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Original Article

Supply Chain Reliability in the Integrated Oil & Gas Industry Post Covid-19: Applying the Supply Chain Reliability Ratio

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Abstract: *The integrated oil and gas industry has historically had a unique supply chain. The nature of producing these commodities has presented oil executives with challenges related to transporting the finished goods to consumers, making the reliability of their supply chains essential in driving profits. The COVID-19 pandemic has exacerbated these challenges in conjunction with worldwide supply chain difficulties. Supply chain reliability has thus become an essential driver of business success and possibly survival. This investigation measures the reliability of the supply chains of the 15 largest companies in the integrated oil and gas industry for the period of 2000-2020. To achieve this, the supply chain reliability ratio (SCRe) is developed, and a reliability score is given to each company to facilitate comparisons across time. Regression results, with a predictive value of supply chain reliability p< .05, suggest an association between the SCRe ratio and supply chain reliability. In addition, all examined companies suffered supply chain reliability disruptions during COVID-19. However, government entities fared better than publicly owned corporations, which suggests that corporate ownership, operational efficiencies, and exogenous event have an impact on supply chain reliability, a finding that aligns with current literature.*

Keywords*: Supply Chain Reliability, COVID-19, Integrated Oil & Gas, Organizational Reliability*.

I. INTRODUCTION

The oil and gas industry is one of the world's foremost economic drivers since its products are the foundation of other vital industries. The volatility of oil and gas, along with fluctuating technology, market structures, and consumer needs, all contribute to a highly competitive industry that relies on minimizing costs and maximizing the efficiency of finished products to boost profits. This structure makes optimizing supply chain efficiencies indispensable for oil and gas companies.

The supply chain of an oil and gas company consists of many facets, which include transportation, logistics, inventory management, internal controls, and information technology, among others. The supply chain in the oil and gas industry is composed of five elements: (a) consumer – the end user; (b) exploration – geological/geophysical operations; (c) marketing – retail sale of the product; (d) production – drilling, facilities, etc.; and (e) refining – conversion of the commodity to the final product.

Historically, oil and gas companies have had difficulties managing the efficiency of their supply chains, with factors like crude oil supply, lead times, and transportation costs being the most arduous (Wang et al., 2022). One of the earliest industry-wide techniques adopted by oil and gas companies was a collaboration agreement that resulted in shared solutions to some of the industry's biggest challenges. This aggregate integration of resources allowed increased management involvement in logistics decisions, resulting in increased efficiencies throughout the supply chain.

The literature suggests the most pressing supply chain constraint in the oil and gas industry is delivering finalized products to the consumer at the minimum cost possible. The COVID-19 pandemic has revealed deficiencies in global supply chains across several industries. The oil and gas industry has been no different, with demand shortages at the beginning of the pandemic followed by excess supply as vaccination rates increased.

The Supply Chain Operations Reference (SCOR) model provides a method to assess different aspects of the supply chain. One of the factors the SCOR model examines is reliability as a contributor to overall supply chain efficiency. Processes in the supply chain of oil and gas companies are trite, requiring greater resources when compared to other industries, making reliability on these supply chains essential to the end product. These inherent features make achieving supply chain economies of scale consequential for competitive advantage. If supply chain processes could be made more reliable, their efficiency would also increase, resulting in lean production (e.g., fewer raw materials, rework, quality inspections, and other non-essential activities) and, therefore, greater profits.

II. LITERATURE REVIEW

In the oil and gas industry, supply chain problems are nothing new. The complexity of the supply chain, coupled with external factors, has bogged down the oil industry in gaining efficient management of the supply chain, despite the attention given by researchers and practitioners. For example, Wang et al. (2022) wrote that an effective and efficient supply chain is critical in the supply of raw materials, production, and costs. In other words, the supply chain is the key to probability for the industry and lower consumer costs. Though the oil industry has great challenges externally (and internally), there is plenty of room for improvements to the supply chain that would result in cost savings. As indicated by Wang et al. (2022), one of these solutions has occurred through collaboration and outsourcing to develop shared resources among competitors to reduce supply chain challenges, which is a collaboration that can offer cost reductions and additional business opportunities.

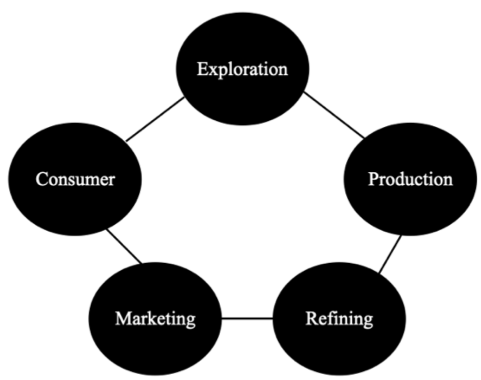
A) Research on the Oil and Gas Industry

Wang et al. (2022) and Urciuoli et al. (2014) indicated that there are ways to seek significant improvements to the oil industry's supply chain problem. Uriciulo et al.'s (2014) article showed that improving logistics in the supply chain significantly improved domestic and international efficiency. Improvements to ordering and inventory visibility controls, material handling and information technology have made gains to the efficiency of the supply chain, which offers managers an opportunity to implement proven supply chain management processes.

Wan Ahmed, De Brito, and Tavassey (2016) indicated that the oil and gas industry is a complex industry made up of operators, contractors, and suppliers. The industry's supplies are transported daily across continents using a variety of transportation modes (truck, ship, barge, rail, etc). Ahmad, de Brito, Rezaei and Tavasszy (2017) indicated that the oil and gas supply chain has a civil responsibility in how companies manage resources and deliver products. Ahmed et al. point to the supply chain as a crucial issue with the increase in demand in the industry and the impact of increasing consumption of a finite resource. Therefore, understanding the importance of the supply chain and making choices that increase efficiencies are part of the sustainable practices of the operators, contractors and suppliers that make up the industry.

