Tactical Supply Chain Planning after Mergers under Uncertainty with an Application in Oil and Gas

by

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FOREWORD

This thesis produced the following journal articles and conference papers.

a) Data-driven supply chain planning and resiliency in post-merger integration: the case of Oil industry. Submitted to the 50th International Conference on Computers and Industrial Engineering, October 25-28, 2020

b) Impact of horizontal mergers on supply chain performance: the case of upstream Oil and Gas Industry, Submitted to Computers and Chemical Engineering (Submission #: CACE-D-21-00824).

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Planification tactique de la chaîne logistique après une fusion sous incertitude avec application dans le secteur du pétrole

Abdalla Rashid Masoud ALNAQBI

RÉSUMÉ

La baisse du prix du pétrole oblige les sociétés pétrolières à réévaluer leur chaîne logistique pour voir si elles peuvent améliorer leur efficacité et réduire leurs coûts. En conséquence, la gestion de la chaîne d'approvisionnement en pétrole brut (COSC) prend une importance croissante dans le contexte commercial. Il y a eu un intérêt croissant pour la gestion de la chaîne d'approvisionnement (SCM) et l'utilisation de modèles de programmation mathématique au cours des cinq dernières années.

Les fusions, si elles sont correctement planifiées, peuvent entraîner une amélioration de l'efficacité et des coûts réduits en raison de la réorganisation interne et des transformations de la chaîne d'approvisionnement. Cependant, les fusions sont complexes et les gains et le succès attendus dépendent fortement de différents facteurs qui affectent l'efficacité de la chaîne d'approvisionnement.

Cette thèse traite de la planification tactique du COSC en amont sous les incertitudes causées par la demande et le coût du service partagé après une fusion horizontale. Tout d'abord, un modèle de programmation linéaire mixtes en nombres (MILP) est développé pour aider les décideurs à comprendre où les efforts doivent être concentrés pour obtenir le rendement le plus élevé pendant et après la fusion dans la chaîne d'approvisionnement de pétrole brut. Le modèle a été validé à l'aide d'une étude de cas réel dans un pays du Moyen-Orient.

Deuxièmement, pour aborder la planification tactique de la chaîne d'approvisionnement en pétrole brut et en gaz en amont soumise à des incertitudes liées à la demande et aux coûts des services partagés, le problème est formulé sous la forme d'un modèle de programmation linéaire en nombres entiers. Le modèle est utilisé pour évaluer dans quelle mesure l'économie de gamme (d’envergure) et l'économie d'échelle ont un impact favorable sur les fusions potentielles. Aussi, il détermine le niveau d'investissement et la mise en œuvre efficace des stratégies opérationnelles au niveau des services partagés et de la production et du traitement du pétrole et du gaz. Un exemple de cas réel de l'industrie pétrolière et gazière de la région du Moyen-Orient est utilisé pour valider le modèle. Les études expérimentales examinent trois scénarios : fusion sous économies d'échelle, fusion sous économies de gamme et fusion sous économies de gamme et d'échelle conjointes. Les résultats révèlent l'impact des différentes stratégies opérationnelles sur les gains synergiques potentiels. Pour cette étude de cas, les résultats des calculs montrent que si seules des économies d'échelle sont réalisées, le COSC ne parvient pas à atteindre le coût/baril cible (coût/bbl) après la fusion. La performance conjointe des économies d'échelle et de gamme dans la réduction des coûts des services partagés à différents échelons de la chaîne d'approvisionnement conduit à un gain de synergie substantiel. Il réduit le coût/bbl en dessous de la valeur cible.

Enfin, avec l'évolution rapide du marché mondial d'aujourd'hui, il est essentiel d'inclure l'incertitude de manière explicite dans les modèles de planification de la chaîne d'approvisionnement. Par conséquent, nous développons un modèle de programmation stochastique pour la planification tactique du COSC dans des conditions d'incertitude des coûts et de la demande. Le modèle gère une chaîne d'approvisionnement multi-périodes, multi-produits, et multi-échelons. Il intègre des pénalités de retard avec des structures de coûts générales. Nous illustrons comment notre modèle s'applique directement à la planification de la chaîne d'approvisionnement. Nous présentons des résultats numériques qui montrent l'impact de l'incertitude des coûts sur les décisions de planification de la chaîne d'approvisionnement et les gains de synergie. Nous mesurons également la valeur de l'incertitude de modélisation par rapport à la planification déterministe.

Mots-clés: chaîne logistique, planification tactique, modélisation mathématique, pétrole brut, fusion, incertitude, optimisation stochastique

Tactical Supply Chain Planning after Mergers under Uncertainty with an Application in Oil and Gas

Abdalla Rashid Masoud ALNAQBI

ABSTRACT

Lower oil prices are causing Oil and Gas (O&G) companies to re-evaluate their supply chain to see if they can improve efficiencies and reduce costs. As a result, the Crude Oil Supply Chain (COSC) management receives increased importance in business. There has been a growing interest in Supply Chain Management (SCM) and the use of mathematical programming models in the past five years.

Mergers, if planned properly, can result in improved efficiencies and reduced costs due to the internal re-organization and transformations of the supply chain. However, mergers are complex, and the expected gains and success are highly dependent on different factors and drivers that affect supply chain efficiency.

This thesis addresses the tactical planning of upstream COSC under uncertainties caused by demand and shared service cost after a horizontal merger. First, a Mixed-Integer Linear Programming (MILP) model is developed to aid decision-makers in understanding where effort should be concentrated to achieve the highest return during and post-merger considering the oil supply chain. The model was validated using a real case study from a Middle East country.

Second, to address the tactical planning of upstream Crude Oil and Gas Supply Chain subject to demand and shared services cost uncertainties, the problem is formulated as a mixed-integer linear programming (MILP) model. The model is used to evaluate the extent to which the economy of scope and the economy of scale favorably impact potential mergers. Also, it determines the investment level and the efficient implementation of operational strategies at shared services and the production and processing of oil and gas. A real case example from the oil and gas industry in the Middle East region is used to validate the model. The experimental studies examine three scenarios: merger under economies of scale, merger under economies of scope, and merger under the joint economies of scope and scale. The results reveal the impact of different operational strategies on potential synergetic gains. For this case study, computational results show if only economies of scale are performed, the COSC fails to achieve the targeted cost/barrel (cost/bbl) after the merger. The joint performance of economies of scale and scope in reducing shared services costs at different supply chain echelons leads to a substantive synergy gain. It reduces the cost/bbl below the targeted value.

Finally, with today's rapidly changing global marketplace, it is essential to include uncertainty in an explicit manner in supply chain planning models. Therefore, we propose a stochastic model for tactical planning of COSC under cost uncertainty. The mathematical model considers a multi-echelon supply chain with multi-products and a multi-period planning horizon. It integrates inventory and backorder penalties. We illustrate how our model directly applies to supply chain planning. We present numerical results that show the impact of cost uncertainty on supply chain planning decisions and synergy gains. We also measure the value of modeling uncertainty against deterministic planning.

Keywords: supply chain, tactical planning, merger, mathematical modeling, optimization, uncertainty, stochastic optimization, oil and gas.

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LIST OF ABBREVIATIONS

ARCO	Atlantic Richfield Company
BP	British Petroleum
COSC	Crude Oil Supply Chain
COT	Crude Oil Terminals
CPD	Capacity Determination
CPE	Capacity Expansion
CVAR	Conditional Value At Risk
DC	Distribution Centers
DP	Deterministic Programming
EOR	Enhanced Oil Recovery
ERM	Effective Risk Management
FAL	Facility Allocation
FL	Facility Location
FMP	Fuzzy Mathematical Programming
FPSO	Floating Production Storage and Offloading
FRL	Facility Relocation
GCC	Gulf Cooperation Council
GOR	Gas to Oil Ratio
HCSC	Hydro-Carbon Supply Chain
HR	Human Resources
IEA	International Energy Agency
INM	Inventory Management
IT	Information Technology
LNG	Liquefied Natural Gas
LP	Linear Programming
LPG	Liquefied Petroleum Gas
MILP	Mixed-Integer Linear Programming

MLP	Mixed-integer Linear Programming
MNLP	Mixed-integer Non-Linear Programming
MOF	Multiple-Objective Function
NLP	Non-Linear Programming
NPV	Net Present Value
OE	Oil Extraction
O&G	Oil and Gas
OFPP	Oilfield Production Planning
OP	Oil Processing
OPEC	Organization of the Petroleum Exporting Countries
PCP	Petrochemical Plant
PJP	Project Planning
PM	Profit Maximization
PP	Production Platforms
RO	Robust Optimization
RP	Refinery Plants
RPP	Refinery Production Planning
SAA	Sampling Average Approximation
SC	Supply Chain
SCM	Supply Chain Management
SCRM	Supply Chain Risk Management
SOF	Single-Objective Function
SP	Stochastic Programming
SSC	Shared Service Cost
SSCM	Sustainable Supply Chain Management
SSCQM	Sustainable Supply Chain Quality Management
UAE	United Arab Emirates
VAR	Value At Risk
WP	Wellhead Platforms

INTRODUCTION

Nowadays, no country in the world can run smoothly without oil and gas, and the development of today's world would not have been possible without it. Up to now, there has been no real competitor to fossil fuels despite the expansion in renewable energy due to the relatively low price of fossil fuel energy compared with these alternative energy sources.

Although oil demand has risen steadily over the past 15 years (Scharf, 2015), the introduction of shale oil in the United States and political and economic factors have led to a volatile oil price over the last 15-20 years. The recent COVID 19 epidemic has caused a dramatic reduction in the demand for petroleum products resulting in much lower oil prices and demand, which provides uncertainty in future oil pricing. Oil demand is unlikely to return to pre-pandemic levels as the world finds new ways of living and working, with our day-to-day lives likely to be permanently transformed. Uncertainty and lower oil prices reduce the profit margins of the Oil and Gas (O&G) supply chain partners forcing them to review their organizational structures to reduce costs and improve efficiencies as part of a continuous improvement process (Ben Amor et Ghorbel, 2018).

Previous research demonstrates that data-driven decision-making capabilities, collaboration, and integration are vital strategies used by different industrial and service sectors (manufacturing, retailers, etc.). It might lead to significant cost savings (Cedillo-Campos et al., 2020; Er Kara, Oktay Fırat et Ghadge, 2020; Long, 2018)

This can be achieved through horizontal and vertical supply chain integration resulting from a merger between two or more companies or internal re-organization and transformation (Hsu, Wright et Zhu, 2017; Milliou et Petrakis, 2007). At the same time, there is evidence that less than 25% of all mergers achieve their stated goals (Marks et Mirvis, 2001). Pinopoulos (2017) found in a study of upstream horizontal mergers and vertical integrations that all were profitable (Pinopoulos, 2017). This thesis looks at the transformation and re-organization of upstream oil & gas companies after a merger.

The oil and gas (O&G) industry have complex supply chains across the various exploration, drilling, field development, operations, and de-commissioning processes. The O&G supply chain involves multiple facilities (wellheads, production facilities, refineries, etc.). Many firms supply equipment and materials required at these locations, and support services such as project and contract management and logistics, as shown in Figure 0.1.

