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Commercial Helicopter Services: Toward Quantitative Solutions for Understanding Industry Phenomena and Achieving Stakeholder Optimization

Jeremy Todd Navarre

COMMERCIAL HELICOPTER SERVICES: TOWARD QUANTITATIVE SOLUTIONS FOR UNDERSTANDING INDUSTRY PHENOMENA AND ACHIEVING STAKEHOLDER OPTIMIZATION

By

Jeremy Todd Navarre

A Dissertation Submitted to the College of Business
in Partial Fulfillment of the Requirements for the Degree of
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Embry-Riddle Aeronautical University
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This Dissertation was prepared under the direction of Dr. Li Zou, the candidate's Dissertation Committee Chair, and has been approved by the members of the dissertation committee. It was submitted to the College of Business and was accepted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy in Aviation Business Administration.

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ABSTRACT

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Title: COMMERCIAL HELICOPTER SERVICES: TOWARD QUANTITATIVE SOLUTIONS FOR UNDERSTANDING INDUSTRY PHENOMENA AND ACHIEVING STAKEHOLDER OPTIMIZATION

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An understanding of industry phenomena and optimization techniques within the upstream energy industry's transportation sector is markedly absent in the extant literature and suitable for rigorous investigation. This manuscript presents analyses related to the optimization of offshore worker transportation and econometric analyses of factors influencing commercial helicopter operators' stock returns, which are represented throughout the manuscript as Part I and Part II, respectively.

The global energy industry transports supplies and personnel via helicopter to offshore locations and has been increasingly focusing on optimizing upstream logistics. Using a unique sample of deepwater and ultra-deepwater permanent offshore locations in the Gulf of Mexico, transportation networks consisting of 58 locations operated by 19 firms are optimized via a randomized greedy algorithm. The model developed in Part I has been found to effectively solve the complex transportation problem and simulation results show the potential advantages of alternative clustered and integrated network structures, as compared to an independent firm-level structure. The evaluation of clustered and integrated network structures, which allow ride sharing via energy firm cooperation, provides evidence that such network structures may yield cost reductions for participating firms.

The extent to which commercial helicopter operators' stock returns are related to commodity prices and other relevant industry variables is absent in the extant literature. Often, firms attribute favorable results to internal factors whereas unfavorable results are attributed to external factors. Using a unique data set from 2013-2018, the current research identifies structural relationships between crude oil prices, natural gas prices, the rotary rig count, a subset of the overall market, firms' degree of diversification and stock returns of commercial helicopter operators. Empirical analyses developed in Part II show that the prevalent price of crude oil and the overall market environment possess explanatory power of commercial helicopter firms' stock returns, ceteris paribus. Specifically, 10% increases in the crude oil price and the S&P 500 index yield a 2.7% and 8.0% increase in stock returns, respectively.

Collectively, the abovementioned parts of this manuscript provide rigorous, quantitative analyses of topics unrepresented within the extant literature, which are foundational for future practice and research. Specifically, new knowledge regarding a practical approach to model development and solution deliverance for the transportation of offshore workers to their respective locations and factors influencing commercial helicopter operators' stock returns has been appropriately designed and empirically evaluated.

DEDICATION

My family, friends and colleagues have been instrumental in supporting me during the entire program. Specifically, my wife, Cherie, has provided me stability, reassurance and support when experiencing unexpected and self-induced turbulence. My parents never ceased to remind me that they knew I had the skill and ability to complete the program. It is their contributions throughout my life that created and developed such ability. My siblings and extended family have always supported me in all that I've strived for and endured. I am grateful for their presence in my life and look forward to reconnecting with them after sacrificing so much personal time with them. For those observing this achievement from afar and unable to celebrate this achievement in person, I'm grateful for the upbringing they've provided to enable me to achieve this great feat.

When considering this endeavor, I sought the support and recommendations of a few people that I greatly admire and respect. I sincerely thank Dr. John Lajaunie, Dr. Natalie Harder and Mr. Jonathan E. Baliff for their support and recommendations.

Embry-Riddle Aeronautical University's David B. O'Maley College of Business support staff, professors and leadership have been a continuous source of encouragement and guidance. It is an honor and privilege to have worked with them and yield a return on their investments. Forever an Eagle!

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Support staff and professors, Ms. Robin Williams, Mr. Patrick Herlehy, Dr. Kathryn Cunningham, Dr. Jayendra Gokhale, Dr. Anke Arnaud, Dr. Tamilla Curtis, Dr. Kiljae Kay Lee, Dr. Dawna L. Rhoades, Dr. Janet Kay Tinoco, Dr. Bijan Vasigh, Dr. Norbert J. Zarb and the Hunt Library staff provided invaluable support and instruction throughout the program. A close friend and classmate, Jeremy A. Frazier, provided support, encouragement and collaboration throughout the program.

This achievement represents the possibility that anyone with the will and discipline to achieve great things personally and academically can be successful. When one possesses the will and discipline to succeed, there is no restricted altitude to which they may climb. My faith in God allowed me to withstand the inherent hardships associated with such an endeavor and persevere with the knowledge that the obstacles in front of me were never greater than the force behind me.

To the many before me and those that will come after me at the greatest university in the world, Embry-Riddle Aeronautical University, Forever an Eagle!

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PROLOGUE

This manuscript presents analyses related to the optimization of offshore worker transportation and econometric analyses of factors influencing commercial helicopter operators' stock returns, which are represented throughout the manuscript as Part I and Part II, respectively. Part I and Part II include chapters 1-5 and 6-10, respectively. Chapter 11 provides the manuscript's comprehensive discussion, conclusion and implications.

The global energy industry transports supplies and personnel via helicopter to offshore locations and has been increasingly focusing on optimizing upstream logistics. Using a unique sample of deepwater and ultra-deepwater permanent offshore locations in the Gulf of Mexico, transportation networks consisting of 58 locations operated by 19 firms are optimized via a randomized greedy algorithm. In Part I, an optimization model is developed for solving the complex transportation problem effectively and the results show the potential advantages of alternative clustered and integrated network structures, as compared to an independent, firm-level structure. The evaluation of clustered and integrated network structures, which allow ride sharing via energy firm cooperation, provides evidence that such network structures may yield cost reductions for participating firms. Notably, the results are mixed and alternative network structures increase costs in many scenarios. The study is represented in Part I.

The extent to which commercial helicopter operators' stock returns are related to commodity prices and other relevant industry variables is absent in the extant literature. Often, firms attribute favorable results to internal factors whereas unfavorable results are attributed to external factors. Using a unique data set from 2013-2018, the current research identifies structural relationships between crude oil prices, natural gas prices, the rotary rig count, a subset of the overall market, firms' degree of diversification and stock returns of commercial helicopter operators. Empirical analyses show that the prevalent price of crude oil and the overall market environment possess explanatory power of commercial helicopter firms' stock returns, ceteris paribus. Specifically, 10% increases in the crude oil price and the S&P 500 index yield a 2.7% and 8.0% increase in stock returns, respectively. This study is represented in Part II.

Collectively, the abovementioned studies included in this manuscript provide rigorous, quantitative analyses of topics unrepresented within the extant literature, which are foundational for future practice and research. Specifically, new knowledge regarding a practical approach to model development and solution deliverance for the transportation of offshore workers to their respective locations and factors influencing commercial helicopter operators' stock returns was appropriately designed and empirically evaluated. A comprehensive chapter including discussion, conclusion and implications is provided and represented in Chapter 11.

CHAPTER I

PART I INTRODUCTION

The Gulf of Mexico's (GOM) energy sector engages in exploration, drilling, production and abandonment activities in pursuit of crude oil and natural gas. Evaluation of the net advantages and disadvantages of firm-level, clustered and fully-integrated network structures for personnel transportation were both timely and judicious. Firm-level network structures consist of entities' contracted helicopters and offshore locations whereas clustered networks consist of helicopters serving locations for multiple firms, which are clustered based on spatial relationships among nodes and, as defined by the extant literature, encompass ride-sharing (Agatz et al., 2012). Lastly, a fully-integrated network structure encompasses all offshore locations among firms engaging in deepwater and ultra-deepwater activities. Similarly, the fully-integrated network structure allows ride sharing across firms. Noteworthy works, Sierksma and Tijssen (1998), Menezes et al. (2010) and Abbasi-Pooya and Husseinzadeh (2017), provided a foundation for such analyses. Specifically, the existing studies evaluated variations of the subject concerned; however, these works exhibit significant differences in contextual data, scope, scale, methodology and research inquiries relative to the current study. The study of firm-level, clustered and fully-integrated network structures in the Gulf of Mexico is original and includes parameters inapplicable to other industries and geographic locations. However, many aspects of the current study are generalizable within the subject industry and others. The problem can be characterized as a heterogeneous capacitated helicopter routing problem with split deliveries and multiple depots (HCHRPSDMD). Based on a literature review, the topic of helicopter transportation within the energy industry was not entirely new. However, there were no studies assessing ride-sharing cooperation within the proposed industry or geographic environment.

The total cost to produce crude oil and natural gas has significantly increased in the recent past. Consequently, energy firms were increasingly focusing on optimizing upstream logistics to reduce their cost structure and enable profitable projects. Therefore, it was sensible and timely to evaluate the potential efficiency gains across firm-level, clustered and fully-integrated network structures for the transportation of personnel. Specifically, there was limited knowledge related to the oil and gas firms' helicopter transportation networks and, therefore, opportunities for enhancement in the Gulf of Mexico and elsewhere were reasonably probable.

In order for exploration, drilling, production and abandonment activities to commence, energy firms gain exclusive use of offshore lands via sealed bids from the United States' Bureau of Ocean Energy Management (BOEM) (Lin, 2009, 2014; Nixon et al., 2016). Platforms used for extraction range from ten to more than two hundred nautical miles from the coasts of Texas, Louisiana, Mississippi and Alabama and include mini tension-leg (MTLP), tension-leg (TLP), fixed, spar, semi-submersible, compliant tower (CT) and floating, production, storage and offloading (FPSO) facilities. In 2014, the Gulf of Mexico's network of more than 2,600 structures produced 596 million barrels of oil and more than 1.5 trillion cubic feet of natural gas (Kaiser, 2015). The BOEM differentiates deepwater and ultra-deepwater activity by water depths from 1,000 ft. to 4,999 ft. and 5,000 ft. and greater, respectively (Nixon et al., 2016). Importantly, offshore activities have been responsive to both commodity prices and global demand (Corts, 2008; Güntner, 2014; Ringlund et al., 2008). Oil and gas activities have fluctuated as microeconomic and macroeconomic variables changed. In the United States, flow and speculative demand shocks accounted for 6.83 and 8.39 percentage points, respectively, of the 15.22% variation in crude oil production (Güntner, 2014). Part II provides an extensive overview of commodity prices' and quantity of active drilling rigs' impact on helicopter operators' stock returns, which was achieved via multi-linear regression analyses.

As a result of the Outer Continental Shelf Lands Act (OCSLA) of 1953, the U.S. Department of the Interior was enabled to lease tracts beyond the shallow-water coast of the Gulf of Mexico. Consequently, researchers explored and concluded that the offshore waters exhibited formations probable of possessing commercial quantities of crude oil and natural gas. The research and exploratory wells yielded the first deepwater field, Cognac, in the latter part of the 1970s (Nixon et al., 2016). Since the initial deepwater well, technology, governmental regulation and investment enabled energy firms to continuously explore deeper waters within the Gulf of Mexico. In 1996, the initial ultra-deepwater well was drilled in Alaminos Canyon at a water depth of 7,620 feet. Shortly after, deepwater and ultra-deepwater production exceeded shallow-water production (Nixon et al., 2016). Exploration, drilling and production techniques have evolved to exploit technological advancements and overcome challenges posed by the environment. As exploration, drilling and production migrated to deeper and more distant locations from shore, transportation assets, such as vessels and helicopters, too, have changed to meet the operational demands of energy clients. Figure 1 depicts a series of events that have shaped the Gulf of Mexico's oil and gas industry from 1953 to 2014.

1950s	1953	Submerged Lands Act passed, enabling states the right to lease tracts for offshore drilling from 3 to 9 nautical miles from the coast
	1953	Outer Continental Shelf Lands Act (OCSLA) passed allowing U.S. Department of the Interior to lease tracts beyond state lands
1960s	1960s	Series of turbidite proble studies by universities and industrial firms confirmed an exploration play in the GOM's deepwater zone
1970s	1975	First deepwater well drilled at MC 194 in 1,022 ft. of water, called the Cognac field
	1978	First production facility, a fixed platform, installed in Cognac's deepwater field
	1979	First production from Cognac's deepwater field
1980s	1983	First compliant tower installed at MC 280 in 1,000 ft. of water, called the Lena field
	1989	First TLP installed at GC 184 in 1,760 ft. of water, called the Jolliet field
1990s	1996	First deepwater well to explore ultra-deepwater at AC 600 in 7,620 ft. of water
	1999	Deepwater production exceeded shallow water production
2000s	2002	First spar installed at VK 826 in 1,930 ft. of water, called the Neptune field
	2003	First semisubmersible installed at MC 474 in 6,340 ft. of water, called the Na Kika Hub and collected gas from 6 fields
	2007	Independence Hub installed at MC 920 in 7,920 ft. of water and represented the water-depth record for a semisubmersible and collected production from 11 fields
	2009	First FPU installed at GC 237 in 2,200 ft. of water and collected production from Boris and Phoenix fields
	2009	Perdido Hub installed at AC 857 in 7,817 ft. of water, which represented the water-depth record for a spar and collected production from 3 fields
	2010	First floating, drilling and production triple column spar, Telemark Hub, installed at MC 941 in 4,050 ft. of water and collected production from 3 fields
	2011	First FPSO located at WR 249 in 8,300 ft. of water, which represented a water-depth record for a FPSO and served as a hub for the Cascade and Chinook fields
	2014	Largest semisubmersible installed at WR 718 in 6,950 ft. of water and collects

Figure 1. Gulf of Mexico's evolution to deepwater discovery. Adapted from "U.S. Department of the Interior Bureau of Ocean Energy Management Gulf of Mexico OCS Region Office of Resource Evaluation. Deepwater Gulf of Mexico" by Nixon et al., 2016 M., U.S. Department of the Interior.

The abovementioned and other GOM structures hosted between 25,000 and 35,000 offshore workers each day, which typically work 14-day cycles (Kaiser, 2009).

Historically, oil and gas extraction was conducted on the Gulf of Mexico's continental shelf whereas projects have been increasingly moving to more distant locations (Kaiser, 2015). Figure 2 depicts the BOEM's Outer Continental Shelf (OCS) administrative boundaries.

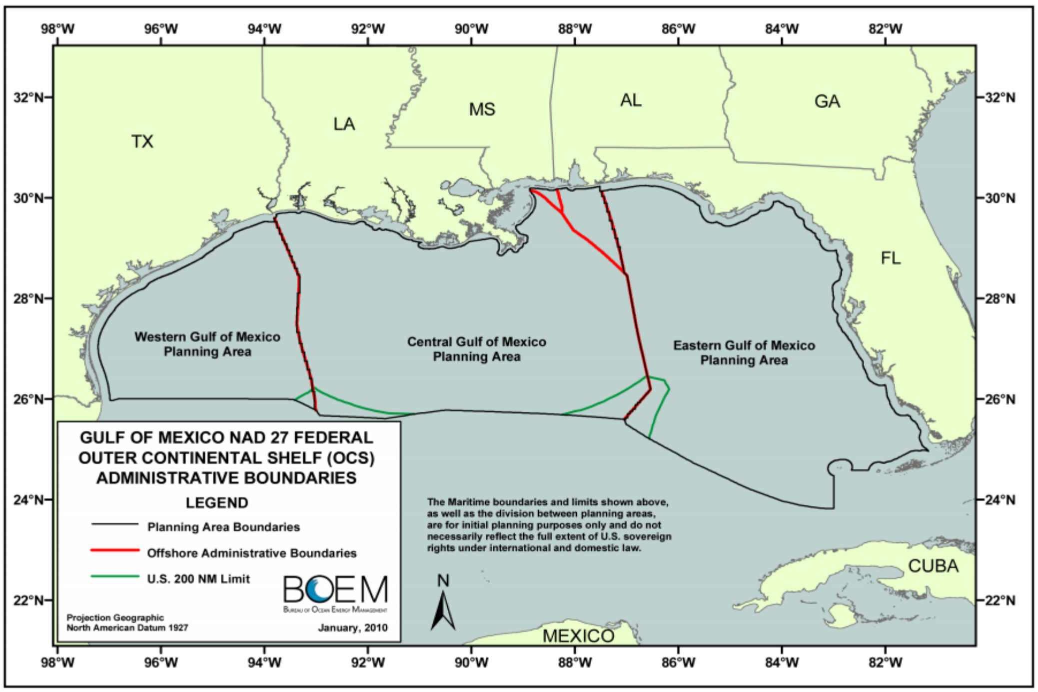
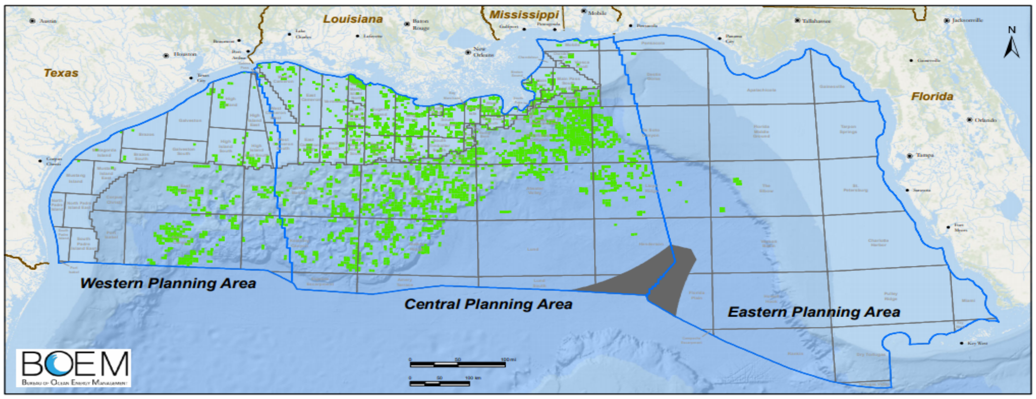


Figure 2. Gulf of Mexico's outer continental shelf administrative boundaries. Retrieved from "Gulf of Mexico NAD 27 Federal Outer Continental Shelf (OCS) Administrative Boundaries" by U.S. Bureau of Safety and Environmental Enforcement, 2010, U.S. Bureau of Safety and Environmental Enforcement.

Within the BOEM OCS boundaries are segmented areas. In total, there are 25, 48 and 23 areas in the west, central and east administrative boundaries, respectively. Notably, not all active leases host facilities engaging in drilling and production activities. The western, central and eastern planning boundary areas' blocks contain 5,240, 12,409 and 11,537 9-mile^2 block locations, respectively. There are 328, 2,189 and 18 active leases within the western, central and eastern administrative boundaries, respectively. In all, there are 13,417,111 acres leased for exploration, drilling and production activities. Figure 3 depicts the planning areas within the BOEM OCS administrative boundaries and active leases in the Gulf of Mexico.

BOEM Gulf of Mexico OCS Region
Blocks and Active Leases by Planning Area
February 1, 2019



Planning Areas	Total Blocks	Total Acres	Number of Leases	Acres Leased
Western	5,240	28,576,813	328	1,873,748
Central	12,409	66,446,351	2,189	11,439,683
Eastern	11,537	64,357,859	18	103,680
Sub-Totals	29,186	159,381,023	2,535	13,417,111
CPA / EPA Shared Blocks*	(86)		0	
Totals	**29,100**	**159,381,023**	**2,535**	**13,417,111**

Active Lease
Exclusive Economic Zone
Northern Portion of the Eastern Gap
Planning Area Boundary

* CPA and EPA contain 86 shared blocks. These blocks are given both a CPA and EPA designation in the data which may account for a higher block total.

Figure 3. Gulf of Mexico's outer continental shelf planning areas and active leases. Retrieved from "BOEM Gulf of Mexico OCS Region Blocks and Active Leases by Planning Area" by U.S. Bureau of Safety and Environmental Enforcement, 2019, U.S. Bureau of Safety and Environmental Enforcement.

Nixon et al. (2016) identified that during 2014, 72% active leases in the Gulf of Mexico were located in water depths exceeding 1,000 ft. In 2015, more than 60% of bids received for the three OCS administrative boundaries, western, central and eastern, were in deepwater and ultra-deepwater zones (Nixon et al., 2016).

The logistics network in the Gulf of Mexico is intricate and includes activities performed by hundreds of service firms (Kaiser & Snyder, 2010). Within the industry, downstream logistics pertains to oil and gas being brought to processing facilities whereas upstream logistics refers to the supplying of facilities engaged in extracting such resources (Aas et al., 2008). Each phase required to extract the aforementioned resources requires personnel and supplies transportation via offshore supply vessel or helicopter. Though some personnel are transported via offshore supply vessels, most have been transported via helicopter due to speed and comfort (Hermeto et al., 2014).

Helicopter transportation services have been executed on a contractual basis between helicopter operators and oil and gas firms and range from one to five years (Bristow Group Inc., 2018). However, these contracts are commonly cancellable with relatively short notice (Bristow Group Inc., 2018). The contractual agreements typically consist of monthly fees with additional flight hour fees; however, helicopter operators also provide ad hoc transportation services to clients (PHI Inc., 2017). Due to the differences in distance and size of platforms, four aircraft manufacturers have supplied approximately 16 aircraft models including the Bell 206BIII, Bell 206L1, Bell 206L3, Bell 206L4, Bell 407, Airbus AS350, Airbus EC135, Airbus EC145, Leonardo AW109, Leonardo AW119, Leonardo AW139, Leonardo AW189, Sikorsky S76A, Sikorsky S76C+, S76C++ and Sikorsky S92. PHI Inc. (2017) and Bristow Group Inc. (2018) identified that clients included, but were not limited to, Shell Oil Company, BP America Production Company, ExxonMobil Production Co., ConocoPhillips Company, ENI Petroleum, Statoil, Chevron and Inpex. A sample of Gulf of Mexico offshore locations was collected from the Bureau of Safety and Environmental Enforcement's (BSEE) data center, which listed 58 permanent deepwater and ultra-deepwater structures that were manned at all times and operated by 19 firms. The firms included in the sample are Anadarko Petroleum Corporation, BHP Billiton Petroleum (GOM) Inc., BP Exploration

& Production Inc., Chevron USA Inc., ConocoPhillips Company, Eni US Operating Co. Inc., EnVen Energy Ventures, LLC, Equinor USA E&P Inc., Exxon Mobil Corporation, Fieldwood Energy, LLC, Hess Corporation, LLOG Exploration Offshore, LLC, MC Offshore Petroleum, LLC, Murphy Exploration & Production Company USA, Petrobras America Inc., Shell Offshore Inc., Talos Petroleum LLC, W&T Energy VI, LLC, and Walter Oil & Gas Corporation. Figure 4 depicts the 58 permanent deepwater and ultra-deepwater structures with eligible service depots, or onshore locations, located from west to east, Galveston, Texas, Abbeville, Louisiana, Patterson, Louisiana, Houma, Louisiana, Galliano, Louisiana and Venice, Louisiana.

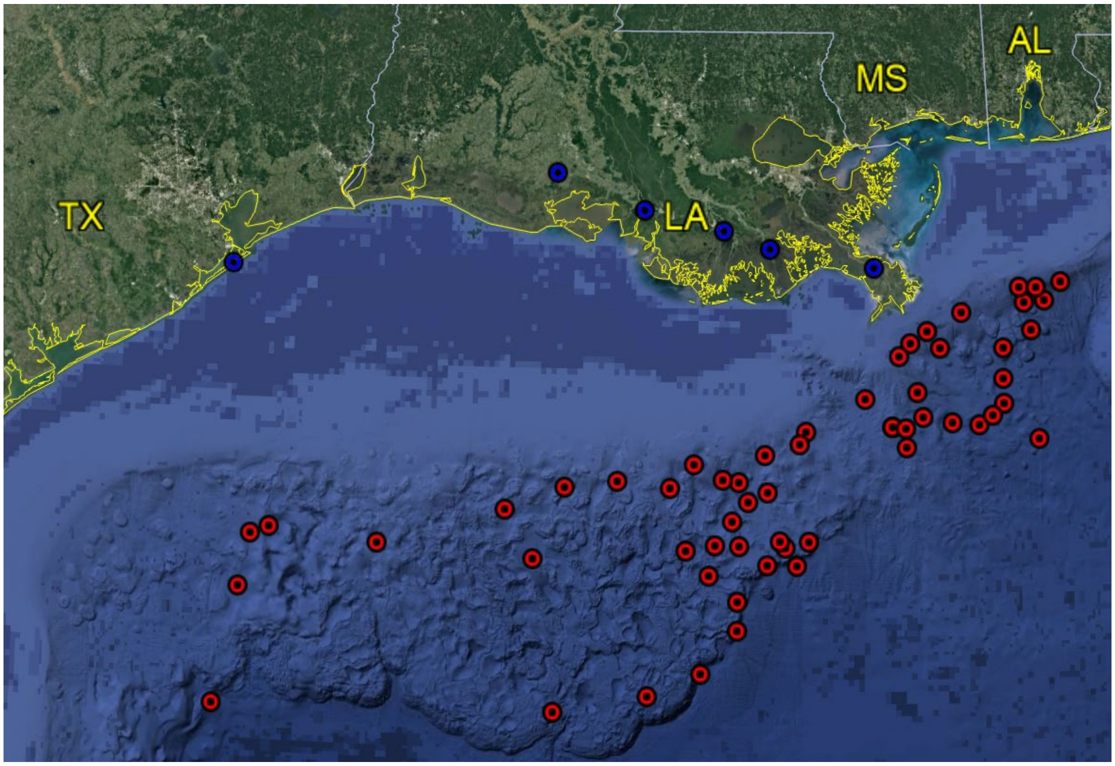


Figure 4. Gulf of Mexico's 58 permanent deepwater and ultra-deepwater structures and depots. Adapted from "Image Landsat / Copernicus 2021 Google" by Data SIO, NOAA, U.S. Navy, NGA, GEBCO, 2021, Google Earth Pro.

Significance of the Study

The current study, utilizing unique data and including all relevant parameters for the heterogeneous capacitated helicopter routing problem with split deliveries and multiple depots, effectively provides practitioners a practical approach to model development and solution deliverance. Complex transportation networks necessitate approaches that produce efficient and feasible solutions, whether optimal or an approximation of global optimum.

Within the extant literature, there exist studies that differ in their parameters due to the inherent nature of the networks their research sought to optimize. In some cases, there are simplifications to the problems to enhance solvability and parsimony. In order to reflect the environment for which this study was designed, robustness was not sacrificed for simplicity or expedience. Specifically, the comprehensive set of deepwater and ultra-deepwater locations, inclusion of multiple depots and a heterogeneous fleet are included. Furthermore, all applicable aviation regulations, aircraft limitations and operational constraints are observed. Overall, the research was designed and executed to enhance the extant literature and provide practitioners a practical tool for implementation. In addition to employing a relatively more rigorous and innovative approach, alternative network structures and ride sharing, which were absent in all extant literature works, are included.

Statement of the Problem

Historically, drilling costs did not exceed 35% of oil and gas revenues; however, from 2007-2010, drilling costs represented 80% to 90% of revenues (Osmundsen et al., 2015). Low oil and gas prices have led to declines in profits, losses, investment degradation and, at times, mergers and acquisitions (Alhajji, 2003). Due to fiduciary obligations and uncertainties enhanced by volatile upstream revenue sources, crude oil and natural gas, energy firms have been increasingly focusing on optimizing upstream logistics (Aas et al., 2009). Notably, the responsibility for scheduling and routing supply vessels and helicopters was assigned to contracting firms, which were conjectured to possess limited competence for such endeavors (Aas et al., 2009). In essence, upstream logistics management has not been a core function of oil and gas firms and, therefore, there exists justification for efficiency analyses. Armstrong-Crews and Mock (2005) identified that the use of the “by-eye” (p. 1586) technique was quite common and rarely, if ever, yielded optimal results. Specifically, practitioners evaluated and chose routes without the use of a decision-making implement and, instead, visualized routes that seemingly yielded minimal total distance or cost (Armstrong-Crews & Mock, 2005). Although primitive methods may be suitable for small and simple networks, robust methods are suitable for relatively larger and more complex networks.