In the oil and gas industry, an industry that is very dependent on small-to-medium enterprises that provide services and technology throughout the supply chain, the efficiency and effectiveness in which they operate have a ripple effect on the entire industry (Yusuf, Gunasekaran, Musa, Dauda, El-Berishy & Cang, 2014). An important concept in the oil and gas industry is the idea of agility and how the interactions between the entire industry play into the efficiency of the entire industry. As stated by Yusuf et al. (2014), up to 40% of oil and gas activities are outsourced, underscoring the need for greater agility and efficient practices among all the industry's suppliers. Piya, Shamsuzzoha, and Khadem (2022) indicated that collaboration, trust, agility, and robustness are essential drivers of success in the supply chain practices of oil and gas. In this way, the industry must collaborate to increase supply chain effectiveness.

Figure 1: Oil & Gas Supply Chain Links



***Source**: Authors*, Conceptual map of oil and gas supply chain links.

Figure 1 shows the current oil and gas supply-chain links. The oil and gas industry has an extremely complex supply chain that requires a bevvy of vendors and constituents to supply the industry. The complexity of the oil and gas supply chain can be seen through the different complex operations of the industry. Oil and gas refining is an extremely complex organization with different moving parts, including marketing the product by selling refined products. In the refinement process, each part of the process could be managed by a different company or part of the firm. This leads to a significant challenge in understanding the economic impact and costs that occur in the supply chain. In this way, the oil and gas industry is uniquely positioned to maximize supply-chain efficiencies.

The oil and gas industry has a variety of different types of shipments. For example, shipments can range from gloves to steel, pipes, valves, cement, cranes, chemicals, and drilling rigs, just to mention a few. This leads to a complex supply chain as supplies are moved frequently in large qualities both domestically and globally. Furthermore, oil and gas operate both onshore but have several large-scale offshoring operations as well, which adds to the complexity.

One point of note is that there is repetitive work and activities in exploration and production. This is due to the nature of the work with oil companies drilling a plethora of oil and gas wells each year. A drilling contractor may outsource up to 45 different services in the drilling and completion of the well. This is significant given the advanced planning that goes into the drilling of each well. Advanced planning does give the opportunity for efficiencies in the process, which could increase value. A major component of this is managing the supply chain and providing high levels of customer service at a reduced cost. The links in the industry supply chain come from how operations are a value-creating proposition via seismic analysis and prospect identification. In essence, the production process is the customer by ultimately using the exploration output whilst refining depends on production, marketing depends on refining, and gasoline depends on all, serving as the customer.

The supply chain needs to be precise because of the industry's uncertainty. Problems with supply due to regulations, wars, pandemics, and other factors mean that the industry needs to be agile, provide customers' exact materials, insulate itself as much as possible from extant factors, and prepare for supply chain uncertainty. Oil and gas companies can increase profit margins through the careful management of their purchasing dollars throughout the entire supply chain. Cooperation would greatly increase the profit margin of everyone in the supply chain in the oil and gas industry to address the threats that significantly impact the entire industry. Stated another way, cooperation between the different supply chain members could have a significant payout with profits and customer satisfaction. All competing firms in the exploration and production sectors have the same product with very narrow differentiation. This has caused difficulty in product differentiation. Therefore, companies must differentiate based on efficiencies and the ability to employ sound supply-chain management practices.

Research on organizational and supply chain reliability in the oil and gas industry is scant, making this study particularly relevant. Griffin, Hodkiewicz, Dunster, Kanse et al. (2014) indicated that the oil and gas company operates under a high-reliability framework and central to that framework is learning, change and adaptation. This is particularly germane when investigating supply chain efficiencies and reliability in the oil and gas industry. The idea of learning, change and adaptation will help increase the connections between the different elements in the supply chain and increase both reliability and profitability for everyone involved in the supply chain.

There have been a few studies on supply chain reliability within the energy sector whose findings are relevant to this study. For instance, Faertes et al. (2010) developed software to model supply chain reliability at PetroBras, the Brazilian oil and gas company. The model assessed the supply chain reliability and network design in transporting oil from the Northeast to the Southeast regions of Brazil. Among the supply chain components assessed were city gates, compressor stations, gas processing units, and pipelines.

The model needed inordinate amounts of information on the supply chain to estimate reliability. Information needed for the software included commodity prices, demand profiles, design configurations, penalties, pressure delivery conditions, shedding priority, and supply contracts. The authors also included in their modeling different gas sources such as boats, offshore platforms, onshore fields, and pipelines, along with company contingency plans for any expected disruptions.

The authors modeled 12 processing plants and compared results across PetroBras. Model results show the developed software is a powerful tool for planning and optimizing the PetroBras supply chain, greatly increasing the reliability. However, the authors note the costs associated with developing the software and the resources needed to acquire the inputs for the model to run effectively were prohibitive. In addition, the complexity of the software was too high, and the inputs were too restrictive for any practical use outside of the 12 processing plants.

In another study on supply chain reliability in the oil and gas industry, Hidayat and Akhman (2016) evaluated oil fuel distribution systems. To assess supply chain reliability, the authors examined multiple systems attributes, including average annual outage time, average outage duration, and failure frequencies. The authors developed a simulation tailored to the specific supply chain and found the software was able to accurately visualize the oil distribution system and foresee potential supply chain disruptions. Thereby meeting consumer demand more accurately and increasing the supply chain's overall reliability. The authors noted the simulation was too specific for any applications beyond the scope of the current supply chain.