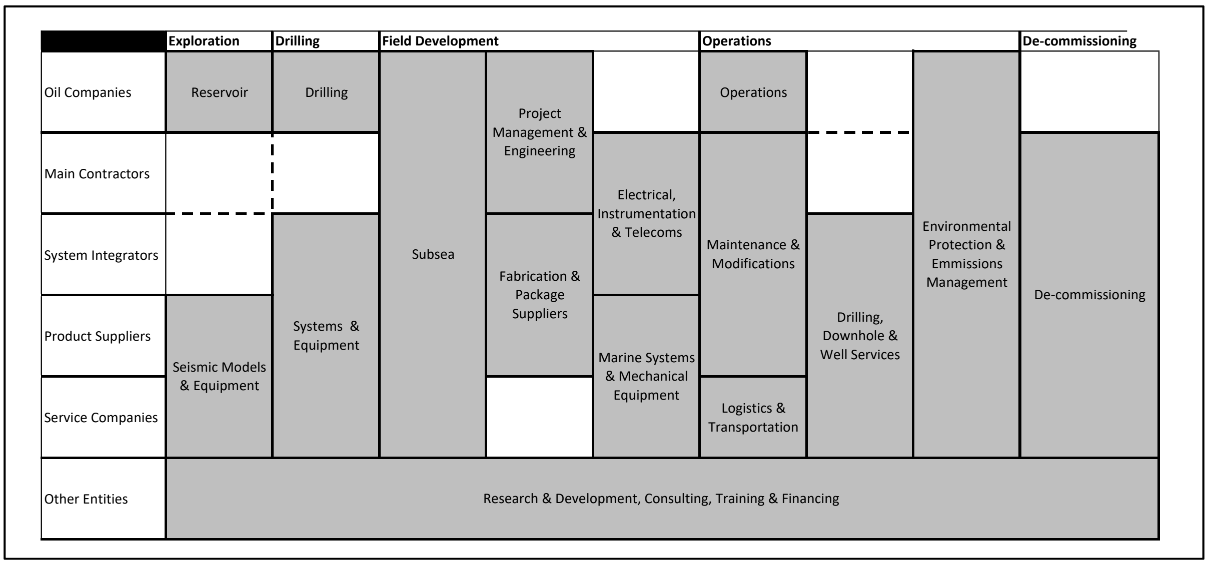


Figure 0.1 Typical supply chain across the value chain
Adapted from Azah D. et al. (2009)

It can be seen that the O&G Companies are reliant on third-party material and service providers (i.e., Main Contractors, System Integrators, Product Suppliers, Service Companies, etc.). Therefore, upstream companies must focus on effective supply chain management (SCM) to improve profitability and cash flows.

The easy oil has already been exploited, and upstream companies have been forced to explore more remote areas. However, upstream companies face many challenges in managing the supply chain (SC) related to material and product transportation to/from remote geographic locations. For offshore upstream companies operating in the Arabian Gulf, this involves transporting people and material to remote wellheads by boat and helicopter and the necessary parts, chemicals, and food to the main installations.

Supply chain re-design has particular significance as part of the merger of two or more oil companies. The new entity can take the best practices of the pre-merged companies and take full advantage of the newly merged entity. This provides an excellent opportunity to review and optimize the COSC and is a critical factor for the likelihood of post-merger success (Langabeer, 2003).

This research will look at optimized supply chains that emerge post-merger. The main objective is to propose a new decision-making framework that can be used during the merger planning stage to make tactical decisions regarding the new supply chain to maximize synergies without reducing flexibility at optimum cost.

0.1 Context

In 2016, a strategic decision was made to merge two separate offshore upstream oil companies into one entity. The two independent offshore companies operate in different geographical areas in the Middle East country with varying bases of supply and separate supply and maintenance contracts. The consolidation of the two companies was expected to complete in 1-2 years and yield significant financial and operational benefits, including a more agile structure, a common supply chain, and the ability to share specialist technologies, skills, and experience. However, the merger took over three years with sluggish progress due to the following reasons:

- The companies had geographically separated fields, logistic depots, and transportation links;
- The companies had differing maintenance strategies;
- The companies had different contract arrangements, different suppliers, and service providers. The merger took longer to unify the contract management, suppliers, and service providers.
- During the merger, the new management decided to make strategic changes to the human capital (by outsourcing non-core personnel and non-core business processes) and optimizing the internal operations of the new organization.

- Uncertainty of oil prices due to the political instability and the fluctuation of Oil & Gas demand.

As a result of these difficulties, it is clear that there is a real need to develop supply chain decision models that can support the management post-merger in the upstream supply chain to maximize profit under the uncertainty of oil prices.

0.2 Problem Statement

Integrating the SC of two upstream oil companies is bound to be difficult due to the complex nature of the supply chains, particularly if the companies are using different suppliers and service providers with different geographical locations.

To understand the complexity of the SC, it is necessary to have a detailed knowledge of the Crude Oil Supply Chain (COSC) and identify which areas of the SC are candidates for optimization during and after the merger. Supply chain decisions can take place on strategic, tactical, and operational levels (Sahebi, Nickel et Ashayeri, 2014) depending on the scope of the planning decisions and the time horizon (Peidro et al., 2009).

Given the increasing challenges in the management of the COSC and the uncertainty that continues to be present at many levels in the SC that affect strategic and tactical decision-making, there is a need to collect and analyze the recent studies in strategic and tactical planning. Although Sahebi et al. (2014) undertook a literature review of all or parts of COSC, there has been limited detailed research since, and Sahebi et al. (2014) identified the study of strategic and tactical decisions in a single model as a gap in the research. This identifies a problem of providing a comprehensive framework for developing integrated strategic and tactical planning models of the supply chain under uncertainty to mitigate risks, particularly as part of the planning before or implementation during a merger.

The presence of uncertainties often complicates the modeling of physical systems. For example, Oil & Gas supply chain modeling involves uncertainties in crude oil production, demand for refined products, and market prices that impact the efficiency (cost) of the supply chain. It is important to incorporate any known uncertainties into input parameters and variables of the supply chain models to quantify the resulting uncertainty in the model outputs.

0.3 Objectives of the Thesis and Significance

Decision-makers considering the merger of two companies or the acquisition of another company either as part of a horizontal or vertical integration strategy can use the model to run different scenarios to look at the location and capacities of the merged facilities and whether the integration will reduce costs by creating a more efficient system. When considering horizontal integration, optimizing the supply chain of the merged entity is essential, and a supply chain planning model can be used to determine the optimum number of suppliers for the merged entity and when combined with strategic contract management, can ensure supplier effectiveness in terms of cost, timeliness, and quality. Supply chain planning models can set appropriate targets for inventory and capacity to make the supply chain much more robust.

Decision-makers considering whether to outsource non-core aspects of the supply chain can use the supply chain planning models to run various outsourcing scenarios to determine whether a particular service can be done more effectively by a third party allowing the company to focus on what it does best.

This research aims to enhance understanding of the potential efficiencies that can be achieved in the O&G upstream supply chain after merger decisions. It is essential to analyze existing O&G planning models and examine the mechanisms to include in merger decisions to achieve this specific objective.

To the best of our knowledge, this is the first study that addresses the specific problem of tactical supply chain planning during the merger of two upstream oil companies under uncertainty. This research could be beneficial for decision-makers to evaluate the expected impact of the supply chain operations. It will give the decision-maker the tools to assess the critical resources, expected costs, and development opportunities during and after the merger process.

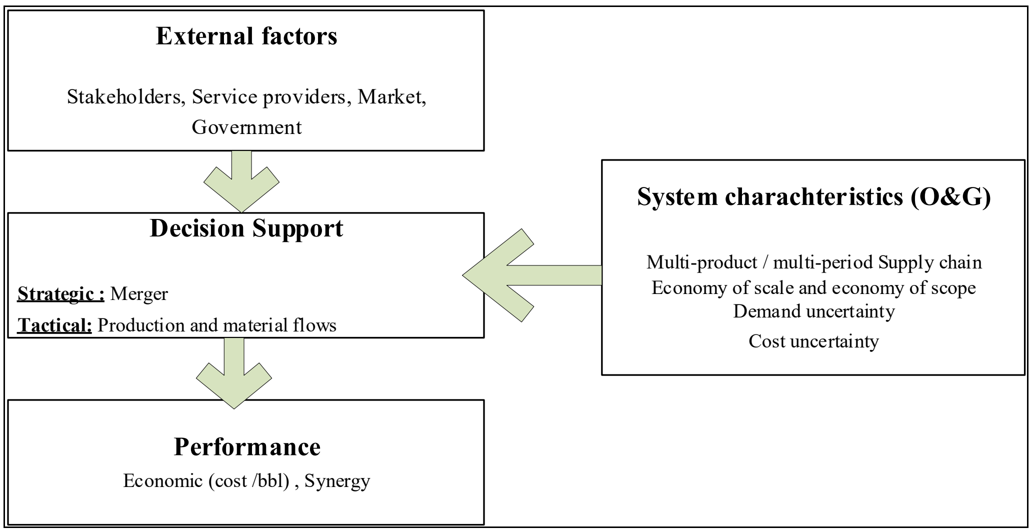


Figure 0.2 Conceptual research model

0.4 Research Questions

Understanding the main characteristics of the upstream supply chain model is key to developing the model; knowing what entities (i.e., wellhead platforms, production platforms, etc.) make up the supply network along with the structure of the COSC and the purpose of the model as a decision tool.
This brings us to our first research question (**RQ1**): *What are the main characteristics of upstream tactical supply chain planning models, and how to integrate merger decisions?*

This thesis will undertake a literature review to collect material related to mergers in the upstream Oil & Gas sector and upstream supply chain planning models. This will answer research question 1. The subsequent analysis will better understand how to transform the strategic supply chain through post-merger planning models in the upstream Oil & Gas sector.

Subsequently, we need to gain more insight into how the upstream strategic supply chain planning model must be structured and develop a general framework for modeling upstream Oil & Gas supply chain planning models. This will allow identification and understanding of the inter-dependencies between merger decisions and oil prices, which are crucial as a pre-cursor to identifying the strengths and weaknesses of the upstream strategic supply chain planning model.

The second research question (**RQ2)** is formulated as follows: *What critical modeling aspects should be considered in planning upstream tactical supply chain models to consider merger decisions?*

The proposed model will be formulated from the general framework and consider site locations, supply chain networks, well capacities, costs, etc. The network comprises a combination of water injection wells, oil production wells and gas wells, riser platforms, separation plants, water injection plants, gas dehydration, and condensate treatment plants, and storage facilities. An oil field layout can comprise several fields, each containing one or more reservoirs. This will help develop the model to re-design the optimal upstream supply chain after a merger and under Oil price uncertainty. In the case of joint mergers, the model can be used in tactical supply chain planning decisions and might potentially reduce the impact of risky situations (cost increase, capacity problems, etc.).

The third research question (**RQ3)** is formulated as follows: *Which decision criteria from joint mergers and tactical supply chain planning can enhance the efficiency of the upstream supply chain?*

The model is validated using a case study of two upstream O&G companies in the Arabian Gulf that merged to form one entity. The model is used to look at various scenarios to assist in the tactical decisions needed post-merger, including selecting which reservoirs to develop, wells production capacities, and the expected fluid production rate for a given or forecasted period of time.

0.5 Structure of the Thesis

This thesis is structured in six chapters, which can be grouped into four major parts: i) Introductory part, ii) Theoretical part, iii) Model development part, and iv) Conclusion part.

The introductory part provides an overview of the COSC, the background and context of the problem, and the research questions' development. The theoretical part presents the literature review relevant to understanding the industry's oil and Gas upstream supply and mergers. This part will conduct an extensive literature review of the COSC and strategic/ tactical models of the SC to assist in developing a general framework for and development of the SC planning model. This part will answer RQ1 and consist of two chapters (chapter 1 and chapter 2) in this thesis.

