 2	CNPC	Lanzhou	18.9	Filled	4Q11	Above ground
	CNPC	Dushanzi 1	18.9	Filled	4Q11	Above ground
	Sinopec	Tianjin 1	20.1	Filled	4Q14	Above ground
	Sinopec	Huangdao 2	18.9	Filled	3Q16	Rock cavern
Phase 3	Sinopec	Tianjin 2	20.1	Filled	2H16	Above ground
	Sinochem	Zhoushan 2	19.0	Filling	1Q17	Above ground
	CNPC	Jinzhou	18.9	Filling	1H17	Rock cavern
	CNOOC	Huizhou	31.4	Filling/being built	2018	Rock cavern
	Sinopec	Zhanjiang	44.0	Being built	2018	Rock cavern
	CNPC	Jintan	15.7	Planned	-	Salt cavern
	Sinopec	Yangpu	18.0	Planned	-	-
	CNPC	Shanshan	39.0	Planned	-	-

Figure 6. The PRC's Strategic Petroleum Reserve, Capacity in Millions of Barrels. Source: IEA (2017a).

3. Summary

Energy is an essential part of the PRC's economy and its security has become an important Chinese national objective. The PRC's increased reliance on oil imports will leave it vulnerable to political instability and to the global oil market. Countries have several tools to ensure energy security, including internal and external, and short-term and long-term policies. The PRC has used several of these in its strategic approach to oil including diversifying its foreign sources, diversifying its shipments, providing security to its sea lines of communication, and by creating a strategic reserve. Despite its best efforts, the PRC will remain reliant on the Malacca Strait and seaborne oil shipments.

C. NAVY PETROLEUM LOGISTICS DURING THE PACIFIC WAR

Rear Admiral (RADM) "Nick" Carter's (1953) seminal *Beans, Bullets and Black Oil* tells the story of the Service Force in the Pacific War during World War II. While War Plan Orange had been developed with a war against the Japanese in mind, the United States never fought a war so distant, with so little support from nearby areas. Most of the materiel used during the Pacific War to support American forces came from the United States, and industrial strength and incredible logistical capabilities sustained operations. RADM Carter (1953) developed the concept of the Service Force as a fleet full of supply and service support ships. This fleet would consist of diverse vessels such as oil tankers, distilled water tankers, provisions stores ships, assembly ships, destroyer tenders, aircraft tenders, repair ships, barracks ships, submarine chasers, ammunition barges, garbage barges, floating drydocks, hospital ships, and hydrographic survey ships (Carter, 1953). Simply put, the Service Force had a ship to support virtually any need for which the Navy could plan. By July 1945, 2,930 ships were assigned to Service Force support squadrons and more than 300 planes to its Utility Wing (Carter, 1953). The number of officers and enlisted assigned to this support element was 456,314, nearly one-sixth of all servicemen in the Navy at the time. RADM Carter commanded Service Squadron Ten in the Pacific War before retiring in 1947, and was recalled to active duty in 1949 to write *Beans, Bullets and Black Oil*, which was published in 1953. The Navy wanted to make sure that lessons from the war were not forgotten, and many of the logistic principles from the book are still in use today. The following are a few logistical themes from the book.

1. Geographical Factors and Force Structure Dictate Supply Chain Infrastructure

In the book's introduction, Admiral Spruance states,

> When we started planning in the summer of 1943 for operations in the Central Pacific, it was obvious that the geography of the area which we hoped to capture had characteristics very different from those of the South Pacific. We did not know how fast we would be able to move ahead, but we did know that in the Gilberts, Marshalls, and Carolines, many of the islands had splendid protected anchorages in the lagoons. However, the land areas surrounding the lagoons were very small. These islands were only large enough, as a rule, to enable us to construct the

> always necessary air strips and to take care of the requirements of the atoll garrison forces.… This geography meant that the logistic support for our fleet during operations in the Central Pacific would have to be primarily afloat, in what developed into the mobile service squadron. (Carter, 1953, p. XXXII)

Logistic requirements for the three operational areas of the Pacific War required three different supply chains. This had to do with the geographic characteristics of the areas and the forces in need of supply. The Central Pacific had very small islands with a lack of close allied support. It received its support primarily from service ships, supplemented by advanced bases. The Southwest Pacific, which had adequate land for bases and close allied support, received its primary support from Australia and New Zealand, supplemented by service ships as forces moved toward Leyte (Carter, 1953). The North Pacific, in the Aleutians, was the least developed supply chain due to the limited Japanese forces in the area. Service ships in that area had to reload from Seattle, San Francisco, and San Pedro, then shuttle supplies back to Adak and the Kodiak Islands (Carter, 1953). The Central Pacific receives most of the attention in *Beans, Bullets and Black Oil* due to the extensive logistics needed to support American forces.

2. Mobile Support and Forward Basing

The Navy used both mobile support and forward basing in its support force concept. There were two basic assumptions prior to the Pacific War, identified by Carter (1953), that were key to these developments: (1) The fleet would arrive in a battle area and any battle would be quickly over. Support ships would be merely used for resupply after the conflict. (2) Naval forces could secure an advanced base in the battlefield area which would need to be built up. Furthermore, if the ships were to leave the acquired base, it would be vulnerable to recapture. The first assumption advocated for forward operating bases over support ships as support ships would be used after the fight. The second assumption prompted planners to integrate support ships in battle plans.

Mobile support and forward basing each had tradeoffs. Mobile support allowed the Navy to bring support activities closer to the battle area and was quicker to set up than building bases. As Admiral Spruance noted, Central Pacific forces' island hopping strategy had few islands amendable to building bases (Carter, 1953). By having mobile support, the

Navy could have the same services offshore that forces could have on a base. However, support ships made easy targets for enemy submarines and were slow during transit. Carter (1953) describes Service Squadron Ten's move from Eniwetok to Ulithi involved ships transiting no more than 10, 15, or 20 knots in formation. The ships had to use zig-zag maneuvering in order to avoid submarine attacks, making actual transit speed six knots. The complicated move also required the squadron to mix up the ship composition within the three slow-moving convoys in case of an attack. While mobile support offered flexibility in a variety of offshore support services, it was comprised of slow, vulnerable ships in need of continuous protection.

In contrast, advanced bases were not limited to the size of support ships, meaning the Navy could have extensive facilities, if the island could support it, but the useful life of each base was limited. Bases usually offered more repair facilities, more fueling availability, and more berthing accommodations than what could be provided by support ships. Moreover, bases allowed for large runways, key to landing planes that expeditiously brought high-priority supplies into the area. The downside to bases was that as the Navy moved further into Japanese territory, their usefulness declined and other bases had to be built. Early bases such as Marianas, Palau, Kwajalein, and Ulithi all gave way to newer bases like Leyte, Kerama Retto, and Okinawa (Carter, 1953). Resources had to be transferred to new bases, drying out older base resources and abandoning expensive infrastructure.

3. Planning Resources and Demand-Based Logistics

RADM Carter (1953) characterized the Guadacanal campaign as risky in *Beans, Bullets and Black Oil* because the logistics support at the time was minimal. There were several disadvantages: a lack of knowledge and experience in logistics planning, a limited service staff, far apart bases, insufficient port handling and storage facilities, little time to prepare details for the attack, and not enough repair facilities to fix ships. Production of support ships could not keep up with combatant ships early in the war, which increased mission risk due to strained logistic capabilities. Following the Guadalcanal campaign, the

Navy responded with a rapid expansion of support ships to fill the sustainment gaps identified during the costly and precarious victory over Henderson Field.

Initially, as Carter (1953) explains, the Navy's lack of demand planning led to pushing as much materiel forward as possible, which caused excess piles of some commodities and critical shortages in others. Due to shortages, Carter says that sailors in Guadalcanal who escaped sinking ships were often without clothes and beds to sleep in until the Navy was able to procure clothing and cots from the Army. Operational staffs, he further explains, were also undermanned in logistics planners at the start of the war. As a result, material was on a "push" basis, meaning stores would be sent to forward bases and afloat units without considering the specific need for particular stores. Warehouses were overwhelmed and materiel was often shipped to the wrong units. As staffs increased, Navy logistics moved toward a "pull" model, where material was sent as a result of a request or forecast that specified the required supplies. This allowed the Navy to become more efficient in supporting deployed units (Carter, 1953).

Due to uncertainties, planners had to develop estimates to determine how many service ships would be needed for an operation. *Beans, Bullets and Black Oil* gives details on how operational logistic figures were developed. To determine the number ships, the planners estimated the service and supply requirement for the theater along with determining the holding capacity of the ships and expected losses due to enemy action. By the time of the Okinawa campaign, logistics requirements were estimated at planning conferences with Service Force representatives and supply officers in regional areas. Planners at these conferences made estimates, checked these estimates with on-hand stock at staging areas, and submitted requisitions for any shortages that were found. This planning was made possible by the increased logistics resources and experienced gained throughout the war (Carter, 1953).