Bento, Garotti and Mercado (2021) investigated organizational resilience in the oil and gas industry and attempted to provide a scope for the problem. They found that there is a lack of research on the processes of organizational resilience. Furthermore, the research does not really address the adaptive nature of organizational resilience or its relation to the oil and gas industry's supply chain.

One important note is that the concept of organizational resilience within the oil and gas industry must focus on safety within the industry and supply chain. Bento et al. called safety a central topic in addition to the concepts of learning and emergence. This has ties to complexity research which relies on informal and formal networks to enact organizational change. Within the supply chain of the oil and gas industry, adaptability, safety, and organizational learning can lead to organizational resilience and ultimately impact the profitability of the organization (Bento et al., 2021). Therefore, a study of supply chain reliability within the oil and gas industry is important.

B) Research on Supply Chain Reliability

Reliability is an essential characteristic of a well-functioning and stable supply chain. There have been several studies on the topic of supply chain reliability. However, past studies have focused on specific issues regarding supply chain structure making it difficult to apply the findings to general supply chain reliability problems (Lukinskiy et al., 2014; Klimov & Merkuryev, 2008). Empirical evidence on supply chain reliability has been gathered from the disaster management, financial, information management, pharmaceuticals, construction, manufacturing, and energy sectors, including the oil and gas industry, which will be the focus of this study (Diabat & Khosrojerdu, 2019; Ha et al., 2018).

The literature is ripe with methods to manage supply chain risk, yet a universal solution for addressing reliability issues persists. Several research gaps on supply chain reliability remain, among them the development of indicators, measurement models, economic valuation, and even a basic definition of the role of reliability in a supply chain. Models that have been developed have run into the same problem as past research findings on supply chain reliability. They are either too specific or complicated to have any real-world applications (Lukinskiy et al., 2014; Klimov & Merkuryev, 2008).

The lean manufacturing philosophy has been the guiding principle of supply chain policies. Lean manufacturing centers on the synchronization of shipments within the supply chain, which makes reliability an essential component of business success (Van Nieuwenhuyse & Vandaele, 2006). In practice, this synchronization has become elusive as many companies aspire to achieve lean manufacturing, but few are successful. The literature suggests that lax supply chain reliability and poor cooperation among supply chain participants may be the culprit (Zaitsev, 2012). Measurable insight into supply chain activities is therefore important in supply planning to include reliability issues. This investigation looks to add to the existing literature by developing a simple ratio that measures supply chain reliability, giving decision-makers a tool to assess an important aspect of their supply chain during the planning phase.

Zhang and Ren (2013) studied the structure of Chinese state-owned petroleum enterprises and their ability to manage emergencies. The authors note that these corporations' unique organizational and supply chain structures make them responsible for maximizing profits and providing an essential public good that society relies on. These responsibilities place a high burden on the supply chain's reliability. The authors developed a reliability model and index for the companies' supply chains. The authors note that the model cannot accurately determine the supply chain's reliability but that a change in model variables may improve the simulations' predictive power.

There has been one study on the reliability of supply chains using the SCOR model as a reference point. Athikulrat et al. (2019) used the SCOR model to determine any failure points in the supply chain of crude palm oil mills. The authors developed a reliability index based on fault tree analysis and analytical hierarchy processes. The study's findings show the indexes' predictive power was low, and the calculations used to determine supply chain reliability were serial. The authors theorize that more suitable indicators to measure SCOR performance need to be found.

Two studies have been conducted on the reliability of supply chains in High-Reliability Organizations (HROs). McBride (2021) looked at how using high-reliability principles in HROs may have contributed to improved food safety systems in the food industry. The author gathered data from 153 management personnel in a 46-item survey. Investigations results showed that commitment to resilience and managerial expertise had a positive impact on the supply chain's reliability. Sawyerr and Harrison (2020) conducted a comparative study between the elements of supply chain resilience and the characteristics of HROs. The study's findings show that many elements of a resilient organization (e.g., flexible decision-making) are present in the HRO structure, except for strong management commitment.

A study on supply chain reliability in the pharmaceutical industry by Tucker and Daskin (2021) showed metrics that can aid in improving reliability. The authors developed a supply chain reliability model for a pharmaceutical company. The authors examined three criteria they deemed important for reliability: configuration, disruption risk, and recovery times. Issues the authors considered included shortages and times. Study findings suggest effectively managing resources like shortages and times may lead to improved supply chain reliability. The authors also note that focusing on redundancy benefits and facility qualities may also reliability.

Korepin et al. (2021) evaluated supply chain reliability improvements via the use of blockchain technology. The authors developed a mechanism to mine the results. Study findings show that management prefers high levels of traceability and visibility of products along the supply chain. In addition, using blockchain for supply chain analysis correlates with improved collaboration among networks, efficient data flows, more transparency, and accountability. However, the authors warn against blockchain technology's potential legal and political risks.

Two studies have been conducted on supply chain reliability for the manufacturing and construction industries. The first was from Dai et al. (2021). The authors used game theory to assess traceability and product reliability within the supply chain and how different pricing strategies impacted product demand. The authors examined two competing manufacturers and developed tailored models to optimize product traceability. The authors also looked at how each product performed within their assigned retailers. Investigation results show a correlation between supply chain reliability, product traceability, and investment cost. Another finding is that product traceability tends to benefit the manufacturer as product recall diminishes. Finally, the authors note an association between increased profits and product traceability.

The second study was done by Zhang et al. (2020) on building information modeling (BIM) and lean supply chains (LSC). The authors developed a process to evaluate supply chain reliability among integrated construction systems. 316 practitioners with BIM and LSC experience completed an exploratory survey, which showed that the system developed by the authors can predict the degree of supply chain reliability. Findings also show that due to the complexity of construction undertakings (i.e., high levels of labor, resources, and technology), the process used for the study may be difficult to apply to other industries.