The model development part consists of 4 chapters. The research methodology is outlined in chapter 3, and an initial model of an upstream COSC is defined in chapter 4. Chapter 5 uses this SC model to develop a Decision Support System (DSS) to assess the impact on SC performance after a horizontal merger. Chapter 6 looks at how uncertainties can affect SC synergies. Finally, the conclusion part summarizes the thesis with a discussion about theoretical and managerial implications. A discussion about research limitations and future research directions is also suggested. The overview of this thesis is also shown in Figure 0.2.

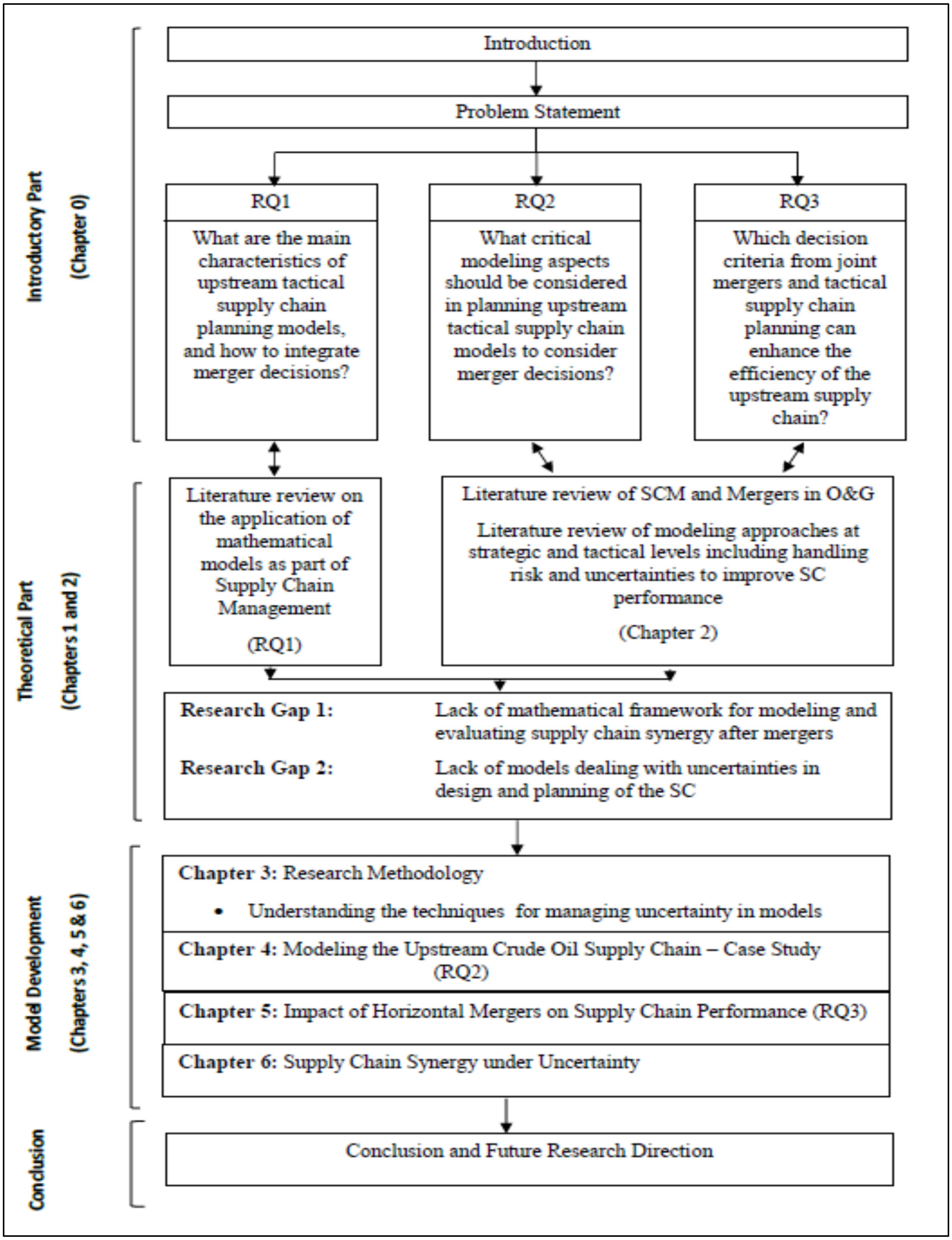


Figure 0.3 Thesis Overview

CHAPTER 1

BACKGROUND: THE PETROLEUM SECTOR

1.1 Introduction

Oil is formed from the natural accumulation of hydrocarbons, thousands of feet below the Earth's surface, from the decomposition of organic material such as plants and marine life that died during the Mesozoic and Palaeozoic Eras between 66 and 541 million years ago. These trapped hydrocarbons were compressed under enormous pressure and high temperature and transformed into crude oil after millions of years, creating natural oil reservoirs in underground geological layers (Qabazard, 2011). This chapter looks at the Crude Oil Industry, the challenges within the oil and gas supply chain, and how to manage this effectively as part of a merger.

The crude oil industry has been classified in three different ways. In the first one, the crude oil industry is divided into upstream and downstream sectors.

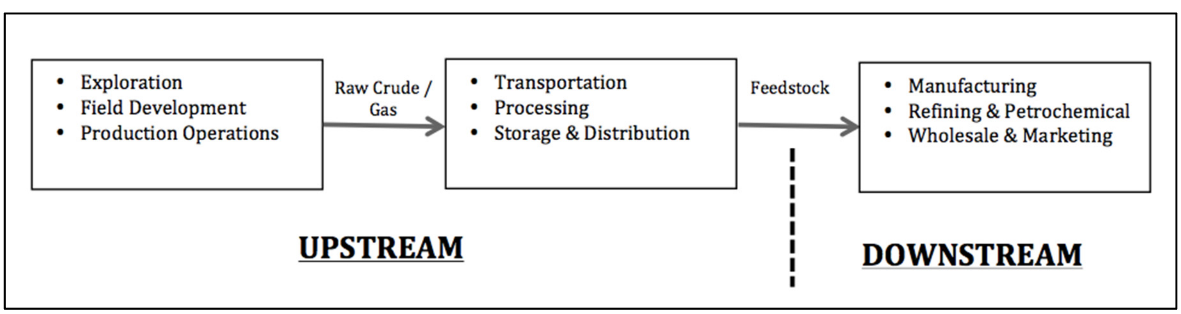


Figure 1.1 Classification 1 – Upstream and Downstream

According to this classification, the upstream sector consists of several functions and units, such as crude oil reservoirs, gas wells, separators, dehydration trains, pipeline networks, storage tanks, oil & gas terminals, and oil & gas tankers. This sector is mainly for the exploration and development of oilfields, including the initial processing facilities to recover, receive, separate, and store the raw product. The downstream sector covers the transformation of crude oil to intermediate and final products in refineries and petrochemical plants, the associated distribution network, and product marketing to the customers and end-users.

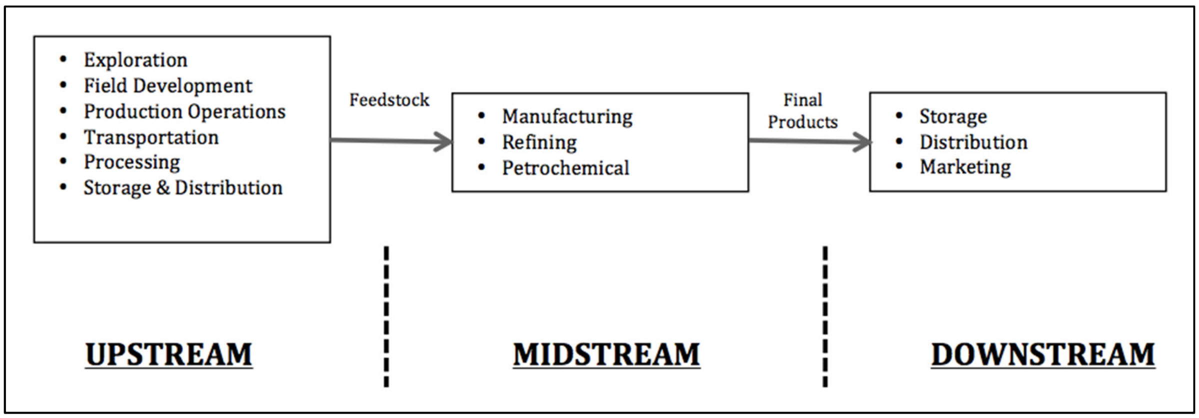


Figure 1.2 Classification 2 – Upstream, Midstream, and Downstream

The crude oil industry is divided into upstream, midstream, and downstream sectors. The upstream sector refers to the exploration, extraction, separation, dehydration, and transportation of crude oil, more or less similar to the first classification. The Midstream sector denotes the crude oil transformation at refineries and petrochemicals. In contrast, the downstream sector relates to the functions after the transformation (i.e., storage, distribution, and marketing).

This thesis will use a third classification arrangement based on previous research (An, Wilhelm et Searcy, 2011; Leiras et al., 2011; Santos Manzano, 2005), as it is more relevant to Oil & Gas industry's current arrangement and more appropriate. In this third classification, the crude oil industry is again divided into three major sectors: upstream, midstream, and downstream, as in the second arrangement. Upstream in this classification covers only exploration and production activities up to the oil terminal. Midstream covers the transportation, processing, storage & distribution, and the last segment covers the remaining activities such as manufacturing, refining, and petrochemicals, wholesale, and marketing, as shown in Figure 1.3.

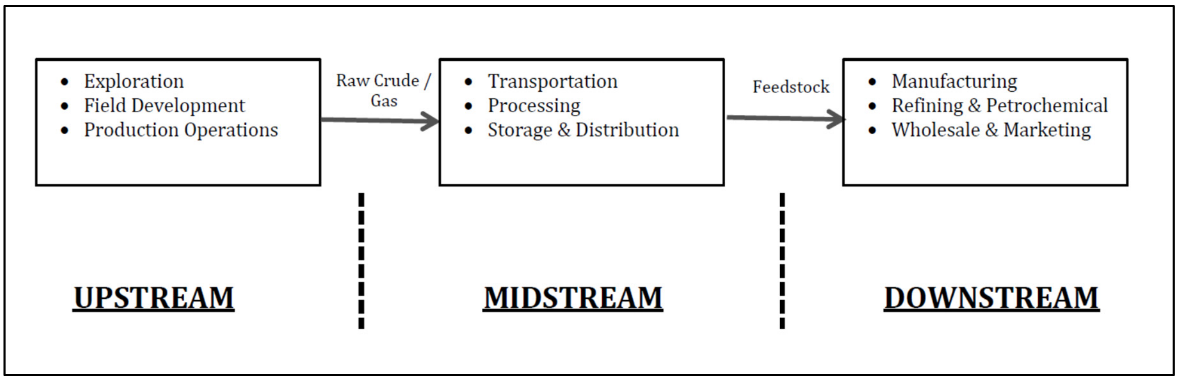


Figure 1.3 Classification 3 – Upstream, Midstream, and Downstream

The crude oil exploration and production can be onshore, where fixed installations are typically used to produce crude oil. Offshore exploration could also be executed through fixed platforms (shallow water), complex or gravity-based platforms dependent on the seawater depth, or through a floating platform such as Floating Production Storage and Offloading (FPSO) platforms.