Purpose Statement

The current study employed combinatorial optimization to generate efficiencies via robust problem definition, iterative mathematical modeling and oil and gas firm cooperation. The study employs a decision-making implement for aircraft routing, aircraft assignment and depot assignment for transporting personnel in a complex transportation network. Furthermore, the current research assessed the results from clustered and integrated network structures for the transportation of personnel in the Gulf of Mexico. These structures were unprecedented in practice and inadequately explored in the extant literature. Across the three network structures, transportation cost per firm, transportation cost per passenger, total network cost, fleet composition, load factors and usage of multi-stop trips were collected, computed and compared.

Due to the prevalent need and interest in energy firms optimizing upstream logistics, this study was both warranted and timely. The study has the propensity to promote increased asset utilization, decreased transportation costs and a robust method for selecting onshore depots. Overall, the study is advantageous for practitioners and researchers. Practitioners are provided a practical approach to model development and solution deliverance whereas researchers are provided an opportunity to apply these techniques to similar transportation networks and compare their respective techniques to the Gulf of Mexico's transportation network.

Research Questions

The evaluation of network structures sought to provide a novel and practical approach to model development and solution deliverance. Specifically, output analyses yield the prevalent usage of split deliveries, prevalent vehicle type usage, load factors derived from vehicles' seat capacity, load factors derived from vehicles' effective capacity and overall network load factors.

Split deliveries represent routes that include two or more nodes. In essence, if passengers destined to be delivered to or picked up from different nodes and are included on the same flight, the flight is considered to be executing a split delivery. Due to the close proximity of some nodes, the utilization of split deliveries was reasonably probable. However, direct flights, too, were probable in that those flights exhibiting maximum utility via load factor will minimize costs via direct flights. Notably, some firm-level networks possess a single offshore node and, consequently, only executed direct flights.

The vehicles exhibit various capabilities and limitations and, therefore, provide a basis for their respective utility in the transportation of personnel in the Gulf of Mexico's offshore environment. The prevalent usage of vehicle type captures the utility of each vehicle type based on vehicles' inclusion, or exclusion, in network models.

Load factors, which represent the model's achievement of utility maximization, is captured by the vehicles' load factors derived from seat capacity and effective capacity. In addition to individual vehicle load factors, network load factors were observed and analyzed. Specifically, network structure load factors were evaluated via weighted average load factors.

To summarize the abovementioned research questions, the research focused on three questions: What percentage of flights utilized direct, 2-stop, 3-stop, 4-stop, 5-stop and 6-stop route configurations? What percentage of flights utilized SK76, AW139 and SK92 aircraft? Lastly, what load factors, based on seat capacity and effective capacity, were achieved by the model?

Delimitations

This research strategically utilizes delimitations in order to reflect the environment for which it was designed and promote a balance between the theoretical underpinnings of the problem and practitioner applicability. Specifically, the delimitations include a unique data set from the Gulf of Mexico's deepwater and ultra-deepwater offshore locations, a limited fleet suited for servicing the locations and a data-driven selection of depots.

The data set consists of offshore nodes in the Gulf of Mexico located off the United States' coast. These locations are, in practice, served by the same commercial helicopter fleets from the same onshore depots. Hence, the network consists of locations suited for inclusion in this transportation network research. Due to the inherent differences among the selected sample and all other locations in the Gulf of Mexico, which utilize supply vessels for personnel transportation and helicopters for supply transfers, the deepwater and ultra-deepwater segment of the industry is ideal for the evaluation of personnel exchanges at offshore locations and alternative network structures.

The fleet, consisting of the SK76, AW139 and SK92 aircraft, are routinely utilized for serving the sample's locations, possess twin engines, and yield suitable capacity and range. Therefore, the heterogeneous, yet limited, fleet is ideal for analyses associated with transporting personnel to and from deepwater and ultra-deepwater nodes. Notably, the vehicle types do exhibit material differences in capabilities and costs. The diversity within the heterogeneous fleet provides a meaningful and practical evaluation of the problem.

There exists a seemingly endless set of options for onshore depots. Through evaluation of the industry's current depots, six onshore depots are evaluated for their respective utility among the offshore nodes. The evaluation is executed via cluster analysis and yields justification for limiting the onshore nodes to those selected for the problem.

Delimitations, listed above, serve to effectively isolate the segment of the Gulf of Mexico's offshore locations, provide a representative fleet for the deepwater and ultra-deepwater environment and sensibly limit the overall quantity of onshore depots. In essence, the delimitations serve to enhance model development, results and conclusions in lieu of limiting the robustness of the problem and solutions.

Limitations and Assumptions

The current study encompasses all deepwater and ultra-deepwater locations, multiple depots and a heterogenous fleet. In doing so, there are some limitations and assumptions worth noting. Importantly, these limitations and assumptions are not deemed detrimental to the creation of flights or conclusions borne. In fact, the limitations and assumptions are deemed necessary and appropriate to reflect the inherent nature of the problem and environment for which it was created.

In lieu of including all structures in the Gulf of Mexico basin, the sample is limited to deepwater and ultra-deepwater structures. Although a limitation, the included structures consist of active sites that routinely utilize helicopters to exchange personnel whereas the remaining structures utilize supply vessels or a combination of both transportation modes. Also, many structures are not manned at all times and, therefore, do not meet the requirement that a structure retain employees for the duration of their work cycle.

The group of eligible depots is seemingly endless as numerous coastal airports and firm-owned heliports are prevalent. Therefore, known depot locations are included and further limited via cluster analysis. Intuitively, the quantity of depots is subject to fixed and variables costs and, therefore, is to be minimized to the extent that operations are minimally interrupted. Due to the method of limiting the quantity of depots, the limitation is deemed appropriate to minimize costs while preserving operational feasibility.

Deepwater and ultra-deepwater structures in the Gulf of Mexico possess fuel systems for aircraft refueling. Therefore, the payload calculations assume refueling at each location and, consequently, pertain to each individual leg of a flight. The reserve fuel requirement is set in order to meet prevalent regulatory requirements.

Also, the weight contribution of each passenger and their respective bag is static across all passengers. However, the designated weight is deemed appropriate to approximate the consumption of payload for each individual. Also, the aircraft empty weights across identical airframes, in practice, may vary. The empty weights of the aircraft utilized in the model are derived from means of actual airframes configured for oil and gas transportation. In an application, the weights of the passengers, passengers' bags and aircraft are known and can be applied within the model.

Pricing in the energy industry's transportation sector is a key component of firms' pursuit of a competitive advantage and, importantly, may differ across firms and firms' customers. Although the absence of exact and verifiable pricing persists, prices are derived from published costs in Conklin & de Decker Associates' 2021 report. The derivation is deemed to be an acceptable method to approximate price spreads across the vehicles included in the model.

The limitations and assumptions identified have been mitigated as much as reasonably possible to achieve an accurate reflection of the environment for which the study was conducted. When generalizing across geographical regions worldwide, these assumptions and limitations must be considered to preserve applicability for practitioners. The structure of this study's model inputs allows for such considerations to be evaluated and, if necessary, modified for dissimilar networks. Overall, mitigating limitations and assumptions for this study has been of great importance and reasonably achieved.

Definitions of Terms

Abandonment	Decommissioning and removal of offshore facility
Block	9-mile^2 location identified by GPS coordinates
Clustered network	Network of nodes grouped via spatial proximity
Deepwater	Water depth from 1,000 ft. to 4,999 ft.
Depot	Onshore facility for flight origin and termination
Downstream	Processes for converting oil and gas to finished products
Drilling	Mechanically boring through the seabed for hydrocarbon extraction

Exploration	Searching for hydrocarbon-rich geographical locations
Firm-level network	Network of nodes leased and operated by a single firm
Integrated network	Network of nodes consisting of all deepwater and ultra-deepwater facilities
Load factor	Utilized percentage of an aircraft's capacity
Node	Offshore facility designated for passenger exchange
Platform	Diverse set of structures used for hydrocarbon exploration, extraction, production and abandonment
Production	Initial processing, such as separating, heating, cooling, measuring and transporting, hydrocarbon materials
Split delivery	Routes consisting of more than one offshore node
Upstream	Processes for exploring, extracting and transporting oil and gas
Ultra-deepwater	Water depth equal to or greater than 5,000 ft.

List of Acronyms

AC	Alaminos Canyon
ALNS	Adaptive Large Neighborhood Search
AP	Assignment Problem
BLFCP	Base Location and Fleet Composition Problem
BOEM	Bureau of Ocean Energy Management
BPP-1	One-dimensional Bin Packing Problem
BSEE	Bureau of Safety and Environmental Enforcement
CHRP	Capacitated Helicopter Routing Problem
CLRP	Capacitated Location Routing Problem
CPP	Carpooling Problem

CT	Compliance Tower
CVRP	Capacitated Vehicle Routing Problem
DARP	Dial a Ride Problem
EB	East Breaks
EW	Ewing Bank
FAA	Federal Aviation Administration
FC	Flight Cost Function
FPSO	Floating, Production, Storage and Offloading
FSMVRP	Fleet Size and Mix Vehicle Routing Problem
FSMVRPMD	Fleet Size and Mix Vehicle Routing Problem with Multiple Depots
GA	Genetic Algorithm
GB	Garden Banks
GC	Green Canyon
GOM	Gulf of Mexico
GPS	Global Positioning System
HCHRPSDMD	Heterogeneous Capacitated Helicopter Routing Problem with Split Deliveries and Multiple Deliveries
HFFVRP	Heterogeneous Fixed Fleet Vehicle Routing Problem
HGES	Hybrid Grouping Evolution Strategy
HRP	Helicopter Routing Problem
KC	Keathley Canyon
LF	Load Factor
LP	Linear Program

MC	Mississippi Canyon
MILP	Mixed Integer Linear Program
MTLP	Mini Tension-leg Platform
NSGA	Non-dominated Genetic Algorithm
NP	Non-deterministic Polynomial-time
OCS	Outer Continental Shelf
OR	Operations Research
OSX	Oil Services Stock Index
PAX	Passenger
PDP	Pickup and Delivery Problem
PFL	Person Flight Hour
PSVPP	Periodic Supply Vessel Planning Problem
PTL	Person Takeoff and Landing
RMSTD	Root Mean Squared across Standard Deviations
SDVRP	Split Delivery Vehicle Routing Problem
SVRPPD	Single Vessel Routing Problem with Pickups
TLP	Tension-leg platform
TSP	Travelling Salesman Problem
UPGMC	Unweighted Pair-group Method with Centroid Approach
V1	Sikorsky SK76
V2	Leonardo AW139
V3	Sikorsky S92
VEC	Vehicle Effective Capacity

VCP	Vehicle Seat Capacity
VK	Viosca Knoll
VRP	Vehicle Routing Problem
WR	Walker Ridge

CHAPTER II

PART I REVIEW OF THE RELEVANT LITERATURE

Transportation networks have been and continue to be extensively studied by researchers and adopted by practitioners. The extent of such research and practice has been attributed to the idiosyncratic characteristics of networks and potential efficiency gains (Agatz et al., 2012). When exchanging personnel and supplies in the offshore energy industry, helicopter and supply vessel fleets are utilized and can be characterized as complex transportation networks. Studies showed that the use of more robust methods materially reduced costs when properly designed and implemented (Romero et al., 2007; Rosero & Torres, 2006; Timlin & Pulleyblank, 1992). In addition to literature surveys evaluating transportation networks over the last 40 years, the extant literature includes numerous studies that explored diverse networks, their respective complexities and optimization models designed to achieve or approximate optimality. Specifically, contributory works relate to supply vessel routing, depot location, fleet composition, vehicle assignment, routing and ride sharing. Notably, the aforementioned topics and themes are occasionally interdependent and, therefore, are aggregated in a single work.

Supply Vessel Routing

Kisialiou et al. (2018) proposed a robust methodology for scheduling supply vessels in an effort to minimize the size of the fleet while, simultaneously, fulfilling demand with the uncertainty of meteorological phenomena. The transportation problem is commonly referred to as the periodic supply vessel planning problem (PSVPP). The research included allocated slack to account for schedule disruptions that may occur due to probabilistic weather conditions that inhibit optimal execution of supply vessel activities. The model, according to the researchers, was robust if it possessed a sufficient degree of inter-voyage and intra-voyage slack to achieve an acceptable service level based on predetermined requirements. The degree of slack was dependent on expected weather phenomena for the operating region, operating season and time of day. The model included an adaptive large neighborhood search (ALNS) heuristic within the PSVPP to incorporate and control solutions with embedded slack. The model was constructed and tested using instances provided by Statoil's networks of 15 and 26 locations and up to 6 vessels. The PSVPP with ALNS heuristic, using location, supply base characteristics, vessel configurations and Norwegian meteorological data, was tested and compared to results without slack robustness. The model including slack yielded a service level of approximately 83.6% whereas the exclusion of slack yielded a reduced service level of 78.9%. Notably, the cost increase for the abovementioned increase in service level was, arguably, an immaterial .31% (Kisialiou et al., 2018). Further testing revealed that an additional increase in slack produced an additional vessel to the fleet, which yielded a service level of 95.2% and increased cost of 22.58%. Kisialiou et al. (2018) developed and executed a practical application to the PSVPP to ensure the model closely reflected the environment to which it was applied. Overall, the research represented academic rigor and applicability for practitioners.

Aas et al. (2007) explored the optimization of supply vessel routing in Norway using data from a Norwegian oil and gas firm, Statoil. The research employed a mixed integer linear program (MILP) model, which included appropriate supply vessel and offshore facility constraints. The use of the aforementioned constraints were deemed to be essential and concluded to be unprecedented in the extant literature. However, the mathematical formulation represented a simplified version of the overall problem and, therefore, the problem was described as a single vessel routing problem with pickups (SVRPPD) (Aas et al., 2007). In essence, the model excluded many complexities that existed in the real problem and, consequently, served as a commencement point for further research and more thorough analyses. For example, splitting the pickups and deliveries among multiple vessels may be more aligned with the supply vessel network consisting of multiple offshore installations. Also, the model presented in the research was deterministic and excluded stochastic elements of the problem. Overall, Aas et al. (2007) validated the potential cost reductions when employing robust techniques to optimize offshore transportation via supply vessel in lieu of less sophisticated techniques.

Fagerholt and Lindstad (2000) evaluated an optimal policy for the supplying of Norwegian offshore locations via supply vessel, which encompassed both quantitative and qualitative methodologies. Notably, the study evaluated the cost effect of restricting night operations and exchanging supplies through a more efficient supply vessel schedule. The recipient of the cost savings was the subject firm of the study, Statoil (Fagerholt & Lindstad, 2000). The network of supply vessels, which was provided by more than one operator, averaged 3.8 vessels and conducted an average of 3.4 trips per week. The optimal supply vessel schedule was found by creating feasible schedules for the fleet and subsequently solving an integer programming model for optimality with the aforementioned schedules. Notably, the objective function's minimized cost was derived from the hiring cost of the supply vessel in lieu of the vessel's sailing time. Therefore, the total quantity of vessels and each vessel type was optimized. The 6 scenarios tested, which may or may not have been operationally feasible due to the inclusion of restricted hours of operation, yielded cost reductions of 66%, 78%, 57%, 66%, 56% and 76%, respectively (Fagerholt & Lindstad, 2000). Scenario 3's annual cost reduction corresponded to approximately US $7 million relative to Statoil's historical supply vessel expenditures. The study demonstrated the ability of optimization models to yield superior results for moderately complex transportation networks.

Halvorsen-Weare et al. (2012) created a methodology for dictating supply vessel type and voyage route to optimize a network of supply vessels for an oil and gas firm, Statoil. The network consisted of one origin, or supply depot, and seven nodes, or offshore locations. The solution was executed via two stages, voyage generation procedure and voyage-based model formulation. Specifically, sailing distances between locations, locations' demand, opening hours, maximum and minimum visits per voyage, vessel capacity and speed were included in the voyage generation procedure whereas visit requirements, spread of visits, time horizon, depot capacity and costs were included in the voyage-based model (Halvorsen-Weare et al., 2012). The model was applied to an actual Statoil project using a depot in Mongstad, Norway. The model's objective function output dictated the vessel type and voyage to be utilized for cost minimization and, seemingly, including all relevant constraints. Importantly, the model had been implemented and yielded a reduction of one supply vessel and cost reduction of approximately US $3 million (Halvorsen-Weare et al., 2012).

Depot Location and Fleet Composition

Pentico (2007) provided an overview of assignment problem (AP) research from 1952 to 2005. Notably, Kuhn (1955) is recognized as the earliest published AP work and employed the Hungarian method to achieve an optimal solution. Since Kuhn's work, there have been a plethora of works published on assignment problems, which differ in their constructions, solution methodologies and applications (Hoff et al., 2010). Among the forms of the AP problem were classic assignment problems in which there was one task per agent. The variations within this class of AP problems were classic assignment problems, classic assignment employing agent qualification, K-cardinality, bottleneck, balanced, minimum deviation, lexicographic bottleneck, Σ_k, semi-assignment, categorized, multi-criteria, combination multiple criteria, sequential multiple criteria, fractional, side constrained, quadratic and robust (Pentico, 2007). AP problems enabling multiple tasks per agent included generalized, multiple resource GAP, bottleneck GAP, imbalanced time-minimizing, β, cardinality β, bottleneck β, weighted β and quadratic generalized (Pentico, 2007). Lastly, there were assignment problems in which there existed more than two indices of objects. The multi-dimensional assignment problems included planar three-dimensional, axial three-dimensional, three-dimensional bottleneck, multi-period, simultaneous and multi-level generalized (Pentico, 2007). Broadly, the AP literature from 1955 to 2005 included assignment problems to optimize one-to-one matching of two sets, one-to-many matching of two sets, many-to-one matching of two sets, and matching variations with more than two sets. Also, the extant literature included assignment problems that consisted of more than a single objective. Due to the idiosyncrasies associated with networks and their subsequent practical applications, future assignment problem evolution is seemingly endless.

Hoff et al. (2010) performed a literature survey of fleet composition and routing works from 1954 to 2010. Specifically, the literature survey focused on operations research (OR) projects that combined fleet composition and vehicle routing (Hoff et al., 2010). Dantzig and Fulkerson (1954) concluded that the problem of routing naval oil tankers could be solved via linear programming. Notably, it was further concluded that the methodology is suitable whether minimizing the quantity of tankers, total sailing time or other metrics deemed essential (Dantzig & Fulkerson, 1954). Hoff et al. (2010) emphasized that for many industrial applications of the fleet composition component of the aforementioned problem, a heterogeneous fleet was more realistic and, consequently, more apt to addressing transportation networks. In contrast to the capacitated vehicle routing problem (CVRP), the fleet size and mix vehicle routing problem (FSMVRP) accounted for the heterogeneity of the fleet in the problem definition. An additional variant of the problem accounted for the heterogeneity of the fleet while including an upper bound on the size of the fleet and was commonly referred to as the heterogeneous fixed fleet vehicle routing problem (HFFVRP). Furthermore, some models extended the HFFVRP to allow for split deliveries, which may limit unused fleet capacity and, therefore, reduce costs. Another variant of the FSMVRP included time windows, which defined the times at which particular transportation activities would take place, and was referred to as a fleet size and mix vehicle routing problem with time windows (FSMVRPTW). A more complex variant of the FSMVRP allowed for multiple depots to be integrated into the optimal fleet composition and routing, which was referred to as the fleet size and mix vehicle routing problem with multiple depots (FSMVRPMD). An extension of the FSMVRPMD allowed for time windows. The initial phase of the FSMVRPMD with time windows problem addressed cost-effective clusters while the second phase of the FSMVRPMD with time windows problem addressed the assignment of clusters to vehicles and routes. The final phase of the FSMVRPMD with time windows problem scheduled arrival times for the aforementioned vehicles serving predetermined clusters. Hoff et al. (2010) offered a rich critique of the extant literature. First, there existed a scarcity of published works on fleet composition and routing. Furthermore, the extant literature seemingly lacked a balance between "strategic or tactical" works and, instead, was excessively focused on operational questions dealing with daily requests given a predetermined fleet size and mix (Hoff et al., 2010, p. 2043). Hoff et al. (2010) provided positive reinforcement for the inclusion of "real world aspects" (p. 2042) in many of the published works surveyed, which was deemed advantageous and proper. Lastly, Hoff et al. (2010) identified a trend in models becoming more complex and, therefore, a more accurate representation of the networks for which they were created and solved.

Norddal (2013) explored the increase in efficiency resultant from implementing the use of transhipment hubs for offshore oil and gas transportation via helicopters. The research endeavor was a response to the shift from relatively closer locations to relatively farther locations for Petrobras' assets in Brazil's Santos basin. The researcher's query was addressed by considering risks and costs metrics. Norddal (2013) developed three deterministic MILP models, arc flow formulation (AFF), path flow formulation I (PFF1) and path flow formulation II (PFF2). Initially, the AFF model established the flow of helicopters and employees between locations over the earth's surface, or arc. Notably, the flow, directed by the objective function and associated constraints, enabled split pickups and deliveries and multiple flights per aircraft per day. Next, the PFF1 model established origins of flights, flight path routes, flight path orders and flight costs. Lastly, the PFF2 model utilized the output from the PFF1 and AFF models and introduced supplemental constraints for the network, direct flight and hub requirements and pickup and delivery requirements. The models indicated that no transhipment hubs were optimal for future Petrobras operations (Norddal, 2013). Also, the model identified that the majority of flights should be conducted utilizing the Sikorsky S92 aircraft in lieu of utilizing the Sikorsky S76 aircraft for transhipment hubs. The Leonardo AW139 and Airbus EC225 aircraft were not optimal in either of the aforementioned network structures. Nordall (2013) concluded that the evaluation of helicopter transportation in the energy sector remained an opportunity for further research.

Fernández-Cuesta et al. (2017) proposed a base location and fleet composition problem (BLFCP) to evaluate the optimal departure point and helicopter fleet mix to serve Brazil's offshore locations and Norwegian operations in the Arctic. In addition to the transportation of passengers between nodes, the model included offshore fuel depots, which were not associated with a pickup or delivery point for passengers. Notably, the demand was deterministic and addressed a single point in time in lieu of projecting optimal base locations and fleet composition over a period of time. The BLFCP sought to minimize the total fleet cost, flight time cost per flight and lease costs associated with the utilized hubs (Fernández-Cuesta et al., 2017). Constraints included base limitations linked to maximum landings and total operating aircraft, aircraft allocation of a maximum of one base per aircraft and aircraft capacity limitations. Notably, the computational processes were allocated five hours, which was inadequate to compute an optimal solution. The best solution was chosen once the allotted time for computational processing was exhausted.

Hermeto et al. (2014) performed analyses aimed at optimizing airfield locations, distribution of demand among airfields and fleet composition within the Campos and Santos basins, which are located off the coast of Brazil. The research emphasized the importance of using helicopter capacity, seat and total weight, to solve for fleet mix (Hermeto et al., 2014). Notably, the abovementioned authors encouraged the use of the proposed model in other regions using helicopters for offshore transport. Hermeto et al. (2014) limited the study to Petrobras' network of offshore facilities in lieu of including a broader network across multiple firms' offshore locations. Also, the demand in the model was deterministic versus stochastic, which may not have accurately reflected the complexities of offshore air transportation. The optimization model was executed using 4 sets of parameters in 6 scenarios. The scenarios exhibited decreasing demand over the time horizon from 2011 to 2020 and transported approximately 11,080 and 9,025 passengers in 2011 and 2020, respectively. From 2020 to 2030, which encompassed the remaining time horizon of the study, demand was considered constant. Over the aforementioned time horizon with fluctuating demand, the fleet consisted of a minimum, maximum and average of 35, 71 and 55, respectively, of Leonardo AW139 aircraft. The larger Airbus EC225 aircraft yielded a minimum, maximum and average of 3,11 and 7, respectively, aircraft for the same time horizon. The remaining constant portion of the time horizon, 2021 to 2030, an average of 70 Leonardo AW139 aircraft were utilized whereas an average of 10 Airbus EC225 aircraft were utilized. Hermeto, Filho and Bahiense (2014) provided a thorough and practical evaluation of the complex network used to service offshore locations in the oil and gas industry and may be regarded as the most comprehensive to date.

Vehicle Assignment and Routing

Archetti and Speranza (2012) conducted a literature survey of vehicle routing problems with split deliveries (SDVRP) from 1989 to 2011. Specifically, the survey observed the main properties, exact and heuristic solution approaches and variants of the SDVRP. The SDVRP, initially introduced by Dror and Trudeau (1989), represented a routing problem that enabled a shipment, person or other physical object, to be served by more than one vehicle. The aforementioned seminal work compared a transportation network that included and excluded split deliveries. In one of many experiments performed, the inclusion of split deliveries yielded a minimum, maximum and average reduction in vehicles of 13, 15 and 14, respectively, and a minimum, maximum and average percentage reduction in distance travelled of 10.0%, 12.5% and 11.2%, respectively (Dror & Trudeau, 1989). Within the broader scope of the SDVRP is the travelling salesman problem (TSP), which an entity travels to predetermined geographic points and returns to the point of origin at the minimum cost derived from the most efficient route. However, if an optimized set of routes are created and executed by a minimum quantity of vehicles, the problem reflects a vehicle routing problem (VRP) and is solved as a bin packing problem. The SDVRP utilizes the VRP methodology but differs in that the constraint restricting more than one vehicle serving a geographic point is relaxed. In one experiment, the SDVRP in lieu of the VRP yielded a vehicle quantity reduction of approximately 33% and cost reduction of approximately 25% (Archetti & Speranza, 2012). Within the scope of SDVRP works, variants included time windows, pick-up and delivery, profit maximization, inventory and production, minimum fraction, heterogeneous fleet, stochastic, discrete demand and arc routing problems (Archetti &

Speranza, 2012). Though most applications have shared some characteristics, they have also significantly relied on the inherent nature of the problem to which they were applied.

Galvão and Guimarães (1990) devised a computerized program to schedule the routing of helicopters in Brazil's offshore oil and gas basin, which was one of the earliest published endeavors within OR using offshore-bound helicopters. The computerized program's algorithm sought to fulfill demand while minimizing cost. During the test phase of the program, which was conducted utilizing 65 routes over 11 consecutive days, the program produced savings of approximately US $4,500.00 (Galvão & Guimarães, 1990). However, the overwhelming reluctance of internal and external stakeholders to modify the scheduling of helicopters inhibited the implementation of the program and realization of monetary benefits. Galvão and Guimarães (1990) demonstrated the potential benefits of a more sophisticated algorithm for helicopter routing while emphasizing the human factors that may obstruct design and implementation.

Motta et al. (2011) utilized heuristic solution methods of genetic algorithms to optimize helicopter routes in the offshore environment of coastal Brazil in an effort to reduce flight time and fuel consumption. The model was imbedded in a program with a user interface for practitioners, planners and pilots, and included helicopters' ranges, total weights and flight time limitations. Notably, the aircraft seat capacity was not included and the helicopter type was dictated by the practitioner. The researchers concluded that testing did not yield consistent or optimal routes. Furthermore, it was concluded that a more advantageous model would incorporate a fleet of aircraft in lieu of a single vehicle to fulfill transportation demand. Overall, the study, while exploring an important aspect of optimized offshore aviation, developed and employed a model that warranted improved alignment with offshore transportation via helicopter (Motta et al., 2011).