4. Fuel Resupply Points and the Shuttle Ship Concept

As described by Carter (1953), at the start of the war, minimal repair capability and fuel support were available in the Pacific, which limited the responsiveness of the Navy's supply chain. Battleships damaged in the Pearl Harbor attack had to be sent to San

Francisco for repair and resupply. The transit time required for these battleships to return to the fight made them unavailable during the Battle of the Coral Sea. They were loaded up and were made battle ready but by the time they returned, it was too late; the battle was already over. After running low on fuel, the battleships had to return once again to San Francisco. This back-and-forth maneuvering was put to rest once the Navy brought in more support ships.

Navy-owned tankers were kept close to the battle with commercial tankers shuttling fuel from the United States to forward bases. *Beans, Bullets, and Black Oil* explores how tankers and fuel service points were moved depending on the battle. Bases and tankers would report their fuel supplies to the area petroleum office of Commander, Service Pacific (COMSERVPAC), who would arrange refueling at specific times and considering the latest operational plan. Fuels were shipped starting at the western continental United States or from the Caribbean, transiting through the Panama Canal. These tankers would then drop off fuel in ports like Hawaii, Guam, or Saipan. Area fuel service points changed depending on the operation. For example, fuel service points required to support landing operations on Leyte Gulf were different from those used in attacks on Formosa or Okinawa. The Navy was able to augment their capacity to deliver fuel to deployed forces by using chartered ships on lower risk supply routes and by creating fuel service points unique to the operational area (Carter, 1953).

Beans, Bullets, and Black Oil identifies how the Navy was able to effectively integrate the operation of chartered ships with Navy owned-tankers during the war in the Pacific. Chartered tankers were used to consolidate their fuel with stationary tankers located near the combat ships in naval operating areas. The chartered tankers served as a shuttle for the fuel that was transferred to the Navy-owned station tankers in the station ship–shuttle ship concept. The station tankers served as the fuel supply point for the combat ships through a method called underway replenishment (UNREP). The fuel was passed at sea using hoses that linked the two ships as they move in tandem. UNREPs were considered risky and were rarely used prior to the war in the Pacific. However, during the war, UNREPs became the primary means of resupply for combat ships and were a critical enabler (Carter, 1953).

5. Time as a Wartime Priority Consideration

A primary basis for logistics planning is timeliness. The placement of advanced bases and mobile support near the battle area, the employment of the station ship-shuttle ship scheme, and the establishment of fuel service points were all designed to shorten resupply times. These shortened resupply times helped Allied combatant ships to stay in the battlespace longer, giving them an advantage over Japanese forces. Timeliness during the Pacific war was prioritized over economic efficiency. RADM Carter (1953) highlighted the importance of time being more important than efficiency in war, when he said,

> For war, with its necessity for quick results, a simple, easily comprehended organization is best, especially when inexperienced young men must be used to accomplish the required rapid expansion. No claim is made that such an organization would be the most efficient and economical for peace. Doubtless, in several respects, efficiency experts would be horrified, especially if this organization were applied to an industrial establishment intended to bring the greatest possible return in dollars. This was for war, however, and in war, time is of such value that it must be given priority over many other considerations. In war the teams are made up of many young men mostly strange to the business at hand, whether it be a supply mission or combat. Therefore, the simpler the team organization, the less time lost in learning it and in executing the mission. War is never economical, but always wasteful of material and men. To be successful it must not be wasteful of time! (p. 302)

6. Lessons from *Beans, Bullets, and Black Oil*

The themes explored in this literature are only a few showcased in *Beans, Bullets and Black Oil*. RADM Carter (1953) does a thorough job describing the operational conditions and how they were complemented with logistics capabilities. The support ship platform was a concept that gave the Americans an enormous tactical advantage. By having much of the base capabilities offshore, the Navy was not limited to the geography ashore. Each time the Navy moved further into Japanese territory, it used a mix of both mobile support and advance bases. Carter (1953) thought while Navy logistics support was limited in Guadalcanal, it was not a limiting factor in the following battles after the number of support ships and logistic staff planners increased. Additionally, commercial ships increased logistics capabilities, serving as shuttle ships for navy tankers. The navy used tactics such as the station ship-shuttle ship concept and replenishments at sea to shorten resupply times for the warfighter (Carter, 1953).

Beans, Bullets and Black Oil was written to capture the many successes and failures seen by the Navy during the Pacific War. The war lasted over three years and eight months, and involved thousands of ships being supported by logistical lifelines thousands of miles away. Just to give an example of the height of operations—during one 13-day period late in the war, the Navy transferred 27 million packs of cigarettes and 1.2 million candy bars to ships in the Pacific (Carter, 1953), numbers sure to bring a smile to any logistics planner reading this book!

D. DEFENSE FUEL PROCUREMENT AND TRANSPORTATION

This section describes the DoD's bulk fuel operations and DLA-E's management of bulk fuel. Combatant Commands (CCMD), with the aid of the JPO, consult subordinate commands to determine their fuel requirements and then send those requirements to DLA-E. DLA-E procures and provides transportation, storage, and distribution of bulk fuel and works with United States Transportation Command (USTRANSCOM) to support fuel delivery requirements and with MSC to provide maritime transportation. MSC uses commercial transportation sources to move refined products from refineries to storage facilities and a finite number of tankers are available to fill this requirement. The DoD is exposed to supply chain risk due to its reliance on commercial sources, so better understanding how the DoD procures energy and carriage will give military leaders and planners an opportunity to mitigate that risk.

1. Bulk Petroleum Organization

The DoD operates worldwide and each military service has its own unique fuel requirements; this complex dynamic makes the DoD's fuel management process a logistical challenge. This logistical challenge is solved by many entities with coordination among all DoD agencies and each of the military services. Joint Publication 4–03 (Joint Chiefs of Staff [JCS], 2017), *Joint Bulk Petroleum and Water Doctrine*, defines the following roles and responsibilities:

> The Under Secretary of Defense for Acquisition, Technology, and Logistics (USD[AT&L]) is responsible for establishing the policies for management of bulk petroleum stocks and facilities and for providing guidance to other DoD agencies, Joint Staff, and Services.
>
> Chairman of the Joint Chiefs of Staff coordinates with DLA-E, Services, and CCMDs to resolve petroleum issues. Key responsibilities include:
>
> 1. Act as the focal point for joint bulk petroleum doctrine.
> 2. Make recommendations to the DoD on wartime fuel sourcing and prepositioning days of supply (DOS).
> 3. Prescribe CCMD procedures for reporting bulk petroleum.
> 4. Provide fuel input to the Joint Strategic Capabilities Plan and review fuels planning in prescribed joint operational plans.
>
> Component commands determine bulk petroleum requirements for submission to the JPO or Sub-Area Petroleum Office (SAPO).
>
> The JPO or SAPO consolidates and validates the requirements for planning and support purposes, and provides these requirements to DLA-E for sourcing, analysis, and development of a support plan.
>
> USTRANSCOM plans for and provides air, land, and sea transportation of fuels for the DoD. MSC is a subcommand of USTRANSCOM and provides the maritime transportation. (JSC, 2017 p. V-1)

DLA-E manages sources of energy for the DoD including jet fuels, automotive gasoline, heating oil, lubricants, coal, natural gas, electricity, alternative fuels, and missile fuels (Defense Logistics Agency [DLA], 2017). DLA-E is organized so that each mission area is covered by a specialized group. These groups are as follows:

> *Bulk Petroleum Products and Bulk Petroleum Supply Chain Services* provide procurement and distribution of military specification petroleum products.
>
> *Direct Delivery Fuels* manages commercial fuels that are delivered directly from the contractor to the customer.
>
> *The Defense Fuel Support Point Management* manages fuel terminal and storage operations, including government-owned, contractor-operated and contractor-owned, contractor-operated facilities. (DLA, n.d.)