Disaster management is also an area in which a few studies on supply chain reliability have been conducted. Dianat and Khosrojerdu (2019) developed a supply chain optimization model for various disaster scenarios. The authors' model looked to reduce delivery time and costs after disaster events. Study results suggest that forecasting disruptions under different scenarios, developing sound reaction plans, and effectively managing the budget and positive correlation to supply chain reliability during disastrous events. Zang et al. (2019) created a mathematical optimization model to measure the reliability of humanitarian relief supply chains. The authors note that effective time and cost management are essential for effective disaster relief supply chains. Study findings also suggest that sound coordination among product flows and unit reliability optimize the overall supply chain.

Several other investigations have been undertaken that examine the optimal use of supply chains along with the role of planning in developing supply chain reliability and performance. For instance, Islam et al. (2020) assessed inventory levels among demand uncertainty and the impact of supply chain reliability. The authors looked at production system output with a specific quantity, reliability factor, reorder point, retailer, and supplier. The authors incorporated supplier uncertainty into their analysis, considering small disruptions along the supply chain. The findings suggest that increased supply chain reliability is dependent on the optimal mix of the production system variables.

Ozkan and Kilic (2019) developed a Monte Carlo simulation to evaluate the reliability of six logistics and supply chain networks within the defense industry. The investigation results reveal a correlation between the Monte Carlo simulation estimate and the real distribution times. Chen and Jing (2017) created a process to assess supply chain reliability for varying levels of data availability post-disruptions. The process considers demand, externalities, organizational structure, and supply. Study findings indicate buyer-supplier relationships, along with the assessed variables, are associated with effective supply chain reliability.

Kamalahmadi and Mellat-Parast (2016) looked at the risks of optimal demand allocation among suppliers within the supply chain. The authors developed a program that would aid in increasing supply chain reliability during disruptions. The program also uses existing contingency plans, network costs, and supplier and transportation selection to assess the supply chain. Investigation results show that having relevant contingency plans in place prior to disruptions mitigates negative effects on the supply chain's reliability.

Artsiomchyk and Zhivitskaya (2016), in their study on multi-state system reliability structures, found that sound supply chain reliability is associated with evaluating reliability levels, system failure considerations, and design analysis during the planning phase. Lin et al. (2014) examined the reliability of a supply chain to deliver goods under the following conditions budget considerations, delivery damage, and limited production capacity. The authors found that delivery damage may have the biggest impact on the reliability of the logistics network.

Tang and Gupta (2014) evaluated the optimal mix of the buyer-supplier relationship by developing two mathematical models. The authors named the models: all-or-nothing and partial disruption. These models looked at the parameters for determining buyer demand and supplier yield during supply chain disruptions. All-or-nothing model results suggest buyers prefer accuracy on order quantities, whilst partial disruption model findings reveal buyers prefer a single supplier regardless of disruption risk.

Soni and Kodali (2012) assessed the reliability of lean and agile supply chains. The authors developed two pillars: common and specific. They examined commonalities and differences in lean supply chains. The study's findings suggest more commonalities in reliable lean supply chains, whilst specifics tended to decrease reliability. Zaitsez (2012) developed a mathematical model to determine optimal supply plans. The author used economic criteria and probability analysis to determine supply chain reliability. Model results showed network systems can have increased supply chain reliability by outsourcing many business processes.

Taghizadeh and Hafezi (2012) explored criteria that decrease the reliability of supply chains. The authors determined the following have an impact: delivery, document, material, quantity, and payment errors, damage and defects on purchase orders, timeliness of orders and warranties, and amount of order returns. Finally, Snyder (2003), in one of the first studies into supply chain reliability, looked at the impact of fluctuating costs. The authors used a Lagrangian model to assess the different cost structures. Investigation results reveal small supply chain investments have an exponential benefit on the entirety of the supply chain's reliability.

This study aims to develop a simple model measuring supply chain reliability and then evaluate it from an operational efficiency lens. The model is based on the efficiency formula from physics and is an extension of the Supply Chain Efficiency (SCE) Ratio from Forehand et al. (2021). Research gaps exist in methods that measure supply chain reliability (Chen & Lui, 2021; Yao & Fabbe-Costes, 2018). This study aims to contribute to the literature by developing a supply chain reliability indicator that will provide insights into the supply chain efficiency of integrated oil and gas companies for external analysts.

III. METHOD

The supply chain efficiency (SCE) ratio first presented by Forehand et al. (2021) was the first attempt to use publicly available information to develop a model that assesses supply chain performance. However, the model lacks ties to supply chain theory. In this investigation, we attempt to improve this shortcoming by recalibrating the SCE Ratio and linking it to the Supply Chain Operations Reference (SCOR) metrics. The Supply Chain Operations Reference (SCOR) metrics were developed in 1996 by the PRTM management consulting firm and later adopted by the Supply-Chain Council and the Association for Supply Chain Management (APICS) to identify supply chain indicators of importance to all businesses. The SCOR model has become the standard for evaluating efficiency in supply chain processes, including supply chain reliability. Given the importance of SCOR metrics in supply chain literature, this investigation aims to extend Forehand's et al. (2021) analyses and develop an SCRe ratio based on the SCOR metrics.

This new ratio will also contribute to the supply chain literature by providing a model to measure supply chain activity for external users of an organization. The SCOR metrics, whilst theoretically robust, have the design flaw that internal analysts are the end users. Several of the data points used to measure supply chain reliability, as noted by the SCOR, are confidential and therefore out of reach to external users like investors, regulators, and academics, among others. The data sources used in this article to develop the SCRe ratio are based on public information found in annual reports. This investigation will link accounts that measure supply chain reliability to the financial statement.