Qian et al. (2011) proposed an additional consideration when planning helicopter flights for oil and gas operations. In essence, the researchers' model limited persons' total takeoff and landings, PTL, and persons' flight hours, PFL, in an effort to reduce the risk of fatality. Though the aforementioned routing technique was valid for safety concerns, the research identified an inverse relationship between cost minimization and total expected number of fatalities, TENF (Qian et al., 2011). Furthermore, the large data set of flight hours with few helicopter accidents did not provide a meaningful justification for accepting the tradeoff. Consequently, this research was relatively unique and, arguably, impractical in the offshore oil and gas industry. The model utilized a homogenous fleet. Overall, the tool may be used in instances when the tradeoff between TENF and total cost is minimal. The authors provided a complementary example that did not yield such a tradeoff and reduced the TENF.

Caballero-Morales and Martinez-Flores (2019) utilized the capacitated vehicle routing problem with failure rate (CVRPFR) in order to optimize helicopter flight routes while preventing incidents and accidents. The failure rate was explained as a function of helicopters' cumulative distance and time travelled, which was incorporated using the probability distribution function that an aircraft is within or beyond a state of control, or airworthiness, during a flight. The locations utilized in the study were obtained from the offshore installations operated by Pemex, which were located off the coast of Mexico (Caballero-Morales & Martinez-Flores, 2019). Notably, the model assumed that the demand for air service is deterministic, used a homogeneous fleet, Airbus H175 aircraft, and departed from and returned to a single onshore heliport. The researchers' MILP was designed to restrict routes if the predetermined time to failure was exceeded and, consequently, lead to more helicopters required than other models seeking to optimize fleets and routes solely from an economic perspective. Furthermore, the model restricted access to some locations via helicopter, which may have inhibited implementation by practitioners. Overall, the model represented a useful addition to the extant literature with limited applicability in the field of offshore upstream logistics.

Velasco et al. (2012) proposed a PDP for the transportation of workers to and from offshore locations using a single helicopter type and with passengers possessing a priority of transport. Specifically, the aircraft could carry up to 13 passengers, had a range of 250 kilometers and had an average velocity of 220 kilometers per hour (Velasco et al., 2012). Each passenger was assigned a priority between 1 and 4 representing the most to least urgent transport, respectively. Other relevant constraints included, but were not limited to, a pairing requirement to exchange one outbound passenger for an inbound passenger, an ordering requirement to ensure the outbound passenger arrived prior to the paired inbound passenger departing, a helicopter capacity constraint and a helicopter flight time per leg constraint (Velasco et al., 2012). The model was solved via Pareto optimality in that a solution was accepted if it was not dominated by a superior solution. The researchers relied on a variation of the Pereto solutions, or Pereto front, which was referred to as a non-dominated sorting genetic algorithm (NSGA-II) framework. The NSGA-II was enhanced by local-search metaheuristics, LS1 and LS2, in comparison to the reference model without a local search metaheuristic. Overall, the bi-objective algorithm, NSGA-II, efficiently solved the specific PDP tested and was enhanced when a local search metaheuristic was incorporated. The research provided insight for practitioners seeking to optimize their respective transportation networks and researchers seeking to study similar transportation problems.

Sierksma and Tijssen (1998) developed a LP model to optimize personnel exchanges via helicopters at 51 North Sea offshore locations. The model optimized crew exchanges via minimizing the total distance travelled to accomplish predetermined transportation goals (Sierksma & Tijssen, 1998). Specifically, the study utilized a SDVRP, which included decision variables representing feasible flights. The LP model was solved as TSP problems and employed the cluster-and-route heuristic and four complementary heuristics, cycle removing, free-tree, 1-opt and 2-opt (Sierksma & Tijssen, 1998). The complementary heuristics employed yielded superior results and may enhance future research endeavors. While Sierksma and Tijssen (1998) evaluated the entire network of offshore locations in the North Sea, limitations included the use of a single helicopter type, the Sikorsky S-61, exclusion of an offshore refueling option and absence of helicopters' useful load constraints.

Rosa et al. (2016) developed a mathematical model, based on the capacitated helicopter routing problem (CHRP), PDP and dial-a-ride problem (DARP) techniques, which were solved via the clustering search (CS) metaheuristic. The research evaluated the model using Petrobras' demand requirements and was claimed to utilize a relatively more realistic objective function, total aircraft cost, and requisite constraints, aircraft total weight limitation, aircraft seat capacity, fuel quantity limitation, fuel reserve requirement, total daily flight time limitation and daily aircraft operating hours (Rosa et al., 2016). The model assumed that workers travelled to and from offshore locations daily, which differs from Gulf of Mexico operations. Furthermore, the model assumed a fixed number of aircraft in lieu of being utilized to solve for the minimum quantity of aircraft to be utilized. Overall, the model performed well in instances with relatively fewer helicopters and relatively lower passenger demand. However, the model failed to execute when relatively more helicopters and relatively higher passenger demand was incorporated due to the computer's lack of processing capability. Importantly, the CS metaheuristic satisfactorily solved the bounded instances and achieved optimality. Rosa et al. (2016) proposed that the research be continued and that there existed additional analyses that may complement their work.

Rosero and Torres (2006) sought to optimize helicopter transportation via travel distance minimization among numerous pickup and delivery nodes. The researchers proposed a hybrid algorithm, which utilized a heuristic procedure to create routes within an ant colony metaheuristic (Rosero & Torres, 2006). Specifically, the study used the helicopter routing problem, which yielded the chronological fulfillment of transportation requests and produced feasible routes using one of two insertion heuristics employed in the study, ACO1 or ACO2. ACO1 and ACO2 insertion heuristics relied on the random proportional rule and the state transition rule, respectively. The insertion heuristics were evaluated in instances with less than and greater than 30 passengers. For instances with less than 30 passengers, both insertion heuristics yielded improvements relative to manual programming. However, in instances with greater than 30 passengers, ACO1 produced superior results relative to manual programming whereas ACO2 produced superior results in most instances with a significant increase in processing time. The authors concluded that the use of the hybrid solution technique may be warranted in future research endeavors.

Timlin and Pulleyblank (1992) utilized two heuristics to determine optimal routing for Mobil Producing Nigeria's 45 offshore locations. One heuristic ignored aircraft seat and weight capacities, which was of minimal use to optimizing the transport of rig crews via helicopter. When accounting for aircraft limitations along with other prevalent constraints, the system performed as well or up to 15% better than Mobil Exploration and Producing Services, Inc.'s manual solution methods (Timlin & Pulleyblank, 1992). Overall, the heuristics achieved fulfillment of demand at minimized cost. Based on the routes selected for the study, the heuristics were expected to yield savings of US $500,000 per year. Importantly, the model was restricted to a single firm's demand, Mobil Producing Nigeria's 12 daily routes.

Romero et al. (2007) pursued the optimization of an oil & gas helicopter transportation network of 5 helicopters transporting 70 individuals. The authors, utilizing genetic algorithms and heuristic optimization, applied their analyses to a Mexican oil firm, Pemex (Romero et al., 2007). Appropriately, the model included helicopters' total weight capacities, flight time restrictions and ranges; however, helicopters' seat capacities were not included as a model constraint. The researchers' pickup and delivery problem (PDP) was solved utilizing a genetic algorithm (GA) for the route planning problem and heuristic optimization for the allocation problem. When testing the methodologies with Pemex data, the GA failed to utilize the aircraft's capacity more efficiently that the manual solution in approximately 18% of instances tested. However, the GA yielded approximately 10% in cost savings relative to the manual solution.

Notably, the manual solution required 16 work hours whereas the GA produced a solution in approximately 5 minutes.

Menezes et al. (2010) developed a large-scale mixed integer program that optimally assigned passengers to flight routes for Brazil's largest oil and gas firm, Petrobras. The column-generation procedure, which relied on a network flow formulation, treated each passenger as a weight to be transported and optimally assigned the passengers to flights. Notably, many constraints, which were not typically included in other vehicle-routing problems, included a requirement that each flight ultimately arrive at the point of origin, flights per aircraft were constrained to 5, each flight after the initial flight required a standard inspection delay at the origin, offshore landings for each flight were bounded, simultaneous offshore landings were not permitted and helicopters' total weights were constrained in accordance with the airframes' prescribed parameters. The program, which was utilized daily and produced results in less than one hour, was estimated to save the firm $20 million annually (Menezes et al., 2010). However, the model accounted for short-run demand and assumed a predetermined quantity of aircraft. Nonetheless, the program reduced flight time and offshore landings by 8% and 18%, respectively.

Abbasi-Pooya and Husseinzadeh (2017) explored two transportation models, jacket-based formulation (JBF) and passenger-based formulation (PBF), which differed in their definitions of the nodes to be utilized. The JBF model defined each jacket, or location, as a node whereas the PBF defined each passenger as a node. The JBF model represented a mixed integer linear formulation consisting of two binary variables for the aircraft's flight route, two binary variables for pickup and delivery of passengers, two nonnegative variables to commence and terminate each flight, two nonnegative variables to constrain the capacity of the helicopter, seat and total weight, and variables for subsortie elimination and completion time conformance. As stated, the underlying difference between the two models was the definition of nodes within the network. The PBF and JBF models' quantity of variables and constraints were sensitive to the quantity of passengers to be transported and jackets to be visited, respectively. The results identified that the JBF was superior to the PBF in that optimum output was achieved in 93% of instances while producing such output was 74% more efficient. Also, the researchers proposed a hybrid grouping evolution strategy (HGES) algorithm to optimize daily offshore trips to and from 11 locations consisting of 28 workers, which was claimed to be more suitable for larger problems. The algorithm was applied to the geographic location between Iran and Qatar, known as the South Pars/North Dome field and yielded a reduction in costs of approximately 6% (Abbasi-Pooya & Husseinzadeh, 2017). Overall, the study exemplified the complexity of offshore transportation and potential benefits of employing robust methods.

Díaz-Parra et al. (2017) developed a transportation problem, oil platform transport problem (OPTP), which optimized the trips of workers to and from offshore facilities. Specifically, the OPTP was a combination of the helicopter routing problem (HRP), which was a generalization of the SDVRP and the one-dimensional bin packing problem (BPP-1) (Diaz-Parra et al., 2017). The model employed 5 instance sets consisting of 50 instances each with varying transportation types, air, maritime and intermodal, fleet configurations, homogeneous and heterogeneous, and vehicle types, helicopters, ships and a combination of helicopters and ships. The model yielded an optimal cost using the

OPTP-36 instance set to transport 720 units, workers or packages, of US $44,044.25 (Diaz-Parra et al., 2017). Overall, the research concluded that the OPTP was a NP-hard/NP-complete problem via polynomial transformation of languages between the VRP and OPTP (Diaz-Parra et al., 2017). Furthermore, the researchers appropriately identified that the subject data utilized in the study, Mexico's largest oil and gas firm, Pemex, were unique and, consequently, should be modified to represent dissimilar data sets.

Cooperative Ride Sharing

Furuhata et al. (2013) conducted a literature survey of ride-sharing works and broadly defined the system as a trip consisting of at least two ride-sharing participants with a shared or diverse origin and destination. More specifically, ride-sharing trips were defined as identical, inclusive, partial and detour, which identified the origin and destination relationships among passengers. The methods of engaging in ride-sharing were identified as organized, which were facilitated by an agency, or unorganized, which were facilitated by participants (Furuhata et al., 2013). Also, within the broad scope of ride-sharing, the researchers defined service operators, which executed ride-sharing trips utilizing their fleet of vehicles, and matching agencies, which facilitated the matching of riders and vehicles on trips using participants' personal vehicles. In the current study, all of the aforementioned ride-sharing trip types will be applicable. Importantly, Furuhata et al. (2013) identified some fundamental components of a ride-sharing network, planning, pricing and evaluation of alternatives.

Baldacci et al. (2004) evaluated the carpooling problem (CPP) and, specifically, sought to minimize the quantity of cars utilized for transportation to work locations via ride sharing. The problem, which was solved by exact and heuristic methods, achieved optimality by minimizing the quantity of vehicles required and distance travelled by all passengers. The model shared a similar constraint to the current research, vehicle capacity, and included some constraints inapplicable to the current research, maximum waiting time and maximum riding time. Mathematically, the CPP employed two integer programming formulations, commodity flow and feasible paths (Baldacci et al., 2004). Baldacci et al. (2004) focused on the solution methods in lieu of highlighting a reduction in vehicles or total costs. However, the work adequately conceptualized the notion of ride sharing as all employees were eligible to be assigned to a vehicle travelling the shortest route within an optimized set of routes.

Taylor and de Weck (2012) measured efficiency gains of an integrated transportation system in the context of overnight package deliveries via aircraft. In essence, the research enabled a transportation system solution matching the transportation system's overall goal, which was achieved by simultaneously solving for vehicle and network objectives (Taylor & de Weck, 2006). Although the research did not explicitly identify ride sharing as a key component, the study's holistic treatment of the system is relevant in that the network's sub-systems were not solved independently or chronologically but, instead, were solved interdependently and simultaneously. Therefore, this study, effectively, allowed packages to engage in ride sharing. For the researchers' first test case, the integrated transportation system yielded cost reductions of 22% and 11% compared to the independent network and independent vehicle solutions, respectively. For the researchers' subsequent test case, the integrated transportation system yielded cost reductions of 10% and 18% compared to the independent network and independent vehicle solutions, respectively. Overall, Taylor and de Weck (2012) highlighted the potential efficiency gains resultant from redefining a system's architecture, which enabled ride sharing.

Agatz et al. (2012) evaluated the components of ride-sharing systems and referred to such systems via strict definitions of passengers and personal vehicles. However, ride sharing, conceptually and mechanically, can be applied to a variety of passengers, vehicles and networks. The researchers appropriately identified the potential cost savings derived from fewer total vehicles required and reduced incremental costs per passenger. Furthermore, Agatz et al. (2012) aptly attributed total distance travelled as the primary cost function to be minimized in a ride-sharing system. Although studies have demonstrated reduced costs via ride sharing, there were instances when an optimized network yielded a sub-optimal result at the individual level of analysis (Agatz et al., 2012). The identification of possible inverse relationships between an optimized network and individuals within the network was significant and is relevant in the current study.

Summary

Though multiple aspects of the current problem were addressed, the aforementioned studies inadequately analyzed and evaluated the Gulf of Mexico's firm-level, clustered and fully-integrated network structures. Offshore logistics in the Gulf of Mexico has not been widely assessed in academic literature due to, in part, the complexity of operations (Kaiser & Snyder, 2010). The Gulf of Mexico's helicopter transportation network, too, exhibits unique nuances, complexity and dynamism. Collectively, the aforementioned works materially contributed to a more thorough understanding of maritime personnel transportation networks. However, these works did not address important components that are addressed in the current research.

Specifically, the current research includes simulation analyses between firm-level, clustered and fully-integrated network structures. The simulation analyses identify optimal airframes, depots and routes within the Gulf of Mexico, which includes ride sharing. Utilization of split deliveries within OR research is common and was applicable to the current research's network structures. Node demand was able to be met by multiple vehicles and routes within the respective network. However, in contrast to split deliveries, ride sharing encompasses the allowance for clustered and fully-integrated nodes' demand to be met by their respective fleets. In essence, the respective total demand, clustered or fully-integrated, may be met by a single fleet and, more specifically, firms' personnel may be included on the same flight. The practice of ride sharing in the oil and gas and similar industries was effectively nonexistent and, consequently, represented a rich opportunity for exploration. The current research contributes to the extant literature and offers practical applications in maritime and other environments. Within the Gulf of Mexico, sharing helicopter assets was unprecedented and potentially an innovative solution to achieving upstream logistics efficiency.

CHAPTER III

PART I METHODOLOGY

The methodology section includes the current study's research approach, design and procedures, sample data, data sources and treatment of data for model inputs. The data employed represent the initial use of variables prevalent in the Gulf of Mexico's transportation sector. Also, the problem represents a holistic representation of offshore transportation in that a heterogeneous fleet, multiple depots, pickup and delivery exchanges and split deliveries are included. Further analyses are conducted to evaluate potential efficiency gains from alternative network configurations, clustered and integrated. Consequently, the contribution of this study is invaluable for both practitioners and researchers. Practitioners are introduced to a practical approach to model development and solution deliverance whereas researchers are provided a complementary work related to this evolving and complex transportation problem.

Research Approach

Complexity and size are characteristics commonly associated with practical problems in combinatorial optimization necessitating the use of approximation methods in lieu of exact methods (Ying & Cheng, 2010). Specifically, many transportation combinatorial optimization problems are characterized as NP-Hard. Hence, exact methods are excluded from consideration when approximated solutions are deemed adequate (Ying et al., 2009). In essence, these problems necessitate approximation methods for solvability and parsimony (Ruiz & Stützle, 2007). One of many useful methodologies is the greedy algorithm, which, broadly, initiates a solution and iteratively seeks to improve the solution. In essence, greedy algorithms reduce computational complexity, increase efficiency and facilitate practical solutions to, otherwise, insoluble problems (Lu et al., 2016). The computational processes associated with the algorithm are typically unique to the problem and, consequently, vary from one algorithm to another (Ruiz & Stützle, 2007). However, greedy algorithms collect optimal solutions at each iterative step without regard for future steps. Practitioners and researchers must develop and employ an iterative schema to define iterative processes to be executed. In cases using a local, or neighborhood, search, programs are susceptible to remaining in local optima, which may be mitigated or resolved via solution restructuring techniques (Ruiz & Stützle, 2007). Solution restructuring techniques, too, are dependent on the problem being evaluated and, consequently, will likely differ from one problem to another. However, there exists ample evidence that the use of local, or neighborhood, search heuristics accompanied by other processes, such as randomized solution structure mutations, enhance greedy algorithms (Ruiz & Stützle, 2007). Among iterative solutions' results, a current solution is replaced if the iterative solution is superior in accordance with the specified objective function.

Design and procedures. The solution methodology employed is referred to as a randomized greedy algorithm, which was solved, iteratively, via a TSP algorithm. The program is further deconstructed in the proceeding subsections. The problem parameters include

- P: Total quantity of outbound passengers,
- F: Total quantity of flights,
- V: Total quantity of vehicle types,
- PW: Total weight (pounds) per passenger,

- $VC_{v,i,j}$: Cost of traveling in vehicle, *v*, from node *i* to node *j* *v {1..V}*, *i,j {1..N}*,
- FV_v: Maximum quantity of flights acceptable for vehicle *v* *v {1..V}*,
- VCP_v: Total seat capacity of vehicle *v {1..V}* and
- $VLC_{v,i,j}$: Total payload (pounds) capacity of vehicle, *v*, from node *i* to node *j* *v {1..V}, i,j {1..N}*.

Using these data, flights, consisting of passenger, vehicle and flight combinations, were randomly constructed to facilitate an initial solution and total network cost. The steps of the optimization method, which approximates global optimum, include the construction of flights, initial solution via random initialization and TSP algorithm, solution refinement via randomized greedy algorithm and final output of best solution.

Construction of flights. Flights were constructed using a vector, *PO*. The vector *PO* represents a vector of size *P* and is assigned a value of 0 or 1 if a passenger is unassigned or assigned to a flight, respectively. The indices of the vector *PO* rows indicate which vehicles are assigned to the flights. Notably, all inbound passengers replace outbound passengers and, therefore, inbound passengers are accounted for by *PO*. Specifically, the total quantity of passengers on a flight remains constant as inbound passengers instantaneously replace outbound passengers at outbound passengers' destination nodes. Although suboptimal, the initial construction of flights represents a feasible solution as defined by the model.

Initial construction of solutions and TSP algorithm. The variables, *F* and *P*, form a matrix, *X*, where each row is the vector *PO* and the vehicle of each flight is inferred by the index of each respective row. In other words, PF_v is assigned a value of 1 if passenger *p* is included on flight *f* in vehicle *v*. Otherwise, a value of 0 is assigned.

The columns of the matrix are represented by, if applicable, assigned passengers represented by an allocation variable, *X*. The matrix, *X*, is defined as follows:

$$X \in \{0,1\}^{F*P}$$

Given the *PO* for a particular flight, the optimal route is solved by a TSP algorithm. Specifically, the TSP optimally routes the flight based on the passengers on the aircraft and their respective destinations. The TSP algorithm also observes the eligible departure node options and optimally assigns the departure node. Importantly, the initial solution randomly groups passengers to flights. Although the initial solution meets passenger demand, the solution requires enhancement, which is achieved via neighborhood search and periodic solution structure mutation.

Adherence to relevant constraints. Many constraints, such as ensuring outbound passengers are replaced by inbound counterparts, aircraft seat capacities and weight capacities, are processed prior to being evaluated by the optimization model or are indirectly achieved via model formulation. Each passenger must be assigned an allocation, *X*, value of 1 in one of the columns. This requirement ensures that each passenger is assigned a single flight and, therefore, total demand is met. Equation 1 represents the demand constraint and is defined as follows:

$$\sum_{i=1}^{F} X_{i,j} = 1 \quad 1 \le j \le P \tag{1}$$

Using PW, VCP_v and $VLC_{v,i,j}$, the effective vehicle capacity, $VEC_{v,i,j}$, can be calculated for each flight leg. In essence, $VEC_{v,i,j}$ represents the total quantity of passengers that may travel in vehicle v from node i to node j. In lieu of explicitly prohibiting infeasible flights in initial, neighboring and mutated solutions, the constraint is, instead, relaxed and the leg is significantly penalized if violated. An intermediate function, referred to as the flight cost (FC) function, within the objective function serves to ensure flights are penalized for exceeding aircraft capabilities. If a flight violates the effective capacity constraint, which is relaxed in all solutions, the flight is assigned a cost of 10^{18}, which indirectly prohibits the flight from being collected as an optimal flight within the network. In essence, flights violating the leg's effective capacity, $VEC_{v,i,j}$, are iteratively discarded as the program seeks to minimize total cost. Equation 2 represents the vehicle effective capacity and is defined as follows:

$$VEC_{v,i,j} = minimum\left(VCP_v, \left\lfloor\frac{VLC_{v,i,j}}{PW}\right\rfloor\right) \quad (2)$$

The requirement for all outbound counterparts to be exchanged with their inbound counterparts and for the inbound counterparts to be delivered to the onshore node from which their outbound counterpart departed is achieved in the FC function. In essence, the FC function evaluates and assigns route nodes based on passengers' destinations that are included on the flight, evaluates and assigns the optimal departure node, optimally routes the aircraft and assigns a cost to the flight, which includes, if applicable, penalties for capacity violations.

Flight cost and objective functions. The FC function evaluates the list of passengers, optimally routes the vehicle based on included passengers' destinations, assigns an optimal departure node and assigns the appropriate cost of the entire flight, $\Sigma VC_{v,i,j}$. Optimal routing is executed via a TSP algorithm. As mentioned, the FC function assigns a penalized cost, 10^{18}, to those flights in violation of the $VEC_{v,i,j}$. The objective function computes the cost of all flights including passengers and retains the lowest total cost achieved through a series of iterations and mutations, which are further described in the following section. Equation 3 represents the objective function and is defined as follows:

$$Minimize \sum_{i=1}^{F} FC\ (X_i, v_i) \tag{3}$$

Randomized greedy algorithm. Neighboring solutions are defined as solutions that differ in that only a single passenger assignment is the difference among them. Each neighboring solution is evaluated and the solution yielding the lowest cost is retained. The process of evaluating neighboring solutions is bounded by a predetermined quantity of iterations, which is set at 10,000 for each model. In essence, the greedy algorithm introduces a neighborhood of flights and is subsequently solved via a TSP. Iteratively, passengers migrate to other flights, which yield flights including no passengers and, consequently, not contributing a cost to the network. Notably, networks are solved three times and differ in mutation intervals and passengers' probability of being randomly assigned a different flight. To evaluate solutions beyond local optimum, solutions are mutated randomly at predetermined stages and, if applicable, automatically if the current solution is superior among all neighboring solutions. For the three solutions created for each network, mutations are executed every 100, 500 and 1,000 iterations, respectively. Passengers are included in mutated solutions probabilistically, which is set at 0.001, 0.01 and 0.1, respectively, for the three solutions. The lowest total cost of the three solutions is retained for interpretation.

Sample

A sample of Gulf of Mexico offshore locations was collected, which lists 58 permanent deepwater and ultra-deepwater structures that are manned at all times and operated by 19 firms. The firms used in the sample include Anadarko Petroleum Corporation, BHP Billiton Petroleum (GOM) Inc., BP Exploration & Production Inc., Chevron USA Inc., ConocoPhillips Company, Eni US Operating Co. Inc., EnVen Energy Ventures, LLC, Equinor USA E&P Inc., Exxon Mobil Corporation, Fieldwood Energy, LLC, Hess Corporation, LLOG Exploration Offshore, LLC, MC Offshore Petroleum, LLC, Murphy Exploration & Production Company USA, Petrobras America Inc., Shell Offshore Inc., Talos Petroleum, LLC, W&T Energy VI, LLC, and Walter Oil & Gas Corporation.

The offshore facilities' locations are identified by their respective area and block, which is a 9-mile^2 geographic location and identifiable via global positioning system (GPS) coordinates. Among the sample locations, 22 of 58, or 37.9%, list their respective quantity of beds within the living quarters. The minimum, maximum and mean beds are 20, 88 and 56, respectively. Using these data, the quantity of beds within the living quarters at each respective offshore location was estimated via random number generation.

Sources of the Data

The sample of deepwater and ultra-deepwater locations were collected from the Bureau of Safety and Environmental Enforcement's (BSEE) data center via www.bsee.gov. The source lists, among other facts, locations' operator, water depth, GPS coordinates, platform type, installation date, platform name, manning schema, area, block and field. In addition to supplemental data, locations' GPS coordinates were retrieved to calculate distances, flight minutes and prices for helicopter transportation. Also, BSEE maintains a document, Complex/Structures List, which lists the quantity of beds for some locations. The quantity of beds for locations within the sample were utilized to derive passenger a count for each location.

Aircraft data was retrieved from the Conklin and de Decker Associates' 2021 report and manufacturers' rotorcraft flight manuals. Specifically, aircraft empty weights, fuel consumption statistics, seating capacities and maximum gross takeoff weights were collected for model inputs. Also, annual costs were collected from the Conklin and de Decker Report to derive price spreads among the aircraft types utilized in the model. All data from the Conklin and de Decker Report were accessed via www.conklindd.com.

Other supplemental data pertaining to the government's involvement in regulatory affairs, mapping, collection and dissemination of industry statistics were retrieved from the United States' Bureau of Ocean Energy Management (BOEM). These data were accessed via www.boem.gov.

Treatment of the Data

Nautical mile distances between offshore facilities and onshore facilities, or depots, were calculated using a method widely used in spherical trigonometry, which is referred to as great circle distances (Mwemezi & Huang, 2011).

Equations 4 and 5 represent the spherical nautical mile distance between GPS locations and are calculated via the following formulae:

$$\mathrm{D}_{\mathrm{nm}}^{\mathrm{s}} = \alpha \mathrm{r} \tag{4}$$

where:

D_{nm}^{s} = Spherical distance in nautical miles between GPS locations

$$\alpha = 2\ arcsine\left(\sqrt{sine^2\frac{\Delta\theta}{2} + cosine\theta_1\ cosine\theta_2\ sine^2\frac{\Delta\emptyset}{2}}\right) \tag{5}$$

where:

$\alpha =$ Central angle measure

$\Theta_1 =$ Latitude at GPS location 1

$\Theta_2 =$ Latitude at GPS location 2

$\Delta\Theta =$ Difference between latitude at GPS location 1 and GPS location 2

$\Delta\emptyset =$ Difference between longitude at GPS location 1 and GPS location 2

$r =$ Nautical mile radius, 3440.0487

GPS coordinates for the sample's locations were collected from BSEE's database of deepwater and ultra-deepwater permanent offshore structures. Utilizing the decimal degrees format of locations' GPS coordinates, the spherical nautical mile distance was calculated.