2. Planning Process

As discussed in the Joint Publication 4-03 (JCS, 2017), planning for energy requirements occurs at both the strategic and operational levels to ensure resiliency of the energy supply chain. The JPO is the lead developer of the petroleum logistics support plan for each services CCMD. The JPO's operational planning team, which includes members from the three component commands and DLA-E, consolidates requirements and build a concept of support. Then the CCMD feeds its requirements for planned operational stock (POS), recommended storage projects, and required pre-positioned war reserve requirements (PWRR) to DLA-E. DLA-E will then turn its requirements into an inventory management plan, which is used for the following purposes (JCS, 2017 p. III-2):

- Determining authorized inventory levels for the fiscal year and building storage data for defense fuel service points (DFSP)
- Building working capital funds budget requests for POS and PWRR
- Deciding whether to use military construction (MILCON) or contracted storage

3. Fuel Contracts

Fuel sourcing can come from several different types of contracting vehicles to support the DoD's unique requirements. The DoD uses four main types of fuel that DLA-E procures (Table 2). The main types of contracts for bulk fuel are the blanket purchase agreement (BPA), into-plane/into truck, and bunker contract (JCS, 2017). Each contract type is used for different circumstances.

Table 2. Main Fuel Sources Used by the DoD. Adapted from DLA-E (2017).

Fuel Type	Description of Fuel
JP5	High flash jet fuel used shipboard by the Navy
JP8	Kerosene based jet fuel comparable to commercial jet fuel
Jet A1	Commercial jet fuel with additive
F76	Naval diesel fuel

A BPA is typically used for anticipated or repetitive needs. DLA-E's Bulk Petroleum Products and Bulk Petroleum Supply Chain Services solicits proposals from suppliers and awards contracts based on lowest price technically acceptable offer to the government. Most bids are awarded for indefinite delivery/indefinite quantity of fuel for a fixed period of time (DLA, 2017). These contracts are firm-fixed price contracts with an economic price adjustment. DLA-E charges a standard price to its customers based on the cost of fuel over the previous 18 months (DLA, 2017). BPA contracts guarantee a quality product that will be delivered within the contracted period of time and to the location specified in the contract (DLA, 2017). The use of a BPA requires planning and coordination of transportation to ensure the fuel is delivered to where it is needed.

Into-plane/into truck contracts support fuel requirements at locations not supported by BPAs and where commercial support is available (JCS, 2017). The into-plane contract gives a unit the ability to procure fuel from a commercial source available at airports. Specific quantities and types are subject to local availability, such as jet fuel A1 instead of JP8. The Aviation Into-Plane Reimbursement (AIR) card can be utilized at civilian airports when into-plane contracts have not been established. Into-truck contracts are similar to into-plane contracts but can be used to fill the different military or contractor vehicles for distribution to customers. These contracts utilize established commercial resources while meeting non-aircraft requirements (JCS, 2017).

Less frequently used contracts are the DLA-E Bunker contracts; Direct Delivery; and Post, Camp, and Station (PC&S) contracts (DLA, 2017). These types of contracts allow the government to receive fuel when there are no available United States government–owned stocks (DLA, 2017). The Ships' Bunkers Easy Acquisition (SEA) card can be used to order fuel online under DLA's bunker program (DLA, 2017). PC&S contracts account for a small portion of total fuel purchased and are not intended to support a full operation (DLA, 2017). However, they can be used for emergent requirements and during limited operations before a BPA contract is created. Once the fuel is requisitioned, the next hurdle is transporting the fuel from the refinery to storage and distribution centers.

4. Transportation

The movement and distribution of fuel is accomplished through a joint effort involving the CCMDs, service components, and DLA-E. DLA-E coordinates the movement of fuel with MSC when the bulk fuel is for locations outside of the operational area (JCS, 2017). MSC provides maritime transportation from refinery to storage and distribution centers, as well as providing transportation and delivery to United States Navy combatants and coalition force ships (MSC, 2017). MSC must maintain a sealift capacity set by DLA-E and meet the DoD's dynamic and frequently changing requirements. MSC's tanker schedules and tanker utilization are based on DLA-E's lift requirements, which are governed by DFSP inventory levels driven by CCMD consumption and requirements that stem from DLA-E's refinery and commercial DFSP contracts.

MSC has control of five time-chartered tankers: MT *Empire State*, MT *Evergreen State*, MT *Maersk Peary*, MT *SLNC Goodwill*, and MT *SLNC Pax* along with one MSC owned tanker, USNS *Lawrence H. Gianella*, in the ready reserve fleet and four tankers that are retained but not ready for sea (MSC, n.d.). MSC is limited in the use of government-owned tankers by laws and regulations that require the chartering of U.S.-flagged privately-owned ships (Table 3). The result of these acts has left MSC dependent on chartered tankers to support bulk fuel delivery. During fiscal year 2017, MSC lifted 31.9 MMBBL (1.49 billion gallons) of DoD petroleum products over 197 voyages for the DLA-E (MSC, 2017). MSC-controlled ships are not enough to fulfill all the DoD's requirements, which requires supplementing the tanker schedule with numerous short-term voyage and time-chartered commercial tankers.

Table 3. Laws and Regulations. Adapted from Federal Acquisition Regulation (FAR) (2018, 47.502).

Laws	Regulations
Military Cargo Preference Act of 1904	States that 100% of military cargo must be carried on U.S. flag and owned vessels at current rates if available.
Cargo Preference Act of 1954	States that at least 50% of cargo purchased or financed by the U.S. government must be carried on private U.S. flagged vessels.

5. Chartered Tankers

The charter market is complex and integral to the movement of energy through the Pacific. MSC uses both U.S.-flagged and foreign-flagged vessels for short-term voyage and time-chartered commercial tankers. Each type of contract has its own set of unique characteristics and the contracting officer will take these into account these when determining whether to use a time or voyage charter to fill DLA-E's movement requirement. According to MSC personnel (personal communication, October 4, 2018) several factors shape the type of contract that MSC uses and the following is a list of the major considerations:

- **Length of requirement:** Voyage charters are used for emergent cargo lifts to a specified destination. Time charter contracts are used for requirements over a period of time that gives MSC more flexibility.
- **Sovereign immunity concerns:** The DoD considers the planned operating areas when determining the type of charter to use. In certain areas it is to

the DoD's advantage to have a claim of sovereign immunities over the vessel, crew and its cargo when using time-chartered vessel. In other areas, the DoD may not need or want to use sovereign immunity and the status of forces agreement (SOFA) to cover the vessel and the crew, at all times the cargo has a claim to sovereign immunity.

- **Operational Control, force protection, and unusual requirements:** The DoD may prefer time charters when it wants to exercise some operational control over the vessels or impose strict force protection measures. Time charters may also be preferred if the DoD wants the vessel to have a non-commercial attribute (e.g., Consolidated Cargo exercise, or Chemical, Biological and Radiological Defense Protection) since vessel owners are more willing to make vessel modifications for long-term commitments.

- **Market considerations:** In a market where assets are tight or hard to procure, long term charters may be sought to ensure MSC has the required capacity to support bulk fuel delivery requirements. (personal communication, October 4, 2018)

In order for MSC to manage which vessels are utilized, MSC works through brokers to source ships and to negotiate charter party requirements with vessel owners. The usual time required to complete a charter contract is 21 days but MSC has procurement processes to solicit tankers within hours, if necessary (e.g., war, humanitarian assistance/disaster relief; MSC personnel, personal communication, October 4, 2018). Additionally, MSC may request requirements with longer lead-times if the market is tightening, or hold onto requirements for days or weeks if the market is expected to loosen. MSC does not include a war cancelation clause within their charter parties, this requires a chartered vessel to perform during war and sail into zones of unusual hazards (MSC personnel, personal communication, October 4, 2018). Ship owners are required to have war risk insurance in addition to membership in property and indemnity association to fully protect the government from loss (MSC personnel, personal communication, October 4, 2018).

Chartering tankers is a complex and time-consuming process, made more challenging when tankers fail to respond to solicitations. MSC meets transportation demands through long term, short term, and voyage charters. However, a contingency may strain this process and limit the DoD's ability to get fuel to storage locations in the INDOPACOM AOR.

6. Storage

DLA-E is the integrated materiel manager for energy commodities and services which includes the DFSP. DLA-E monitors and manages the DFSP's stocking levels and working with carriers to provide deliveries of fuel to units. DFSPs are strategically placed throughout the world to reduce costs and time associated with moving inventories. Christopher Goulait (2015) reported that, "storage in the Pacific, including the commercial storage, is made up of 850 million gallons of prepositioned war reserve stock in 66 DFSPs and facilities with a storage capacity of 1.2 billion gallons of fuel." Locations of these fuel stocks include Hawaii, Alaska, Korea, Japan, Guam, Singapore, Diego Garcia, and the Philippines among other locations (Goulait, 2015). These fuel supply points give INDOPACOM the capability to support a variety of operations; however, in a contingency these DFSP are vulnerable to attack. The loss of just a few DFSPs could cripple the DoD's capabilities and place more reliance on commercial tankers to get large volumes of fuel to new and temporary storage facilities.