SCOR metrics derive from the following indicators: asset management, costs, flexibility, reliability, and responsiveness. Reliability (i.e., the metric used in this investigation) is linked to externalities in the supply chain via the following accounts: inventory, operational expenses, operational income, property, plant & equipment (PP&E), revenue/sales, and unearned revenue. The Supply Chain Reliability variables can be organized into the following function:

***f* = (Revenue/Sales, Operating Expenses, Operating Income, Inventory, PP&E, Unearned Revenue)**

Guided by the SCOR Level 1 Metric for reliability along with the research of Forehand et al. (2021), we determine the variables representing the process output (i.e., operating margin ratio) and the process inputs (i.e., unearned revenue, inventory, PP&E). The results of the SCRe ratio will also provide insight into the level of organizational reliability. Table 1 below details the SCRe formula with additional details.

Table 1: Supply Chain Operations Reference (SCOR) Flexibility Metrics

Attribute	Performance Attribute Definition	Level 1 Metric	Chart of Accounts	Ratio	Financial Statement
Supply Chain Reliability	The performance of the supply chain in delivering the correct product, to the correct place and customer, at the correct time, in the correct condition and packaging, and with the correct quantity and documentation.	Delivery Performance Fill Rates	Sales/Revenue	Operating Margin Ratio / (Unearned Revenue / (Inventory + PP&E))	Income Statement
		Product Order Fulfillment	Operational Expenses Operational Income Inventory Property, Plant, & Equipment Unearned Revenue		Balance Sheet

Source: *Supply Chain Council (2017).*

Figure 2 presents the conceptual map of the SCRe ratio, which includes the variables that make up the model, their relationship, and the estimate that the model generates.

Figure 2: SCRe Ratio

Source: *Authors Research Model*, Conceptual map of the SCRe Ratio

The SCRe ratio is interpreted in the same manner as the SCE Ratio. The higher the ratio result, the more reliable the organization's supply chain. A high SCRe figure suggests the organization can be counted on to deliver their product correctly and on time.

This investigation aims to extend the model developed by Forehand et al. (2021) that measures supply chain efficiency. The Supply Chain Reliability (SCRe) ratio has its foundation in the efficiency formula and the Supply Chain Efficiency (SCE) Ratio from Forehand et al. (2021). The literature on supply chain reliability is scarce, especially studies aiming to quantify supply chain efficiencies by measuring reliability. This study is the first attempt to develop a simplified supply chain reliability ratio that will provide insights into the supply chain efficiencies of business in the integrated oil and gas industry.

The objective is this investigation is to develop the SCRe for the top 15 market cap companies in the oil and gas industry through the 2000–2020 time frame (Table 2). The 15 companies include a wide array of organizational structures, including public corporations, government-held entities, national companies, and multinational corporations. The variety of business organizations allows for cross-structure analysis. The SCRe ratio is based on changes to revenue/sales, operating expenses, operating income, inventory, PP&E, and unearned revenue. A secondary objective is to apply the SCRe ratio and assess any impact on supply chain reliability during the COVID-19 pandemic.

Table 2. Integrated Oil & Gas Companies

Company	Country	2020 Market Cap (U.S. $ Billions)
Exxon-Mobil Corporation	U.S.	$310.19
Chevron Corporation	U.S.	$247.61
Royal Dutch Shell PLC	Netherlands	$190.03
Total Energies SE	France	$148.71
PetroChina Company Ltd.	China	$148.29
Best Petroleum PLC	U.K.	$103.23
Equinor ASA	Norway	$92.69
Petróleo Brasileiro S.A. - PetroBras	Brazil	$82.51
China Petroleum & Chemical Corporation	China	$77.05
Eni SpA	Italy	$52.81
SunCor Energy Inc.	Canada	$41.20
Ecopetrol SA	Colombia	$29.91
Cenovus Energy Inc.	Canada	$29.70
Sasol Limited	South Africa	$12.96
National Fuel Gas Company	U.S.	$5.50

Source: *Yahoo! Finance (2022)*

A) Research Design

This investigation uses a quantitative non-experimental descriptive cross-sectional design. The quantitative design is appropriate because the investigation aims to collect available financial data from the 15 integrated oil and gas companies to analyze supply chain reliability. The ratio combines several independent variables that collect supply chain information. The variables in the model allow the researcher to assess the supply chain reliability based on previously published financial data. A cross-sectional non-experimental design is appropriate because the collected data is from a specific time frame (i.e., 2000-2020), and the observed phenomenon is preexistent (i.e., COVID-19). Finally, a descriptive method is applicable because the phenomenon is being analyzed in its natural state without manipulating any of the assessed variables in the SCRe model (Field, 2015).

This investigation looks to extend the work begun by Forehand et al. (2021) on measuring supply chain efficiency and continuing the underpinning of supply chain efficiency to the SCOR metrics by developing a supply chain reliability ratio. The goal is to assess if the SCRe ratio is a predictor of supply chain reliability. Combining several independent variables related to supply chain reliability is useful in conducting our analysis. The data points used to build the model are public and found on the financial statements. The accessibility of data allows for results testing and validation through various methods.

The annual reports from each company are used to gather the research data with MS Excel® 2010, and the SCRe ratio is used as the research instrument. Annual reports for the assessed years were gathered for all analyzed companies. Reports were accessed either on the company website or the EDGAR database. Data on revenue/sales, operating expenses, operating income, inventory, PP&E, and unearned revenue from each report for the years 2000 through 2020 (i.e., when available) were collected, tabulated, and placed into the SCRe model.

The simulation produces a "score" useful in comparative analysis, allowing cross-sector and cross-industry evaluations like those used in financial ratio analysis. The ratio result is scrutinized within selected categories to assess its significance. A multiple regression model was applied to determine the significance of each hypothesis since various predictors were used to determine a reliability score.