Due to the data set including deepwater and ultra-deepwater permanent facilities, which range from 36.93 to 218.16 nautical miles from their respective nearest depot, three aircraft models were considered including Lockheed Martin's Sikorsky S76 and Sikorsky S92 and Leonardo's AW139. These aircraft were chosen due to their respective seating capacity and range. Flight costs are a function of an hourly rate assigned to each aircraft type and the flight time of each flight leg. The hourly SK76, AW139 and SK92 costs are $1,000, $1,330 and $1,769, respectively (Conklin & de Decker Associates, 2021). Notably, costs were derived from annual costs, which are functions of fixed and variable costs, and were collected from the Conklin and de Decker Report. Equation 6 represents flight minutes for each aircraft type, SK76, AW139 and SK92, between each location, offshore and onshore, and was calculated via the following formula:

$$M_v = \frac{D_{nm}^S}{(S_v * 60)} \tag{6}$$

where:

M_v = Aircraft, v, flight minutes $\quad v\ \{1..V\}$

D_{nm}^s = Spherical distance in nautical miles between GPS locations

S_v = Aircraft, v, cruise speed $\quad v\ \{1..V\}$

The cruise speeds for the SK76, AW139 and SK92 are 140 knots, 140 knots and 130 knots, respectively. Equation 7 represents the useful payload calculation for each aircraft type, SK76, AW139 and SK92, between all locations, offshore and onshore, and was calculated via the following formula:

$$P_v = MG_v - EW_v - CW - \left(\left[\frac{D_{nm}^S}{S_v} * FB_v\right] + RF_v\right) \tag{7}$$

where:

P_v = Aircraft, v, payload (pounds) $v\ \{1..V\}$

MG_v = Aircraft, v, max gross weight (pounds) $v\ \{1..V\}$

EW_v = Aircraft, v, empty weight (pounds) $v\ \{1..V\}$

CW = Crew weight (pounds)

D_{nm}^S = Spherical distance in nautical miles between GPS locations

S_v = Aircraft, v, cruise speed $v\ \{1..V\}$

FB_v = Aircraft, v, fuel burn per hour $v\ \{1..V\}$

RF_v = Aircraft, v, reserve fuel (pounds) $v\ \{1..V\}$

Aircraft maximum gross weights are prescribed by the manufacturers', Lockheed Martin and Leonardo, rotorcraft flight manuals and yield limitations of 11,700, 14,994 and 26,500 pounds for the SK76, AW139 and SK92 aircraft, respectively. The empty weights used in this data set are 7,747, 10,240 and 17,839 pounds for the SK76, AW139 and SK92, respectively. Crew weight represents the total weight of both pilots and their flight gear, which was estimated to be 500 pounds for all aircraft types. Aircraft reserve fuel weights represent 45 minutes of flight time in pounds of fuel. Aircraft reserve fuel weights for the SK76, AW139 and SK92 are 525, 750 and 1,050 pounds, respectively. Notably, the seat capacity for the SK76 and AW139 is 12 whereas the seat capacity for the SK92 is 19. Cluster analyses were executed to group nodes into groups based on spatial relationships and determine a suitable quantity and location of depots.

Hierarchical Cluster Analysis

Hierarchical cluster analyses were executed using three hierarchical methods, centroid linkage, single linkage and Ward. Cluster analysis, broadly, is a method for numerically categorizing data into groups that are similar based on some identifiable feature (Everitt et al., 2011). Centroid linkage assembles data points based on metrics of association, which enables researchers and practitioners to establish objective and hierarchical groupings (Sokal & Michener, 1958). Furthermore, centroid linkage, also known as the unweighted pair-group method using the centroid approach (UPGMC), measures the distance between clusters' centroids in lieu of evaluating clusters' points that are closest to each other, which is the case for the single linkage method (Everitt et al., 2011). Single linkage, also known as the nearest neighbor method, is described as a method for classifying data based on equally-weighted features and enables similarity features to be expressed and evaluated numerically (Everitt et al., 2011; Sneath, 1957). Notably, single linkage clustering is executed by ensuring cluster members are relatively closer associated with each other than members of other clusters, which is achieved by creating dense clusters via measurement of closest members of separate clusters (Collica, 2017). Ward's method enables researchers to create hierarchical subsets of a group based on an investigator's similarity attribute and is suitable for large sets (Ward Jr., 1963).

Ward's method creates clusters via minimization of the within-cluster sum of squares error when coalescing clusters and tends to create spherical clusters of relatively similar size (Everitt et al., 2011). The aforementioned methods are considered agglomerative hierarchical clustering methods, which are executed by classifying each data point as a cluster and combining these individual clusters until the set is a single cluster; however, techniques can be employed to dictate the quantity of clusters prior to a single group, or cluster, being created (Ferreira & Hitchcock, 2009). Cluster analyses were performed using the single linkage, centroid linkage and Ward methods, which were constrained to produce three distinct clusters among the nodes. The clusters were formed via spatial distance, which were organized for input via a distance matrix. Among the clusters formed, the single and Ward methods produced identical clusters. Specifically, these clusters include two clusters containing 52 and 4 nodes, respectively, whereas the third cluster contains a single node. The centroid method produced more balanced clusters, which more accurately reflects the depiction of nodes' positions, which contain 24, 28 and 5 nodes among the three clusters. Figure 5 depicts the cluster methods' 3-cluster hierarchical cluster output.

Centroid			Single			Ward		
Observation	**Location**	**Cluster**	**Observation**	**Location**	**Cluster**	**Observation**	**Location**	**Cluster**
1	VK915	CL1	**1**	VK915	CL1	**1**	VK915	CL1
2	VK826	CL1	**2**	VK826	CL1	**2**	VK826	CL1
3a	MC807	CL1	**3**	GC608	CL1	**3**	GC608	CL1
3b	MC807	CL1	**4**	GC653	CL1	**4**	GC653	CL1
4	MC809	CL1	**5a**	MC807	CL1	**5a**	MC807	CL1
5	MC778	CL1	**5b**	MC807	CL1	**5b**	MC807	CL1
6	MC736	CL1	**6**	MC809	CL1	**6**	MC809	CL1
7	MC194	CL1	**7**	MC778	CL1	**7**	MC778	CL1
8	MC109	CL1	**8**	MC736	CL1	**8**	MC736	CL1
9	VK956	CL1	**9**	GC205	CL1	**9**	GC205	CL1
10	MC941	CL1	**10**	GC158	CL1	**10**	GC158	CL1
11	VK823	CL1	**11**	MC941	CL1	**11**	MC941	CL1
12	MC243	CL1	**12**	MC724	CL1	**12**	MC724	CL1
13	MC724	CL1	**13**	MC194	CL1	**13**	MC194	CL1
14	MC474	CL1	**14**	MC109	CL1	**14**	MC109	CL1
15	MC650	CL1	**15**	VK956	CL1	**15**	VK956	CL1
16	MC127	CL1	**16**	VK823	CL1	**16**	VK823	CL1
17	MC254	CL1	**17**	MC650	CL1	**17**	MC650	CL1
18	MC280	CL1	**18**	EW921	CL1	**18**	EW921	CL1
19	VK786	CL1	**19**	EW834	CL1	**19**	EW834	CL1
20	MC547	CL1	**20**	GC787	CL1	**20**	GC787	CL1
21	MC773	CL1	**21**	MC243	CL1	**21**	MC243	CL1
22	VK989	CL1	**22**	GC468	CL1	**22**	GC468	CL1
23	MC920	CL1	**23**	GC338	CL1	**23**	GC338	CL1
24	MC582	CL1	**24**	MC280	CL1	**24**	MC280	CL1
25	GC608	CL2	**25**	GC645	CL1	**25**	GC645	CL1
26	GC653	CL2	**26**	GC641	CL1	**26**	GC641	CL1
27	GC205	CL2	**27**	GC254	CL1	**27**	GC254	CL1
28	GC158	CL2	**28**	GC782	CL1	**28**	GC782	CL1
29	EW921	CL2	**29**	MC474	CL1	**29**	MC474	CL1
30	EW834	CL2	**30**	MC547	CL1	**30**	MC547	CL1
31	GC468	CL2	**31**	VK786	CL1	**31**	VK786	CL1
32	GC338	CL2	**32**	MC127	CL1	**32**	MC127	CL1
33	GC645	CL2	**33**	GC613	CL1	**33**	GC613	CL1
34	GC641	CL2	**34**	MC773	CL1	**34**	MC773	CL1
35	GC782	CL2	**35**	MC254	CL1	**35**	MC254	CL1
36	GC787	CL2	**36**	GC860	CL1	**36**	GC860	CL1
37	GC613	CL2	**37**	GC680	CL1	**37**	GC680	CL1
38	GC254	CL2	**38**	WR29	CL1	**38**	WR29	CL1
39	WR29	CL2	**39**	WR249	CL1	**39**	WR249	CL1
40	WR249	CL2	**40**	GC65	CL1	**40**	GC65	CL1
41	GC65	CL2	**41**	GC237	CL1	**41**	GC237	CL1
42	GC237	CL2	**42**	EW1003	CL1	**42**	EW1003	CL1
43	GC860	CL2	**43**	VK989	CL1	**43**	VK989	CL1
44	GC680	CL2	**44**	MC582	CL1	**44**	MC582	CL1
45	EW1003	CL2	**45**	MC920	CL1	**45**	MC920	CL1
46	GB783	CL2	**46**	GC184	CL1	**46**	GC184	CL1
47	GB426	CL2	**47**	WR551	CL1	**47**	WR551	CL1
48	GB260	CL2	**48**	GB783	CL1	**48**	GB783	CL1
49	GC184	CL2	**49**	GB426	CL1	**49**	GB426	CL1
50	WR718	CL2	**50**	GB260	CL1	**50**	GB260	CL1
51	WR551	CL2	**51**	WR718	CL1	**51**	WR718	CL1
52	KC875	CL2	**52**	KC875	CL1	**52**	KC875	CL1
53	EB602	CL3	**53**	EB602	CL2	**53**	EB602	CL2
54	EB643	CL3	**54**	EB643	CL2	**54**	EB643	CL2
55	AC25	CL3	**55**	AC25	CL2	**55**	AC25	CL2
56	GB668	CL3	**56**	GB668	CL2	**56**	GB668	CL2
57	AC857	CL3	**57**	AC857	CL3	**57**	AC857	CL3

Figure 5. 3-Cluster hierarchical cluster output, nodes.

The 3-cluster program yields identical results for the single linkage and Ward methods, which place 91%, 7% and 2% of observations into distinct clusters. The centroid linkage method yields clusters containing 49%, 42% and 9% of observations. The centroid linkage method produced clusters that are more balanced than the single linkage and Ward methods. The centroid method's clusters were chosen for the cluster schema used to determine members of the cluster groups due to superior cluster balance.

K-means Cluster Analysis

In evaluating the departure points, or depots, for routes to and from offshore destinations, k-means clustering was applied to determine the most suitable quantity of depots and their geographic locations. Specifically, k-means clustering was conducted including all points, depots and destinations, to determine the prevalent clusters that existed in the data set. K-means clustering divides quantitative observations into distinct groups such that no observation belongs to more than a single group. Based on least-squares estimation, the cluster centers equal the means of the observations contained within the clusters (SAS Institute Inc., 1999). In essence, k-means clustering assigned observations to clusters based on their proximity to each other. The k-means procedure was executed to complete convergence. The set of eligible depots consisted of five Louisiana locations, Venice, Galliano, Houma, Patterson and Abbeville and one Texas location, Galveston. The k-means algorithm was designed to create six clusters and the proportion of destinations allocated per depot was evaluated. Figure 6 depicts the cluster summary statistics including frequency, nearest cluster and distance between centroids.

Cluster Summary					
Cluster	Depot	Frequency	Nearest Cluster	Distance Between Cluster Centroids	Proportion
1	Venice, LA	18	6	1.6443	0.315
2	Galliano, LA	2	3	3.0992	0.035
3	Houma, LA	3	5	3.0588	0.052
4	Patterson, LA	13	1	1.7623	0.228
5	Abbeville, LA	5	4	2.7050	0.087
6	Galveston, TX	16	1	1.6443	0.280

Figure. 6 K-means cluster output, nodes and depots.

As shown in Figure 6, there are three clusters containing approximately 82.3% of observations. Specifically, three depots, located at Venice, Patterson and Galveston contain approximately 31.5%, 22.8% and 28.0% of offshore locations, respectively. Consequently, the k-means cluster analysis supports a 3-cluster depot configuration for the offshore locations in the set located in Venice, Patterson and Galveston.

Descriptive statistics. The 58 nodes included in the sample are located in the Gulf of Mexico's eastern, central and western administrative boundaries, which encompass the East Breaks, Garden Banks, Green Canyon, Keathley Canyon, Mississippi Canyon Viosca Knoll, Walker Ridge, Alaminos Canyon and Ewing Banks area blocks. The facilities are identified by their respective block numbers, which are identified via GPS coordinates and well names. Among the locations listed, the oldest well was installed in 1978 whereas the newest among the wells was installed in 2017. Several structure types are prevalent including spar, tension-leg, mini tension-leg, semi-submersible, control tower, fixed and floating production, storage and offloading facilities. Table 1 lists descriptive statistics of the sampled facilities, or nodes.

Table 1

Nodes

Company Name	Area	Block	Well Name	Water Depth (ft)	Year Installed	Structure Type
Anadarko Petroleum Corporation	EB	602	Nansen	3,675	2001	SPAR
Anadarko Petroleum Corporation	EB	643	Boomvang	3,650	2002	SPAR
Anadarko Petroleum Corporation	GB	668	Gunnison	3,150	2003	SPAR
Anadarko Petroleum Corporation	GC	608	Marco Polo	4,300	2004	TLP
Anadarko Petroleum Corporation	GC	645	Holstein	4,340	2004	SPAR
Anadarko Petroleum Corporation	GC	680	Constitution	4,970	2005	SPAR
Anadarko Petroleum Corporation	GC	860	Heidelberg	5,300	2016	SPAR
Anadarko Petroleum Corporation	KC	875	Lucius	7,000	2014	SPAR
Anadarko Petroleum Corporation	MC	127	Horn Mountain	5,400	2002	SPAR
Anadarko Petroleum Corporation	MC	920	Independence	8,000	2007	SEMI
Anadarko Petroleum Corporation	VK	915	Marlin	3,236	1999	TLP
BHP Billiton Petroleum (GOM) Inc.	GC	613	Neptune	4,250	2007	MTLP
BHP Billiton Petroleum (GOM) Inc.	GC	653	Shenzi	4,375	2008	TLP
BP Exploration & Production Inc.	GC	782	Mad Dog	4,420	2004	SPAR
BP Exploration & Production Inc.	GC	787	Atlantis	7,050	2007	SEMI
BP Exploration & Production Inc.	MC	474	Na Kika	6,340	2003	SEMI
BP Exploration & Production Inc.	MC	778	Thunder Horse	6,200	2005	SEMI
Chevron U.S.A. Inc.	GC	205	Genesis	2,590	1998	SPAR
Chevron U.S.A. Inc.	GC	641	Tahiti	4,000	2008	SPAR
Chevron U.S.A. Inc.	MC	650	Blind Faith	6,480	2008	SEMI
Chevron U.S.A. Inc.	VK	786	Petronius	1,754	2000	CT
Chevron U.S.A. Inc.	WR	29	Big Foot	5,185	2018	TLP
Chevron U.S.A. Inc.	WR	718	Jack St. Malo	6,950	2014	SEMI
ConocoPhillips Company	GB	783	Magnolia	4,670	2004	TLP
Eni US Operating Co. Inc.	EW	921	Morpeth East	1,700	1998	MTLP
Eni US Operating Co. Inc.	GC	254	Allegheny Sea	3,294	1999	MTLP
Eni US Operating Co. Inc.	MC	773	Devils Tower	5,610	2004	SPAR
EnVen Energy Ventures, LLC	EW	1003	Prince	1,500	2001	TLP
EnVen Energy Ventures, LLC	GC	158	Brutus	2,900	2001	TLP
EnVen Energy Ventures, LLC	MC	194	Cognac	1,023	1978	FIXED
Equinor USA E&P Inc.	MC	941	Titan	4,050	2010	SEMI
Exxon Mobil Corporation	AC	25	Hoover	4,825	2000	SPAR
Exxon Mobil Corporation	MC	280	Lena	1,000	1983	CT
Fieldwood Energy LLC	MC	736	Thunder Hawk	6,050	2009	SEMI
Fieldwood Energy LLC	VK	826	Neptune	1,930	1996	SPAR
Fieldwood Energy LLC	GC	65	Bullwinkle	1,353	1988	FIXED
Hess Corporation	GB	260	Baldpate	1,648	1998	CT
Hess Corporation	GC	468	Stampede	3,360	2017	TLP
Hess Corporation	MC	724	Gulfstar 1	4,600	2014	SPAR
LLOG Exploration Offshore, L.L.C.	MC	254	Delta House	4,400	2014	SEMI
LLOG Exploration Offshore, L.L.C.	MC	547	Who Dat	3,280	2011	SEMI
MC Offshore Petroleum, LLC	GC	184	Jolliet	1,760	1989	TLP
Murphy Exploration & Production	GC	338	Front Runner	3,330	2004	SPAR
Murphy Exploration & Production	MC	582	Medusa Spar	2,223	2003	SPAR
Petrobras America Inc.	WR	249	BW Pioneer	8,300	2011	FPSO
Shell Offshore Inc.	AC	857	Perdido	7,835	2009	SPAR
Shell Offshore Inc.	GB	426	Auger	2,860	1994	TLP
Shell Offshore Inc.	MC	807	Olympus	3,028	2013	TLP
Shell Offshore Inc.	MC	807	Mars	2,933	1996	TLP
Shell Offshore Inc.	MC	809	Ursa	3,970	1998	TLP
Shell Offshore Inc.	WR	551	Turritella	9,560	2016	FPSO
Talos Petroleum LLC	GC	237	Helix	2,200	2009	MTLP
Talos Petroleum LLC	MC	109	Amberjack	1,100	1991	FIXED
Talos Petroleum LLC	VK	956	Ram Powell	3,216	1997	TLP
Talos Petroleum LLC	VK	989	Pampano	1,290	1994	FIXED
W & T Energy VI, LLC	MC	243	Mattehorn	2,850	2003	MTLP
W & T Energy VI, LLC	VK	823	Virgo	1,130	1999	FIXED
Walter Oil & Gas Corporation	EW	834	Coelacanth	1,186	2015	FIXED

Note. Retrieved from U.S. Bureau of Safety and Environmental Enforcement, 2010, U.S. Bureau of Safety and Environmental Enforcement.

CHAPTER IV

PART I RESULTS

Firm-level network results

The firms included in the sample differ in their quantity of locations, location of their respective facilities and, consequently, their usage of the available vehicles, Sikorsky S76 (V1), Leonardo AW139 (V2) and Sikorsky S92 (V3), V1, V2 and V3. Five firms, ConocoPhillips Company, Equinor USA E&P Inc., MC Offshore Petroleum LLC., Petrobras America Inc. and Walter Oil & Gas Corporation, each operate single locations. The remaining firms operate multiple locations ranging from two to eleven sites. Hence, there exists ample differences in the quantity of passengers each firm must move to and from the offshore locations. Specifically, the quantity of passengers across firms yields a minimum, maximum and mean of 74, 1,492 and 336, respectively.

Across the firms represented in the sample, there exists usage of all three, V1, V2 and V3, aircraft types. Across all firms, the minimum, maximum and mean usage percentage of V1 is 14.3%, 100% and 56.1%, respectively. Leonardo's AW139 yields minimum, maximum and mean usage values of 4.5%, 42.9% and 24.3%, respectively. Lastly, V3 usage yields minimum, maximum and mean usage values of 18.2%, 79.5% and 49.2%, respectively. Overall, the mean usage values across all aircraft types reveals that the Sikorsky S76 is utilized mostly, 56.1%, whereas the Sikorsky S92 is utilized slightly, 49.2%, less. The Leonardo AW139's mean usage is the least, 24.3%, and, therefore, the least utilized aircraft type.

Table 2 depicts firm-level network results including locations' quantity of passengers, V1 usage, V2 usage, V3 usage and resultant minimum, maximum, mean and standard deviation summary statistics.

Table 2

Firm-level network quantity of passengers and vehicle usage statistics

	Quantity of Passengers	V1 Usage	V2 Usage	V3 Usage
Anadarko	1,458	15.9%	4.5%	79.5%
BHP	92	75.0%	-	25.0%
BP	444	25.0%	25.0%	50.0%
Chevron	682	18.2%	13.6%	68.2%
ConocoPhillips	100	100%	-	-
ENI	310	36.4%	18.2%	45.5%
EnVen	420	14.3%	28.6%	57.1%
Equinor	130	100%	-	-
ExxonMobil	150	57.1%	42.9%	-
Fieldwood	368	35.7%	35.7%	28.6%
Hess	408	21.4%	28.6%	50.0%
LLOG	198	100%	-	-
MC	92	100%	-	-
Murphy	272	45.5%	36.4%	18.2%
Petrobras	160	100%	-	-
Shell	534	22.2%	16.7%	61.1%
Talos	366	16.7%	25.0%	58.3%
W & T	134	83.3%	16.7%	-
Walter	74	100%	-	-
Minimum	74	14.3%	4.5%	18.2%
Maximum	1,458	100%	42.9%	79.5%
Mean	336	56.1%	24.3%	49.2%
Standard Deviation	313	35.9	10.9	18.9

Note. Firm-level network results including quantity of passengers, V1 usage, V2 usage, V3 usage and resultant minimum, maximum, mean and standard deviation statistics.

Firm-level seat capacity load factor results are, as expected, advantageous in terms of seating capacity. Importantly, seat capacity load factors are presented as the percentage of seats filled relative to the aircraft's seat capacity, VCP_v. The SK76, $V1$, yields minimum, maximum and mean seat capacity load factors of 58.3%, 91.7% and 79.5%, respectively. The AW139, $V2$, yields minimum, maximum and mean seat capacity load factors of 88.9%, 100% and 95.2%, respectively. Lastly, the SK92, $V3$, yields minimum, maximum and mean seat capacity load factors of 93.7%, 100% and 97.1%, respectively. The SK76 yields the lowest load factor ranking whereas the SK92 yields the superior ranking among the vehicle types. Across all networks, an 87.7% weighted average load factor is achieved. The weight utilized is the percentage of flights conducted by vehicle type. A more precise evaluation of the model's ability to efficiently and effectively minimize network costs is to calculate and analyze the vehicle effective capacity load factors. In many cases, the effective vehicle capacity is less than the seat capacity due to the fuel required to travel between nodes and, specifically, the aircraft's maximum takeoff weight restriction. Table 3 depicts firm-level network results including V1, V2 and V3 VCP load factors and resultant minimum, maximum and mean summary statistics.

Table 3

Firm-level network VCP load factor statistics

	V1 VCP LF	V2 VCP LF	V3 VCP LF	Weighted VCP LF
Anadarko	70.2%	95.8%	97.3%	92.9%
BHP	75.0%	-	100%	81.3%
BP	86.1%	93.8%	96.1%	93.0%
Chevron	64.6%	94.4%	96.8%	90.6%
ConocoPhillips	68.1%	-	-	68.1%
ENI	87.5%	100%	93.7%	92.6%
EnVen	58.3%	97.9%	99.3%	93.7%
Equinor	90.3%	-	-	90.3%
ExxonMobil	89.6%	88.9%	-	89.3%
Fieldwood	88.3%	98.3%	94.7%	93.7%
Hess	77.8%	97.9%	97.0%	93.1%
LLOG	91.7%	-	-	91.7%
MC	76.7%	-	-	76.7%
Murphy	90.0%	91.7%	100%	92.4%
Petrobras	74.1%	-	-	74.1%
Shell	62.5%	88.9%	98.1%	88.6%
Talos	91.7%	94.4%	95.5%	94.6%
W & T	91.7%	100%	-	93.1%
Walter	77.1%	-	-	77.1%
Minimum	58.3%	88.9%	93.7%	68.1%
Maximum	91.7%	100%	100%	94.6%
Mean	79.5%	95.2%	97.1%	87.7%
Standard Deviation	11.1	3.9	2.1	8.0

Note. Firm-level network results including V1, V2, V3 VCP load factors and resultant minimum, maximum and mean statistics.

Vehicle effective capacity load factors are presented as the percentage of seats filled relative to the aircraft's effective seat capacity, $VEC_{v,i,j}$. The SK76, *V1*, yields minimum, maximum and mean effective capacity load factors of 58.3%, 100% and 92.1%, respectively. The AW139, *V2*, yields minimum, maximum and mean seat capacity load factors of 97.0%, 100% and 99.2%, respectively. Lastly, the SK92, *V3*, yields minimum, maximum and mean seat capacity load factors of 93.7%, 100% and 97.1%, respectively. The SK76 yields the lowest load factor ranking whereas the AW139 yields the superior ranking among the vehicle types. Across all networks, a 95.7% weighted average load factor is achieved. The weight utilized is the percentage of flights conducted by vehicle type. Table 4 depicts firm-level network results including V1, V2 and V3 VEC load factors and resultant minimum, maximum and mean summary statistics.

Table 4

Firm-level network VEC load factor statistics

	V1 VEC LF	V2 VEC LF	V3 VEC LF	Weighted VEC LF
Anadarko	85.5%	100%	97.2%	95.5%
BHP	90.0%	-	100%	92.5%
BP	100%	97.9%	96.0%	97.5%
Chevron	86.3%	97.2%	96.8%	94.9%
ConocoPhillips	90.7%	-	-	90.7%
ENI	95.4%	100%	93.6%	95.4%
EnVen	58.3%	100%	99.3%	93.6%
Equinor	98.4%	-	-	98.4%
ExxonMobil	89.5%	96.9%	-	92.7%
Fieldwood	98.1%	98.3%	94.7%	97.2%
Hess	96.6%	100%	96.9%	97.7%
LLOG	100%	-	-	100%
MC	92.0%	-	-	92.0%
Murphy	98.1%	100%	100%	99.1%
Petrobras	98.7%	-	-	98.7%
Shell	82.5%	100%	98.0%	94.9%
Talos	100%	100%	95.4%	97.3%
W & T	100%	100%	-	100%
Walter	88.6%	-	-	88.6%
Minimum	58.3%	97.0%	93.7%	88.6%
Maximum	100%	100%	100%	100%
Mean	92.1%	99.2%	97.1%	95.7%
Standard Deviation	9.7	3.0	1.9	2.9

Note. Firm-level network results including V1, V2, V3 VEC load factors and resultant minimum, maximum and mean statistics.

There exists a 284% difference between the firm realizing the lowest average cost per passenger and the firm realizing the highest average cost per passenger, which indicated an important, yet expected, revelation. In essence, some firm's locations are relatively more spatially concentrated with each other and with onshore departure nodes, which directly impacted useful loads and leg costs. Also, as indicated in the introduction of results, there exists significant cost savings as the weighted average load factor increases. For residual passengers required to be transported, the use of split deliveries may reduce costs for firms. In these instances, multi-stop trips are executed.

The methodology employed in the model utilizes split deliveries to minimize the total quantity of flights and, consequently, total cost. The minimum, maximum and mean usage of direct flights are 50.0%, 100% and 89.6%, respectively. Trips utilizing 2 offshore nodes to pickup and deliver passengers yield minimum, maximum and mean values of 7.1%, 38.6% and 18.0%, respectively. Trips utilizing 3 stops yield minimum, maximum and average usage rates of 5.6%, 9.1% and 7.3%, respectively. Lastly, a single firm, Anadarko, utilized a single 4-stop trip, which accounted for 2.3% of the firm's flights. Correlation analysis reveals that as passenger quantities and locations increase, the use of multi-stop trips increases. Specifically, the correlation coefficients between passenger quantity and direct and 2-stop trips are -.728 and .614, respectively. Notably, five firms have a single offshore node and, therefore, required direct flights only. Table 5 depicts the firm-level network's usage of direct, 2-stop, 3-stop and 4-stop trips. Also, Table 5 lists the itemized network cost for the sample firms, which range from $5,200 to $180,414. The mean cost across firms is $34,167 and yields a standard deviation of $40,845.