7. Distribution

Final delivery involves the components attached to a joint command and covers the movement of refined petroleum products from storage and distribution facilities to the end users. JCS (2017) describes duties and responsibilities for the individual services:

> The United States Army normally provides management of overland petroleum support, including inland waterways, to United States land-based forces of all DoD components.
>
> The United States Air Force (USAF) maintains the capability to provide tactical fuel support to USAF units at improved and austere locations. It also provides distribution of petroleum products by air where immediate support is needed at remote locations.

> The United States Navy (USN) provides seaward and over-the-shore petroleum products to the high-water mark for United States sea-based and land-based forces of all DoD components. The USN maintains the capability to provide petroleum support to naval forces afloat, to include United States Coast Guard forces assigned to the DoD, and ashore.
>
> The United States Marine Corps maintains a capability to deliver bulk petroleum support to its units. (JCS, 2017 p. xiii)

8. Summary

The DoD fuel supply chain is complex and has many different entities working together to ensure that the DoD has its fuel at the right time and location. Within each of those entities, there are a lot of variables that must be considered from the beginning to the end of the supply chain. If any of these areas or variables are disrupted, either through natural disaster or some variation of a contingency, then the whole supply chain will have to adjust. This adjustment could lead to depleting the current bases of supplies or not having the required fuel on time, potentially hindering or stopping current operational commitments or future plans.

The fast pace and long reach of modern military weapons may deny United States forces space and time to build up large bases of supplies. The DoD has a limited amount of tanker assets in the strategic fleet that are used to support global operations. Although MSC has long-term chartered vessels to support the shipment of fuel, it does not have the capability to ship all of the currently required fuel. If a contingency arises, the additional fuel needs will widen the gap between MSC's current capabilities and the requirement. Additionally, it may take a significant amount of time to get the MSC-owned tankers ready for sea and into the rotational fleet. These two factors will in turn increase the requirement for commercial clean shipping. The world tanker fleet is always trying to balance expected supply with demand, so large shifts in requirements will result in competition for the limited assets that are capable of moving jet fuel; if MSC is not able to find charters to fill those requirements, it could lead to shortfalls in the DoD fuel supply chain.

E. DEFENSE INFORMATION TECHNOLOGY AND PETROLEUM PRODUCT SUPPLY CHAIN MANAGEMENT

In order to manage the DoD's petroleum product supply chain, several systems are used but enterprise architecture is racing to catch up with joint information needs. In the past, the Pacific Fleet (PACFLT) and other branches had started to develop and commission ad hoc IT systems built to meet unique service requirements. PACFLT developed a logistics common operating picture (LOGCOP) system that provided logistics information to subordinate planners to be used in the analysis of logistics supportability of OPLANs (Burke, 2009). In general, a LOGCOP is used to keep a shared picture of the current status of logistics and supply in a specified geographic area. PACFLT's LOGCOP was a web-based application that resided in the cloud on the secret internet protocol router network (SIPRNet; Burke, 2009). In 2014 Defense Information Systems Agency (DISA) received a favorable acquisition decision memorandum and an approved acquisition program base line that allowed the building of a joint logistics IT system (Defense Acquisition Management Information Retrieval [DAMIR], 2016). DISA is using an iterative process to build and design the new system to bring together disparate sources of data under DISA's enterprise architecture, giving planners and logisticians a one-stop shop for information (DAMIR, 2016). Although the DoD's information systems are developing significant capabilities, most information sharing and research is done through manual and personal communication methods. This often results in an information lag as data is manually collected, reports are manually populated, and slides or spreadsheet based LOGCOPs are briefed to decisions makers.

1. Global Combat Support System–Joint

The Global Combat Support System–Joint (GCSS-J) enterprise architecture is designed to be a single source for logistics data for joint planners and staff. GCSS version 8.2 has been launched and is deployed to joint users, improving the information available to logisticians (Defense Information Systems Agency [DISA], 2017). The web-based system is accessed on the SIPRNet using a browser to give users access to near real-time information (DISA, 2017). GCSS-J allows logisticians at the joint and component levels to connect and share information with the services and supporting agencies (DISA, 2017).

GCSS-J is used to gather and disseminate information on the DoD's fuel supply chain giving the JPO, components, MSC, and DLA-E a shared picture of the fuel LOGCOP. Logisticians using GCSS-J have access to energy information to include bulk fuel contracts, worldwide refinery capabilities, seaport information, and port schedules (DISA, 2017). Additionally, GCSS-J has information that is critical to the managing of the DoD's fuel supply chain, where logisticians have access to fuel Inventory management plan, bulk fuel inventory levels of DFSPs, and war reserves levels.

2. IT Systems Used by MSC to Manage Tankers

The MSC tanker project office utilizes mostly non-classified internet protocol router network (NIPRNet) based messaging systems like email, spreadsheets, and other shared reports (personal communication, 2018). MSC stated that it does not use an automated identification system (AIS) to support tracking of charted vessels in real time because MSC may have ships disable AIS reporting for operational security concerns. The principal report that MSC receives for updated chartered ship status is the daily noontime report, which is received over NIPRNet, contains current positions, weather conditions, and other voyage-related information. Additionally, the primary communication between MSC, tanker brokers, and DLA-E occurs via email and over the phone. Currently MSC does not subscribe to any market intelligence products like Information Handling Services (IHS) Sea-web or Maritime Research Inc. databases, but it uses data from ship brokers, classification agencies, and internally produced reports and tanker performance data to conduct market research and make source selection decisions.

3. LOGCOP at the Operational Level

The activities of the Joint Logistics Operation Center (JLOC) and component-levels operation centers are focused on keeping an updated LOGCOP. This LOGCOP is manually updated with Microsoft PowerPoint slides and spreadsheets prior to briefings or before being posted on web portals. Information contained on a fuel LOGCOP is primarily focused on fuel requirements, fuel levels, fuel delivery schedules, and fuel infrastructure status. The majority of the fuel data collection is labor intensive and consists of staff officers collecting data from emailed reports, meetings, and phone conversations to determine the status of the fuel supply chain. This often requires personnel to comb through reports like the Army’s logistics status update (LOGSTAT) or the Navy’s Operational Report-Five (OPREP-5) to get updated fuel status from the military units attached to the command. This data is then transferred to other information portals to build a LOGCOP, like GCSS-J, that is used at the CCMD and DLA-E to make decisions. Since the majority of the data is populated manually at a specified time schedule or battle rhythm events there is a significant lag in the flow of information, resulting in leadership not having accurate information to make decisions. One of the authors had experience in the logistics readiness center (LRC) of a joint command, and this experience was used to document the information practices cited in this section.

III. LITERATURE REVIEW

The purpose of this literature review section is to familiarize the reader with the research that is representative of what has been published. It begins with a brief summary of how *Beans, Bullets, and Black Oil* (Carter, 1953) relates to this project. Continuing, it includes an overview of research on models used to ensure that INDOPACOM has the energy it needs and energy in the right places for future conflicts.

A. *BEANS, BULLETS, AND BLACK OIL*

Beans, Bullets and Black Oil covers the development of operational logistics and helps planners conceptualize how forces could be sustained in the INDOPACOM AOR. One of the key enablers that the Navy developed during the war in the Pacific was the use of chartered shipping to augment organic lift, although RADM Carter does not discuss how sources were selected or the various types charters that were used. Due to the lethality of modern naval forces, the next conflict may not allow for the buildup of logistics capability over long periods of time. A flexible and responsive supply chain will be needed to project power and dominate the Pacific in the next conflict.

B. OPERATIONS RESEARCH MODELS

The operations research (OR) community has built models to help commanders and planners get the information they need to make better decisions. Many of these models have been focused on the energy supply chain and its ability to meet the demands of a potential conflict in the INDOPACOM AOR. These models are capable of delivering powerful and relevant information to the military planners by offering them critical insights into the sustainability of the operations they are planning. This portion of the literature review summarizes three of the models.

1. Fleishchmann's Pacific Tanker Delivery Model

Fleischmann (2013) developed the Pacific Tanker Delivery Model (PTDM) to optimize fuel deliveries to military operations by minimizing shortages at the DFSP. A notional OPLAN was developed for a scenario located in the INDOPACOM AOR to give the model demand requirements. To meet this demand, the model used supply nodes of fuel coming from refineries where tankers would transport the fuel to DFSPs spread throughout INDOPACOM AOR. Once the notional demand data was input into the model along with the refineries, DFSP capacities, and MSC tanker assets, Fleischmann established a baseline for all refineries and tankers operating in the Pacific. Fleischmann then ran simulations to determine the impact of losing refineries and MSC tankers. The PTDM showed it was able to reduce shortages by optimizing deliveries and estimate the amount of unmet demand resulting from the loss of refiners and tankers.