The regression model used the six financial indicators needed for the SCRe ratio along with established time intervals at .05 significance. The research instrument aims to assess the predictability of the independent variables throughout the 20-year time span. Minimal biases like participant biases or human error are accounted for since the data sources are public. The researchers maintained objectivity when managing the research instrument and its input data.

B) Research Questions

This investigation aims to develop a supply chain reliability ratio for the top 15 market cap companies in the oil and gas industry through the 2000–2020 time frame based on changes to revenue/sales, operating expenses, operating income, inventory, PP&E, and unearned revenue. A secondary objective is to apply the SCRe ratio and assess any impact on supply chain reliability during the COVID-19 pandemic. As such, the following research questions can be developed:

RQ1: What is the association between supply chain reliability and the SCRe ratio?
RQ2: Are there any outliers in supply chain reliability based on the SCRe ratios for the 2000–2020 time frame?

C) Research Hypothesis

The research questions on the association of supply chain reliability and the SCRe ratio, along with any outliers in the ratio within the 2000-2020 time period, engineer the following research hypothesis:

Null Hypothesis ($H1_o$): There is no statistically significant relationship between Supply Chain Reliability and the SCRe ratio.

Null Hypothesis ($H2_o$): There are no statistically significant outliers identified by the SCRe ratio for the 2000-2020 time frame.

This study makes a novel contribution to the body of knowledge on supply chain reliability by being the first attempt at developing a simple performance ratio for the integrated oil and gas industry, examining any potential impact COVID-19 disruptions had on the supply chain reliability of integrated oil and gas companies, and whose results are tailored for the user outside of the organization.

IV. RESULTS

The first hypothesis examined is the presence of a statistically significant association between supply chain reliability and the SCRe ratio. A multiple regression model based on the SCRe ratio was used to test the hypothesis. Model results suggest the ratio is an adequate predictor of supply chain reliability in the integrated oil and gas industry. Hypothesis testing indicates a p-value of less than 0.05 for the SCRe ratio suggesting the statistical significance of the results and the rejection of the first null hypothesis.

The investigation then examined if statistically significant outliers could be identified using the SCRe ratio for the 2000-2020 period. Model results suggest a statistically significant link among the SCRe ratio variables for the examined time frame. Hypothesis test results show a p-value of less than 0.05, suggesting a rejection of the second null hypothesis.

Table 3. Regression Results for the Investigation's Hypotheses

	Variables	Coefficients	t Stat	P-value	F-value	R Square	H1	H2
BP	Operating Margin Ratio	51.3219098	36.8894495	2.05444E-18	686.7312	0.9871	Null hypothesis is rejected.	Null hypothesis is rejected.
	Unearned Revenue/ Inv+PP&E	-206.7878	-10.196521	6.61401E-09				
Cenovus	Operating Margin Ratio	172.68396	16.4489177	5.05225E-08	158.3986	0.9724	Null hypothesis is rejected.	Null hypothesis is rejected.
	Unearned Revenue/ Inv+PP&E	1086.38563	1.68262443	0.001267403				
Chevron	Operating Margin Ratio	7.97290917	38.2780348	1.06486E-18	753.0371	0.9882	Null hypothesis is rejected.	Null hypothesis is rejected.
	Unearned Revenue/ Inv+PP&E	-6.5488244	-13.009216	1.36085E-10				
China Petroluem	Operating Margin Ratio	-4398.5364	-0.2496373	0.008058593	2.8479	0.2510	Null hypothesis is rejected.	Null hypothesis is rejected.
	Unearned Revenue/ Inv+PP&E	-5219422.2	-2.1742809	0.04409597				
Ecopetrol	Operating Margin Ratio	3.77E+02	3.17282078	0.008873914	16.6703	0.7519	Null hypothesis is rejected.	Null hypothesis is rejected.
	Unearned Revenue/	-26415.845	-5.6307114	0.000153143				

	Inv+PP&E							
Eni SPA	Operating Margin Ratio	65.3101263	7.22564343	1.41823E-06	30.1733	0.7802	Null hypothesis is rejected.	Null hypothesis is rejected.
	Unearned Revenue/ Inv+PP&E	-215.45232	-5.7124456	2.54083E-05				
Equinor	Operating Margin Ratio	52.2262567	10.591151	3.66393E-09	56.2754	0.8621	Null hypothesis is rejected.	Null hypothesis is rejected.
	Unearned Revenue/ Inv+PP&E	-180.29033	-7.2322495	9.99641E-07				
Exxon Mobil	Operating Margin Ratio	34.5555064	14.6375003	1.93967E-11	140.5628	0.9398	Null hypothesis is rejected.	Null hypothesis is rejected.
	Unearned Revenue/ Inv+PP&E	-237.52295	-10.452911	4.49778E-09				
National	Operating Margin Ratio	40.2042069	34.5436217	6.59948E-18	614.6549	0.9856	Null hypothesis is rejected.	Null hypothesis is rejected..
	Unearned Revenue/ Inv+PP&E	-186.27039	-7.811457	3.43619E-07				
Petrobras	Operating Margin Ratio	74.5914888	16.6483923	2.22512E-12	139.9787	0.9396	Null hypothesis is rejected.	Null hypothesis is rejected.
	Unearned Revenue/ Inv+PP&E	-518.60535	-6.5583353	3.66625E-06				
PetroChina	Operating Margin Ratio	1826.84368	3.41913525	0.003059048	29.6212	0.7670	Null hypothesis is rejected.	Null hypothesis is rejected.
	Unearned Revenue/ Inv+PP&E	-801228.46	-5.1753079	6.36262E-05				
Royal Dutch Shell	Operating Margin Ratio	75.7945187	9.73960634	2.27613E-08	47.5822	0.8484	Null hypothesis is rejected.	Null hypothesis is rejected.
	Unearned Revenue/ Inv+PP&E	-140.23339	-5.6167731	3.08078E-05				
Sasol Lmtd.	Operating Margin Ratio	157.588552	22.6702894	1.37449E-13	257.3794	0.9699	Null hypothesis is rejected.	Null hypothesis is rejected..
	Unearned Revenue/ Inv+PP&E	-1717.1536	-8.4546928	2.68731E-07				
Suncor	Operating Margin Ratio	1308.99259	6.86514124	5.36733E-06	23.5897	0.7588	Null hypothesis is rejected.	Null hypothesis is rejected.
	Unearned Revenue/ Inv+PP&E	-28273.123	-3.743467	0.001956943				
.Total SE	Operating Margin Ratio	175.578838	15.3662891	8.60291E-12	194.8618	0.9559	Null hypothesis is rejected.	Null hypothesis is rejected.
	Unearned Revenue/	-1986.8373	-15.138598	1.10505E-11				