1.2 The Oil & Gas Industry Constituent Parts

1.2.1 Reservoirs

Oil and gas reservoirs are pools (or reserves) of hydrocarbons contained in subsurface permeable or fractured rock formations. The reservoirs are usually classified as either conventional or unconventional *reservoirs.*

C*onventional reservoirs* form where porous rock is covered by a non-porous layer (called cap rock) such as salt, shale, chalk, or mud rock where naturally occurring hydrocarbons, such as crude oil or natural gas, are trapped. *Unconventional reservoirs* are where the rocks have high porosity and low permeability, keeping the hydrocarbons trapped without a cap rock. Using geophysical hydrocarbon exploration methods, reservoirs are found by gravity, magnetic and seismic surveying to detect large-scale features of the subsurface geology that may contain hydrocarbon deposits.

An energy source (or drive mechanism) is required to recover hydrocarbons from the reservoir to the production wellhead. Generally, drive mechanisms are divided into two groups, natural drive mechanisms usually utilizing the connected water aquifer and artificial drive mechanisms where an external energy source (i.e., water or gas) is used to assist in or enhance the recovery process. Natural drive mechanisms are also termed *primary recovery,* whereas artificial drive mechanisms are termed *secondary recovery* and *tertiary recovery or Enhanced Oil Recovery (EOR). These two mechanisms are* specified by some typical performance attributes such as ultimate recovery factor, pressure decline rate, Gas to Oil Ratio (GOR), and water production. Artificial drive mechanisms are used when a reservoir's natural drive mechanism has low efficiency in recovering crude oil, and an intervention is required by using one of these techniques: Water injection or Gas injection.

1.2.2 Oil Wellhead

Upon completing the drilling activities, the wellhead is ready to extract hydrocarbons from the underground formation, preventing oil or natural gas from leaking out of the well and preventing blowouts due to the accumulation of high pressure. The wellhead consists of the Christmas tree, the tubing head, and the casing head. The installed topside wellhead facilities consist of various equipment to regulate and monitor the recovery of crude oil from the reservoir through pipelines connecting the wellhead to the main processing facilities for crude oil separation along with produced water disposal processes. Wellheads can comprise a single or multiple wells. In addition to the production wells, wellhead may include injection wells (i.e., those used to inject water injection, gas injection, CO_2 injection, etc., into reservoirs as a secondary or tertiary drive mechanism).

1.2.3 Pipeline Network

The main purpose of the pipeline network is to transport the produced crude oil from various wells into the main production and processing facilities. This network may consist of many different manifolds and associated pipelines to monitor and control production from different wells within the reservoir based on recovery guidelines. The manifolds are usually placed on the surface at the platform or subsea, depending on the system's design and site-specific requirements. Pipelines sizes may vary from 1" to 48" and even bigger in some cases, depending on the design and throughput capacity. In addition to the crude oil pipelines from the wellhead to the processing facilities and from the processing facilities to the storage tanks and shipping terminals, other pipelines are carrying the gas, condensate, produced water, instrument, and plant air for facilities equipment and general use respectively, chemical lines for processing purposes, water injection pipelines, so on and so forth.

1.2.4 Crude Oil Separator

A crude oil separator is a pressure vessel that separates produced well fluids from oil and gas wells into their constituent components of Oil, gas, and produced water. Separators are of different types such as:

- Two-phase separators knock out the gas from the liquid (oil and produced water); the produced water will remain with the oil and be separated at later processing stages.

- Three-phase separators, which separate the oil, gas and produced water as separate components, which are treated differently at later processing stages.

The separation method is straightforward and consists of reducing the pressure in several stages. After a suitable retention time, water settles at the bottom of the separator (usually in a boot), gas bubbles out, and accumulates at the top of the separator. At the same time, the oil stays in the middle (Sahebishahemabadi, 2013b).

Separators are of different types according to the facilities' requirements included in the design, such as gravity separators, centrifugal and special type separators (Coalescer, Electrostatic Desalter, Water treatment).

1.2.5 Gas dehydration units

The associated gas from the separators usually goes to dehydration units for further processing before exporting to midstream facilities. One of the most commonly used methods for removing the water from produced gas is by using glycol. Glycol dehydration units are of different types related to the process used for removing the water by the glycol and the glycol regeneration process. Control of air emissions from these units usually satisfies international environmental requirements. Following the process of knocking out the water from the wet gas through a series of heat-treating and exposure to lean glycol, the outcome is Dry Gas, which goes to the midstream facilities.

1.2.6 Crude Oil Storage Tank

After further processing to satisfy the international market specification, the separated crude oil may be transported via pipeline directly to the refinery/customers or to a terminal where it is stored and shipped through crude oil tankers. On production platforms without connecting flowlines or pipelines, crude oil must be stored in crude oil storage tanks at the production platforms and then offloaded to the oil tankers for transportation to refineries or other downstream facilities. In addition, storage tanks are needed to allow for metering, sampling, and gauging of oil properties to achieve the international specification for crude oil.

A crude oil storage tank facility is usually designed to store more production than a regular cycle for unanticipated delays due to unforeseen situations such as bad weather, natural disaster, or uncertainty in the arrival of tankers due to any unforeseen circumstance. For example, a set of storage tanks must store sufficient crude oil productions for a regular cycle and additional weeks as a contingency.

1.2.7 Sea Port Terminal

In most producing countries, crude oil is being transported from the crude oil storage tanks after sampling and the gauging station to the seaport terminal for loading or vice versa in the unloading case as the sea port terminal is usually equipped with the loading and unloading systems from/to the crude oil shipping tankers. The sea port terminal is fully equipped with safety and utility systems to ensure that the loading and unloading are safely and efficiently be carried out. Alternatively, crude oil is transported to downstream refineries by pipelines.

After treatment, Associated Gas and Gas from Wellhead to knock out the moisture and condensate is usually transported through separate Gas pipelines to downstream facilities for further treatment to produce LNG and further export via separate sea port terminals to countries like Japan, China, Singapore, etc. Alternatively, the gas can be fed to local downstream facilities for producing LPG and industrial gases.

The Oil & Gas industry customers are either wholesale customers or big consumers such as power plants, airlines, industrial customers, and shipping or retail customers. Oil & Gas products are transported to the customers via pipelines, shipping tankers, rail, vessels, and trucks. The quantities may vary and can reach multiple hundred thousand tons per shipment. This type of customer is domestic transportation, domestic heating, and the production of petrochemical-related products.

The above provides an introductory knowledge of the Oil & Gas Industry considered prerequisite information required for our research topic.

1.3 Crude Oil Supply Chain

Agarwal, Sharma, and Alex (2016) identified that the oil and gas industry has complex supply chains. It involves several companies supplying material and equipment required at multiple locations (wellheads, production facilities, refineries, etc.) and support services such as project and contract management and logistics (Agarwal, Sharma et Alex, 2016). An overview of the COSC from upstream to downstream is shown in Figure 1-4.

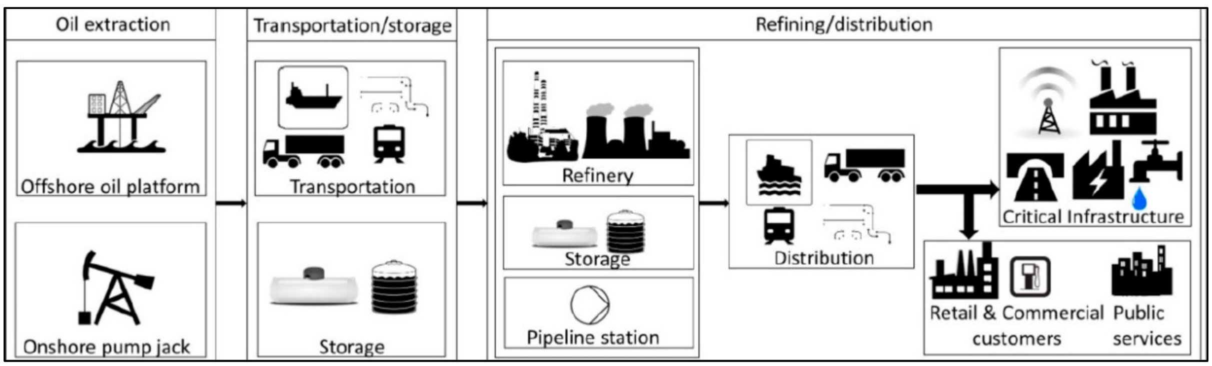


Figure 1.4 Overview of COSC
Taken from Katopodis and Sfetsos (2019)

Reliability is a crucial factor in supplying these materials and services in terms of quality and timing. Oil & Gas companies face challenges in managing the supply chain are related to material and product transportation to and from remote geographic locations. Challenges are seen for any COSC and might create problems with ripple effects (Agarwal, Sharma et Alex, 2016).

New extraction methods (i.e., fracking) require large quantities of water, sand, and fracking chemicals, which exacerbates the challenges within the COSC. Agarwal et al. (2016) postulated that the upstream companies heavily depend on third-party material and service providers (80% of total operating costs). Therefore, to improve cash flows, the upstream companies need to focus on effective Supply Chain Management.

As part of effective SCM, decisions can be made at three different levels (i.e., strategic, tactical, and operational) to optimize the design and planning of the COSC. Strategic level supply chain decisions are related to the design of the supply chain network. They involve investment, facility location (or relocation), capacity expansion or reduction, the use of technology, and whether parts of the supply chain should be outsourced. The pre-determined strategy will be refined at the tactical level as the company's environment becomes more defined; product and market demands, price, exchange rates, and other uncertain factors become more predictable and certain (Sahebishahemabadi, 2013a). At the operational level, day-to-day problems and logistics are solved to ensure that the right product gets to the right customer on time.

Uncertainty exists in most supply chains, and sources of uncertainty in the SC can be classified into three groups; demand, process/manufacturing, and supply (Peidro et al., 2009). For the COSC, uncertainty in supply is caused by the variability brought about by how the supplier(s) operate collectively within the market and may be affected by price and political factors. Demand uncertainty is due to the volatility of demand (exacerbated by the current COVID-19 situation) or inexact forecasting of the demand.

Mergers and acquisitions are often undertaken as a strategic initiative to enable the organization to grow and expand with respect to its geographical reach, product lines, sales, assets, and profits. This has particular significance after the merger of two or more oil companies. The new entity can take the best practices of the pre-merged companies and redesign the supply chain to take full advantage of the newly merged entity. Synergies are often identified as part of the merger planning to enable operational efficiencies and cost-cutting. The pre-merged companies will often have geographically separated logistic depots and transportation links and different contract arrangements, and different suppliers and service providers. The process of merging the companies is a golden opportunity to review the supply chain configuration and develop an optimal Supply Chain system.

1.4 Conclusion

It is clear from this background review that significant gains can be made post-merger from synergies and efficiency in the operation of the combined company, mainly if additional synergies can be obtained from the redesign of the new entity's supply chain. In the oil & gas industry, the uncertainty and volatility of the oil price have to be considered in all critical decisions, including mergers and acquisitions and redesign of any business process.

CHAPTER 2

RESEARCH OPPORTUNITIES IN UPSTREAM SUPPLY CHAIN

2.1 Introduction

The Crude Oil Supply Chain (COSC) management is receiving increased importance in the business context. The industry acknowledges developing strategic and tactical decision levels of supply chain models (Shapiro, 2004). Companies can achieve significant savings in the order of 5-10% by utilizing strategic and tactical supply chain models (Calleja et al., 2018), which is the topic of this thesis and underlies the focus on research in this area.