The PTDM established a valuable model to optimize bulk fuel deliveries, but it did not address all assets that the DLA-E would use to deliver fuel. The tankers used in the model were MSC assets that were either owned or under long-term charters (Fleishchmann, 2013). By only modeling the tankers directly controlled by MSC, Fleishman did not look at voyage charters for the direct delivery of fuel by barge or tanker. Voyage charters would need to play a key role in getting fuel from the refineries to the DFSPs or the military end user.

2. Rodgers's Bulk Fuel Supply Chain Model (BFSCM)

Rodgers (2015) built upon the work started by Fleischmann and others by bringing greater focus on the capabilities of the refiners and how they can impact the flow of fuel to a potential conflict. The model accomplishes this by assigning penalties for not meeting demand or for not maintaining safety stock. The Bulk Fuel Supply Chain Model (BFSCM) seeks to minimize the penalty by moving product from the supplier nodes to the DFSPs that have simulated demand. Rodgers did not focus on specific refiners but looked at the capability of energy producing countries or regions and limited how much product was available by adding notional production capability to each supply node. Rodgers then used the model to find where fuel should be acquired, and to which DFSP the product would be delivered. The study then ran simulations with varying levels of starting inventories and days available for buildup, and turned on or off different regions of suppliers. Rodgers (2015) found, as expected, that faster supplier response times were correlated with higher flows of fuel through DFSPs. This highlights the critical enabler that the clean tankers provide to the DoD’s energy supply chain.

The BFSCM did not develop criteria for identifying suppliers and assumed unlimited transportation would be available (Rodgers, 2015). Rodgers developed a model capable of providing actionable information if the data in the model is accurate. However, the study left developing criteria for evaluating suppliers of petroleum products to future projects, and used notional data for his simulations. If supplier selection criteria and expected refinery capability were fully developed, this would be a valuable tool to rationalize the supply chain base. The BFSCM assumed if a shipment of fuel was ready and a DFSP had demand then there was a tanker available and in port. This model showed, even with perfect coordination and immediate availability of tankers, an optimized network can still fail to meet demand.

3. Beaumont’s Network Optimization Model

Beaumont (2017) built on Rodgers’ (2015) BFSCM to give more fidelity to the model’s output. The study used design of experiments (DOE) and sensitivity analysis to better understand inventory levels and which suppliers are critical to supply chain responsiveness. Through sensitivity analysis he identified additional factors that better accounted for the complexity of the energy supply chain. Using these factors, the model utilized the Random Forest Machine Learning Concept to determine which suppliers were the most important. The model’s solution gives planners critical information for constructing a supplier development plan and the rationalization of the supply base.

Beaumont’s (2017) model took several steps further by allowing planners the ability to understand how uncertainty in fuel distribution can impact operations. Even though the model can identify which suppliers would be critical to sustainment during a conflict, it does not help with identifying which suppliers would likely be available. Additionally, the model only accounted for the capacity and duration of transportation, and not the availability of transportation. While the model achieves a greater understanding of the impact refiners have on the supply chain, the availability of transportation between nodes was not addressed (Beaumont, 2017).

C. SUMMARY

While there are studies and models on how the military can build resiliency in the fuel supply chain, there are gaps in looking at the sourcing of tankers during a contingency. This study will fill this gap by focusing on the transportation of fuel, and the development of criteria to identify suppliers of transportation services that would likely be available during a potential conflict in the INDOPACOM AOR. Regardless of where the fuel is sourced, it must be moved to the DFSP and ultimately to the unit in need of the energy. By looking at transportation suppliers, INDOPACOM can estimate the amount of fuel they are able to move in the AOR. The selection criteria could be used to help forecast the amount of tanker support INDOPACOM can expect to receive.

IV. METHODOLOGY

This chapter explains the methodology used in this project. It will explain how the data for this project was extracted, the models from which the simulations were run, and the limitations and assumptions of the simulations. The first model was used to simulate the worldwide charter market, while the second model was to simulate the East Asia charter market.

A. DATA EXTRACTION

Fedbizopps.gov (FBO) was used to access MSC contract solicitations, known as requests for proposals (RFPs). These RFPs were used to determine an acceptable charter tanker profile. Information Handling Services (IHS) Markit databases were used to extract data on both the worldwide tanker market and the East Asia tanker market.

1. FEDBIZOPPS

FBO is the government-wide point of entry (GPE) for all federal contracts greater than $25,000. It contains synopses of proposed contract actions, solicitations, and associated information (FAR, 2018, 2.101). Government agencies use FBO to advertise procurement requirements and businesses utilize it to search for contracting opportunities.

FBO allows users to search contract RFPs by the North American Industry Classification System (NAICS) code. NAICS is the standard used by federal statistics agencies to classify economic activities (Office of Management and Budget [OMB], 2017). NAICS code 483111 is the code for Deep Sea Freight Transportation (OMB, 2017). FBO also allows users to search by keyword or by organization. To find MSC's tanker RFPs, we used FBO's advanced search function to look for "Department of the Navy/Military Sealift Command" along with NAICS code 483111 and the keyword "tanker." By using the keyword "tanker," 48 contract notices were located for further analysis and identification of requirements.

2. Defining an Acceptable Charter

Voyage and time charters were reviewed to determine the characteristics that MSC requires. Charterparties for both the Middle East and the Far East use standardized requirements to give MSC the flexibility to shift routes when needed (MSC personnel, personal communication, October 4, 2018). The reviewed RFPs were N32205-18-R-3223, N32205-18-R-3225, N32205-18-R-3226, N32205-18-R-3273, and N32205-18-R-3508; none of the RFPs differed in ship characteristic requirements.

The following characteristics defined an acceptable charter tanker:

- Double hulled: Reduces the likelihood of an oil spill.
- Built less than 20 years ago: MSC prefers ships built less than 15 years ago; however, the RFPs state ships up to 20 years old can receive waivers.
- Satellite communications system: Ships are required to make daily position reports.
- Epoxy or zinc coated tanks: Makes tank cleaning easier and reduces the likelihood of contamination.
- Segregated ballast tanks: Prevents water contained in ballast tanks from coming into contact with fuel tanks.
- Inert gas systems: Reduces chance of explosion caused by vapors mixing with oxygen.
- Laden draft less than 15.5 meters: Determines the depth of navigable water.
- Length overall (LOA) of less than 260 meters: Important for docking the ship.
- DWT less than 120,000 metric tons: Prevents the ship being dangerously below the water line.

- Maximum beam of less than 50 meters: Determines the width of navigable water.

The two characteristics included in the acceptable charter profile but not listed in the RFPs were related to adversarial ownership and PSC inspection failures. The adversarial ownership characteristic excludes ships whose owners, operators, or management companies were registered in the PRC, Russia, Syria, North Korea, Cuba, or Venezuela. The PSC inspection failure characteristic excludes ships that had PSC inspection failures within the previous three years.

3. IHS Maritime

IHS Maritime was the database used to conduct market research on the clean shipping market. According to its website, users can "track latest ship movement, and monitor world fleet and competitor activity, global trade flows to understand trends, business threats and opportunities" (IHS Markit, 2018). IHS Maritime includes two products: Sea-web and AISLive.

Sea-web allows users to search ships for specific characteristics, companies of ownership or operations, or ports; giving users access to data on more than 200,000 ships, 240,000 companies, and 15,500 ports (IHS Markit, 2018). Sea-web's ship profiles are derived from Lloyd's Register and show details such as the ship's name, IMO number, seven types of ownership, flag of registration, port history, state control history, casualty data, and past ship inspection data. Additionally, Sea-web has fixture data provided by Maritime Research Inc, that lists ships available for hire up to seven days from the report (IHS personnel, personal correspondence, October 1,2018).

AISLive uses the Automated Identification System (AIS), giving users access to real time data on ship location. It allows users to filter AIS data, sorting ships by destination port or country, estimated time of arrival (ETA), draft, speed, and other ship characteristics. It allows users to look at a specific geographical area in order to monitor activity within that area and look at a history of past ship movements. Applicable product tanker data was exported from Sea-web into a spreadsheet and select ship profiles were downloaded. The spreadsheet and ship profiles allowed us to determine which tankers would be eligible for chartering and needed to be included in the simulation.

B. SIMULATION MODELING

Two different simulations using models based on data collected from the IHS database were run using Microsoft Excel. The first simulation estimated the charter market over the course of a year utilizing month-long rounds with worldwide data. The second simulation estimated the immediate availability of tankers in and around East Asia. This section will define the models and variables used and explain the information they produced.