Table 5

Firm-level network usage of split deliveries and total cost statistics

	Direct	**2-Stop**	**3-Stop**	**4-Stop**	**Network Cost**
Anadarko	50.0%	38.6%	9.1%	2.3%	$180,414
BHP	75.0%	25.0%	-	-	$10,249
BP	87.5%	12.5%	-	-	$46,392
Chevron	81.8%	18.2%	-	-	$83,525
ConocoPhillips	100%	-	-	-	$16,188
ENI	90.9%	9.1%	-	-	$22,574
EnVen	85.7%	14.3%	-	-	$32,558
Equinor	100%	-	-	-	$8,160
ExxonMobil	100%	-	-	-	$12,460
Fieldwood	100%	-	-	-	$29,848
Hess	92.9%	7.1%	-	-	$37,809
LLOG	77.8%	22.2%	-	-	$9,663
MC	100%	-	-	-	$10,040
Murphy	100%	-	-	-	$22,452
Petrobras	100%	-	-	-	$26,964
Shell	94.4%	-	5.6%	-	$62,065
Talos	83.3%	16.7%	-	-	$26,735
W & T	83.3%	16.7%	-	-	$5,882
Walter	100%	-	-	-	$5,200
Minimum	50.0%	7.1%	5.6%	2.3%	$5,200
Maximum	100.0%	38.6%	9.1%	2.3%	$180,414
Mean	89.6%	18.0%	7.3%	2.3%	$34,167
Standard Deviation	12.9	9.1	2.5	0	$40,845

Note. Firm-level network results including direct, 2-stop, 3-stop, 4-stop route and total cost statistics

Clustered networks results

The clusters included in the sample differ in their quantity of locations, location of their respective locations and, consequently, their usage of the available vehicles, V1, V2 and V3. Cluster 1 (CL1), Cluster 2 (CL2), and Cluster 3 (CL3) include locations operated by 24, 28 and 5 firms, respectively. Hence, there exists ample differences in the quantity of passengers each firm must move to and from the offshore locations.

Specifically, the quantity of passengers across clusters, CL1, CL2 and CL3, yields minimum, maximum and mean values of 500, 3,360 and 2,095, respectively.

Across the clusters represented in the sample, there exists usage of all three, V1, V2 and V3, aircraft types. Across all clusters, the minimum, maximum and mean usage percentage of V1 is 18.8%, 22.1% and 20.6%, respectively. Leonardo's AW139 yields minimum, maximum and mean usage values of 10.4%, 18.8% and 15.6%, respectively. Lastly, V3 yields minimum, maximum and mean usage percentage values of 68.8%, 60.2% and 63.8%, respectively. Overall, the mean usage values across all aircraft types reveals that the Sikorsky S92 is utilized mostly, 56.1%, whereas the Sikorsky S76 is utilized 20.6% less. The Leonardo AW139's mean usage is 15.6% and, therefore, the least utilized aircraft type.

Table 6 depicts cluster networks results including quantity of passengers, V1 usage, V2 usage, V3 usage and resultant minimum, maximum, mean and standard deviation summary statistics.

Table 6

Cluster networks quantity of passengers and vehicle usage statistics

	Quantity of Passengers	V1 Usage	V2 Usage	V3 Usage
Cluster 1	2,426	20.8%	10.4%	68.8%
Cluster 2	3,466	22.1%	17.7%	60.2%
Cluster 3	500	25.0%	25.0%	50.0%
Minimum	500	18.8%	10.4%	60.1%
Maximum	3,466	22.1%	18.8%	68.8%
Mean	2,131	20.6%	15.6%	63.8%
Standard Deviation	1,229	1.7	4.6	4.5

Note. Cluster networks results including quantity of passengers, V1 usage, V2 usage, V3 usage and resultant minimum, maximum, mean and standard deviation statistics.

Cluster networks seat capacity load factor results are, as expected, advantageous in terms of seating capacity. Importantly, seat capacity load factors are presented as the percentage of seats filled relative to the aircraft's seat capacity, VCP_v. The SK76, $V1$, yields minimum, maximum and mean seat capacity load factors of 85.3%, 99.0% and 92.0%, respectively. The AW139, $V2$, yields minimum, maximum and mean seat capacity load factors of 98.2%, 99.5% and 98.9%, respectively. Lastly, the SK92, $V3$, yields minimum, maximum and mean seat capacity load factors of 88.9%, 93.9% and 91.6%, respectively. The SK76 yields the lowest load factor ranking whereas the AW139 yields the superior ranking among the vehicle types. Across all networks, a 91.6% weighted average load factor was achieved. The weight utilized is the percentage of flights conducted by vehicle type. A more precise evaluation of the model's ability to efficiently and effectively minimize network costs is to calculate and analyze the vehicle effective capacity load factors. In many cases, the effective vehicle capacity is reached prior to the seat capacity due to the fuel required to travel between nodes and the aircraft's maximum takeoff weight restriction. Table 7 depicts cluster networks results including V1, V2 and V3 VCP load factors and resultant minimum, maximum and mean summary statistics.

Table 7

Cluster networks VCP load factor statistics

	V1 VCP LF	**V2 VCP LF**	**V3 VCP LF**	**Weighted VCP LF**
Cluster 1	67.2%	99.0%	98.2%	91.8%
Cluster 2	64.2%	85.3%	99.1	88.9%
Cluster 3	77.8%	91.7%	99.5%	93.9%
Minimum	64.2%	85.3%	98.2%	88.9%
Maximum	77.8%	99.0%	99.5%	93.9%
Mean	69.7%	92.0%	98.9%	91.6%
Standard Deviation	7.1	6.8	.6	2.5

Note. Cluster networks results including V1, V2, V3 VCP load factors and resultant minimum, maximum and mean statistics.

Vehicle effective capacity load factors are presented as the percentage of seats filled relative to the aircraft's effective seat capacity, $VEC_{v,i,j}$. The SK76, $V1$, yields minimum, maximum and mean effective capacity load factors of 74.4%, 100% and 85.4%, respectively. The AW139, $V2$, yields minimum, maximum and mean seat capacity load factors of 96.8%, 100% and 98.6%, respectively. Lastly, the SK92, $V3$, yields minimum, maximum and mean seat capacity load factors of 98.2%, 99.5% and 98.9%, respectively. The SK76 yields the lowest load factor ranking whereas the AW139 and SK92 yield identical superior rankings among the vehicle types. Across all networks, a 95.9% weighted average load factor is achieved. The weight utilized is the percentage of flights conducted by vehicle type. Table 8 depicts cluster networks results including V1, V2 and V3 VEC load factors and resultant minimum, maximum and mean summary statistics.

Table 8

Cluster networks VEC load factor statistics

	V1 VEC LF	**V2 VEC LF**	**V3 VEC LF**	**Weighted VEC LF**
Cluster 1	74.4%	99.0%	98.2%	93.3%
Cluster 2	81.7%	96.8%	99.1%	94.8%
Cluster 3	100%	100%	99.5%	99.7%
Minimum	74.4%	96.8%	98.2%	93.3%
Maximum	100%	100%	99.5%	99.7%
Mean	85.4%	98.6%	98.9%	95.9%
Standard Deviation	10.8	1.3	0.5	2.7

Note. Cluster networks results including V1, V2, V3 VEC load factors and resultant minimum, maximum and mean statistics.

There exists an 88.8% difference between the cluster realizing the lowest average cost per passenger and the cluster realizing the highest average cost per passenger, which indicated an important, yet expected, revelation. In essence, some cluster locations are relatively more spatially concentrated with each other and with onshore departure nodes, which directly impacted useful loads and leg costs. Also, as indicated in the introduction of results, there exists significant cost savings as the weighted average load factor increases. For residual passengers required to be transported, the use of split deliveries may reduce costs for firms. In these instances, multi-stop trips are executed.

The methodology employed in the model utilizes split deliveries to minimize the total quantity of flights and, consequently, total cost. The minimum, maximum and mean usage of direct flights are 30.1%, 75.0% and 46.7%, respectively. Trips utilizing 2 offshore nodes to pickup and deliver passengers yield minimum, maximum and mean values of 25.0%, 41.6% and 35.2%, respectively. Trips utilizing 3 stops yield minimum, maximum and average usage rates of 15.6%, 17.7% and 16.6%, respectively. Trips utilizing 4 stops yield minimum, maximum and average usage rates of 15.6%, 17.7% and 16.6%, respectively. Trips utilizing 5 stops yield minimum, maximum and average usage rates of 15.6%, 17.7% and 16.6%, respectively. Lastly, a single cluster, CL2, utilized a single 6-stop trip, which represents 0.9% of all trips. Correlation analysis reveals that as passenger quantities and locations increase, the use of multi-stop trips increases. Specifically, the correlation coefficients between passenger quantity and direct and 2-stop trips are -.975 and .890, respectively. Table 9 depicts the cluster network's usage of direct, 2-stop, 3-stop and 4-stop trips. Also, Table 9 lists the itemized costs for the clusters, which range from $60,906 to $457,915. The mean cost across clusters is $231,129 and yields a standard deviation of $204,459.

Table 9

Cluster networks usage of split deliveries and total cost statistics

	Direct	2-Stop	3-Stop	4-Stop	5-Stop	6-Stop	Network Cost
Cluster 1	35.1%	41.6%	15.6%	7.8%	N/A	N/A	$174,566
Cluster 2	30.1%	38.9%	17.7%	10.6%	1.8%	0.9%	$457,915
Cluster 3	75.0%	25.0%	N/A	N/A	N/A	N/A	$60,906
Minimum	30.1%	25.0%	15.6%	7.8%	1.8%	0.9%	$60,906
Maximum	75.0%	41.6%	17.7%	10.6%	1.8%	0.9%	$457,915
Mean	89.6%	18.0%	7.3%	2.3%	1.8%	0.9%	$231,129
Standard Deviation	24.6	8.9	1.5	2.0	0	0	$204,459

Note. Cluster networks results including direct, 2-stop, 3-stop, 4-stop, 5-stop, 6-stop route and total cost statistics.

Firm-level and cluster results provide a significant revelation regarding firms' potential to realize efficiency gains, or cost reductions, via cooperation. Specifically, there exist mixed results related to firms' relative advantage from participating in clustered networks allowing ride sharing. Three firms, Anadarko, Petrobras and Shell, realize efficiency gains from participating in their respective clusters. Conversely, the remaining firms realize a degradation of efficiency via participation in their respective cluster networks. The largest firm-level network, Anadarko, realized an efficiency gain of 5.9%, or $7.36 per passenger cost reduction. A relatively small firm-level network, Petrobras, realized an efficiency gain of 9.8%, or $16.56 per passenger cost reduction. Lastly, a moderately sized firm-level network, Shell, realized an 11.4% efficiency gain, which equates to a reduction in cost per passenger of $13.27. The remaining firm-level networks realize efficiency losses resultant from participation in cluster networks. The results exhibit relatively minimal, 2.6%, to relatively extensive, 57.0%, increased costs via cooperation. The average cost reduction realized is 9.03%, or $12.39 per passenger, whereas the average cost degradation realized is 21.5%, or $103.32 per passenger. Among the firms realizing a cost increase via cooperation, there exists a negative correlation, -.246, between quantity of passengers and the percentage increase in degradation of efficiency. Overall, the realization of efficiency gains via cooperation is significant in that such an evaluation among firms is prudent and may enable a mutually beneficial commercial agreement. In a practical setting, firms may engage in such an evaluation as a result of goal commonality and past partnerships. In essence, cluster analyses may not drive the creation of hybrid networks for evaluation in a commercial setting. However, there exists a reasonable opportunity to realize efficiency gains via firm cooperation. Table 10 depicts itemized results comparing firm-level and cluster networks.

Table 10

Cluster and firm-level networks cost variance statistics

	Firm-level Cost	Cluster Cost	Variance	Cost/PAX Variance
Anadarko	$180,414	$169,684	-5.9%	-$7.36
BHP	$10,249	$10,834	5.7%	$6.36
BP	$46,392	$50,385	8.6%	$8.99
Chevron	$83,525	$85,736	2.6%	$3.24
ConocoPhillips	$16,188	$17,319	7.0%	$11.31
ENI	$22,574	$27,614	22.3%	$16.26
EnVen	$32,558	$43,822	34.6%	$26.82
Equinor	$8,160	$8,396	2.9%	$1.82
ExxonMobil	$12,460	$14,006	12.4%	$10.31
Fieldwood	$29,848	$37,796	26.6%	$21.60
Hess	$37,809	$45,367	20.0%	$18.52
LLOG	$9,663	$12,754	32.0%	$15.61
MC	$10,040	$11,871	18.2%	$19.90
Murphy	$22,452	$26,792	19.3%	$15.96
Petrobras	$26,964	$24,314	-9.8%	-$16.56
Shell	$62,065	$54,980	-11.4%	-$13.27
Talos	$26,735	$31,996	19.7%	$14.37
W & T	$5,882	$9,105	54.8%	$24.05
Walter	$5,200	$8,165	57.0%	$40.07
Minimum	$5,200	$8,165	-11.4%	-$16.56
Maximum	$180,414	$169,684	57.0%	$40.07
Mean	$34,167	$36,365	16.7%	$11.47
Standard Deviation	$40,845	$38,165	18.5	$13.85

Note. Cluster and firm-level networks cost variance statistics.

Integrated network results

Cluster network structures identify the potentiality of efficiency gains for individual firms. The integrated network structure, which includes all firms' locations in a single network, too, identifies potential efficiency gains. Thus far, firm-level networks, consisting of 58 locations operated by 19 firms, are solved individually. Also, the 58 locations are clustered into 3 distinct networks and solved. The final model evaluates all

58 locations as a single network. The firms included in the sample differ in their quantity of locations, location of their respective facilities and, consequently, their usage of the available vehicles, Sikorsky S76 (V1), Leonardo AW139 (V2) and Sikorsky S92 (V3), V1, V2 and V3.

Across the locations represented in the sample, there exists usage of all three, V1, V2 and V3, aircraft types. Across all firms, the usage percentage of V1, V2 and V3 is 19.9%, 16.5% and 63.6%, respectively. Overall, the mean usage values across all aircraft types reveals that the Sikorsky S92 is utilized mostly, 63.6%, whereas the Sikorsky S76 and Leonardo AW139 are utilized less. Specifically, the Sikorsky S76 and Leonardo AW139 represent 19.9% and 16.5% of flights, respectively.

Table 11 depicts the integrated network's results including locations' quantity of passengers and V1, V2, V3 usage statistics.

Table 11

Integrated network quantity of passengers and vehicle usage statistics

	Quantity of Passengers	**V1 Usage**	**V2 Usage**	**V3 Usage**
Integrated	6,392	19.9%	16.5%	63.6%

Note. Integrated network results including quantity of passengers, V1 usage, V2 usage and V3 usage

Integrated network seat capacity load factor results are, as expected, advantageous in terms of seating capacity. Importantly, seat capacity load factors are presented as the percentage of seats filled relative to the aircraft's seat capacity, VCP_v. The V1, V2 and V3 aircraft achieve seat capacity load factors of 75.0%, 91.1% and 98.7%, respectively. The

SK76 yields the lowest load factor ranking whereas the SK92 yields the superior ranking among the vehicle types. Across the integrated network, a 92.7% weighted average load factor is achieved. A more precise evaluation of the model's ability to efficiently and effectively minimize network cost is to calculate and analyze the vehicle effective capacity load factors. In many cases, the effective vehicle capacity is less than the seat capacity due to the fuel required to travel between nodes and, specifically, the aircraft's maximum takeoff weight restriction. Table 12 depicts the integrated network results including V1, V2 and V3 VCP load factors.

Table 12

Integrated network VCP load factor statistics

	V1 VCP LF	**V2 VCP LF**	**V3 VCP LF**	**Weighted VCP LF**
Integrated	75.0%	91.1%	98.7%	92.7%

Note. Integrated network results including V1, V2 and V3 VCP load factors

Vehicle effective capacity load factors are presented as the percentage of seats filled relative to the aircraft's effective seat capacity, $VEC_{v,i,j}$. The V1, V2 and V3 aircraft achieve effective capacity load factors of 88.7%, 99.4% and 98.8%, respectively. The SK76 yields the lowest load factor ranking whereas the SK92 yields the superior ranking among the vehicle types. Across the integrated network, a 96.9% weighted average load factor is achieved. Table 13 depicts the integrated network results including V1, V2 and V3 VEC load factors.

Table 13

Integrated network VEC load factor statistics

	V1 VEC LF	V2 VEC LF	V3 VEC LF	Weighted VEC LF
Integrated	88.7%	99.4%	98.8%	96.9%

Note. Integrated network results including V1, V2 and V3 VEC load factors

The methodology employed in the model utilizes split deliveries to minimize the total quantity of flights and, consequently, total cost. The usage of direct flights represents 26.7% of all flights. Trips utilizing 2 offshore nodes to pickup and deliver passengers represent the greatest, 33.0%, proportion of all flights. Trips utilizing 3 stops represent 21.4% of all flights. Trips including 4, 5, 6, 7 and 8 stops represent 9.2%, 5.8%, 1.9%, 0.5% and 1.0% of all flights. Table 14 depicts the integrated network's usage of direct, 2-stop, 3-stop, 4-stop, 5-stop, 6-stop, 7-stop and 8-stop trips. Also, Table 14 lists the integrated network's total cost, which is $793,917.

Table 14

Integrated network usage of split deliveries and total cost statistics

	Direct	2-Stop	3-Stop	4-Stop	5-Stop	6-Stop	7-Stop	8-Stop	Network Cost
Integrated	26.7%	33.0%	21.4%	9.2%	5.8%	1.9%	0.5%	1.0%	$793,917

Note. Integrated network results including direct, 2-stop, 3-stop, 4-stop, 5-stop, 6-stop, 7-stop and 8-stop route and total cost statistics.

Firm-level and cluster results provide a significant revelation regarding firms' potential to realize efficiency gains, or cost reductions, via cooperation. The integrated network, too, identifies that cost savings are possible via cooperation. However, there exist mixed results related to firms' relative advantage from participating in the integrated network. Six firms, Anadarko, ConocoPhillips, EnVen, Murphy, W&T and Walter realize efficiency gains from participating in the integrated network. Conversely, the remaining firms realize a degradation of efficiency via participation in the integrated network. The largest firm-level network, Anadarko, realizes an efficiency gain of 7.5%, or $10.05 per passenger via participation in the integrated network. ConocoPhillips realizes an efficiency gain of 2.3%, or $8.29 per passenger. EnVen realizes an efficiency gain of 4.2%, or $5.53 per passenger. Murphy realizes the least efficiency gain of 0.3%, or $0.39 per passenger. Walter realizes an efficiency gain of 9.1%, or $8.32% per passenger. Lastly, W&T realizes the greatest efficiency gain of 11.9%, or $8.32 per passenger. The remaining firms realize efficiency losses resultant from participation in the integrated network. The results exhibit relatively minimal, 2.3%, to relatively extensive, 212.7%, increased costs via participation in the integrated network versus the clustered network configuration. The average cost reduction realized is 5.9%, or $7.27 per passenger, whereas the average cost degradation realized is 35.9%, or $40.05 per passenger. Notably, among the firms realizing efficiency losses includes a single outlier, BHP, which realizes an efficiency loss of 212.7%, or $257.33 per passenger. Overall, the realization of efficiency gains via an integrated network is significant in that such an evaluation among firms is prudent and may enable a mutually beneficial commercial agreement. In a practical setting, firms may engage in such an evaluation as a result of goal commonality and past partnerships. In essence, firm cooperation via alternative network structures may enable the realization of efficiency gains in a practical setting. Table 15 depicts itemized results comparing cluster and integrated networks.

Table 15

Integrated and cluster networks cost variance statistics

	Cluster Cost	Integrated Cost	Variance	Cost/PAX Variance
Anadarko	$169,684	$156,934	-7.5%	-$10.05
BHP	$10,834	$33,880	212.7%	$257.33
BP	$50,385	$56,332	11.8%	$13.57
Chevron	$85,736	$123,731	44.3%	$57.34
ConocoPhillips	$17,319	$17,721	-2.3%	-$8.29
ENI	$27,614	$32,992	19.5%	$16.91
EnVen	$43,822	$41,982	-4.2%	-$5.53
Equinor	$8,396	$11,589	38.0%	$28.51
ExxonMobil	$14,006	$18,949	35.3%	$39.50
Fieldwood	$37,796	$39,271	3.9%	$2.73
Hess	$45,367	$50,718	11.8%	$15.01
LLOG	$12,754	$16,078	26.1%	$14.73
MC	$11,871	$12,313	3.7%	$3.08
Murphy	$26,792	$26,718	-0.3%	-$0.39
Petrobras	$24,314	$28,011	15.2%	$20.90
Shell	$54,980	$75,295	36.9%	$41.75
Talos	$31,996	$34,480	7.8%	$9.27
W & T	$9,105	$8,019	-11.9%	-$8.32
Walter	$8,165	$7,426	-9.1%	-$11.06
Minimum	$8,165	$7,426	-11.9%	-$11.06
Maximum	$169,864	$156,934	212.7%	$257.33
Mean	$36,365	$41,707	22.7%	$25.11
Standard Deviation	$38,165	$39,347	47.8	$59.39

Note. Integrated and cluster networks cost variance statistics.

Aggregate networks results

The aggregate networks results show that the same quantity of passengers, 3,692, were included in all alternative network structure analyses. Also, the aggregate results show that the SK92, V3, is utilized mostly in all network structures, firm-level, cluster and integrated. Specifically, the aircraft is used for 44.6%, 63.8% and 63.6% of flights in the firm-level, cluster and integrated networks, respectively. The SK92 can accommodate 19 passengers whereas the V1, or SK76, and V2, or AW139, accommodate 12 passengers. Also, the SK92, in contrast to the V1 and V2 aircraft types, nearly always has an effective capacity equal to the seating capacity. These performance metrics may explain the usage rates of the SK92 relative to the other vehicle types. Too, in all network structures, the V1, or SK76, is utilized more than the V2, or AW139. Specifically, the aircraft is used for 39.0%, 20.6% and 19.9% of flights in the firm-level, cluster and integrated networks, respectively. Lastly, the V3, or AW139, is utilized the least across the network structures. Specifically, the aircraft is used for 16.4%, 15.6% and 16.5% of flights in the firm-level, cluster and integrated networks, respectively. Aircraft type usage is relatively stable with the exception of the smallest network structure, firm-level, and the largest network structure, integrated. The smallest network structure employs usage of the SK76 to a greater degree, 39.0%, relative to the integrated network structure, which employs the aircraft for 19.9% of flights. These results may be due to the diversity of passengers within the integrated network. In essence, passengers from all 58 locations are eligible to engage in ride sharing with each other whereas the firm-level networks include passengers concentrated based on the energy firm for which they work. Table 16 depicts network structures' usage of the vehicle types, V1, V2 and V3.

Table 16

Aggregate networks quantity of passengers and vehicle usage statistics

	Quantity of Passengers	V1 Usage	V2 Usage	V3 Usage
Anadarko	1,458	15.9%	4.5%	79.5%
BHP	92	75.0%	-	25.0%
BP	444	25.0%	25.0%	50.0%
Chevron	682	18.2%	13.6%	68.2%
ConocoPhillips	100	100%	-	-
ENI	310	36.4%	18.2%	45.5%
EnVen	420	14.3%	28.6%	57.1%
Equinor	130	100%	-	-
ExxonMobil	150	57.1%	42.9%	-
Fieldwood	368	35.7%	35.7%	28.6%
Hess	408	21.4%	28.6%	50.0%
LLOG	198	100%	-	-
MC	92	100%	-	-
Murphy	272	45.5%	36.4%	18.2%
Petrobras	160	100%	-	-
Shell	534	22.2%	16.7%	61.1%
Talos	366	16.7%	25.0%	58.3%
W & T	134	83.3%	16.7%	-
Walter	74	100%	-	-
Firm-level	3,692	39.0%	16.4%	44.6%
Cluster	3,692	20.6%	15.6%	63.8%
Integrated	3,692	19.9%	16.5%	63.6%

Note. Aggregate networks results including quantity of passengers, V1 usage, V2 usage and V3 usage

Across all network structures, the seating capacity load factors achieved are consistent. Specifically, the SK76 achieves the lowest average load factors of 79.5%, 69.7% and 75.0% for the firm-level, cluster and integrated networks, respectively. Next, the AW139 achieves load factors of 95.2%, 92.0% and 91.1% for the firm-level, cluster and integrated networks. The SK92 aircraft achieves the greatest seating capacity load factors. Specifically, the SK92 achieves load factors of 97.1%, 98.9% and 98.7% for the firm-level, cluster and integrated networks, respectively. The SK76 and AW139 aircraft, in many cases, exhibits an effective capacity lower than the seating capacity. In essence, these aircraft reach their respective maximum gross takeoff weight prior to accommodating the quantity of passengers allowed by their respective seating capacity. This phenomenon is due to the minimum fuel requirements for deepwater and ultra-deepwater locations. In contrast, the SK92 routinely exhibits the ability to accommodate passengers for all available seats while adhering to minimum fuel requirements. Table 17 depicts the network structures' seating capacity load factors.

Table 17

Aggregate networks VCP load factor statistics

	V1 VCP LF	**V2 VCP LF**	**V3 VCP LF**	**Weighted VCP LF**
Anadarko	70.2%	95.8%	97.3%	92.9%
BHP	75.0%	-	100%	81.3%
BP	86.1%	93.8%	96.1%	93.0%
Chevron	64.6%	94.4%	96.8%	90.6%
ConocoPhillips	68.1%	-	-	68.1%
ENI	87.5%	100%	93.7%	92.6%
EnVen	58.3%	97.9%	99.3%	93.7%
Equinor	90.3%	-	-	90.3%
ExxonMobil	89.6%	88.9%	-	89.3%
Fieldwood	88.3%	98.3%	94.7%	93.7%
Hess	77.8%	97.9%	97.0%	93.1%
LLOG	91.7%	-	-	91.7%
MC	76.7%	-	-	76.7%
Murphy	90.0%	91.7%	100%	92.4%
Petrobras	74.1%	-	-	74.1%
Shell	62.5%	88.9%	98.1%	88.6%
Talos	91.7%	94.4%	95.5%	94.6%
W & T	91.7%	100%	-	93.1%
Walter	77.1%	-	-	77.1%
Firm-level ($\bar{X}$)	79.5%	95.2%	97.1%	87.7%
Cluster ($\bar{X}$)	69.7%	92.0%	98.9%	91.6%
Integrated	75.0%	91.1%	98.7%	92.7%

Note. Aggregate networks results including V1, V2 and V3 VCP load factors

The An alternative measure of load factor performance is to evaluate load factors relative to vehicles' effective capacities. The effective capacity, in essence, is the quantity of passengers allowable based on an aircraft's available payload. The evaluation of effective capacity load factors shows that performance across all aircraft types is improved relative to seating capacity load factors. The SK76 achieves average effective capacity load factors of 92.1%, 85.4% and 88.7% for the firm-level, cluster and integrated networks, respectively. The AW139 achieves average effective capacity load factors of 99.2%, 98.6% and 99.4% for the firm-level, cluster and integrated network structures, respectively. Lastly, the SK92 achieves average effective capacity load factors of 97.1%, 98.9% and 98.8% for the firm-level, cluster and integrated load factors, respectively. The firm-level network structure shows the AW139 achieves the greatest load factor whereas the SK76 achieves the lowest load factor. The cluster network shows the SK92 achieves the greatest load factor whereas the AW139 achieves a nearly identical load factor. For the cluster network, the SK76 achieves the lowest load factor. The integrated network shows similar achievements to the cluster network regarding aircraft rankings and load factor achievements. Table 18 depicts the effective capacity load factors achieved for the firm-level, cluster and integrated networks.