Environmental uncertainties due to unpredictable and ever-changing weather and the remoteness of the oil & gas facilities lead to a need for higher reliability and flexibility within the Supply Chain's production, planning, and control systems. The management of the COSC requires up-to-date decision-making across different tasks, functional areas, and organizational barriers to deal with problems and uncertainties (Saad, Udin et Hasnan, 2014).

To understand the COSC challenges, we provide a literature review of SCM's current thinking and direction and the modeling approaches at strategic and tactical decision levels related to the design and planning of the crude oil supply chain. To achieve this, we initially study the previous effort associated with literature review works in Section 2.2, then, in Section 2.3, introduce the review methodology to be followed. Section 2.4 outlines a taxonomy framework of the reviewed work as a prerequisite for the systematic review; the subsequent review results are also tabulated in Section 2.4. Section 2.5 deals with supply chain risk while section 2.6 looks at supply chain performance strategy, and finally, Section 2.7 what can be concluded from the literature review.

2.2 Previous review works

The main purpose of the review is to provide an overview of recent relevant literature related to Supply Chain Management (SCM) generally and within the context of the Oil & Gas and Petroleum industries. The review will also provide an overview of mergers within the context of the Oil & Gas and Petroleum industries.

2.2.1 Supply Chain Management

There is no universal agreement on the definition of a supply chain. Calleja et al. (2018) proposed the following definition: "*A Supply Chain (SC) is a network of entities that collaborate to obtain and deliver a product or set of products*" (Calleja et al., 2018). It includes the operations that take place in some or all of the supply chain entities. It includes the procurement of raw materials, converting materials into intermediate and finished products, and distributing finished products to the final customer (Goetschalckx, 2011).

Corominas (2013) provides an overview of the literature related to supply chains and the origins of SCM itself. Oliver and Webber introduced the term 'SCM' in 1982 (Corominas, 2013), and the literature has been growing substantially through the field of Strategic Management (Chen et Paulraj, 2004). Corominas (2013) identified problematic areas from actual supply chains, including uncertainty in supply and demand and the evolution of technology available for use within the supply chain. This is a topic taken up by Ben-Daya, Hassini and Bahroun (2019), who undertook a literature review of the Internet of Things (IoT) and its impact on SCM and concluded that this technology was confined to isolated areas of the supply chain; namely manufacturing and delivery (Ben-Daya, Hassini et Bahroun, 2019).

Another area receiving much attention is Sustainable Supply Chain Management (SSCM), and Silvestre (2016) undertook a comprehensive literature review of the topic covering the period 2008 to 2015 and argued that supply chain risks and opportunities are the key drivers for the sustainability of the SC with supply chains evolving from more traditional to more sustainable approaches over time (Silvestre, 2016). Also, Bastas and Liyanage (2018) expanded the concept of SSCM further by looking at Quality Management within the context of both SCM and Sustainability Management and identified a new emerging research area; Sustainable Supply Chain Quality Management (SSCQM) (Bastas et Liyanage, 2018).

Considering the Oil and Gas industry rather than SCM in general, Alhosani et al. (2019) undertook an extensive literature review of SCM concepts applied in the Oil & Gas industry. They identified 52 different models of SCM, which were used in the industry (Alhosani et al., 2019). Wan Ahmad, de Brito, and Tavasszy (2016; 2017) looked at SSCM in the Oil & Gas industry. In the earlier paper, Wan Ahmad et al. (2016) undertook a review of the annual sustainability reports of 30 Oil & Gas companies with an emphasis on supply management, product stewardship, and logistics management (Ahmad, de Brito et Tavasszy, 2016). The second paper followed this study area, which proposed a framework for SSCM practices in the oil & gas industry following a literature review (Ahmad et al., 2017).

Ceryno et al. (2013) undertook a literature review of Supply Chain Risk Management (SCRM) in general (Ceryno et al., 2013). In contrast, Fernandes, Barbosa-Póvoa and Relvas (2011) and Amor and Ghorbel (2018) looked at SCRM in the context of Petroleum Supply Chains. Fernandes et al. (2011) identified specific risks associated with supply, demand, operations, and information systems and mitigation strategies to reduce the risks (Fernandes, Barbosa-Póvoa et Relvas, 2011). Amor and Ghorbel (2018) determined that risk is dependent on certain operations within the SC and whether the country is a net importer or a net exporter (Amor et Ghorbel, 2018).

In the context of the COSC, Sahebi et al. (2014) undertook a review of academic papers over 30 years related to all parts of the COSC, and they concluded that the area of supply chain design and supply chain planning had emerged and matured during this period but identified several gaps that required further research:

- The integration of strategic and tactical decisions in a single model
- Capturing the complete integration of the COSC
- Dealing with non-linear models, which is essential for refinery operation models
- The emerging “uncertainties” and environmental impacts associated with COSC problems.

In the downstream sector, Lima, Relvas, and Barbosa-Póvoa (2016) undertook a review of supply chain management and looked at optimization methods and optimization direction in the sector as well as uncertainties, risk and reliance, sustainability, and information sharing (Lima, Relvas et Barbosa-Póvoa, 2016). Ahmad, de Brito, and Tavasszy (2015) looked in detail into sustainability in managing the supply chain in the overall oil & gas industry, looking at the sustainability intent and reporting of oil & gas companies. They concluded that the companies generally have clear sustainability policies in both environmental protection and corporate social responsibility but identified weaknesses in reporting (Ahmad, de Brito et Tavasszy, 2016).

Khor and Varvarezos (2017) looked at the various aspects of a refinery-wide optimization, including logistics and distribution, planning and scheduling, product blending, and advanced process control. They concluded that development in modeling and optimization techniques over the last half-century and advances in computing power had made a significant difference in the way refineries are designed and operated. However, refinery-wide optimization is still a couple of decades away due to the industry's complexity of operations and conservative nature (Khor et Varvarezos, 2017). More recently, Abdussalam et al. (2020) analyzed the evolution of sustainable supply chain planning in the petroleum sector (Abdussalam et al., 2021).

Table 2.1 outlines the most relevant review papers published in the area of supply chain management in the petroleum and O&G industry in the last ten years and includes new research areas of SSCQM and a more comprehensive look at uncertainty in the COSC.

Table 2.1 Previous reviews in SCM in the oil and gas suppl chain

Reference	Time horizon	Sample size	Sector	Specific objective
(Leiras et al., 2011)	1991- 2011	76	Refinery	Refineries planning
(Fernandes, Barbosa-Póvoa et Relvas, 2011)	1992-2011	247	Integrated	Risk in petroleum supply chains
(Nikolopoulou et Ierapetritou, 2012)	1980- 2012	97	Petro-chemical	Sustainable supply chains in chemical processes
(Schneider et al., 2013)	2001-2013	35	Integrated	Sustainability petroleum industry
(Sahebi, Nickel et Ashayeri, 2014)	1988-2013	93	Crude oil	Planning models within the crude oil
(Wan Ahmad, de Brito et Tavasszy, 2016)	2003-2015	48	Integrated	Corporate sustainability practices
(Khor et Varvarezos, 2017)	1979-2015	173	Refinery	Petroleum refineries planning
(Lima, Relvas et Barbosa-Póvoa, 2016)	1996-2015	81	Refinery	Downstream petroleum supply design
(Ben Amor et Ghorbel, 2018)	1972-2017	127	Integrated	Risk in petroleum supply chain
(Abdussalam et al., 2021)	2010-2019	23	Integrated	Green supply chain planning

2.2.2 Mergers within the industry

Surbhi and Sandeep (2017) presented an overview of the main concepts related to mergers and acquisitions and identified many types of mergers, including horizontal and vertical mergers (Bedi et Vij, 2017). Horizontal mergers involve firms within the same industry, such as the merger of Exxon and Mobil (1998-2000), which created the world’s largest oil company ExxonMobil. Vertical mergers involve firms again within the same industry but at different levels of the supply chain.

Surbhi and Sandeep (2017) and Barrows (2017) also noted that mergers and acquisitions occur in waves, and Surbhi and Sandeep (2017) identified six waves; the first from 1893 to 1904, which was dominated by horizontal mergers in the US oil industry and the last 2003 to 2007 which included consolidation in the oil and gas. A combination of these mergers occurred in 1999 when British Petroleum Amoco (BP) announced the acquisition of Atlantic Richfield Company (ARCO). ARCO and BP were both present in the upstream market (horizontal merger), but ARCO was also present in the downstream (vertical merger). Surbhi and Sandeep (2017) found that the failure rate for mergers and acquisitions is relatively high, with over 60% of all mergers and acquisitions resulting in partial or complete failure. Barrows (2017) analyzed seven mergers during a 16-year time frame (1998-2013) and concluded that mergers in the oil industry are becoming less profitable, and increased returns may not always be the outcome. The use of models to optimize supply chains post-merger may increase profitability (Barrows, 2017).

Overall, there are several literature reviews related to petroleum supply chain management. Few of them focus on integrated decision-making in a strategic and tactical context. The main limitation of previous review papers is that they don’t clearly understand how uncertainty in the market could impact the integrated supply chain, including the COSC. Moreover, few authors try to address the challenges of uncertainty and risks using a quantitative approach.

Given the increasing challenges in optimizing integrated strategic and tactical decision-making in the O&G supply chain, and given the uncertainty that continues to be present at many levels in the SC, there is a need to collect and analyze the recent studies in strategic and tactical planning. This fact motivates the author to propose the literature review that provides a comprehensive framework for developing integrated strategic and tactical supply chain planning under uncertainty. Practitioners and researchers may find this thesis useful from the managerial insights to mitigate risks, particularly as part of the planning before or implementation during a merger and future research direction for supply chain planning.

2.3 Review methodology

This research presents a Systematic Literature Review (SLR) on developing mathematical models for strategic/tactical planning in the crude oil supply chain. It expands the work undertaken by Sahebi et al. (2014) by reviewing research in the context of strategic/tactical mathematical programming models within the COSC from 2014 to 2019. It also establishes a link with the study of risk mitigation strategies to tackle uncertainties in the petroleum supply chains. Mainly, the SLR answer the following research question (RQ): literature review

> ***RQ:*** *What are the main characteristics of upstream tactical supply chain planning models, and how to integrate merger decisions in supply chain models?*

To achieve this, literature was collected from academic papers published in creditable peer-reviewed journals and from internationally accredited conferences. To ensure the credibility of the material, only articles published in the scientific publishing portals were chosen (i.e., from Elsever, Springer, Taylor & Francis, or Wiley. The data sources were limited to those published between 2014 and 2019 (to extend the work of Sahebi et al., 2014) and to ensure that any subsequent analysis is relevant and current.

The keywords used in this search are: "*supply chain management*", "*logistics*", or "*network design,*" which was separately combined with "*crude oil industry*", "*petroleum industry*", or "*refinery plants*". Furthermore, the references of the studied papers and those works cited in the studied papers have served as a secondary source to search relevant literature. After careful review, a total of 31 references were selected to answer the research question (see ANNEX I). Tables 2.2 and 2.3 display the distribution of reviewed papers by journals and by year, respectively.