1. Forming the Model Using Worldwide Tanker Data

This model and simulation are intended to generate data on the worldwide tanker charter market under current conditions. An overview of the variables used in the model is shown in Table 4. The rest of this section will define the model and explain how the simulation was implemented.

Table 4. Overview of the Variables Used in the Model Depicting the Worldwide Tanker Market

Definition	Unit
Percentage of ships off-fixture	%
Business in Asia	%
Number of ships with acceptable charter profile	Ship
Liquid load amount	Metric Ton

a. Percentage of Ships Off-fixture

This variable seeks to estimate the number of ships available for charter. Data on ships was sampled over 10 days to determine the mean number of ships coming off-fixture. The mean number of the ships coming off-fixture (188 tankers) was divided by the total number of petroleum product tankers listed in Sea-web (2,363 tankers) to establish the percentage of the fleet that is off-fixture. This resulted in about 8% of the total tanker fleet being off-fixture on any day. Since the data set is small and an accurate estimation of the mean is unknown, a pseudo random number generator (PRNG) was used to assign a value between 6% and 10% for the simulation.

b. Business in Asia Variable

This variable represents the percentage of tankers that have established support operations or regularly conducts business in East Asia. From the total population of petroleum product tankers, a random sample of 48 ships was selected for a detailed collection of data. From the tanker sample, vessels were identified as having business in East Asia if they carried cargo to or from East Asia or Australia in the last 12 months. Only a small sample was collected so a confidence interval of 14% was used to establish lower limits (LL) and upper limits (UL). This sample showed 52% of the tankers traded in the Asia and Australia regions in the past 12 months. The PRNG in Excel was used to assign a value for the business in Asia variable with an LL of 38% and a UL of 66% in the simulation.

c. Number of Ships with an Acceptable Charter Profile

This variable represents the number of tankers eligible to carry fuel for the DoD based off the acceptable charter profile that was developed. After creating this profile, a binary list for each characteristic was built, which either met or did not meet the requirement. The binary list was then applied to the random sample of 48 ships to determine which tankers would meet all of the characteristics required. From the sample, it was found that 62.46% of the ships met the acceptable charter tanker profile. This percentage was applied to the population of petroleum product tankers to find how many would likely be acceptable for charter. The mean was estimated at 1,476 with a margin of error of 321, which resulted in a range with an LL of 1,155 and a UL of 1,797 tankers meeting the requirements.

d. Liquid Load Amount

The petroleum product tankers population was sorted by liquid load using Excel's population and rank function under the data analysis tab. The population was divided into groups of 10 by the percentage with the largest group consisting of 90% to 100% and the smallest group being made of the tankers between 0.0% to 9.9%. The mean of the tanker liquid load size was then taken from each subgroup and put into a table with probabilities listed from 0.0 to 0.9. The PRNG was used in the simulation to select a random number in a lookup table that determined the liquid load amount available for chartering.

e. Defining the Formulas

The model was used to estimate the amount of petroleum product tankers expected to be available for chartering by the DoD. The model's formula was as follows:

- [Tankers available a month] = (off-fixture %) x (business in Asia %) x (ships with acceptable charter profiles)

- [Liquid lift capacity available a month] = (tankers available a month) x (liquid load amount)

f. Simulating the Worldwide Tanker Charter Market

A Monte Carlo simulation was used to understand the interplay between the variables. Each round of the simulation generated one year's worth of data on the expected number of tankers available for chartering worldwide. The simulation ran 1,000 rounds with randomized variables to generate data for further analysis. Statistics were computed on the generated data using the Excel function, descriptive statistics. The model was intended to generate data on the amount of tankers likely available over a month.

2. Forming the Model Using Data from the East Asia AOR

This model on East Asia AOR was constructed to estimate what would likely be available for immediate charter in the area. An overview of the variables used for this model are shown in Table 5. On a random day, data was collected on all of the 43 petroleum product tankers operating in East Asia. This random sample will be used to develop the model and make inferences to the population.

Table 5. Overview of the Variables Used in the Model Depicting the East Asia Tanker Market

Definition	Unit
From non-adversary country	%
Willing to do business with the DoD	%
Number of ships with acceptable charter profile in East Asia	Ship
Liquid load amount	Metric Ton

a. *Probability Not an Adversary*

In the East Asia simulation, the adversary requirement from the acceptable charter profile was separated as an independent variable to calculate its affect in East Asia. This variable was broken out separately for this simulator since the energy markets in East Asia are significantly influenced by actions of the PRC. The sample's 43 tankers were divided into two groups: one for ships with no linkages to adversarial countries, and another group with linkages. It was found that 65% of these tankers had no adversarial ownership or control. Due to the small sample size and the uncertainty surrounding this variable, a margin of error equal to 14% was used, setting the LL to 51% and the UL to 79%.

b. *Willing to Contract with the DoD*

The limitations on who MSC charters with is driven both by market demands and MSC's perception of the available charters. MSC maintains a database of vessels with previous performance and identified issues encountered during the last charter period that can be referenced prior to chartering (MSC personnel, personal communication, October 4, 2018). Additionally, MSC has established relationships with brokers who are consulted for market research and to gage interest in the released RFPs (MSC personnel, personal communication, October 4, 2018). It is common in the commercial sector for brokers to work with the same ship charting companies and often ships carry for the same group of charterers repeatedly (Forsberg, 2009). This can be due to past performance, developed networks, and relationships built up between the different parties, but the cost of keeping a tanker idle or moving it to another location empty is often very costly (Kendall, 1986). In Asia there are many dynamic and growing economies requiring the services of the petroleum product tankers that MSC will have to compete with to fill transportation requirements. Trust and working relationships are built up over time, and repeat business is key to ensuring the assets you need are available when you need them.

To simulate this risk, a variable was used to estimate the willingness to charter with MSC. Since this variable cannot be directly measured, the model attempts to estimate it and give a margin of error to measure the possible impacts. The last time there was a worldwide conflict was during World War II (WWII), when the United States was an industrial powerhouse and was supporting the ongoing wars in Europe and the Pacific. By 1945, the United States controlled about 70% of the shipping not employed by the Axis Powers (Sarty & Zabecki, 2003). Moreover, the United States economy accounted for over 62% of the cumulative GDP of the great powers that were not part of the Axis alliance at the end of 1944; these nations were the Soviet Union, France, the United Kingdom, and Italy (Harrison, 2000). Currently the world is more integrated and dependent on each other for trade, this has greatly increased the GDP of the world with the United States portion of the GDP at 15%. Since the size of the United States maritime fleet appeared approximately correlated to the size of the GDP during WWII, this relationship will be used as a proxy for this model. The mean amount of ships willing to do business with MSC was set at 15%, with the PRNG being used to select the percentage value between 10% and 20% during the simulation.

c. Number of Ships with Acceptable Charter Profile

This variable is the same as what was used during the simulation of the worldwide tanker data with the exclusion of the adversary variable. Another difference is that it was limited to the smaller East Asia geographic area. Figure 7 shows the geographic area defined as within the East Asia AOR.

Figure 7. Map of the Geographic Area Depicting the Area Considered in the East Asia AOR

d. Liquid Load Amount

This variable is derived in the same manner as was used in the simulation of the worldwide tanker market.

e. Defining the Formula

The model was used to estimate the amount of petroleum product tankers expected to be available immediately for chartering in the INDOPACOM AOR. The following is the formula of the model used in the simulation:

- [Amount of tankers available] = (Not an adversary %) x (Willing to charter %) x (ships meeting RFP in Asia)
- [Liquid lift capacity available any week] = (Tankers available any week) x (liquid load amount)

f. Computing the Charter Market in East Asia

A Monte Carlo simulation was used to estimate the amount of petroleum product tankers likely be available at the start of a contingency. Each round of the simulation simulated a week and was run 1,000 times to build data for analysis. Descriptive statistics were then computed on the generated data using the Excel function descriptive statistics, with the output estimating availability for any given week.

C. LIMITATIONS

The results from the simulation are limited by the following factors below.

- Not all ship characteristics can be identified via Sea-web. It would have been useful to know the last load of each product tanker and the date of its last maintenance period. Both characteristics could limit a ship's eligibility to be chartered as tank cleaning may be required to ready a ship to carry certain fuels. This limitation is likely to result in the ships available for charter being overestimated.

- We do not have the results of the inspections conducted by MSC on chartered ships that look at safety, pollution controls, and condition of tank coating. Moreover, we do not have access to internal source selection ratings used by the MSC office, which include past performance information on tanker contractors used by MSC. Having access to inspection results and source selection ratings could help us understand MSC's priorities during source selection.