Table 18

Aggregate networks VEC load factor statistics

	V1 VEC LF	V2 VEC LF	V3 VEC LF	Weighted VEC LF
Anadarko	85.5%	100%	97.2%	95.5%
BHP	90.0%	-	100%	92.5%
BP	100%	97.9%	96.0%	97.5%
Chevron	86.3%	97.2%	96.8%	95.0%
ConocoPhillips	90.7%	-	-	90.7%
ENI	95.4%	100%	93.6%	95.5%
EnVen	58.3%	100%	99.3%	93.7%
Equinor	98.4%	-	-	98.5%
ExxonMobil	89.5%	96.9%	-	92.7%
Fieldwood	98.1%	98.3%	94.7%	97.3%
Hess	96.6%	100%	96.9%	97.8%
LLOG	100%	-	-	100%
MC	92.0%	-	-	92.0%
Murphy	98.1%	100%	100%	99.2%
Petrobras	98.7%	-	-	98.8%
Shell	82.5%	100%	98.0%	95.0%
Talos	100%	100%	95.4%	97.4%
W & T	100%	100%	-	100%
Walter	88.6%	-	-	88.6%
Firm-level ($\bar{X}$)	92.1%	99.2%	97.1%	95.7%
Cluster ($\bar{X}$)	85.4%	98.6%	98.9%	95.9%
Integrated	88.7%	99.4%	98.8%	96.9%

Note. Aggregate networks results including V1, V2 and V3 VEC load factors

The usage of split deliveries is a key component to the evaluation of alternative network structures. The prevalent usage of multiple stops increases as the network size increases. This is likely due to the diversity of passengers regarding their final destinations and the subsequent opportunity for ride sharing. The firm-level networks, on average, predominantly utilized direct flights to and from offshore destinations. Next, these networks utilized 2-stop trips. Two firm-level networks, Anadarko and Shell, utilized a 3-stop trip whereas a single network, Anadarko, utilized a 4-stop trip. Similarly, the cluster network configuration mostly utilized direct trips. However, among the cluster networks, 2-stop, 3-stop, 4-stop, 5-stop and 6-stop trips were conducted. The integrated network predominantly utilized 2-stop trips followed by direct trips. Although utilized minimally, the integrated network conducted trips ranging from 2 through 8 stops. The results of the prevalent use of multi-stop trips are positively related to the network size and inherent diversity of passengers within the networks.

The alternative network structure total cost statistics show that the cluster and integrated network structures do not reduce total costs. Whereas the firm-level total cost is $649,178, the cluster and integrated networks' total costs are $690,936 and $793,917, respectively. Notably, specific firms do realize reduced total cost within the cluster and integrated networks. Therefore, the results show that evaluating commercial partnerships by combining networks or portions of networks is worthwhile. Conclusively, the cluster and integrated network structures do not yield cost savings whereas alternative cluster schema may yield mutually beneficial results for partners. Overall, the inherent size and complexity of the cluster and integrated networks may explain the increased total costs. Table 19 depicts the usage of multi-stop trips and total costs among the alternative network structures.

Table 19

Aggregate networks usage of split deliveries and total cost statistics

	Direct	2-Stop	3-Stop	4-Stop	5-Stop	6-Stop	7-Stop	8-Stop	Network Cost
Anadarko	50.0%	38.6%	9.1%	2.3%	-	-	-	-	$180,414
BHP	75.0%	25.0%	-	-	-	-	-	-	$10,249
BP	87.5%	12.5%	-	-	-	-	-	-	$46,392
Chevron	81.8%	18.2%	-	-	-	-	-	-	$83,525
ConocoPhillips	100%	-	-	-	-	-	-	-	$16,188
ENI	90.9%	9.1%	-	-	-	-	-	-	$22,574
EnVen	85.7%	14.3%	-	-	-	-	-	-	$32,558
Equinor	100%	-	-	-	-	-	-	-	$8,160
ExxonMobil	100%	-	-	-	-	-	-	-	$12,460
Fieldwood	100%	-	-	-	-	-	-	-	$29,848
Hess	92.9%	7.1%	-	-	-	-	-	-	$37,809
LLOG	77.8%	22.2%	-	-	-	-	-	-	$9,663
MC	100%	-	-	-	-	-	-	-	$10,040
Murphy	100%	-	-	-	-	-	-	-	$22,452
Petrobras	100%	-	-	-	-	-	-	-	$26,964
Shell	94.4%	-	5.6%	-	-	-	-	-	$62,065
Talos	83.3%	16.7%	-	-	-	-	-	-	$26,735
W & T	83.3%	16.7%	-	-	-	-	-	-	$5,882
Walter	100%	-	-	-	-	-	-	-	$5,200
Firm-level ($\bar{X}$)	89.6%	18.0%	7.3%	2.3%	0.0%	0.0%	0.0%	0.0%	$649,178
Cluster ($\bar{X}$)	46.7%	35.2%	16.6%	9.2%	0.6%	0.3%	0.0%	0.0%	$690,936
Integrated	26.7%	33.0%	21.4%	9.2%	5.8%	1.9%	0.5%	1.0%	$793,917

Note. Aggregate networks results including direct, 2-stop, 3-stop, 4-stop, 5-stop, 6-stop, 7-stop and 8-stop route and total cost statistics.

CHAPTER V

PART I DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

In this paper, the design and execution of a randomized greedy algorithm for the transportation of offshore workers to their respective work locations is presented. Commonly, primitive methods are executed for such planning, which may not achieve optimality or an approximation of optimality. Also, the evaluation of alternative network structures is novel and a potentially innovative improvement to the status quo. The design and employment of the randomized greedy algorithm achieves efficient results for firm-level networks while identifying the advantages of alternative network structures. The implications of such knowledge resultant from these analyses are discussed further in the proceeding sections.

Discussion

The current study yields significant contributions to the extant literature and provides implications for practitioners, implications for future research endeavors and noteworthy implications for society. The decision-making process includes complexity commonly found in practice but lacking in previous studies. With a more holistic and realistic representation of the problem, the findings from this paper will help practitioners gain a practical approach to model development and solution deliverance. Future research may be enhanced by adopting a systematic approach and incorporating variable development for new or underutilized optimization methodologies. Lastly, the management implications from this paper would also generate broad impacts on the society due to the importance of the energy industry and its direct, indirect, and induced effects on local, regional, and national economies. The abovementioned contributions and implications are further discussed in the proceeding subsections.

The cluster networks include an evaluation of ride sharing and potential savings associated with energy firm cooperation. The cluster schema employed in the study identifies that there exist opportunities for firms to reduce costs via ride-sharing cooperation. This revelation is an important contribution to the extant literature and an opportunity for future practice. Notably, the mixed results identify that cooperation may not yield advantageous results. One plausible explanation for the increased cost is a function of the network size. Clustered networks are inherently larger than independent firm-level networks and exhibit moderately increased costs. In essence, as energy firms seek to reduce transportation costs within their respective networks, cooperation among firms may or may not further enhance such endeavors. As demonstrated by the results, the assessment of cooperation is advisable.

The integrated network, too, includes an evaluation of ride sharing and potential savings associated with energy firm cooperation. The integrated network configuration reveals that there exists an opportunity for efficiency gains via firm cooperation. This revelation is an important contribution to the extant literature and an opportunity for future practice. Notably, the mixed results identify that cooperation may not yield advantageous results. One plausible explanation for the increased cost is a function of the network size. The integrated network, which is the largest of all evaluated networks, exhibits the highest cost. In essence, as energy firms seek to reduce transportation costs within their respective networks, cooperation among firms may or may not further enhance such endeavors. Although the integrated network evaluation fails to yield advantageous results for all firms, alternative network structures promote consideration in future research and practical endeavors.

Implications for future practice. As described by previous researchers, energy firms may more efficiently utilize their contracted aircraft via implementation of a decision-making mechanism for passenger assignment, aircraft selection, depot selection and aircraft routing. Most energy firms possess numerous and spatially segregated offshore facilities and, therefore, are unable to efficiently and effectively make such decisions. Ultimately, the efficient use of firms' contracted helicopters can enhance profitability via reduced costs without compromising operational performance. Reduced costs are likely to be realized by a potential workforce or workload reduction, reduced flight hours and enhanced bargaining power with commercial helicopter operators. Specifically, enhanced bargaining power may be realized as a result of minimized depots from which the aircraft are operated and an overall reduction of aircraft via increased asset utilization. In essence, the efficient use of commercial helicopters may yield systemic efficiencies that can be shared among all stakeholders, contracting energy firms and commercial helicopter operators. The achievement of operational efficiencies, ultimately, may determine the realization of target performance or solvency of a plethora of firms in the future (Krishnan et al., 2019).

The creation and implementation of clustered networks for the transportation of personnel among firms is a potential source of cost savings without sacrificing other competitive advantages or proprietary knowledge. The creation of clustered networks in the future will likely be a function of spatial relationships among locations, firms' history of cooperation among one another and other factors naturally uniting participants. The implementation, too, will likely represent a function of goal congruence and minimum requirements to be met by the commercial helicopter operator from the perspective of energy firm partners. Incentives for energy firm cooperation include greater bargaining power with commercial helicopter firms via demand concentration, reduced heliport infrastructure costs and cost reduction distribution resultant from an overall fleet reduction and increased asset utilization. Importantly, the United States' Title 14 of the Code of Federal Regulations allows such cooperation for firms exercising privileges of their Federal Aviation Regulations Part 135 operating certificate. Overall, ride sharing via energy firm cooperation is feasible and may potentially yield mutual benefits for participating firms.

The integrated network structure reveals a form of cluster network in that it includes firms operating in the deepwater and ultra-deepwater zones in the Gulf of Mexico. Notably, there are numerous other cluster schema that can be employed among operators interested in evaluating potential efficiency gains via commercial relationships. As demonstrated by the study, such configurations must be evaluated to determine if relationships yield efficiency gains for all or only some participants.

Implications for future research. The extant literature encompasses works that inadequately observed the complexity associated with the transportation of personnel. Specifically, this research, unlike many works in the extant literature, utilizes a heterogeneous versus homogeneous fleet, multiple depots versus a single depot and allowance for split deliveries. Also, the current research ensures all relevant aircraft capabilities and limitations are observed. In particular, the current research takes into account vehicles' seat capacities, effective capacities via maximum gross takeoff weights and reserve fuel requirements. The current model, which is built upon the heterogeneous capacitated helicopter routing problem with split deliveries and multiple depots (HCHRPSDMD), sufficiently provides a practical approach to model development and solution deliverance while promoting future research endeavors. Future research may utilize these findings for other geographical regions and similar transportation networks. Also, future research may obtain and include firm-specific price variables instead of the estimated average hourly costs of operating the aircraft types. In order to validate results of the model, Monte Carlo simulation may be employed to account for unknown and stochastic demand at offshore facilities. Lastly, alternative objective functions may be incorporated to evaluate various aspects of the problem from the perspectives of additional stakeholders. Furthermore, in addition to load factor and direct versus split delivery metrics, other complimentary efficiency measurements may provide additional insights to the model's performance. Such measurements include revenue and cost achievements per seat mile and passenger mile.

Clustered networks allowing ride sharing among energy firms is unrepresented in the extant literature. As demonstrated in the current study, the practice may yield mutual benefits across firms. Future research may be enhanced via exploration of alternative clustering techniques. The foundation of knowledge associated with ride sharing via energy firm cooperation is provided; however, the topic remains a rich opportunity for future research in the energy industry as well as other transportation networks.

The integrated network, similar to the cluster networks, reveals that efficiency gains from firm cooperation are possible but not guaranteed. Future research may enhance methods of cluster formation and solution techniques to improve the realization of efficiency gains. The current study provides a foundation for such analyses and a benchmark for comparison.

Implications for society. For economies, communities and industries depending on crude oil and natural gas production, people's livelihoods are significantly impacted due to price fluctuations (Rostan & Rostan, 2020; Solaymani, 2019). Based on a unique set of inputs and outputs, the International Energy Agency region (IEA), which includes the current study's sample set, was found to achieve greater overall production efficiency relative to the Organization of the Petroleum Exporting Countries (OPEC) and the Organization of Arab Petroleum Exporting Countries (OAPEC) (Ohene-Asare et al., 2018). Therefore, enhanced logistics efficiency within the energy industry's transportation sector across the globe is reasonably likely. For countries relying on these commodities' exportation, production efficiency is and will continue to be a priority. With limited resources available in industry and society, efficiency is prone to yield advantageous results for all stakeholders. Furthermore, in the context of this study, a reduction of carbon dioxide and noise pollution in air, above water and on land will contribute to society's drive to protect the environment and preserve our natural resources for future generations.

Similar to the societal benefits associated with any level of increased efficiency, greater efficiency via ride sharing resultant from the use of clustered networks or an integrated network may enable transportation needs to be met while reducing costs, reducing emissions, reducing workloads or workforces and enabling profitable offshore projects otherwise failing to be pursued. With an increase in offshore projects, local and regional economies may benefit via reduced unemployment.

Conclusions

The current study, utilizing unique data and including all relevant parameters for the heterogeneous capacitated helicopter routing problem with split deliveries and multiple depots, effectively provides practitioners a practical approach to model development and solution deliverance. Complex transportation networks necessitate approaches that produce efficient and feasible solutions, whether optimal or an approximation of global optimum. As demonstrated, the randomized greedy algorithm enables efficient solutions for a variety of networks. As expected, results indicate that all aircraft models, depots and multi-stop trips are useful in minimizing costs associated with transporting personnel to and from offshore facilities. Although the current study is complementary to the extant literature, the study is somewhat limited, which yields opportunities for continued scholarship of the energy sector's transportation network.

The evaluation of clustered networks and an integrated network provides meaningful information for future practice, future research and society. Specifically, the evaluations reveal that although there exist opportunities for cost reduction via ride sharing, most networks achieved minimal cost without being part of a clustered or integrated network. Therefore, in a practical setting, specific locations among firms must be evaluated to definitively discern whether firm cooperation is advantageous. To promote this network structure in future practice and research, the proceeding section provides recommendations for practitioners and researchers.

Recommendations

Future works may be enhanced with actual cost data in lieu of estimations. In the current study, cost data were not available; however, estimations do not inherently proscribe sound interpretations of the models' outputs. Also, future research endeavors including manual method results may enable comparative results to establish cost variance analysis. Although the current study is, to some extent, limited, the practicality for practitioners and contribution to researchers is comprehensible. Due to the idiosyncrasies and complexity prevalent in modern transportation networks, optimization is and will continue to be a rich opportunity for implementation and research.

Future research associated with clustered and integrated network structures may benefit from considering additional cluster schema in conjunction with logical pairs or groups of energy firms and their respective locations. Also, an evaluation including locations absent from the deepwater and ultra-deepwater database may be warranted. Overall, the evaluation of clustered and integrated network structures remains a rich topic for academic inquiry and practical implementation.

CHAPTER VI

PART II INTRODUCTION

Commercial helicopter services in the Gulf of Mexico are utilized for the transportation of supplies and personnel to and from offshore facilities engaged in exploration, drilling, production and abandonment activities in pursuit of crude oil and natural gas. Commercial helicopter operators, to varying degrees, rely on this key market for the derivation of revenues. Consequently, there may exist strategic risks within this segment of the industry due to fluctuations in the underlying commodity markets, crude oil and natural gas. Specifically, these strategic risks may influence firms' investment and acquisition strategies (Kot & Dragon, 2015). Although these firms are known to rely on their respective contracts serving oil and gas firms, it is not known to which degree their stock returns are related to the prices of the abovementioned commodities. Furthermore, it is unknown if firms' stock returns fluctuate in unison with the rotary rig count, which is a count of active drilling rigs. Within the broader aviation industry, the price of oil and gas represents a risk to airlines' input prices (Kang et al., 2021; Mohanty et al., 2014; Yun & Yoon, 2019). Similarly, the helicopter industry serving the energy industry may be negatively impacted by such prices; however, it is hypothesized that oil and gas price fluctuations will impact demand for air travel. The abovementioned gaps in this segment of the aviation industry within the extant literature provide the foundation for the current study. Furthermore, identification and a more thorough understanding of these phenomena are requisite knowledge for practitioners' developing and executing strategies and foundational for researchers as well.

Beginning in 2008, the price of crude oil had dropped significantly and, as a result, the utilization of helicopters had decreased. Commercial helicopter operators relying on this market subsequently sold assets, deferred aircraft purchases and reduced workforces (Cameron, 2016). These phenomena support the notion that commercial helicopter operators in the energy industry segment may be engaged in a dynamic environment as defined by the extant literature. Dynamic environments have been broadly described as possessing observable or foreseeable changes that occur rapidly and significantly impact an entity or industry, which can be positive or negative (Figueira de Lemos & Hadjikhani, 2014). Though there exists no universal measure to identify a dynamic environment in which a firm or industry operates, particular phenomena and subsequent results adequately support the notion of a dynamic environment. In some cases, dynamic environments have been described as having "fleeting opportunities and urgent threats" which require rapid reorganization or reconfiguration (Girod & Whittington, 2017, p. 1123). One such phenomenon is a significant change in an industry's fundamental characteristics, which may be induced by an emergent technology, governmental regulation or supply and demand movements or shifts. Notably, the environment may exhibit a combination of these and other phenomena that yield or may yield detrimental volatility.

During the period from 2013-2018, the price of crude oil exhibited ample volatility. Specifically, the minimum and maximum values were $32.13 and $114.48, respectively. The minimum and maximum values were realized in February 2016 and August 2013, respectively. During the period from 2013-2018, the price of natural gas, too, exhibited ample volatility. Specifically, the minimum and maximum values were

$1.72 and $5.41, respectively. The minimum and maximum values were realized in February 2016 and January 2014, respectively. In the same period, the Baker Hughes rotary rig count, which is the quantity of rigs engaged in drilling operations in the Gulf of Mexico, also exhibited substantial volatility. Specifically, the minimum and maximum values were 13 rigs and 63 rigs, which were prevalent in March 2018 and September 2013, respectively. Notably, the quantity of drilling rigs represents new developments. In essence, the rotary rig count reflects facilities actively drilling new wells and does not include drilled wells, seismic surveillance, existing production facilities or facilities undergoing abandonment. According to industry pundits, active drilling projects can commence and be terminated relatively quickly. However, at peak crude oil prices, some projects were delayed due to a lack of available drilling vessels. With the exception of the S&P 500, all variables exhibit negative slopes for the period. Figure 7 depicts the price of crude oil from January 2013 to December 2018, which is listed as it is sold in the market, U.S. dollars per 42-gallon barrel.

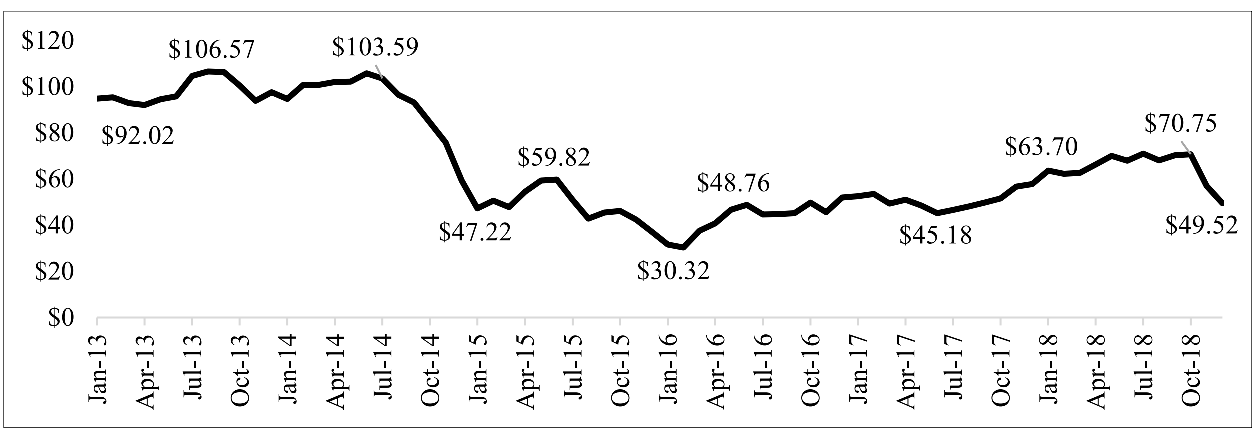


Figure 7. West Texas Intermediate crude oil spot price, 2013-2018.

During the period from 2013-2018, the price of crude oil exhibited ample volatility. As shown in Figure 7, the price of crude oil is downward sloping and realized a significant price decrease in the latter portion of 2014. As depicted by the chart, subsequent price recoveries were rarely sustained after the aforementioned drop in 2014. However, beyond the lowest price recorded in February 2016, the price of crude oil exhibited a positive slope. Notably, the price of crude oil is subjected to numerous drivers such as advancements in technology, geopolitical environments, demand, supply and regulation. These factors can have immediate and significant impacts to current and future prices. During the period from 2013-2018, the price of natural gas exhibited ample volatility. As shown in Figure 8, the price of natural gas is downward sloping and realized a significant price decrease in 2015. Notably, the price of natural gas, unlike the price of crude oil, exhibited a price recovery during the period. Importantly, natural gas and crude oil are naturally found in and recovered from the same wells. Although crude oil is the primary commodity sought, natural gas is produced from oil wells. The ratio of crude oil to natural gas differs among the wells. Nonetheless, these hydrocarbons are commonly found, recovered and commercialized together. Figure 8 depicts the price of natural gas from January 2013 to December 2018, which is listed as it is sold in the market, U.S. dollars per million Btu.

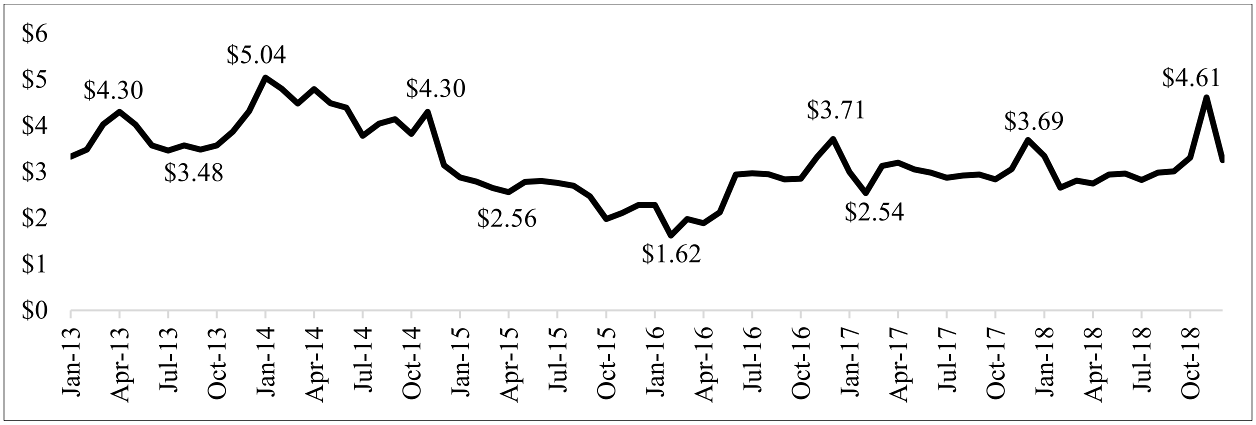


Figure 8. Henry Hub natural gas spot price, 2013-2018.

During the period from 2013-2018, the rotary rig count exhibited ample volatility. The quantity of rigs is downward sloping for the period and exhibits a significant decrease in early 2015. Figure 9 depicts the quantity of rigs actively engaged in drilling operations from January 2013 to December 2018.

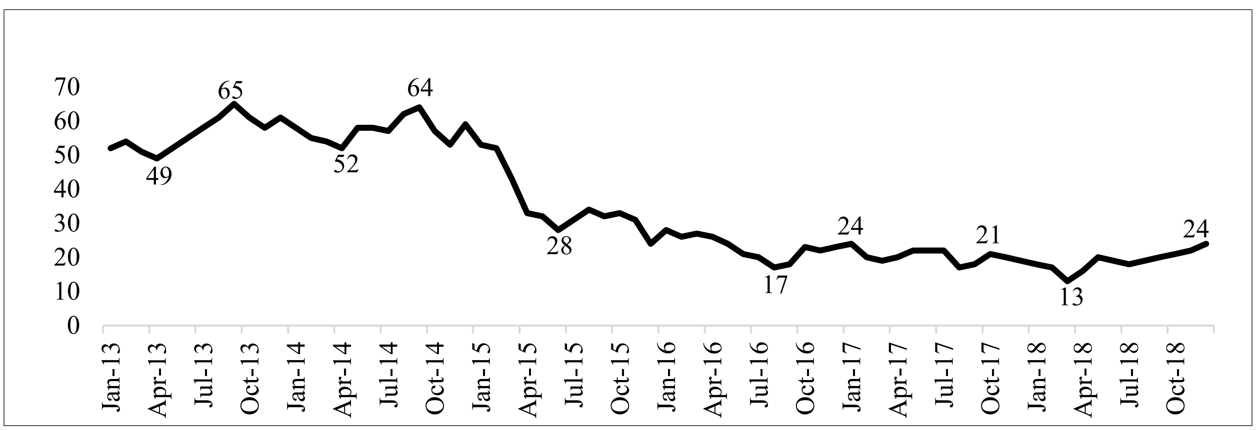


Figure 9. Baker Hughes rotary rig count, 2013-2018.

During the period from 2013-2018, the S&P 500 exhibited relatively minimal volatility. Furthermore, as shown in Figure 10, the S&P 500 is upward sloping.

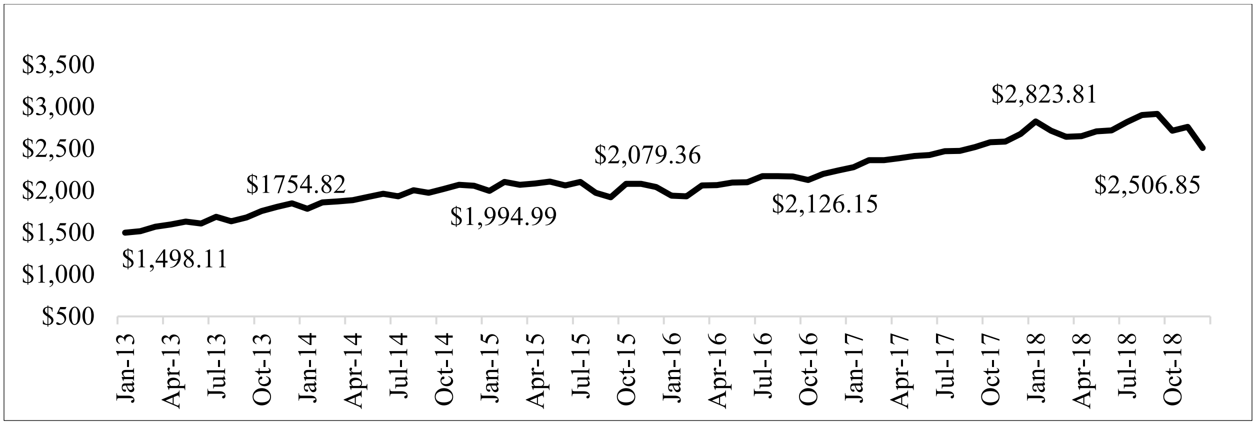


Figure 10. S&P 500 stock index, 2013-2018.

During the period from 2013-2018, the commercial helicopter operators' stock prices exhibited ample volatility. Commodity prices during the period, too, exhibited significant volatility and many industry participants attribute stock performances to such phenomena. These relationships will be evaluated empirically via regression analysis. Notably, no stock splits occurred during the period and, interestingly, the stock prices converged in December 2017 at approximately $15 per share. Figure 11 depicts the stock prices for the three largest operators, Bristow Group Inc., Era Group Inc. and PHI Inc., from January 2013 to December 2018, which are listed in U.S. dollars.