Table 2.2 Distribution of the reviewed papers by Journal

Journal	Number of Articles
Computer and Chemical Engineering	6
Chemical Engineering Research and Design	2
Computers & Operational Research	2
European Journal of Operational Research	1
Journal of Cleaner Production	2
Transportation Research	2
Procedia Manufacturing	1
Journal of Information and Optimization Sciences	1
International Journal of Production Research	1
International Transactions in Operational Research	1
Soft Computing	1
Applied Energy	1
Energy	2
Applied Mathematical Modeling	1
Applied Mathematical Modeling	1
Industrial & Engineering Chemistry Research	1
Oil & Gas Science & Technology	1
International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering	1
Industrial & Engineering Chemistry Research	2
Industrial Engineering & Management Science	1
IEEE Access	1

Table 2.3 Distribution of the reviewed papers by year

Year	**Number of Articles**
1988 -2013 (Sahebi et al., 2014)	**54**
2014	6
2015	2
2016	4
2017	7
2018	8
2019	4

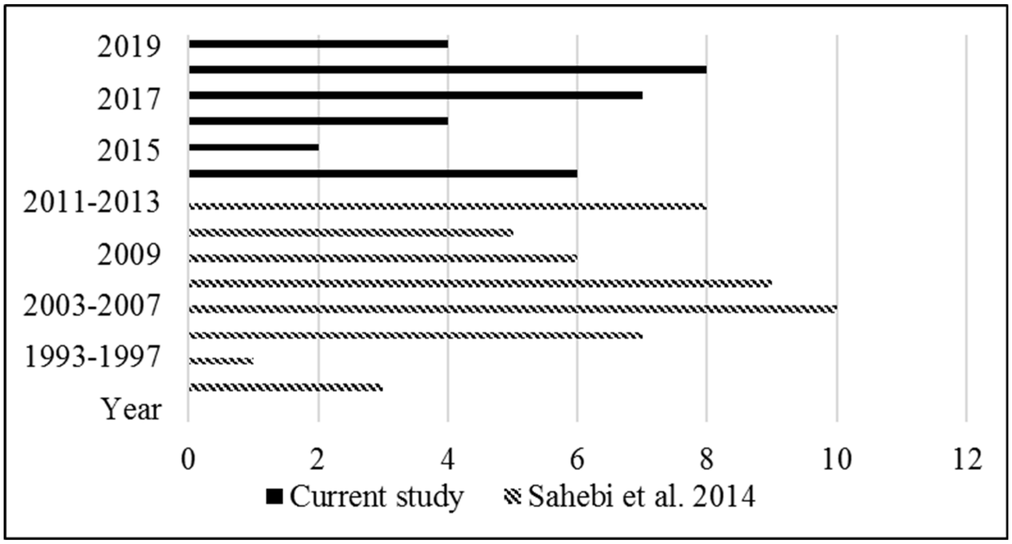


Figure 2.1 Distribution of papers per year

2.4 Taxonomy Framework

The taxonomy framework for this review is based on Huang, Lau, and Mak (2003) but specific to the COSC (Huang, Lau et Mak, 2003). It follows a similar approach to Sahebi et al. (2014). The taxonomy framework includes the following five classification criteria:

- Crude oil supply chain structure,
- Decision level,
- Design & Planning Subsystem,
- Modeling Approach,
- Purpose.

Heckmann, Comes, and Nickel (2015) identified that making well-informed decisions in the context of SCM requires risk analysis, control, and mitigation (Heckmann, Comes et Nickel, 2015). In section 2.5, we review other papers regarding new classification criteria related to risk and risk management:

- Source of the risk (Type of risk) in the supply chain: risk factors
- Risk modeling approaches
- Risk mitigation strategy

2.4.1 Crude Oil Supply Chain Structure

Attia et al. (2019) recognized that the activities of the COSC were segmented into three sectors; upstream, midstream, and downstream (Attia, Ghaithan et Duffuaa, 2019). The first sector covers exploration and production activities up to the oil terminal. The second covers transportation, processing, storage & distribution. The last sector covers the remaining activities such as manufacturing, refining, petrochemicals, wholesale, and marketing. Oil & Gas products are transported to the customers via pipelines, shipping tankers, rail, vessels, and trucks. In each segment, there is a different kind of entities that form part of the supply network:

- Upstream comprises of Wellhead Platforms (WP), Production Platforms (PP), and Crude Oil Terminals (COT).
- Midstream comprises Refinery Plants (RP) and Petrochemical Plants (PCP).
- Downstream comprises Distribution Centres / Depots (DC), Markets (M), and Customers(C)

There exist various classification schemes for the supply chain structure as defined by Beamon and Chen (2001):

- Convergent (CV), where each entity in the supply chain has only one successor but many predecessors – the upstream segment of the typical network in Figure 2.3.
- Divergent (DV), where the entity has only one predecessor but many successors – the downstream segment of the typical network in Figure 2.3.
- Conjoined (CJ) a combination of a divergent and convergent structure.
- Network (NW) a structure that cannot be classified as either CV, DV or CJ.

Huang et al. (2003) identified supply chain structures in different ways arriving at five classes of the supply chain including CV, DV, and NW plus the following additional classifications (Huang, Lau et Mak, 2003):

- Dyadic (DD) where the supply network comprises two business entities (e.g. buyer and vendor).

- Serial (SR) where the structure is represented by joining several dyadic structures.
- The structures of the reviewed papers are classified according to six structural classes (DV, CJ, and NW) as shown in Table 2.4 below along with COSC segments serviced and the entities involved. If the paper was not specifically related to a supply chain structure or was not specifically related to upstream, midstream, or downstream then it was identified as Unclassified (UC). It should be noted that the structural classes DD, SR and CV were not identified in the reviewed papers.

Table 2.4 Network Structure, Segments, and Entities

Reference (See Appendix A)	**Structures**				**Segments and Entities**							
					Upstream			**Midstream**		**Downstream**		
	DV	**CJ**	**NW**	**UC**	**WP**	**PP**	**COT**	**RP**	**PCP**	**DC**	**M/C**	**UC**
(Ye, Liang et Zhu, 2017)	X									X	X	
(Attia, Ghaithan et Duffuaa, 2019)		X			X	X	X					
(Zhang et al., 2018)			X				X	X				
(Gülpınar, Canakoglu et Pachamanova, 2014)				X								X
(Oliveira, Grossmann et Hamacher, 2014)			X					X			X	
(Kirschstein, 2018)		X								X	X	
(Azadeh et al., 2017a)					X	X	X			X		
(Moradinasab et al., 2018)			X					X			X	
(Norlund et Gribkovskaia, 2015)			X									X
(de Assis et Camponogara, 2016)			X		X	X	X					
(Saad, Elsaghier et Ezaga, 2018)		X				X	X	X		X	X	
(Khorramshahgol, Tamiz et Al-Hussain, 2014)				X								
(Chan, Shekhar et Tiwari, 2014)			X							X	X	
(Fiorencio et al., 2015)	X							X		X	X	
(Guo et al., 2018)			X									X
(Kesharwani et al., 2019)			X									X
(Tan et Barton, 2017)			X		X			X		X	X	
(Farahani et Rahmani, 2017)			X		X	X	X					
(Ghaithan, Attia et Duffuaa, 2017)			X			X		X		X	X	
(de Assis et al., 2017)			X				X	X				
(Lima, Relvas et Barbosa-Póvoa, 2018)			X				X	X		X	X	
(Dimas et al., 2018)			X				X	X				
(Assis et al., 2019)			X		X	X	X	X				
(Liu, Alhasan et Papageorgiou, 2016)			X		X	X						
(Azadeh et al., 2017b)			X		X	X	X	X				
(Beiranvand et al., 2018)			X		X	X	X	X	X		X	
(Al-Sharrah, Lababidi et Ali, 2016)			X		X	X	X	X	X		X	
(Sahebi, Nickel et Ashayeri, 2014)			X		X	X					X	
(Zhao, Rong et Feng, 2014)			X					X				
(Alfares, Murty et AlSaaty, 2019)			X		X							
(Zhang et al., 2019)			X					X		X		

2.4.2 Decision Level

Supply chain decisions can occur on strategic, tactical, and operational levels (Sahebi et al., 2014), where each has a different planning horizon. Strategic decisions focus on a relatively long horizon (e.g., upwards of 5 years). They deal with how the various entities (principle, supply chain partners, distributors, customers, and even end-users) are going to work together) and will be based on business goals, relationship strategy, people, process, and technology (Happek, 2005 (Saban, Mawhinney, and Drake, 2017). Strategic level supply chain decisions are related to the design of the supply chain network. They involve investment, facility location (or relocation), capacity expansion or reduction, the use of technology, and whether parts of the supply chain should be outsourced.

Tactical problems over a time scale of 1-2 years optimize product flows and resource utilization in manufacturing plants, distribution centers, transportation, etc. The pre-determined strategy will be refined at the tactical level as the company's environment becomes more defined; product and market demands, price, exchange rates, and other uncertain factors become more predictable and certain (Sahebishahemabadi, 2013). Tactical decisions cover discussions related to production planning, project planning, inventory management, and distribution. Operational problems are concerned with detailed decisions such as scheduling, sequencing, and transportation, with planning horizons lasting 1–2 weeks (Peidro et al., 2009). At the operational level, day-to-day problems and logistics are solved to ensure that the right product gets to the right customer on time.

This thesis focuses on the application of mathematical models at the strategic and tactical levels of design and optimization of the COSC, and the classification of COSC decisions at the Strategic and Tactical level will follow Sahebi et al. (2014) and is detailed in Table 2.5:

Table 2.5 Classification of COSC Decisions

Decision Level	Decision Type	Code
Strategic	Investment (project selection)	IVM
	Facility Location -Capacity Determination	FL CPD
	Facility Allocation	FAL
	Facility Relocation -Capacity Expansion	FRL CPE
	Technology Selection, upgrading, downgrading	TCM
	Outsourcing	OS
Tactical	Project Planning	PJP
	Production Planning Oilfield Production Planning Refinery Production Planning	PP OFPP RFPP
	Inventory Management	INM
	Distribution	DB

A paper was noted as Unclassified (UC); if it could not be assigned to a COSC decision classification. There was only one such paper, that by Khorramshahgol et al. (2014). The COSC decisions tackled by the reviewed papers are shown in Table 2.6 below.

Table 2.6 COSC Decision Types

Reference (See Appendix A)	**Strategic**							**Tactical**				
	UC	**IVM**	**FL**	**FAL**	**FRL**	**TCM**	**OS**	**PJP**	**OFPP**	**RFPP**	**INM**	**DB**
(Ye, Liang et Zhu, 2017)												X
(Attia, Ghaithan et Duffuaa, 2019)									X			
(Zhang et al., 2018)									X			
(Gülpunar, Canakoglu et Pachamanova, 2014)		X										
(Oliveira, Grossmann et Hamacher, 2014)		X										
(Kirschstein, 2018)												X
(Azadeh et al., 2017a)		X	X	X		X		X	X	X		X
(Moradinasab et al., 2018)					CPE						X	
(Norlund et Gribkovskaia, 2015)												X
(de Assis et Camponogara, 2016)											X	X
(Saad, Elsaghier et Ezaga, 2018)									X	X		
(Khorramshahgol, Tamiz et Al-Hussain, 2014)	X											
(Chan, Shekhar et Tiwari, 2014)												X
(Fiorencio et al., 2015)		X			CPE						X	
(Guo et al., 2018)											X	
(Kesharwani et al., 2019)			CPD									
(Tan et Barton, 2017)		X	CPD									
(Farahani et Rahmani, 2017)				X								
(Ghaithan, Attia et Duffuaa, 2017)										X		
(de Assis et al., 2017)									X			
(Lima, Relvas et Barbosa-Póvoa, 2018)										X		
(Dimas et al., 2018)												X
(Assis et al., 2019)												X
(Liu, Alhasan et Papageorgiou, 2016)			CPD									
(Azadeh et al., 2017b)		X	X	X		X		X	X	X		X
(Beiranvand et al., 2018)									X	X		
(Al-Sharrah, Lababidi et Ali, 2016)									X	X		
(Sahebi, Nickel et Ashayeri, 2014)			X	X		X						
(Zhao, Rong et Feng, 2014)										X		
(Alfares, Murty et AlSaaty, 2019)			X							X		
(Zhang et al., 2019)												X

2.4.3 Design and Planning Subsystems

The three levels of decisions (i.e., strategic, tactical, and operational) can be used to optimize the design and planning of the crude oil supply chain model subsystems, including field development, crude oil transportation, refinery planning, and product distribution (Shah, li and Ierapetritou, 2010). A literature review of the strategic and tactical decisions related to the design and planning of the crude oil supply-chain considers the following classes:

- Oilfield Development (i.e., oilfield infrastructure investment and planning),
- Oil Transformation planning,
- Transportation of crude oil, and
- Distribution planning.