- Off-fixture days are only tracked up to seven days in Sea-web. In this project, we assumed it takes 21 days for MSC to conduct its pre-contract phase, including solicitation and source selection. Ships that are coming off fixture in 21 days aren't displayed in Sea-web. Additionally, ships could work with brokers for charterparties and never show up on the off-fixture list. This limitation likely results in underestimating ships available for charter.

- Ships could turn off their AIS transmitters. This would not be uncommon, since even MSC chartered ships are required at times to turn off their transmitters due to security reasons (MSC personnel, personal correspondence, October 4, 2018). It is possible that some ships may have had their AIS transmitters turned off during our sample of East Asia activity, which would result in an underestimation of ships available for charter.

- Our trial access to IHS Maritime was only for 14 days. The finite access to its databases resulted in a small-time sample for this project.

- MSC's tanker charter RFPs are not port specific. MSC uses generic requirements to give it flexibility but these generic requirements may disqualify ships that could potentially be used in smaller ports. This limitation is likely to underestimate ships available for charter.

D. ASSUMPTIONS

The following assumptions were used to run the simulations:

- No systematic evidence of seasonality in the spot market for tankers. While demand may drop in December, there does not seem to be systematic attempts to remove assets from the market in accordance with the season (Adland & Strandenes, 2006). Therefore, there is not a need to adjust data collected for seasonality.

- It takes 21 days from the release an RFP to find a tanker and negotiate the charterparty (MSC personnel, personal communication, October 4, 2018). Additionally, it was estimated that it would take another nine days to make preparations and conduct movement to port of embarkation. As a result, it takes one month to get a tanker in port and ready to receive fuel.

- All available or active tankers are listed in the Lloyd's Register that feeds into Sea-web.

- All tankers coming off-fixture and actively looking for a charter are known to Maritime Research Inc. that feeds into Sea-web and AISLive.
- Monthly changes are serially correlated, resulting in the growth or decline in tanker assets being based on the past performance of charter market (Adland & Strandenes, 2006). In the spot market, an increase in the freight rate above the break-even rate of the least efficient assets will bring in additional assets. Likewise, a reduction in the freight rate will encourage the least efficient to exit the market or choose a strategy to reduce costs. As a result, during the course of the simulation, tankers will not leave or exit the market.
- Tankers with a history of trading in East Asia and Australia will seek charters in that area.; this is because the tankers are more likely to have organic or contracted support in the areas they frequent such as fuel bunkering and maintenance contracts.
- The MSC RFP Section M "Evaluation Factors for Award" describes all of the ship selection criteria.
- Adversary-operated or controlled vessels would not be eligible for charter in a contingency event.
- A PSC inspection failure results in a vessel not being selected.

V. RESULTS

This analysis compares the results of the simulations, as described in the methodology chapter, to the actual fuel requirements within the current DoD operating environment, both on the worldwide market and within the East Asia AOR. It also compares the simulation results to the Gulf War (Operations Desert Shield and Desert Storm) requirements to show how a contingency might affect total fuel availability. While a war in the INDOPACOM AOR is likely to have different fuel requirements from the Gulf War, it is a relevant comparison due to the maritime assets employed during Desert Shield. The analysis of the simulations could help INDOPACOM logistics planners, MSC, and DLA-E estimate how many tankers would be available during a contingency and what risks might be involved.

A. WORLDWIDE TANKER MARKET SIMULATION

The results of the worldwide simulation estimated how many tankers would likely be available for charter worldwide within a given month. The simulation returned a monthly average of 61 tankers available for charter, with a minimum of 26 tankers and a maximum of 78 tankers available for charter, as displayed in Table 6.

Table 6. Worldwide Simulation Results

Tanker	
Monthly Avg	
Mean	61
Minimum	26
Maximum	78

Comparing these values against the actual average monthly DoD requirements, during normal operations and during a contingency can be used to identify any potential risks of shortfalls that the DoD may encounter within the charter market.

Estimating the number of tankers required to transport DLA-E's normal, monthly, operational fuel requirements requires both the amount of fuel required per month and the average capacity of a tanker. The average monthly DoD fuel requirements for normal operations are estimated by assessing DLA-E's annual procurement figures over the last three years. During the fiscal years 2015 to 2017, DLA-E purchased an average of one million metric tons (MMT) of fuel per month (DLA, 2017). The average tanker in the IHS database had an average total load capacity of 40,000 metric tons (MT). Due to factors such as expansion of gas and the tankers' own fuel requirements, tankers never utilize their total capacity. We estimate that the average tanker utilizes 90% of its total capacity; 36,000 MT is a viable estimate of average tanker capacity. The total requirement of one MMT of fuel divided by the average load capacity of 36,000 MT results in DLA-E requiring 38 tankers over the course of a month to transport its total fuel requirement.

Comparing the DoD's normal operational requirements of 38 tankers per month to the results of the simulation shows how variations in the charter market affect the DoD's ability to maintain a constant flow of fuel. When the requirement of 38 tankers is compared to the monthly average tankers available for charter (Table 6), the DoD requires 38/61, or 62%, of potential charters available in order to maintain current stock levels. Comparing that requirement to the 26 tankers available in a minimum month, the DoD has a potential shortfall of 12 tankers every month. MSC currently has five long-term chartered tankers, effectively reducing that shortfall to seven tankers.

Estimating the tankers required to transport DLA-E's fuel requirements during a contingency on a monthly basis requires the amount of fuel required per month during normal operations plus the fuel requirement of a contingency and the average capacity of a tanker. Desert Storm will be used as a proxy for a major contingency; this was the last war where the United States had a large number of forces deployed. The daily requirement during the conflict was 56,000 MT (Thomas, 1993). Over the course of a month, this equals approximately 1.7 MMT. Adding the contingency requirement to the normal operational requirement comes to 2.74 MMT of fuel required on a monthly basis. The total requirement of 2.74 MMT of fuel divided by the average load capacity of 36,000 MT results in DLA-E requiring 77 tankers over the course of a month to transport its fuel during a contingency.

Comparing the DoD's contingency requirements of 77 tankers per month to the results of the simulation shows how variations in the charter market affect the DoD's ability to maintain constant flow of fuel during a contingency. When that requirement of 77 tankers is compared to the monthly average tankers available for charter (Table 6), the DoD has a potential shortfall because the requirement is 16 tankers more than the 61 tankers available. Comparing that same requirement to the 26 tankers available in a minimum month, the DoD has a potential shortfall of 51 tankers. Once more, MSC currently has five long-term chartered tankers effectively reducing that shortfall to 46 tankers per month. In 2017, DLA-E reported that its worldwide bulk fuel ending inventory, including total on-hand and in transit, was 53 MMBBL, equal to approximately 189 tankers (DLA, 2017). Given the DLA's ending inventory of 53 MMBBL, if MSC was not able to contract 46 tankers it would reduce the total fuel stored by 24% the first month. This same percentage would not hold in the second month since it would no longer be at 53 MMBBL at the start of the month. Each month that MSC was unable to contract enough tankers to fulfill the requirement, further depletion of DFSPs would occur at a higher rate.

B. EAST ASIA TANKER MARKET SIMULATION

The results of the East Asia simulation estimated how many tankers would likely be available for charter within the INDOPACOM AOR within a given week. The simulation returned a weekly average of four tankers available for charter, along with a minimum of two tankers and a maximum of seven tankers available for charter, as displayed in Table 7.

Table 7. East Asia Simulation Results

Weekly Tanker	
Mean	4
Minimum	2
Maximum	7

The comparison of these values against a major contingency, can be used to identify potential risks of shortfalls that the DoD may encounter within the charter market.

Estimating the minimum number of tankers required to transport DoD fuel requirements during a contingency on a weekly basis also requires both the amount of fuel required per week and the average capacity of a tanker. However, unlike the worldwide simulation calculation, in order to consider the AOR environment and DFSP locations, a different calculation that accounts for cycle time will be utilized. The cycle time is the time it takes to load out, transit to the area for a fuel transfer, offload, and then return to the port for a load out. Load out and offload are each estimated at two days, for a total of four days. The transit time was calculated using the average time distance requirement between three DFSPs in the area: Guam, Sasebo, and Singapore. The average was 14 days round trip, for a total cycle time of 18 days. The distances were calculated using the port distance calculator from Sea-distances.org (n.d.) utilizing 14 knots as a speed. These distances are depicted in Figure 8.

Figure 8. Map of the Geographic Area Depicting the Distance between DFSPs

We estimate the minimum number of tankers needed by

(Number of tankers needed) = [(Daily requirement)(cycle time)]/average tanker capacity.