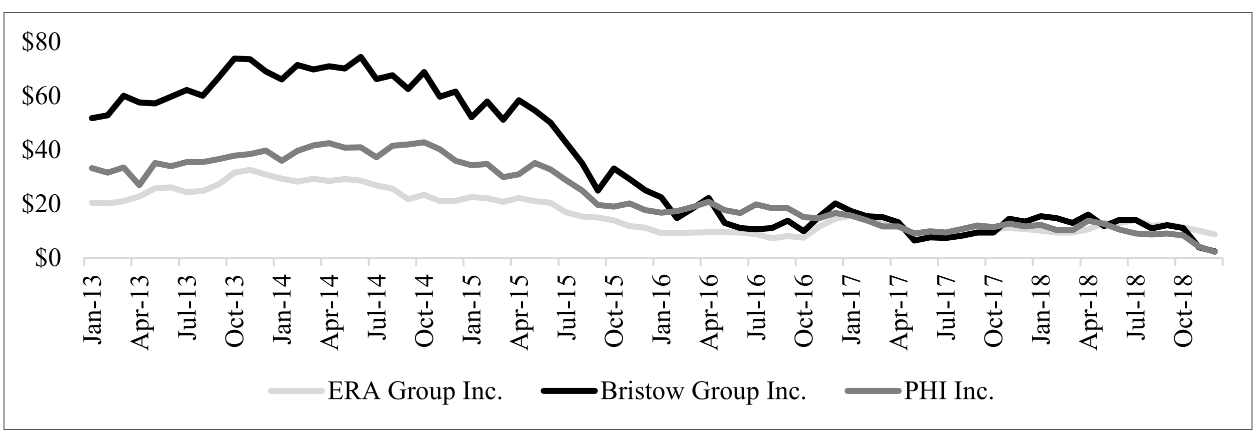


Figure 11. Commercial helicopter operators' stock prices, 2013-2018.

Decreasing oil prices have reduced offshore oil and gas activity, which includes helicopter services. Notably, offshore activity may include delayed expenditures, suspended production and an increased use of offshore supply vessels in lieu of helicopters. Recently, the U.S. commercial helicopter operators operating in the Gulf of Mexico have experienced diminishing flight hours, cancelled contracts, and declining share prices. Bristow Group Inc. owned a 60% interest in Eastern Airways and a 100% interest in Airnorth, which are fixed-wing, or airplane, operations. Also, Bristow Group Inc. earned a contract to provide public search and rescue services for the United Kingdom Department of Transport. Average revenue for the time period, 2013-2018, from oil and gas, fixed wing and search and rescue operations represented approximately 77%, 11% and 8% of total revenue, respectively. As depicted, Bristow Group Inc.'s concentration of revenue is decreasing for the period as the fixed-wing and search & rescue revenues represent greater shares of total revenue. Notably, this result may have been influenced by the revenue deterioration from oil & gas services. Figure 12 depicts the concentration of revenue for Bristow Group Inc., which consisted of oil and gas, fixed wing and search and rescue business lines.

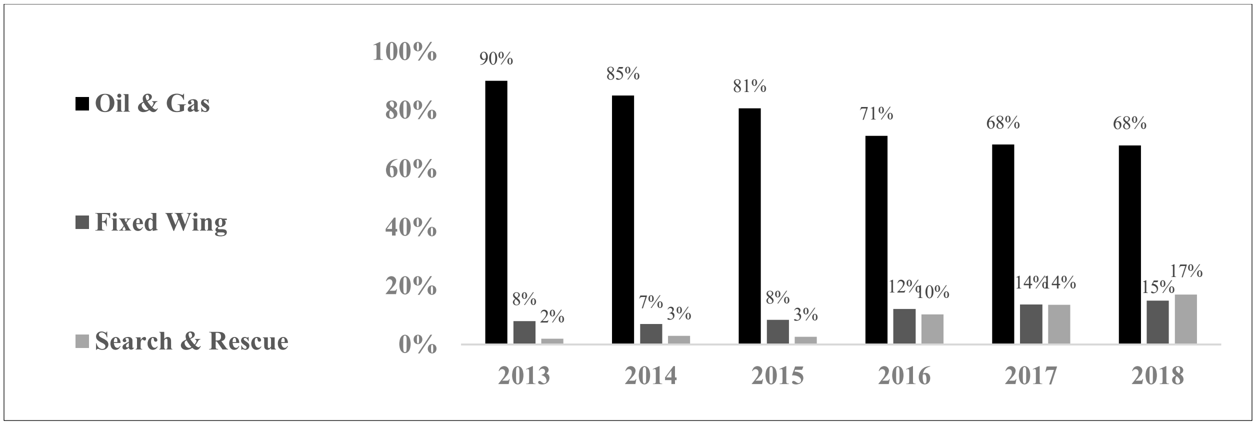


Figure 12. Bristow Group Inc. business line revenue concentration, 2013-2018.

PHI Inc. exhibited the least concentrated revenues and, outwardly, relied less on the volatile energy sector. Collectively, two of PHI Inc.'s oil and gas customers contributed approximately 25% of oil and gas revenues for the time period of 2015-2018 (PHI Inc., 2018). No single air medical client accounted for more than 2% of air medical revenues during the time period of 2015 through 2018 (PHI Inc., 2018). Average revenue for the time period, 2013-2018, from oil and gas, air medical and technical service operations represented approximately 56%, 39% and 5% of total revenue, respectively. Figure 13 depicts the concentration of revenue for PHI Inc., which consisted of oil and gas, air medical and technical services business lines.

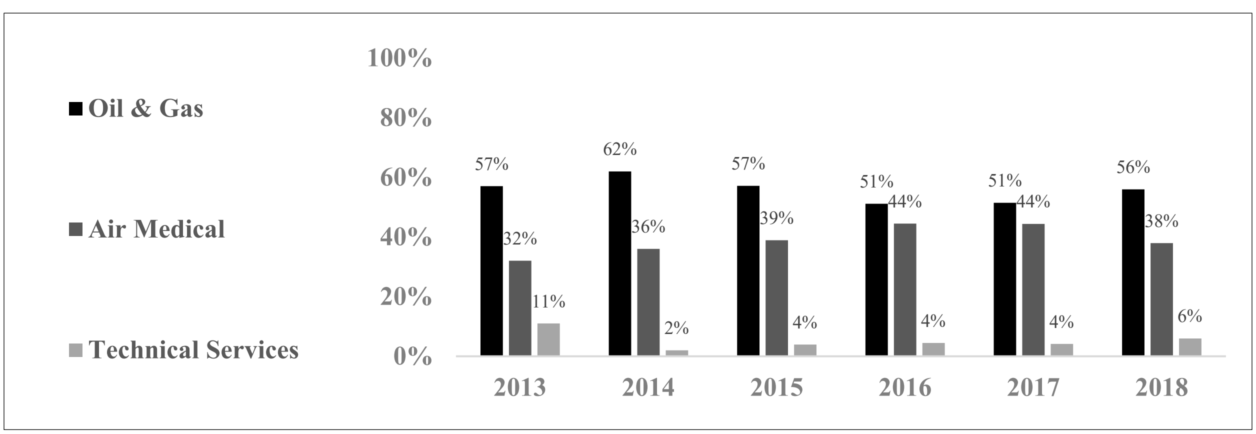


Figure 13. PHI Inc. business line revenue concentration 2013-2018.

For Era Group Inc., a significant portion of revenues were derived from oil and gas operations. Specifically, due to many lease and emergency response activities being tied to oil and gas operations, the firm indicated that for the years 2015 through 2018, most revenues were linked to the volatile energy sector (Era Group Inc., 2018). Furthermore, 28%, 22% and 16% of oil and gas sector revenues are earned from Anadarko, Petrobras and the U.S. Bureau of Safety and Environmental Enforcement, respectively (Era Group Inc., 2018). As depicted in Figure 14, average revenue for the time period from oil and gas, lease, emergency response and flightseeing operations represented 78%, 11%, 7% and 2% of total revenue, respectively. Notably, Era Group Inc. sold its flightseeing operations on February 3, 2018 (Era Group Inc., 2018).

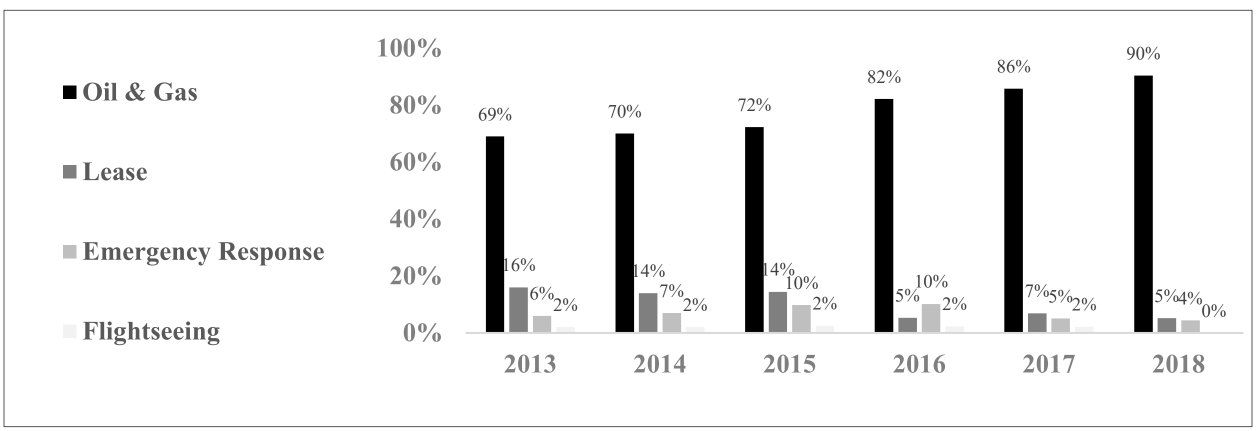


Figure 14. Era Group Inc. business line revenue concentration, 2013-2018.

This research empirically evaluated the abovementioned relationships and explored additional idiosyncratic phenomena within the energy industry's transportation network. The focus of the study was to identify the existence and strength of the structural relationships between the crude oil spot price, natural gas spot price, rotary rig count, a subset of the overall market, firms' degree of diversification and stock returns of commercial helicopter operators. Specifically, the relationship was estimated via ordinary least squares and generalized least squares methods, and supplemented by relevant summary statistical analysis. Four explanatory variables, including West Texas Intermediate crude oil spot price, Henry Hub natural gas spot price, Baker Hughes rotary rig count and the S&P 500 were tested for statistical significance and degrees of impact on stock returns of the three largest commercial helicopter operators including Bristow Group Inc., Era Group Inc. and PHI Inc. The model took into account four control variables, including firm revenue, diversification indices, firm identification and year dummy variables. This research represents the lone or one of few works contributing to the body of knowledge related to commercial helicopter operators' stock returns resultant from prevalent commodity prices, active drilling activity, business diversification strategy and a subset of the overall market environment.

Significance of the Study

There are numerous factors influencing the stock returns of public firms. In this paper, the objective was to empirically investigate external industry-specific variables and, specifically, test their respective explanatory power in affecting stock returns of commercial helicopter operators. If the prices of crude oil and natural gas can explain the stock returns of commercial helicopter firms, firms may be able to utilize current prices and commodity futures markets to assist in risk analysis, contract stipulations and operational and investment decisions. Similarly, the rotary rig count may exhibit explanatory power enabling commercial helicopter firms to assess real-time market conditions impacting their stock returns. Although diversification is prescribed for some firms and industries, strict adherence to core competencies and resultant efficiencies, in contrast, may yield more favorable stock returns. Therefore, it was worthwhile empirically examining whether commercial helicopter operators may benefit from a higher degree of business diversification in terms of stock return, and the empirical findings from this paper are instrumental in validating much of the anecdotal information available.

Statement of the Problem

Commercial helicopter firms' revenues, to varying degrees, are directly and indirectly dependent on their client's investment and operational activities. Other revenue streams are seemingly unrelated to the offshore energy industry. The current study evaluated the explanatory power of energy industry variables on commercial helicopter firms' stock returns. This knowledge is essential for practitioners and researchers whereas a lack of this knowledge may be detrimental to practitioners. The study aimed to establish the existence and significance of relationships between commercial helicopter firms' stock returns and industry-specific variables, effectiveness and impact of business line diversification on firms' stock returns and provide insight regarding firms' organizational control of their respective stock returns, which is indirectly measured via employment of external phenomena affecting the industry.

As demonstrated by the literature review, there was limited knowledge related to the broad commercial helicopter industry and, more specifically, the stock returns of commercial helicopter operators. Although it is discernable that these operators serve the energy industry and, consequently, are reliant on this segment for revenue generation, the specific relationships that are prevalent and the impact of such relationships on firms' stock returns were unknown. The lack of knowledge represented an important opportunity for practitioners to account for these phenomena when making future decisions and an opportunity for the extant literature to reflect a more holistic interpretation of these segments of the energy and aviation industries.

In addition to the relationships among external variables, such as crude oil, natural gas and the rotary rig count, firms' degree of diversification may yield insights central for all stakeholders. There is no universal consensus whether business line diversification is advantageous or imprudent for firms and industries. Therefore, the analysis of the relationship of commercial helicopter operators' stock returns and diversification indices was deemed vital, and is included in this study. Broadly, the commercial helicopter firms in the sample may be deemed relatively diversified; however, within the industry, due to the specialization of skills and assets, they are deemed to be moderately diversified across business lines. This study aimed to discern the impact of firms' varying degrees of business line diversification.

Purpose Statement

The purpose of this study was to observe the relationship between commodity prices and stock returns of commercial helicopter operators via econometric analysis. Specifically, the research evaluates the influence of external phenomena on stock returns while including an internal variable, diversification, on firms' stock returns. Overall, this analysis enables knowledge associated from such relationships absent from the extant literature, potential corroboration of anecdotal linkages and a utilitarian foundation for further analyses.

This study evaluated the influence of external phenomena on commercial helicopter firms' stock returns. Hence, in doing so, the potential influence of internal phenomena is exposed. Although the concept of the locus of control is generally applied to individuals and their life experiences, organizational locus of control provides insight into firms' strengths, weaknesses, opportunities and threats, or SWOT analysis (Helms & Nixon, 2010). Although this study was not intended to provide prescriptive actions, the results provide a foundation for such research.

This paper focuses on four primary questions: What is the impact of the price of crude oil on firms' stock returns? What is the impact of the price of natural gas on firms' stock returns? What is the impact of the rotary rig count on firms' stock returns? Lastly, what is the relationship of the S&P 500 and firms' stock returns?

Hypotheses

To varying degrees, the publicly-traded U.S. commercial helicopter firms utilized in this research rely on the offshore oil and gas industry for a significant percentage of their revenues and, conceivably, stock returns. The oil and gas industry's transportation needs may be related to current and forecasted crude oil and natural gas prices. If so, firms must be able to survive during cycles and effectively forecast changes in underlying industry forces. In essence, these phenomena may materially impact demand for commercial helicopter services in the offshore oil and gas industry. Conversely, commercial helicopter operators may intend to be in a position to take advantage of appreciating commodity prices and, therefore, be flexible enough to respond efficiently to increased demand for their services. Regardless of how firms are able to respond to the knowledge of how commodity prices impact their stock returns, which is beyond the scope of this study, the knowledge is foundational for future strategy development and execution. Numerous industry, commodity and financial experts agreed that there existed no consensus on the future of oil and gas prices (Newman, 2015). Specifically, the range provided by some industry participants was between $30 per barrel to $100 per barrel, which was not particularly narrow or optimistic (Macalister, 2016). Furthermore, the price to produce a barrel of oil differs geographically and may fluctuate as a result of geopolitical phenomena, demand shifts and shocks, technology advancements, restrictive regulations and, conversely, deregulation. The relative cost of oil production in the Gulf of Mexico has been higher relative to lands in the Middle East, South America and Africa. In order to evaluate the structural relationships between industry factors and transportation firms' stock returns, the following four hypotheses were developed, and then estimated by an empirical model.

Hypothesis 1. Commercial helicopter firms' stock returns are positively related to the prevalent price of crude oil, holding other factors constant.

Commercial helicopter firms provide transportation of personnel and supplies to and from energy firms' offshore facilities. Hence, it was hypothesized that the price of crude oil impacted the operational needs, investment activities and, consequently, the demand for transportation services. Iledare & Olatubi (2004) indicated that a clear relationship existed between the prevalent price of crude oil and drilling and production activity. Thus, the prevalent price of crude oil may drive decisions for drilling and production. If the current crude oil price yields profitable project estimates, firms may increase their drilling and production activities whereas, in contrast, prices may influence firms to forego or delay such activities. Calvert (1991) stated that when oil prices fluctuated downward, oil companies failed to justify and execute expenditures on new offshore projects. Overall, the commercial helicopter market and, importantly, commercial helicopter firms' stock returns were hypothesized to be correlated to and potentially caused by such phenomena.

Hypothesis 2. **Commercial helicopter firms' stock returns are positively related to the prevalent price of natural gas, holding other factors constant.**

The current price of natural gas, similar to crude oil, was hypothesized to impact the operational needs, investment activities and, consequently, the demand for transportation services. The prevalent price of natural gas may drive decisions for drilling and production. If the current natural gas price yields profitable project estimates, firms may increase their drilling and production activities whereas, in contrast, prices may influence firms to forego or delay such activities. Walls (1994) found a positive relationship between natural gas discoveries, higher expected net present value of natural gas, leased tracts and drilling activity. Overall, the research found that drilling activity was positively related to the net present value of production earnings, which was a function of expected crude oil and natural gas prices. Thus, the commercial helicopter market and, importantly, commercial helicopter firms' stock returns were hypothesized to be correlated to and potentially caused by such phenomena.

Hypothesis 3. **Commercial helicopter firms' stock returns are positively related to the prevalent quantity of active drilling rigs, holding other factors constant.**

Baker Hughes' Rotary Rig Count is a published quantity of facilities actively drilling new wells designed to extract crude oil and natural gas. Calvert (1991) found that the demand for helicopter services is a function of personnel positioned at offshore locations. Therefore, the rotary rig count, or count of active drilling rigs, may impact the underlying market conditions of commercial helicopter operators and explain a portion of variation associated with operators' stock returns. Walls (1994) found that drilling activity was positively related to the expected net present value of production earnings, which was a function of crude oil and natural gas prices. In essence, it was hypothesized that the quantity of active drilling rigs possessed explanatory power for the stock returns of commercial helicopter operators.

Hypothesis 4. Commercial helicopter firms' stock returns are positively related to prevalent market conditions as represented by the Standard & Poor's 500 stock index, holding other factors constant.

The Standard & Poor's 500 stock index is a capitalization-weighted collection of the 500 largest publicly-traded firms in the United States' exchanges. Intuitively, the index is used to approximate the prevalent economic environment and, consequently, potential impact on public shares. The S&P 500 is primarily included as a control variable. However, it was hypothesized that commercial helicopter firms' stock returns are positively related to the index's value. Notably, although the abovementioned relationship was hypothesized to be positive, there are theories supporting a negative relationship. In essence, due to the fact that hydrocarbon commodities are inputs for a plethora of industries, higher prices may contract economic activity and aggregated market values of firms.

Delimitations

An evaluation of relationships between commercial helicopter firms' stock returns and industry phenomena were inherently and strategically delimited. During the sampled period, there existed three public commercial helicopter firms operating in the Gulf of Mexico. In order to collect accurate and suitable data, public firms, in lieu of the inclusion of all firms in the industry, are included. Furthermore, to indirectly account for idiosyncratic phenomena within the target sample, the sample is restricted to the transportation sector in the Gulf of Mexico. In essence, this delimitation achieves a balance between a generalizable conclusion and practical significance.

The data were collected for the years 2013-2018, which provided a range of ample volatility among the variables and enabled relationships to be exposed. Due to some variables' reporting structure, all data are or were converted to monthly values. Baker Hughes rotary rig count data were restricted to only those observations consisting of drilling assets in the offshore waters of the Gulf of Mexico, which sufficiently provided alignment with other data.

Limitations and Assumptions

The current study encompasses all known industry-specific variables that may impact commercial helicopter operators' stock returns, employs robust methods for the estimation of parameters and estimation confirmation. In doing so, there were some limitations and assumptions worth noting. Importantly, these limitations and assumptions are not deemed detrimental to the estimation of parameters or conclusions borne.

With the exception of firms' diversification indices, explanatory variables are external, specific to the subject sample and comprehensive. Although the explanatory variables are limited, the research effectively identifies the targeted relationships, provides criteria for hypotheses testing and provides a foundation for further research.

Stock returns and commodity prices fluctuate constantly throughout various exchanges where they are traded. Therefore, it is assumed that monthly data sufficiently capture the fluctuations and provide suitable variables for the development and testing of hypotheses. Notably, the use of monthly data limits the total quantity of observations and is deemed a limitation to the research. Also, the exclusion of other commercial helicopter operators is seemingly a limitation. However, these operators have no shares listed or traded and do not produce annual reports; therefore, these firms are excluded from the data set. Importantly, the three public firms included represent a significant portion of the overall commercial helicopter activity and, therefore, mitigate the limitation of excluding some operators.

The lone internal variable, diversification index, represents an index derived from firms' percentage of revenues from their respective business lines. A limitation to the index is that is captures the percentage of revenue and does not include direct measures of their contribution to free cash flow, accounting profit, economic profit, capital employed or other relevant metrics commonly utilized by stock analysts. However, the index is deemed to effectively evaluate the intended relationship and measure the degree to which firms are reliant on commodity prices.

Limitations and assumptions listed above, although noteworthy, do not diminish the results achieved. In essence, the potential adverse effects from the limitations and assumptions are, where possible, eliminated or mitigated. Overall, the study was designed and executed to effectively develop and test hypotheses, produce robust outputs and contribute to the extant literature while, simultaneously, providing practitioners with a key component of their stock returns' relationship with industry phenomena.

Definitions of Terms

Abandonment	Decommissioning and removal of offshore facility
Drilling	Mechanically boring through the seabed for hydrocarbon extraction
Exploration	Searching for hydrocarbon-rich geographical locations

HHNG spot price	Henry Hub natural gas spot price
Production	Initial processing, such as separating, heating, cooling, measuring and transporting, hydrocarbon materials
Rig	Diverse set of structures used for hydrocarbon exploration, extraction, production and abandonment
Rotary rig count	Baker Hughes rotary rig count of active drilling rigs
WTI spot price	West Texas Intermediate crude oil spot price

List of Acronyms

BHRRC	Baker Hughes Rotary Rig Count
CPI	Consumer Price Index
DI	Diversification Index
DOD	United States Department of Defense
DW	Durbin-Watson
GDP	Gross Domestic Product
GLS	Generalized Least Squares
GOM	Gulf of Mexico
HHNG	Henry Hub Natural Gas Spot Price
HRP	Helicopter Routing Problem
IP	Industrial Production Index
OLS	Ordinary Least Squares
S&P	Standard & Poor’s 500 Stock Index
TB	Treasury Bill Yield
VAR	Vector Autoregression
VIF	Variance Inflation Factor

WTI	West Texas Intermediate Crude Oil Spot Price

CHAPTER VII

PART II REVIEW OF THE RELEVANT LITERATURE

There is a distinct absence of literature enabling the enrichment of knowledge associated with the commercial helicopter sector of the aviation industry. In fact, there were no published works on the helicopter fleet or providers in the Gulf of Mexico region. However, the extant literature showed direct relationships between crude oil and natural gas prices, drilling and production investment and regional economies (Iledare and Olatubi, 2004; Calvert, 1991). Furthermore, studies have shown that with decreasing drilling and production investment, service firms were susceptible to declining revenues and insolvency (Iledare and Olatubi, 2004). According to a leading helicopter manufacturer, AgustaWestland, oil and gas helicopters accounted for 26% of the global helicopter fleet. Cameron (2016) found that one fifth, or approximately two thousand, oil and gas helicopters were unused or underutilized. Calvert (1991) found that the quantity of helicopters deployed was a function of personnel on board offshore locations; therefore, as personnel decreased, the demand for helicopter services decreased. Conclusively, Calvert (1991) claimed that oil prices will have played a vital role in future levels of helicopter activity. Airline travel demand has been found to be influenced by per capita gross domestic product (GDP), index of manufacturing production and business and leisure attractiveness (Akinyemi, 2019). The current research explored the direct relationships between the price of crude oil, natural gas and sector growth, active drilling activity, and helicopter operators' stock returns in the Gulf of Mexico.

Reddy and Narayan (2016) performed a literature review of stock return analysis using 368 works from 63 journals published within a 15-year period, 2000-2014, using qualitative and quantitative methods. The majority of works in the study included two main topics, volatility and predictability, an emerging topic, liquidity, and three relatively less researched topics, inflation, oil price moments and correlation (Reddy & Narayan, 2016). Reddy and Narayan (2016) claimed that more research related to oil prices and shocks remains a rich topic for exploration due to the relatively limited quantity of works, price fluctuations realized in the recent past and importance to the global economy. The relevant extant literature included works associated with commodity prices' impacts on energy firms, industry investment, aerospace firms and regional economies.

Commodity Prices' Impact on Energy Firms and Industry Investment

Walls (1994) employed a hybrid model, which was claimed to be superior to separated econometric and engineering models, to model and forecast oil supply from the United States' Gulf of Mexico Outer Continental Shelf. Specifically, the research linked exploration to economic variables conducive for investment and, concurrently, linked new reserve discovery to aggregate drilling activity (Walls, 1994). Notably, Walls (1994) identified that econometric analyses modeling oil and gas failed to include the perishable nature, or "nonrenewability" (p. 455), associated with oil and gas extraction and, therefore, a hybrid approach was warranted. Economic variables deemed prudent and utilized included the prices of crude oil, drilling contracts and land lease contracts. Noteworthy relationships included a positive relationship between crude oil and natural gas discovery, higher expected net present value of crude oil and natural gas and leased tracts and drilling activity. Importantly, the research assumed that crude oil and natural gas prices exhibited a "random walk" variation and, therefore, the prior periods', *t-1*, prices were utilized to model the current periods', *t*, prices (Walls, 1994, p. 463).

Appropriately, Walls (1994) incorporated lagged variables to account for potential delays in responses to the aforementioned economic variables. Overall, the research found that drilling activity was positively related to the expected net present value of production earnings, which was a function of expected crude oil and natural gas prices.

Ergun and Ibrahim (2013) conducted analyses using multivariate regression and an impulse response function to measure firms' stock price adjustments resulting from crude oil and natural gas prices. The research identified that previous studies showed a positive relationship between energy firms, crude and natural gas prices and stock market indices. Notably, the data were daily and monthly for two firms located in Turkey, Aygaz and Tupras. In addition to crude oil and natural gas prices, Turkey's ISE100 stock index was included and, as expected, found to materially and positively impact stock price movements (Ergun & Ibrahim, 2013). Interestingly, global oil and natural gas price shocks were found to have a lagged response of up to one year.

Kang et al. (2017) investigated energy firm stock responses resultant from demand shocks and regulatory uncertainty. Specifically, the research employed a vector autoregressive model (VAR) to explore the impact of the policy uncertain index and petroleum market data on integrated oil and gas firms' stock returns (Kang et al., 2017). Notably, integrated oil and gas firms engage in upstream, midstream and downstream markets and, therefore, may be impacted by both demand and supply phenomena. The data utilized were monthly and included seven firms, Royal Dutch Shell, ExxonMobil, BP, Chevron, ConocoPhillips, TransCanada Corporation and Valero Energy Corporation. In addition to various commodity data such as changes in production and global market price, the policy uncertainty index was incorporated and included news-based, tax legislation, economic forecasts and governmental expenditure data. Kang et al. (2017) found that demand shocks materially and positively impacted stock returns of integrated energy firms. Notably, there existed heterogeneous impacts on stock returns based on the degree to which firms were diversified into the industry's three main segments, upstream, midstream and downstream. Conclusively, integrated energy firms successfully demonstrated balanced and diversified portfolios to effectively avoid detrimental impacts resultant from isolated shocks (Kang et al., 2017).