Oilfield development is a costly and complex undertaking for the oil company that needs careful analysis at a strategic level, considering the projected wells, platforms, and connecting pipeline networks. Many papers deal with oilfield development at strategic and tactical levels – refer to Iyer, Grossmann, Vasantharajan, and Cullick (1998) and Haugland, Hallefjord, and Asheim (1988) as typical papers on the subject. At the strategic level, most articles are concerned with where the various facilities are located or whether these facilities should be changed due to capacity expansion or reduction.

The **oil transformation** process from crude oil to final intermediate products is complex and involves crude oil unloading, transforming, and blending intermediate and final products (Bengtsson and Nonås, 2010). Many articles are concerned with transformation planning, but Escudero, Quintana, and Salmeron (1999) are well worth mentioning.

This thesis used linear programming techniques to tackle the uncertainties involved in the transformation process, including spot supply cost and product demand. Strategic crude oil logistics involved in **transporting** the crude oil from the wellhead to the refinery (or customer storage facility) are important within the crude oil supply chain. Many papers exist that tackle crude oil transportation from a strategic standpoint, including Neiro and Pinto (2005), who developed an integrated model for the refinery supply chain as well as Iakovou (2001) and Chen, Lu, and Qi (2010), who both studied pure crude oil transportation models.

Distribution planning is associated with transporting refined products from the refinery to the customers (e.g., petrol stations, airports, or retailers). An oil company is involved in both the upstream and downstream sectors. To obtain a combined optimized network, it is necessary to consider the distribution planning with the crude oil logistics.

A number of the papers (around 25%) considered at least two kinds of these classes. Where a paper could not be classified into one of the above subsystems, it was classified as 'other.' There were four such papers; Zhang et al. (2018), Khorramshahgol et al. (2014), Guo et al. (2016), and Kesharwani et al. (2019).

Table 2.7 Classes of Design and Planning Subsystems

Reference (see ANNEX I)	Oilfield Development	Crude Oil Transportation	Transformational Planning	Distribution	Other
(Ye, Liang et Zhu, 2017)				X	
(Attia, Ghaithan et Duffuaa, 2019)			X		
(Zhang et al., 2018)				X	
(Gülpunar, Canakoglu et Pachamanova, 2014)					X
(Oliveira, Grossmann et Hamacher, 2014)		X			
(Kirschstein, 2018)		Pipeline			
(Azadeh et al., 2017a)	X	X			
(Moradinasab et al., 2018)	X	X			
(Norlund et Gribkovskaia, 2015)				X	
(de Assis et Camponogara, 2016)				X	
(Saad, Elsaghier et Ezaga, 2018)			X		
(Khorramshahgol, Tamiz et Al-Hussain, 2014)					X
(Chan, Shekhar et Tiwari, 2014)		X			
(Fiorencio et al., 2015)				X	
(Guo et al., 2018)					X
(Kesharwani et al., 2019)					X
(Tan et Barton, 2017)	X	X		X	
(Farahani et Rahmani, 2017)	X			X	
(Ghaithan, Attia et Duffuaa, 2017)			X	X	
(de Assis et al., 2017)		X			
(Lima, Relvas et Barbosa-Póvoa, 2018)				X	
(Dimas et al., 2018)				X	
(Assis et al., 2019)		X			
(Liu, Alhasan et Papageorgiou, 2016)	X				
(Azadeh et al., 2017b)	X	X	X		
(Beiranvand et al., 2018)		X	X		
(Al-Sharrah, Lababidi et Ali, 2016)	X	X	X		
(Sahebi, Nickel et Ashayeri, 2014)	X				
(Zhao, Rong et Feng, 2014)			X		
(Alfares, Murty et AlSaaty, 2019)	X				
(Zhang et al., 2019)				X	
Percentage of papers	30%	33%	20%	30%	13%

2.4.4 Modeling Approach

Optimizing these economic networks involves various solution methodologies and techniques, including Linear and non-Linear Programming, Multi-criteria Goal Programming, Heuristics, and Metaheuristics. The classification of the modeling approach will follow Mula et al. (2010)(Mula et al., 2010). Sahebi et al. (2014) adapted the same classification schema and is detailed in Table 2.8.

Table 2.8 Modeling Approach Classifications

Modeling Approach	**Detail**	**Code**
Linear Programming	Linear Programming	LP
	Mixed-integer / linear programming	MLP
Non-linear Programming	Non-linear Programming	NLP
Non-Linear Programming	Mixed integer /integer non-linear programming	MNLP
Mult- single objective function	Single-objective function	SOF
	Multi-objective function	MOF
Deterministic or uncertain variables	Deterministic Programming	DP
	Stochastic Programming	SP
	Fuzzy Mathematical programming	FMP

2.4.5 Purpose

The purpose of a supply chain model can be qualitative or quantitative performance-based. This thesis will follow the approach proposed by Sahebi et al. (2014) and focus on quantitative performance measures with classification as follows. The purpose 'Others' for the supply chain model is used to capture all other purposes except cost minimization, profit maximization and effective risk management. It includes those related to cost (i.e. revenue maximization, return on investment maximization), customer service (i.e. maximization of flows, maximization of service level), etc.

Table 2.9 Purpose of SC Model

Purpose	Code
Cost Minimization	CM
Profit Maximization	PM
Effective Risk Management	ERM
Others*	Others

Table 2.10 Modeling Approaches, Solution Technique, and Purpose of the Models

Reference	Linear		Non-linear		Objective		Analytical Model			Purpose			
(See Appendix A)	LP	MLP	NLP	MNLP	SOF	MOF	DP	SP	FMP	CM	PM	ERM	Others
(Ye, Liang et Zhu, 2017)		X			X		X						X
(Attia, Ghaithan et Duffuaa, 2019)		X				X	X			X			X
(Zhang et al., 2018)		X			X		X			X			
(Gülpınar, Canakoglu et Pachamanova, 2014)								X					X
(Oliveira, Grossmann et Hamacher, 2014)						X		X					X
(Kirschstein, 2018)								X					X
(Azadeh et al., 2017a)				X		X			X		X		
(Moradinasab et al., 2018)		X				X			X		X		X
(Norlund et Gribkovskaia, 2015)		X			X					X			X
(de Assis et Camponogara, 2016)		X			X		X			X			
(Saad, Elsaghier et Ezaga, 2018)					X					X			
(Khorramshahgol, Tamiz et Al-Hussain, 2014)						X				X			
(Chan, Shekhar et Tiwari, 2014)						X				X			X
(Fiorencio et al., 2015)		X			X					X			
(Guo et al., 2018)								X		X			
(Kesharwani et al., 2019)		X				X				X			X
(Tan et Barton, 2017)		X			X			X			X		
(Farahani et Rahmani, 2017)		X			X						X		
(Ghaithan, Attia et Duffuaa, 2017)		X				X				X	X		X
(de Assis et al., 2017)		X	X			X							X
(Lima, Relvas et Barbosa-Póvoa, 2018)					X			X			X		
(Dimas et al., 2018)		X			X					X			
(Assis et al., 2019)				X	X								X
(Liu, Alhasan et Papageorgiou, 2016)		X			X					X			
(Azadeh et al., 2017b)				X		X					X		X
(Beiranvand et al., 2018)					X						X		
(Al-Sharrah, Lababidi et Ali, 2016)	X					X				X		X	
(Sahebi, Nickel et Ashayeri, 2014)	X					X					X		X
(Zhao, Rong et Feng, 2014)				X	X						X		
(Alfares, Murty et AlSaaty, 2019)	X				X					X			
(Zhang et al., 2019)		X											

2.5 Supply Chain planning under uncertainty

The following section of this literature review looks at the modeling and optimizing supply chain performance under uncertainty. Amor and Ghorbel (2018, p.141) recognized that the COSC is inflexible and complicated. Sahebi et al. (2014, p.57) identified it as one of the most complex networks (Sahebi et al., 2014, p.57), where this complexity results in different types of risks, which need to be considered when designing, planning, and operating the SC (Amor and Ghorbel, 2018, p.141).

The first section of the literature review focuses on the risks in the upstream supply chain, which comprises crude oil exploration, production, and transportation (Fernandes, Barbosa-Póvoa et Relvas, 2009). The risks to any supply chain are well documented and can include delays, disruptions, forecast inaccuracies, systems breakdowns, intellectual property breaches, procurement failures, inventory problems, and capacity issues (Chopra et Sodhi, 2004) (Chopra and Sodhi, 2004, p.53). In general, supply chain risk can be categorized as either operational risks or disruption risks (Tang, 2006) (Tang, 2006, p.482).

Operational risks relate to inherent uncertainties in the supply chain such as customer demand, supply, and costs, and disruption risks relate to disruptions caused by natural and man-made disasters, economic crises, or events such as the recent COVID-19 pandemic. Chopra and Sodhi (2004) provide an analysis of and mitigation strategy for disruption risks, which can seriously interrupt or delay material, information, and cash flows, any of which can damage sales and/or increase costs. Operational risks in the upstream supply chain are related to uncertainties in the oil and gas supply chain. Christopher and Peck (2004) identified five sources of risk; process and control (risks internal to the company), demand and supply (risks external to the company but internal to the network), and environmental (external to the network) (Christopher et Peck, 2004). Process risk in the context of the upstream supply chain includes the reliability of supporting transport, communication, and infrastructure (i.e., pumping and compression systems). Control risks relate to the setting of production rates from individual wells as well as daily production targets. Capolei, Foss and Jørgensen (2015, p.215) identified that, for new wells, these risks are related to the high uncertainty in seismic data, core samples, and borehole logs (Capolei, Foss et Jørgensen, 2015). Svensson (2000) identified that demand risks are related to downstream supply chain activities, including market risk due to price instability and market fluctuations (Svensson, 2000). Risk can also be instigated from demand shocks triggered by events such as the global economic crises (Jessen, 2008). Demand-side risks can also include disruption to transportation routes.

Fazli et al. (2015, p.463) identified that supply risks are associated with the upstream side of the supply chain and are risks related to purchasers, suppliers, supplier relationships, and supply networks (Fazli, Kiani Mavi et Vosooghidizaji, 2015). These risks include exploration and drilling risk, production risk, and product quality risk. The inherent nature of exploration and drilling involves significant risk due to the high costs and the geological, engineering, and mechanical uncertainties involved in the process (Fazli, Reza and Vosooghidizaji, 2015, p.463). Production risks include fires or explosions at storage facilities. Fires on large storage tanks (containing more than 100,000 m3 of crude oil) can have a catastrophic consequence on the SC infrastructure (Shebeko et al., 2007).