There are three variables in the equation required to calculate the number of tankers required: daily fuel requirement, cycle time, and the average tanker load capacity. In the worldwide analysis the daily requirement of a contingency was 56,000 MT of fuel per day, the cycle time is 18 days as calculated above, and the average capacity remained unchanged from the worldwide simulation and is still 36,000 MT of fuel.

[(56,000 MT)(18 days)]/36,000 MT = 28 tankers needed

The minimum amount of tankers in order to maintain operations is 28 tankers, which equals about 11 tankers per week. The requirement of 11 tankers a week exceeds all three outputs of the simulation. The best case scenario, seven maximum tankers available, there is a shortfall of four tankers per week, equal to a 37% shortage of the fuel requirement. The worst case scenario, two minimum tankers available, there is a shortfall of seven tankers per week, this is equal to a 82% shortage of the fuel requirement. Once more, MSC currently has five long-term chartered tankers that could reduce that shortfall; however, all five tankers may not be able to be pulled from supporting all the other operational requirements worldwide. Another factor that would further hinder MSC's long-term charter tankers from reducing that shortfall is that those tankers may not be within the AOR to support immediate requirements.

The conclusions, recommendation, and areas for further research are presented in the next chapter.

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VI. CONCLUSION, RECOMMENDATION, AND AREAS FOR FURTHER RESEARCH

A. CONCLUSION

The physical and political geography of the INDOPACOM AOR creates a dependency on the maritime domain for the delivery of bulk fuel to ensure continuity of supply; consequently, a disruption in the charter market will result in a shortage of fuel. Several countries in East Asia are major exporters of refined petroleum products, with seven of the highest capacity refineries located in East Asia. Japan, Singapore, and South Korea are key partners of the United States and important sources of fuel supplies in the East Asia region (BP, 2018). Additionally, the United States is the largest exporter and producer of petroleum products in the world, which further reduces the risk of finding a source to produce military grade fuels (BP, 2018). The one thing that cannot be avoided, regardless of where DoD sources its fuel from, is the movement of fuel and delivery to military units across the joint operating area (JOA). Any conflict in the INDOPACOM AOR will likely require long supply lines dependent on the maritime movement of petroleum products. Therefore, product tankers are key to ensuring the reliability of global markets in providing the required energy to the DoD in the advent of a contingency in East Asia.

1. DFSPs Are Vulnerable to Interdiction

DFSPs store fuel to smooth over supply and demand uncertainty and give the DoD a hedge against disruptions, but they are susceptible to interdiction by an adversary. While DFSPs may be able to reduce the uncertainty of United States forces having access to fuel markets during a limited war, they can give planners a false sense of security in a major conflict. The infrastructure and concentration of stored fuel at DFSPs burdens deployed forces, as they are given an additional task of defending these inflexible fuel distribution nodes to ensure the continuity of supply. The immense size of DFSPs prevents them from being relocated or effectively hidden from view, making DFSP locations vulnerable to attack. Experts have widely reported that adversarial nations such as North Korea, Russia, and PRC have ballistic missile capabilities with the capability to strike almost any location in world (Pecanha, & Collins, 2018). In sum, dependency on DFSPs increases the risk of the INDOPACOM fuel distribution system being impaired since the locations of the DFSPs are well known and are within the strike capability of potential adversaries. To overcome the potential loss of the DFSP fuel distribution system, INDOPACOM planners need to consider the number of tankers required and the impact on the charter market.

2. Charter Market Is a Source of Uncertainty

DLA and MSC will continue to be dependent on the charter market to move fuel, due to the aforementioned regulations and the great cost of maintaining a fleet of fuel tankers. Supply chain risks are amplified during a contingency and could be detrimental if not accounted for during planning, especially if the use of DFSPs is denied. Using our chartering criteria, model, and simulation, we found the amount of tankers that would likely be available for chartering, and identified a shortfall in charter tankers could occur during a contingency within the INDOPACOM AOR. When the simulation output was compared to the three defined parameters in the results section, a shortage of tankers was observed that would have likely resulted in reduced fuel throughput.

3. Databases Are Available to Understand the Charter Market

It is critical for INDOPACOM to understand the charter market. A maritime research service would give its fuel stakeholders access to the same information ship owners and brokers currently use to manage their businesses. Although we had limited access to IHS Markit Sea-web and AISLive, we found these programs useful in monitoring the charter market. These resources could be used by MSC contracting to conduct market research and for source selection during their procurement of tanker services. AISLive can assist with market research by showing tanker activity in an area and by indicating how many tankers would be available for charter. Sea-web can support source selection by indicating crew proficiency with historical transit data, PSC and classification information. It could also reveal maintenance issues discovered during inspections. This information may help MSC identify cost-effective ways to utilize its long-term charters and supplemental voyage charters. Furthermore, data offered by these databases can identify risks in the supply chain, by helping logisticians predict future charter market availability, a point which leads to our recommendation.

B. RECOMMENDATION

Our recommendation is for the fuel stakeholders to initiate a project using the System Development Life Cycle (SDLC) to spur the development of an IT system that can predict changes in the maritime charter market. The SDLC process is used to determine the capability required for users to improve a process; subsequently leading to the development and deployment of an IT solution that increases efficiencies (Dennis, Wixom, & Roth, 2015). The first step would be for INDOPACOM, DLA, and MSC to further explore the maritime research tools available on the open market, with the objective of understanding the capabilities and information available on these research platforms. This would equip users with knowledge on available data and help identify variables that can predict changes in the charter tanker market. At this point, the business needs should be developed as part of the planning phase of the SDLC process with the documentation of how a predictive analytical model would be used (Dennis et al. 2015). Additionally, an OR group like the DLA Office of Operations Research and Resource Analysis (DORRA) should be consulted to develop the model and simulation mechanism. Once a complete model and simulation engine is developed, it could be incorporated into a platform like GCSS-J for use by logistics planners. Additional capabilities could be added to GCSS-J that delivers relevant and actionable information to logisticians and staff by giving access to a real-time dashboard with both descriptive and predictive analysis.

To continue the SDLC process, further steps should be pursued to predict the fuel market's ability to support the DoD’s fuel requirements. Currently, there is a multitude of data produced and stored making it difficult to find relevant data to analyze in order to improve decisions in the DoD fuel supply chain. The quantity of and speed at which data is produced makes it essential to capture and interpret data in real-time using big data analytics to develop actionable information. Supply chain analytics (SCA) can be used to assist human users or automate sourcing decisions based on usage rates, signals from the fuel or charter markets, and other data (Chase, 2013). The DoD does not currently have the competencies required to utilize big data in the supply chain, therefore it does not know what questions to ask in determining operational sustainability. The energy demands of modern military equipment, along with the tactical necessity to have a distributed and agile logistics supply chain, requires DoD to rethink how logistics is executed. Lora Cecere, from Supply Chain Insights, stated the complexity of the modern supply chain means the days of running operations via spreadsheets and PowerPoint effectively is in the past (2015). While big data applications may take years to fully implement, the DoD needs to initiate the an SDLC project to put itself on the path towards gaining the skills needed to apply models and information systems to improve supply chain decision making. The data is out there, and it is time for it to be able to be used by logisticians!

C. AREAS FOR FURTHER RESEARCH

Additional research should be conducted in SCA to improve supply chain strategies and networks. Research has been done using SCA methods to predict where supply chain disruptions will occur by mapping the supply chain and monitoring enterprise social networking (Wang, Gunasekaran, Ngai, & Papadopoulos, 2016). Moreover, SCA has identified supply chain network problems by looking at changes in demand patterns, product mixes, production processes, sourcing strategies, and operating costs (Wang et al, 2016). SCA experimentation in academics has shown promise but applying it to a physical supply chain and achieving improvements has proven elusive (Wang et al., 2016). Research needs to be done on how SCA and big data application can be used to improve the fuel supply chain performance.

Other follow-on research projects could focus on the industrial mobilization capacity of tanker construction and the capability of chartering vessels in a contingency. Industrial mobilization could be an alternative if the tanker charter market is unsatisfactory in fulfilling DoD’s requirements. As noted in the background chapter, the Pacific War featured innovative concepts of operational logistics. However, a major reason for the United States victory in the war was the ability of industry to mobilize extra capacity for ship construction. A study can be conducted on America’s ability to mobilize its industry using cost-reimbursement contracts. It would investigate not just current capabilities but the time it would take to shift industry to war time production. The second project, on the capability of chartering vessels in a contingency, would expand on this project as we essentially made inferences from a peace-time environment. This project used a variable for willingness to be chartered based on an inference made by comparing the ratio of the United States maritime fleet and GDP to the global shipping market. It would need to go further in researching which considerations are involved in determining a more accurate *willingness to charter* variable. These two projects may assist CCMDs in gathering the whole picture of the tanker chartering market during a contingency.

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