Commodity Prices' Impact on Aerospace Firms and Regional Economies

Iledare and Olatubi (2004) evaluated the economic impacts associated with changes in crude oil and natural gas prices on coastal states, Texas, Louisiana, Alabama and Mississippi, along the Gulf of Mexico's shoreline. Specifically, econometric modeling was employed to identify the existence and strength of relationships between commodities', crude oil and natural gas, prices and states' economies, which were derived via states' revenues, individual incomes, and unemployment rates (Iledare & Olatubi, 2004). Interestingly, important differences in the abovementioned states were prevalent and may have provided explanatory power for the research endeavor. Louisiana was identified as a relatively undiversified economy and net exporter of crude oil and natural gas. Alabama was categorized as having a relatively diversified economy, net importer of crude oil and net exporter of natural gas. Mississippi was identified as a net petroleum importer and having a moderately-diversified economy. Lastly, Texas, identified as exhibiting a relatively diversified economy, was categorized as a net petroleum exporter and materially reliant on petroleum refining. Iledare and Olatubi (2004) found that the prices of crude oil and natural gas significantly impacted

Louisiana’s unemployment rate, personal income and state revenue. Notably, there was no discernible relationship between petroleum production and unemployment whereas moderate relationships existed between petroleum production and individual income and state revenue. The study found that crude oil and natural gas prices and shocks were significantly related to Alabama’s unemployment rate, individual income and state revenue (Iledare & Olatubi, 2004). Mississippi’s unemployment, personal income and state revenue were materially impacted by the prices of crude oil and natural gas. However, there was no identifiable relationship between the state’s unemployment and petroleum production. In contrast, there existed a significant relationship between Mississippi’s state revenue and individual income and petroleum production. Texas’ individual income and state revenue were significantly impacted by commodity price fluctuations whereas Texas’ unemployment rate was relatively less sensitive. Fluctuations in petroleum production exhibited a relatively minor impact on Texas’ economic variables. Notably, the research indicated that there may exist lagged responses to petroleum price shocks and fluctuations in production. Overall, Iledare and Olatubi (2004) showed that petroleum production was significantly and positively related to petroleum prices.

Bae and Duvall (1996) performed analyses in order to identify the existence and strength of relationships between market and industry variables and aerospace firms’ stock returns. Specifically, independent variables included the S&P 500 stock index (S&P), Consumer Price Index (CPI), 3-month Treasury bill yield (TB), Industrial Production Index (IP), aircraft shipments and U.S. Department of Defense (DOD) expenditures. The aerospace firms included General Dynamics, McDonnel Douglas, Lockheed, Northrop and Grumman. Bae and Duvall (1996) found the S&P 500 index and United States' Department of Defense (DOD) expenditures to be materially and positively related to firms' stock returns in the aerospace industry. However, other seemingly relevant variables were not statistically significant. Using the six independent variables, S&P, CPI, TB, IP, aircraft shipments and DOD expenditures, the models for five firms, General Dynamics, McDonnel Douglas, Lockheed, Northrop and Grumman, fail to produce significant models (Bae & Duvall, 1996). Overall, Bae and Duvall (1996) demonstrated the inherent difficulty of identifying meaningful relationships between seemingly related variables and firms' stock returns.

Summary

Helicopters are versatile machines that are utilized in numerous markets such as electronic news gathering, emergency medical services, law enforcement, regional charter services, firefighting, pilot training, tourism, and civilian search and rescue. Therefore, if the current commercial helicopter operators in the Gulf of Mexico are significantly relying on crude oil prices, natural gas prices and growth, there may be justification for diversification or other mechanisms for coping with commodity price deterioration and cycles. Kaiser & Snyder (2010) indicated that their research on the offshore supply vessels was the only research to date related to the transportation sector in the Gulf of Mexico. Therefore, there remained minimal empirical evidence on the structure and idiosyncrasies associated with the Gulf of Mexico's commercial helicopter sector. The current study's empirical analyses aimed to fill this identified gap.

CHAPTER VIII

PART II METHODOLOGY

The methodology section includes the current study's research approach, sample data, data sources, data treatment, descriptive statistics and the empirical model. The data employed represent an evaluation of industry factors that are hypothesized to exhibit explanatory power of firms' stock returns. Therefore, the contribution of this study is invaluable for both practitioners, researchers, regulators and investors. Practitioners are provided enhanced insight into what factors and to what extent such factors impact stock returns. Researchers gain a novel understanding of segments of the energy and aviation industries. Regulators and investors are provided a more definitive relationship among the variables employed to enhance decision making in their respective fields. The empirical model, model diagnostics and results support the use of the employed methodology, multiple regression analysis.

Research Approach

The evaluation of factors influencing commercial helicopter operators' stock returns is conducted via multiple regression analyses. Specifically, ordinary least squares (OLS) and generalized least squares (GLS) methods are employed to evaluate variables' relationships and ensure robustness and consistency in parameter estimation. Specifically, OLS regression is employed to measure the aforementioned relationships whereas GLS regression is employed to ensure parameter estimates are reliable and consistent. Whereas GLS estimation of the trend line and intercept is unbiased and of minimum variance, OLS does not include the autocovariances of the regression errors (Lee & Lund, 2012). Broadly, OLS regression is estimated via minimization of the sum of squared deviations of each datum to the regression line (Rijnhart et al., 2017). Importantly, parameter coefficients are vulnerable to bias due to autocorrelation, multicollinearity or heteroskedasticity and, therefore, diagnostic procedures to check for robustness are warranted (Altman & Krzywinski, 2016). In the absence of the abovementioned problematic phenomena, OLS is an adequate measurement of relationships among variables chosen on the basis of theoretical underpinnings (Allen & Fildes, 1992). The regression and diagnostic procedures are further discussed in the proceeding sections.

Sample

The data utilized in the current study include Bristow Group Inc.'s, Era Group Inc.'s and PHI Inc.'s monthly stock returns, the Baker Hughes monthly rotary rig count, the West Texas Intermediate crude oil monthly spot price, the Henry Hub natural gas monthly spot price, firms' diversification indices and the Standard & Poor's 500 monthly index price from February 2013 to December 2018. All variables stated in dollars are converted to 2018 real dollars.

Sources of the Data

Bristow Group Inc.'s, Era Group Inc.'s and PHI Inc.'s stock returns, West Texas Intermediate crude oil spot prices, Henry Hub natural gas spot prices and Standard & Poor's 500 index prices were retrieved from finance.yahoo.com. Firms' revenues and diversification indices were retrieved and calculated, respectively, from U.S. Securities and Exchange Commission 10-K filings. The stock data include all splits and dividend payments that occurred during the period. The Baker Hughes rotary rig count was retrieved from bakerhughes.com and includes only active drilling rigs in the Gulf of Mexico offshore basin.

Treatment of the Data

The dependent variable is commercial helicopter firms' monthly stock returns whereas the explanatory variables include the natural logarithmic transformations of the crude oil spot price, natural gas spot price, Baker Hughes rotary rig count and S&P 500 stock index. The remaining variables are the control variables including the diversification index, firm revenue and dummy variables for firm and year. The diversification index measures business line revenue concentration. Specifically, business line revenue shares in the total revenue are squared and summed. The inverse of the calculation represents the diversification index for firm i in year t.

Descriptive statistics. Table 16 depicts the summary statistics, minimum, maximum, mean and standard deviation, for the firms' stock returns, West Texas Intermediate (WTI) crude oil spot price, Henry Hub natural gas (HHNG) spot price, an industry growth metric, Baker Hughes rotary rig count (BHRC) the S&P 500 (SNP) index and firms' diversification indices (DI) from 2013-2018. Table 17 depicts the correlation matrix for key variables.

Table 20

Descriptive Statistics for Key Variables

Variable	**Description**	**Min.**	**Max.**	**Mean**	**(St. Dev.)**
Stock_R	Firms' stock returns	-0.64	0.56	-0.02	(0.16)
WTI ($)	West Texas Intermediate crude oil	32.13	114.48	69.25	(24.94)
HHNG ($)	Henry Hub natural gas	1.72	5.41	3.37	(0.82)
BHRC	Baker Hughes rotary rig count	13	63	34	(16)
SNP_000 ($)	S&P 500 stock index value in 000s	1.64	2.90	2.26	(0.32)
DI	Business diversification index	1.22	2.28	1.81	(0.35)

Note. Stock_R = Firms' Stock Returns; WTI = West Texas Intermediate Crude Oil Spot Price; HHNG = Henry Hub Natural Gas Spot Price; BHRC = Baker Hughes Rotary Rig Count; SNP_000 = S&P 500 Stock Index; DI = Firms' Diversification Indices; Min. = Minimum; Max. = Maximum; St. Dev. = Standard Deviation.

Table 21

Correlation Matrix for Key Variables

Variable	1	2	3	4	5	6
1 *Stock_R*	1					
2 *WTI*	0.13	1				
3 *HHNG*	0.04	0.81	1			
4 *BHRC*	0.07	0.80	0.67	1		
5 *SNP_000*	-0.08	-0.53	-0.39	-0.77	1	
6 *DI*	0.05	-0.04	0.05	0.04	0.00	1

Note. Stock_R = Firms' Stock Returns; WTI = West Texas Intermediate Crude Oil Spot Price; HHNG = Henry Hub Natural Gas Spot Price; BHRC = Baker Hughes Rotary Rig Count; SNP_000 = S&P 500 Stock Index; DI = Firms' Diversification Indices.

Empirical model. The preceding exploratory data analyses reveal that the current study's hypotheses are reasonable and consistent with available anecdotal information. However, the extant literature lacks results from rigorous empirical analysis. Thus, the following empirical model, Equation 8, is developed to test the four hypotheses:

$$Stock\ Returns_{it} = \beta_0 + \beta_1 ln(WTI_{it}) + \beta_2 ln(HHNG_{it}) + \beta_3 ln(BHRC_{it}) \quad (8)$$

$$+ \beta_4 ln(SNP_{it}) + \beta_5 Revenue_{it} + \beta_6 DI_{it} + \beta_7 FIRM_{it} + \beta_8 YEAR_{it} + \mathcal{E}_{it}$$

CHAPTER IX

PART II RESULTS

Stock prices and stock returns are influenced by numerous factors, both objective and subjective. Objectively, financial results are monitored and assessed by shareholders, investors and analysts. Therefore, if results warrant concern, share prices and returns may be negatively impacted. Subjectively, regardless of results, shares may be impacted by earnings forecasts versus actual results, upward earnings forecast revisions and downward earnings forecast revisions. In this study, it is empirically observed that the price of crude oil possesses statistically significant and material explanatory power of commercial helicopter firms' stock returns. Also, it is apparent that there exist other factors yet to be empirically discovered, which is indicated by the model's R^2 statistic. Specifically, approximately 16.73% of stock returns' variation is explained by the variables included in the model.

Regression analyses based on the GLS method reveal that, similar to the OLS results, the prevalent price of crude oil has a positive coefficient (= .271) and yields statistically significant ($p < .01$) explanatory power of commercial helicopter firms' stock returns. Specifically, a 10% increase in the price of crude oil is expected to yield a 2.7% stock return increase, *ceteris paribus*. The prevalent price of natural gas nor the rotary rig count yield statistically significant results. The relationship between the S&P 500 stock index and firms' stock returns is positive and statistically significant ($p < .001$). Specifically, a 10% increase in the S&P 500 yields an 8.0% increase in stock return, *ceteris paribus*. Table 23 depicts the OLS and GLS regression results.

Table 22

OLS and GLS Regression Results

	Model I (OLS)	**Model II (GLS)**
WTI	.271** (.095)	0.271** (.092)
HHNG	-.181 (.114)	-.181 (.110)
BHRC	-.082 (.061)	-.082 (.059)
S & P 500 (000)	.806*** (.216)	.806*** (.209)
DI	-.046 (.039)	-.046 (.037)
Revenue (000)	-.000 (.000)	-.000 (.000)
ERA_ID	-.195 (.145)	.014 (.026)
PHI_ID	-.116 (.096)	-.007 (-026)
BRS_ID	Omitted	Omitted
DUM Y1	.476*** (.123)	.430*** (.114)
DUM Y2	.362** (.104)	.320*** (.098)
DUM Y3	.334*** (.087)	.294*** (.076)
DUM Y4	.366*** (.085)	.355*** (.082)
DUM Y5	.188** (.053)	.189*** (.052)
DUM Y6	Omitted	Omitted

Note. Dependent variable: Commercial helicopter firms' stock returns; N = 210; R^2 = .1673; * $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$ (Robust standard errors)

Results Summary

In sum, the estimation results, as shown in Table 23, suggest that other external and, importantly, internal phenomena likely possess explanatory power of firms' stock returns. Evaluating firms' annual reports and industry articles, it appears that commercial helicopter firms seemingly do not possess sufficient bargaining power with suppliers or clients. For example, customers utilize cancellation clauses within contracts to forego helicopter services with minimal notice and essentially no penalty. In environments where commodity prices do not support continuous operations and growth, commercial helicopter firms may realize a diminishing balance between revenues and expenses. Also, firms' degrees of diversification may impact their ability to mitigate risks associated with volatile or deteriorating commodity prices. Nevertheless, the estimation results do not provide evidence to validate the relationship between stock return and business diversification of helicopter operators, given an insignificant coefficient on the diversification index. In addition to the detrimental impact of deteriorating prices, commodity price appreciation, too, is important to consider. In essence, firms may benefit from price appreciation if strategically positioned to do so.

Reliability Testing

Equation 8 is estimated via ordinary least squares (OLS) and generalized least squares (GLS) regression models. In essence, ordinary least squares regression is executed to estimate parameter coefficients whereas generalized least squares regression is executed to insure consistency, robustness and rigor in the estimation of parameter coefficients. Robust standard errors are utilized to obtain unbiased standard errors and promote adherence to the Gauss Markov assumption of homoskedasticity. To test for autocorrelation, the Durbin Watson statistic is calculated and evaluated. The OLS model yields a Durbin Watson (DW) statistic of 2.192, which is within the acceptable range of 1.5 < DW < 2.5. Correlation coefficients (r) and variance inflation factors (VIF) are evaluated for potential multicollinearity. Potential issues are addressed via variable exclusion and, ultimately, excluded variables are included as parameter coefficients remain virtually unchanged. Specifically, the models are executed without those variables, *BRHC* and *DI*, exhibiting close to or greater than 10. However, exclusion of these variables does not materially impact the results. Due to their theoretical underpinnings associated with the model and hypotheses, *BHRC* and *DI* are included. Table 23 depicts the variables' variance inflation factors (VIF).

Table 23

Variance Inflation Factors for Key Variables

Variable	VIF
WTI	6.776
HHNG	3.067
BHRC	10.525
SNP_000	4.558
DI	8.238

Note. VIF = Variance Inflation Factor; Stock_R = Firms' Stock Returns; WTI = West Texas Intermediate Crude Oil Spot Price; HHNG = Henry Hub Natural Gas Spot Price; BHRC = Baker Hughes Rotary Rig Count; SNP_000 = S&P 500 Stock Index; DI = Firms' Diversification Indices.

Hypothesis Testing

Hypothesis 1 evaluates the issue of whether stock returns of commercial helicopter firms are positively related to the prevalent price of crude oil. Regression analyses show that there exists a positive and statistically significant relationship between the prevalent price of crude oil and commercial helicopter firms' stock returns. Although the firms are diversified to varying degrees, their stock returns' relationship to crude oil prices is clear. In essence, a 10% increase in the price of crude oil is expected to yield a 2.7% increase in stock return, *ceteris paribus*. This relationship is imperative for management to take into account when strategizing to take advantage of favorable prices and reduce losses when unfavorable prices prevail. As identified by the model's results, the prevalent price of crude oil is linked to firms' stock performance of commercial helicopter operators. This information may be quite complimentary in the development and execution of strategies.

Hypothesis 2 and Hypothesis 3 evaluate whether or not there exist relationships between commercial helicopter firms' stock returns and the prevalent price of natural gas and the rotary rig count, respectively. Regression analyses do not reveal statistically significant relationships for these variables. These results may be due to the primary hydrocarbon sought in offshore wells, crude oil, and the possible lag of prevalent crude oil prices and subsequent increase in active rotary rigs. Importantly, delaying investment, ceasing active drilling and production projects and renegotiating service contracts can be accomplished nearly instantaneously when prevalent and futures prices decline. However, drilling new wells is far more time consuming and may exhibit a lagged relationship with rig activity. As indicated by these results, crude oil prices are more suitable for understanding and forecasting commercial helicopter firms' stock returns as compared to the use of natural gas prices and rotary rig counts.

Hypothesis 4 evaluates the relationship between commercial helicopter firms' stock returns and the S&P 500 stock index. The relationship is positive and statistically significant. In essence, a 10% increase in the S&P 500 stock index is expected to be accompanied by an 8% increase in stock returns, *ceteris paribus*. Intuitively, the relationship between the S&P 500 index and commercial helicopter firms' stock returns is not so straightforward. On one hand, many firms' stock returns are positively related to the overall market. Therefore, when overall economic activity increases, these stock values will align with the overall market. However, hydrocarbon inputs are prevalent in many industries including transportation, agriculture, manufacturing, construction, and mining. Therefore, economic activity may be reduced when input prices increase. Consequently, these results provide invaluable insight that otherwise may be somewhat unclear to researchers and practitioners.

CHAPTER X

PART II DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

In this paper, the impact of external factors, which are, arguably, beyond the direct control of managers, on commercial helicopter firms' stock returns were evaluated. Commonly, when firms achieve favorable results for shareholders, internal factors are attributed to such success. In contrast, when unfavorable results are realized, the external environment is commonly identified as a significant contributing factor. The current study develops hypotheses regarding the relationship between commercial helicopter firms' stock returns and external factors including the price of crude oil and natural gas, the S&P 500 stock index and count of active drilling rigs. In addition, the degree of business diversification and firm size, as measured by revenue, are also considered in the estimation model. These hypotheses were empirically tested using data for three commercial helicopter firms over the period 2013-2018. The analyses allow shareholders, practitioners, researchers and other stakeholders to objectively discern the relationship between the external environment and commercial helicopter firms' stock returns.

Discussion

The prevalent price of crude oil exhibits explanatory power of commercial helicopter firms' stock returns. Historical studies, such as Calvert (1991) and Walls (1994), showed that energy service firms are susceptible to offshore activity decline and subsequent investment decline. These relationships are consistent with the findings of the current study. More recently, Kang et al. (2017) found that integrated energy firms mitigated negative impacts of depressed commodity prices via diversification, upstream, midstream and downstream. Due to the historic and projected volatile nature of crude oil prices, internal strategies at helicopter operators may warrant review and revision. For example, various forms of diversification, such as horizontal, vertical, concentric, conglomerate, defensive and offensive, may assist in minimizing the impacts of commodity price downturns. Similarly, firms may strategize to realize a competitive advantage when prices are favorable and increasing. The extant literature showed that integrated energy firms have successfully mitigated shareholder impact during commodity price downturns via diversification. Also, financing, investing and operational activities may warrant review and revision. Firms' balance sheets influence the ability to execute obligatory payments to creditors. There are numerous strategies employed when operating in a dynamic environment. One implication of the current study is that it enables requisite insight for firms' review of their internal strategies. Notably, the relationships revealed in the current study, although statistically significant and material, reveal, too, that there exist other factors in addition to the commonly known forces explaining the variation of stock returns. In other words, the findings suggest that during the study period, the external environment was not the sole determinant impacting stock returns of commercial helicopter firms. Although the findings are consistent with those studies measuring commodity prices' impact on energy firms, integrated energy firms are relatively less reliant due to diversification. Therefore, an evaluation of internal factors, such as financial ratios, asset leasing policies, contract terms with customers and vendors and diversification strategies may be useful for a more holistic understanding of this segment of the aviation industry. In the current study, a diversification index was developed for the commercial helicopter firms. However, firms' annual reports and industry presentations lacked a granular explanation of overall diversification, which may have led to the statisically insignificant parameter coefficient. Future research may benefit from a more refined diversification measure and, specifically, yield economic insight related to the efficacy of firms' diversification strategies.

Conclusions

In order to determine the contributing factors related to firms' stock returns, empirical analyses were required, and conducted in this paper. Using a unique data set from 2013-2018, the current research identified structural relationships between crude oil prices, natural gas prices, the rotary rig count, a subset of the overall market and stock returns of commercial helicopter operators, which is a unique addition to the extant literature and provides researchers and practitioners foundational knowledge for future research inquiries and operational and investment decision making, respectively. The results show that the prevalent price of crude oil influences commercial helicopter operators' stock returns and, too, that other factors contribute to firms' stock performance. Practitioners may utilize these results to explore strategies to maximize shareholder return in the future whereas researchers may seek to identify additional contributing factors affecting commercial helicopter operators' stock returns.

Recommendations

Although this study effectively fills the gap identified within the literature, it has a few limitations including the utilization of monthly data, absence of non-public commercial helicopter firms' data and targeted focus of the external environment. First, utilization of monthly data does not fully capture the daily fluctuation of commodity prices and stock returns. Although monthly data effectively capture relationships aligned with the current study's hypotheses, utilization of daily data may provide enhanced insight through more granular observations. Second, although the three helicopter firms included in the current study represented a significant portion of the activity among operators, the inclusion of all commercial helicopter operators is ideal. Lastly, this study mainly focused on external factors and, consequently, does not fully evaluate internal factors related to the operational and financial aspects of helicopter firms. To provide a truly holistic evaluation of the determinants for commercial helicopter firms' stock returns, future research endeavors may include both internal and external factors such as the price of crude oil and the S&P 500 index. Future research endeavors should include firm-specific variables representing the operational characteristics, management style, business strategy and other internal characteristics of commercial helicopter operators for a more comprehensive empirical model estimation. Also, the sample size should be further expanded if possible. Although this study possesses limitations, the contribution is invaluable for shareholders, managers, analysts and researchers. The identified absence of literature associated with this segment of the aviation industry indicates that opportunities for future research remain rich.

CHAPTER XI

COMPREHENSIVE DISCUSSION, CONCLUSION, AND IMPLICATIONS

The global energy industry transports supplies and personnel via helicopter to offshore locations and has been increasingly focusing on optimizing upstream logistics. Collectively, the abovementioned studies included in this manuscript provide rigorous, quantitative analyses of topics unrepresented within the extant literature, which are foundational for future practice and research. Specifically, new knowledge regarding a practical approach to model development and solution deliverance for the transportation of offshore workers to their respective locations has been appropriately developed and factors influencing commercial helicopter operators' stock are empirically evaluated.

Comprehensive Discussion

Using a unique sample of deepwater and ultra-deepwater permanent offshore locations in the Gulf of Mexico, transportation networks consisting of 58 locations operated by 19 firms were optimized via a randomized greedy algorithm. Through developing an optimization model and solving it effectively for the complex transportation problem, the simulation results of the model show the potential advantages of alternative clustered and integrated network structures. The evaluation of clustered and integrated network structures, which allow ride sharing via energy firm cooperation, provides evidence that such network structures may yield cost reductions for participating firms. Notably, the results are mixed and alternative network structures increase costs in many scenarios. The mixed results are potentially resultant from the inherent size of the networks encompassing ride sharing among firms. Also, the dispersion of locations across the Gulf of Mexico's vast geographic region may explain the mixed results.

Future research, using a representative network and fleet structure as provided in this study, may benefit from alternative cluster schema and solution techniques. Specifically, within the OR literature, alternative methods such as genetic algorithms, ant colony optimization, particle swarm optimization, simulated annealing, tabu search and other evolutionary algorithms have been utilized for various optimization problems. Future research may benefit from these alternative solution techniques or combinations of these techniques. Also, precise demand measurement, in lieu of estimating demand via random number generation, will enable superior applicability in practice. The demand estimation technique, which is based on the quantity of beds from 38.5% of sites included in the study, does not precisely reflect demand and, therefore, does not perfectly reflect locations' demand and may not be comparable to results realized in practice. Lastly, the solution may benefit from greater computing capability. As computers become more capable, larger and more complex transportation networks may be effectively evaluated more efficiently. In essence, as the networks become large, such as the clustered and integrated networks in the current study, supercomputing will allow more iterations in the same or less time.

The extent to which commercial helicopter operators' stock returns are related to commodity prices and other relevant industry variables is absent in the extant literature. Often, firms attribute favorable results to internal factors whereas unfavorable results are attributed to external factors. Unlike findings related to airlines and similar transportation firms, which have found a negative relationship with crude oil prices due to subsequent fuel price increases, helicopter firms exhibit a positive relationship with crude oil prices. Although helicopters, too, realize increased fuel prices resultant from commodity price increases, the favorable demand impact offsets this phenomenon. Therefore, the empirical evaluation of the net effect of crude oil prices on commercial helicopter firms' stock returns is worthwhile and beneficial to researchers and practitioners. Using a unique data set from 2013-2018, the current research identifies structural relationships between crude oil prices, natural gas prices, the rotary rig count, a subset of the overall market, firms' degree of diversification and stock returns of commercial helicopter operators. Empirical analyses show that the prevalent price of crude oil and the overall market environment possess explanatory power of commercial helicopter firms' stock returns, ceteris paribus. Specifically, 10% increases in the crude oil price and the S&P 500 index yield a 2.7% and 8.0% increase in stock returns, respectively.

Collectively, these studies provide a holistic understanding of the commercial helicopter market in the Gulf of Mexico and potential sources of increased efficiency and financial performance. Specifically, the optimization of transporting passengers to their respective work locations and identification of the potential for commercial partnerships to further optimize networks in the industry is novel and of practical significance.

Comprehensive Conclusion

The design and employment of the randomized greedy algorithm achieves efficient results for firm-level networks while identifying the potential advantages of alternative network structures. The decision-making processes evaluated include complexity commonly found in practice but lacking in previous studies. With a more holistic and realistic representation of the problem, the findings from this paper will help practitioners gain a practical approach to model development and solution deliverance.

The empirical analysis identified structural relationships between crude oil prices, natural gas prices, the rotary rig count, a subset of the overall market and stock returns of commercial helicopter operators, which is a unique addition to the extant literature and provides researchers and practitioners foundational knowledge for future research inquiries and operational and investment decision making, respectively. The results show that the prevalent price of crude oil influences commercial helicopter operators' stock returns and, too, that other factors contribute to firms' stock performance. Practitioners may utilize these results to explore strategies to maximize shareholder return in the future whereas researchers may seek to identify additional contributing factors affecting commercial helicopter operators' stock returns.

Comprehensive Implications

The efficient use of firms' contracted helicopters can enhance profitability via reduced costs without compromising operational performance. Reduced costs are likely to be realized by a potential workforce or workload reduction, reduced flight hours and enhanced bargaining power with commercial helicopter operators. Specifically, enhanced bargaining power may be realized as a result of minimized depots from which the aircraft are operated and an overall reduction of aircraft via increased asset utilization. In essence, the efficient use of commercial helicopters may yield systemic efficiencies that can be shared among all stakeholders, contracting energy firms and commercial helicopter operators. The empirical results obtained from the regression analysis show that the prevalent price of crude oil influences commercial helicopter operators' stock returns and, too, that other factors contribute to firms' stock performance. Practitioners may utilize these results to explore strategies such as ride-sharing and fleet pooling to maximize shareholder return in the future. Additionally, the findings suggest that a greater degree of business diversification may be warranted as the hydrocarbon industry may be progressively declining due to environmental concerns and renewable energy sources.

The studies, comprehensively, contribute to the extant literature by providing a model which accurately reflects the complexities in the commercial helicopter industry and identifying relationships among key industry variables and stock returns of commercial helicopter operators. Future research may aim to discover additional solution techniques to evaluate large alternative network structures and other phenomena impacting stock returns of commercial helicopter operators. These studies provide a foundation for such analyses in future research endeavors.

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