	Inv+PP&E							
YPF	Operating Margin Ratio	1515.03398	1.90018815	0.000745055	2.0099	0.1912	Null hypothesis is rejected.	Null hypothesis is rejected.
	Unearned Revenue/ Inv+PP&E	-3668.5536	-0.5015057	0.000622448				

Note: Results of the regression model.

V. DISCUSSION

The SCRe ratio suggests an association between supply chain reliability and model results (see Table 4). Variable correlations reveal the SCRe ratio can serve as an indicator of organizational supply chain reliability. Ratio results also suggest SCRe differences based on corporate ownership. For instance, in 2020, all publicly owned oil & gas corporations had negative SCRe ratios, indicating possible weaknesses in supply chain reliability, whilst all government-owned or national corporations maintained positive SCRe scores, suggesting a reliable supply chain. The findings align with research on public versus government-owned corporations, which suggests that although publicly-owned companies tend to be more efficient in resource use, government entities are more dependable (Chen, 2010).

Examining the individual results of each corporation, we find that over the 2000–2019 time span, only eight companies had negative SCRe ratios, with none having more than two years of negative ratios. These findings suggest that companies in the integrated oil & gas industry tend to have reliable supply chains. A possible result of the industry's focus on cost management and increasing process efficiencies.

A) Discussion of SCRe Results in the Integrated Oil & Gas Industry

In the examined period, several companies experienced negative SCRe ratios resulting from reasons as varied as inefficient cost structures, oil price fluctuations, and accidents. In 2015, BP had a $6.4 billion loss due to lower-than-expected oil prices and excess supply, which, paired with the company's commitment to pay out a $7.3 billion dividend to shareholders, resulted in a negative SCRe ratio. BP also had a negative SCRe ratio in 2010, which was the year in which their Deepwater Horizon oil drilling rig had a spill in the Gulf of Mexico. The resulting spill caused havoc on BP operations, including disruptions to their supply chain.

In 2018, Cenovus had a negative SCRe ratio, likely due to challenges in gaining access to international markets, which along with a fatal work-related accident in one of their manufacturing plants, led to a $2.7 billion loss, a significant reduction in share price, and disruptions in their supply chain. In 2016, the negative SCRe ratio was likely due to reductions in operating capacity and workforce to control costs due to lower-than-expected oil prices, which led to an overall reduced production capacity. These record low oil prices and similar cost-controlling efforts also resulted in Chevron having a negative SCRe ratio for the year.

Table 4: SCRe Ratios for Integrated Oil & Gas Companies

Year	*BP*	*Cenovus*	*Chevron*	*China Petro*	*Ecopetrol*	*Eni SPA*	*Equinor*	*Exxon Mobil*	*National*	*PetroBras*	*PetroChina*	*Shell*	*Sasol*	*Suncor*	*Total*	*YPF*	*Industry*
2020	-6.361	-53.481	-0.628	15.223	335.434	-3.763	-8.245	-5.128	0.844	15.188	39.417	-14.714	-95.334	-498.895	9.559	-1978.868	-140.610
2019	1.691	10.425	0.289	42.420	445.248	5.260	5.817	2.666	13.800	22.844	51.267	8.110	11.055	124.089	13.002	-331.722	26.641
2018	2.877	-35.418	1.096	90.493	426.097	5.906	10.746	4.356	13.913	12.425	40.464	9.147	17.515	215.074	10.657	578.110	87.716
2017	1.921	23.288	0.565	301.901	432.887	6.753	12.167	2.981	15.226	9.324	34.653	3.303	28.409	289.656	34.243	158.193	84.717
2016	-0.105	-6.395	-0.164	260.544	334.116	2.829	0.118	1.265	-10.842	4.627	36.943	0.870	31.295	4.320	35.195	-258.816	27.237
2015	-1.506	5.253	0.290	615.425	65.503	-2.105	1.309	2.872	-14.622	-1.007	43.042	0.330	48.589	-66.475	24.652	180.303	56.366
2014	0.865	6.999	1.186	3312.655	184.723	3.833	6.126	4.304	11.698	-4.849	70.110	3.888	20.385	119.532	20.872	74.908	239.827
2013	4.536	6.057	1.169	2304.343	229.690	3.579	10.454	4.381	10.467	11.425	68.220	4.680	19.167	43.433	20.463	46.157	174.264
2012	2.631	12.179	1.314	9528.803	221.866	3.877	5.528	4.625	8.224	10.910	66.724	6.156	19.733	28.103	12.000	39.838	623.282
2011	6.449	17.153	1.254	1620.114	252.145	7.750	4.082	4.790	6.581	11.622	187.499	2.271	14.863	123.208	11.008	26.895	143.605
2010	-0.687	11.584	0.893	3188.999	97.883	7.397	3.827	3.989	5.814	19.087	351.372	3.784	21.172	76.855	18.069	8.950	238.687
2009	4.992	14.757	0.633	449.455	72.219	5.025	6.436	2.655	2.468	15.250	483.338	2.556	19.978	34.717	11.044	8.406	70.871
2008	4.207	-	0.880	229.712	65.991	4.152	6.158	4.627	5.147	10.520	881.890	3.856	41.389	18.895	29.708	8.089	87.681
2007	6.371	-	0.817	602.837	49.261	5.868	3.427	4.377	5.229	10.380	1509.983	4.857	9.383	25.594	55.839	12.679	153.794
2006	4.040	-	1.017	354.191	-	26.109	5.644	5.541	6.479	18.138	1660.365	4.020	11.057	28.211	49.267	14.047	156.295
2005	4.465	-	0.820	344.878	-	12.241	9.879	5.235	7.026	17.235	1709.453	3.061	24.884	16.034	59.718	21.651	159.756
2004	5.935	-	0.790	290.945	-	3.277	10.974	4.904	8.093	11.591	665.360	2.117	9.060	54.071	19.967	22.867	79.282
2003	4.105	-	0.636	173.265	-	2.949	4.627	5.217	9.287	17.231	616.244	1.807	15.848	54.107	18.488	26.632	67.889
2002	3.621	-	0.441	165.440	-	2.452	3.537	3.512	7.924	4.517	621.438	1.539	17.836	-	16.316	13.489	66.312
2001	4.122	-	0.820	186.995	-	2.875	4.271	9.627	2.212	9.360	210.822	1.963	-	-	22.349	3.709	38.260
2000	6.832	-	1.287	-	-	-	9.384	9.758	3.773	20.779	276.952	-	-	-	13.910	8.555	39.026
Average	2.905	1.033	0.734	1203.932	229.504	5.313	5.536	4.122	5.654	11.743	458.360	2.680	15.068	38.363	24.111	-66.224	121.427

Source: *Author's computation, SCRe Ratio Results for Integrated Oil & Gas Companies*.

Eni SPA had a negative SCRe ratio in 2015. The downturn is likely a result of lower-than-expected oil prices, repayment of a large debt, and restructuring of their refining and marketing business. The reduction in oil prices and higher-than-average debt levels had a similar impact on National Fuel Gas Company's financial and SCRe ratios for 2015 and 2016. PetroBras' revenues were also affected by the volatile oil pricing in fiscal years 2014 and 2015. The company acknowledged that overreliance on oil pricing to generate adequate returns paired with substantial liabilities exposed its business to a weakened supply chain.

Suncor Energy also had a negative SCRe ratio in 2015 due to the reduction in oil prices and commitment to a previously announced increased dividend payment, which urged drastic cuts in operating and capital budgets. YPF's financial success, given it is a national corporation, depends on local economic conditions and oil price volatility. The company had a negative SCRe ratio in 2016 and 2019 due to local inflationary pressures, currency devaluations, and volatile oil prices.

According to Ha et al. (2018), a supply chain's reliability depends on the likelihood that the product will operate correctly for a defined period. The authors note that supply chain reliability is increased by strengthening the organization's associations with its supplier. The COVID-19 pandemic affected private corporations across all sectors, weakening business associations and diminishing reliability. A trend is confirmed in the Integrated Oil & Gas industry via the SCRe ratio. In addition, those companies that experienced decreased supply chain reliability during the worldwide oil price reduction of 2015-2016 appear also to have had weak business associations with their suppliers, as evidenced by diminished cash flows, on-the-job accidents, and high debt levels, among other issues.

VI. CONCLUSION

This study makes a novel contribution to the body of knowledge on supply chain reliability by being the first attempt at developing a simple performance ratio for the integrated oil and gas industry, examining any potential impact COVID-19 disruptions had on the supply chain reliability of integrated oil and gas companies, and whose results are tailored for the user outside of the organization. Model results show associations between the SCRe ratio and supply chain reliability.

The investigation's findings may offer evidence of any supply chain deficiencies experienced by the corporations examined along with an insight into organizational reliability, which according to Lukinskiy et al. (2014) and Klimov & Merkuryev (2008), is a gap in the existing literature. The differences in supply chain reliability based on corporate ownership, operational efficiencies, and exogenous events (e.g., volatile oil prices, accidents, etc.) in the Integrated Oil & Gas industry can be traced to align with the current literature and published financial results. Investigation results revealed that all publicly owned corporations had supply chain reliability disruptions during the COVID-19 pandemic, as opposed to government-owned entities. These differences in corporate ownership ultimately impacted the business's ability to generate revenues.

Additional research on supply chain reliability is needed to validate further the SCRe ratio in the context of oil and gas, energy, and other sectors and industries. Because of the statistical significance of the SCRe ratio, practitioners should apply the SCRe ratio as a supply chain reliability metric to further validate the model, especially among high-reliability organizations (HROs). The literature suggests that additional research is needed on organizational reliability, its relationship to supply chain reliability, and its impact on corporate performance. The results of this study address the research gap in developing simplified models applicable to real-world scenarios and used by external stakeholders (Islam Azeem et al., 2020; Athikulrat et al., 2019; Lin & Huang, 2014; Lun et al., 2009). The investigation is also an original contribution to the literature on supply chain reliability in the Integrated Oil & Gas industry by examining the effects of the global pandemic on their supply chain. Researchers were motivated to expand the work begun by Forehand et al. (2021) on supply chain efficiencies, measuring SCOR metrics across other supply chain channels, and the role of COVID-19 on global supply chains. However, more research is needed on how the COVID-19 pandemic impacted global supply chains.

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