The following section of this literature review looks at the papers addressing strategic and tactical aspects of COSC that explicitly model uncertainties. As we mentioned, three main modeling approaches are being used to manage uncertainty in existing COSC models: stochastic, robust, and fuzzy methods. In Table 2.11, below, we analyzed recent papers from 2014 to 2021 to overview the most critical uncertainties among crude oil supply chains and mainly to understand what types of mitigation strategies have been proposed in the previous literature to cope with these supply chains risks. As shown in Table 2.11, almost 80% of the papers consider the uncertainty related to the demand for oil products, is the most frequent source of uncertainty addressed in COSC. While over a third of the models tackle supply uncertainties (Gulpinar et al. 2014; Tong, Gong, Yue and You, 2014a; Tong, Gong, Yue and

You, 2014b; Tong, Gong, Yue and You, 2014c; Tan et al. 2017), very few of them have focused on costs among supply chains (Tong et al. 2014a; Lima et al. 2021).

Moreover, most of the uncertainties related to costs are restricted to the production activities (Azadeh et al., 2017; Wang et al., 2019). The modeling approaches that the authors use to consider COSC risks are mainly stochastic programming (57.1%), fuzzy technique (28.6%), and robust optimization (14.3%). Regardless of the type of risk considered, most of the research in this sector is still focused on the economic aspect of supply chain operations with cost minimization (64%) or profit maximization (36%). Among these, very few models address environmental or social aspects of COSC (Azadeh et al., 2017; Moradinasab et al., 2018).

From a managerial insight perspective, it is interesting to denote that some of the mitigation strategies used to cope with COSC risks are recurrent. The actions required can be highly strategic and very costly, for example, the location of new facilities such as refineries, warehouses, hubs, or depots (Guo et al. 2016; Xie and Huang. 2018; Zhang et al., 2019; Lima, Relvas and Barbosa-Póvoa, 2021) or setting new pipelines' connections (Moradinasab et al. 2018; Wang, Liang, Zheng, Yuan and Zhang, 2019). We also notice investments at the facility level, such as upgrading infrastructures or equipment (Tong et al. 2014b; Tong et al. 2014c; Tan et al. 2017) or expanding the capacities of existing sites or storage tanks (Azadeh et al. 2017; Moradinasab et al. 2018; Lima et al. 2021). Indeed, some of the authors underline that these types of actions can be successfully implemented only in the case of an optimized long-term investment strategy (Gulpinar et al. 2014; Oliveira et al. 2014; Tan et al. 2017).

Table 2.11 Mathematical optimization models under uncertainty

Papers under study	Uncertainty targets	Modeling approach			Objective Function	Critical decisions for mitigation strategy
		R	S	F		
(Gülpınar, Canakoglu et Pachamanova, 2014)	Supply	×			Max. returned profits	Adjust portfolio investments strategy
(Oliveira, Grossmann et Hamacher, 2014)	Demand		×		Min. supply chain costs	Network investments, inventory levels & unmet demand management
(Tong et al., 2014)	biomass availability, fuel demand, crude oil prices, technology evolution		×		Min supply chain costs	Timing of the installation for pre-conversion facilities, bio-refineries, and hydro-treating units in petroleum refinery. Biomass supply management over planning horizon
(Tong, You et Rong, 2014)	supply and demand	×			Min. supply chain costs	Upgrading facilities, bio-refineries, and petroleum refineries & harvesting decisions
(Guo et al., 2018)	Well location		×		Min. supply chain costs	Selection of oilfield warehouse location
(Tan et Barton, 2017)	supply, demand, and prices		×		Max. expected NPV	Optimizing investment in the various types of infrastructure and operating decisions (purchasing, selling or converting resources to higher quality products)
(Azadeh et al., 2017a)	production costs, refineries' capacity, and consumption rate of crude oil for each product			×	Max. NPV and Min. environmental damage (eco indicator 99)	Capacity development of existing facilities & additional facility settings (wells and production storage)
(Lima, Relvas et Barbosa-Póvoa, 2018)	oil price and demand		×		Max. expected profits	Flows and inventory management
(Moradinasab et al., 2018)	price and demand for refinery products			×	Max. profits, Max. job creation, Min. pollution	Installation and capacity expansion of facilities and pipelines & inventory management
(Xie et Huang, 2018)	Biofuel demand		×		Min. supply chain costs	Selection of location and capacities of new refineries & existing refinery expansions
(Wang et al., 2019)	oil demand and production		×		Min. supply chain costs	New pipeline routes setting
(Zhang et al., 2019)	cities' demand, refineries' production, and depots' failure		×		Min. supply chain costs	Setting pipelines, hub cities, and depots & transportation mode selection
(Lima, Relvas et Barbosa-Póvoa, 2021)	All network costs and refined products' demand			×	Min. supply chain costs	Selection of warehouse locations, storage tanks capacities, and refining levels

R: Robust programming; S: Stochastic programming; F: Fuzzy numbers; NPV: Net Present Value

However, among the techniques used to cope with uncertainty and mitigate COSC risks, we also find tactical decisions such as inventory level management (Lima et al. 2018; Moradinasab et al. 2018), dealing with unmet demand quantities (Oliveira et al. 2014), purchasing and selling management or petroleum product conversion into higher quality products (Tong et al. 2014b; Tong et al. 2014c; Tan et al. 2017). Overall, the consideration of uncertainties in COSC design and planning is critical and failing to include it may very well lead to poor performance scenarios in the future. However, we can see that the literature covering this topic is still very scarce. There are opportunities to develop more advanced models that will include uncertainties in the COSC sector, mainly when some events like a merger occur and increase the supply chain risks.

2.6 Gaps analysis and contributions

Even though supply chain management and mergers are two research topics well established in the literature, the link between the two areas still requires further research in specific areas such as oil and gas. In the past, this sector observes different mergers. For instance, the collapse in oil price and a global economic downturn have led to mergers between oil companies at both local and global levels. Two offshore oil companies in UAE merged (2017-2019) to form a combined entity. Also, the merger of Exxon and Mobil (1998-2000) created the world's largest oil company ExxonMobil. Achieving the full potential of the calculated or perceived synergies is not always possible. For example, the acquiring company may have been too optimistic with its estimates of the potential cost savings, or the projected post-merger sales growth cannot be realized.

Therefore, this research is the first to present a mathematical framework for modeling and evaluating supply chain synergy after the horizontal merger in the oil and gas supply chain. The developed framework enables the decision-makers to fully investigate the synergies at different levels of the upstream oil and gas supply chain concerning the goals of operational efficiency at a time of reduced and less stable demand, as is being faced by the industry, as well as at a time of a pandemic. The unstable market and oil prices will continue in the future (Rizvi et Itani, 2021), and supply chain mergers and acquisitions will increase to create more collaborative ecosystems; hence, the impact evaluation of mergers is critical.

The proposed study considers site locations, supply chain structure, technologies, well capacities, costs, etc. The SC network comprises water injection wells, oil production, gas wells, riser platforms, separation plants, water injection plants, gas dehydration and condensate treatment plants, and storage facilities. The tactical problem is formulated using a MILP model, where tactical decisions include contractual investment decisions, capacity allocation, and facility operations. In contrast, tactical decisions include extraction, processing, transportation, and storage decisions.

Uncertainty is present in the objective function (shared services and processing costs) and the constraint (crude oil demand). The main objective is to minimize the total cost of the supply chain. A real-world case study from the oil and gas industry in the Middle East region is used to validate the model. The study will show the model's value as a decision tool to aid decision-makers in understanding where the effort should be concentrated to achieve the highest return after a horizontal merger.

2.7 Conclusion

Overall, considering uncertainties in COSC planning is critical, and failing to include it may lead to poor performance scenarios in the future. However, we can see that the literature covering this topic is still very scarce. Therefore, there are opportunities to develop more advanced models that will include uncertainties in the COSC sector, mainly when some events like mergers occur and increase the supply chain risks.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

A model is a simplified representation of a real system (Renard, Alcolea et Gingsbourger, 2013). A mathematical model describes a system by variables and equations that establish the relationship between the variables and prevailing parameters. The mathematical modeling process is outlined in Figure 3.1.

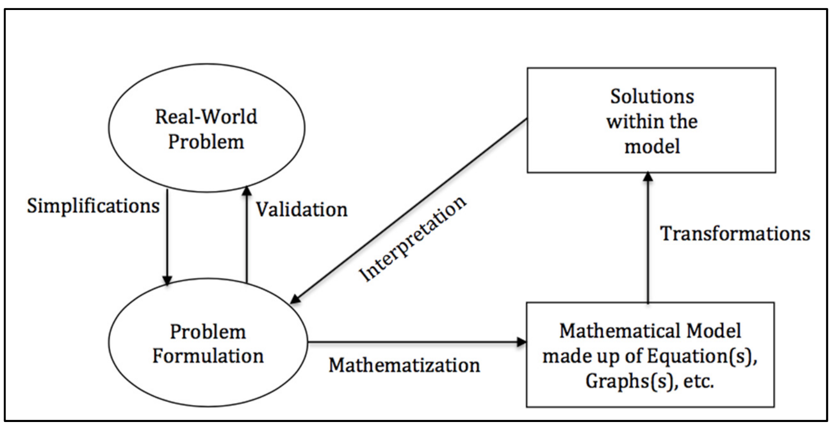


Figure 3.1 Mathematical modeling process

A mathematical model is developed for a real problem by making assumptions and simplifications of the process. The mathematical model then provides mathematical results, which are interpreted and validated against real-world situations (Şen Zeytun, Çetinkaya et Erbaş, 2017). Mathematic models can be deterministic or stochastic. Deterministic models have known parameters and provide a unique solution for certain parameters and initial conditions. Stochastic models use random variables or probability distributions rather than a single value and yield many equally likely solutions (Renard, Alcolea et Gingsbourger, 2013).

3.2 Research Method

A mathematical model uses mathematical symbols, functions, and relationships to describe the objectives and constraints of a problem. The conditions include an Objective Function, limited resources, linearity in the relationship between the Variables and the objective function, and Constraints (Shapiro, 2007). If the relationships are linear them the mathematical model is a linear program or linear programming problem. Linear Programming (LP) is a mathematical technique that can arrive at the optimal solution to a specific problem. Oil Companies have used LP since the 1940s for optimizing product mix from multiple sources or multiple sites (Nash, 2000). It grew in popularity after George Dantzig created a simplex algorithm to solve linear problems for planning and decision-making.

The *Objective Function* is a mathematical equation with a numerical value that typically represents cost or production, which needs to be minimized (in the case of cost) or maximized (in the case of production). *Decision Variables* usually represent inputs that can be controlled to alter the objective function. The goal is to determine the value of the variables that maximize or minimize the objective function. *Constraints* are the limitations imposed by the system under investigation. Constraints can be 'soft' constraints using inequalities (≤ or ≥) or 'hard' constraints using equalities (Glover et al., 1992). Bounded variables (for example, production capacity) are $x_j \leq u_j$ and are also constraints. Some variables can take positive or negative values, while others might be restricted to non-negative values. A general linear program for the decision variables $x_1, x_2, \dots, x_n$ is in the following form:

Maximize or Minimize $\quad Z = c_0 + c_1 x_1 + c_2 x_2 \dots\dots + c_n x_n$

Subject to:

$$a_{i1} x_1 + a_{i2} x_2 + \dots + a_{in} x_n \begin{array}{c} \leq \\ \geq \\ = \end{array} b_i \qquad i = 1, \dots, m$$

$$x_j \begin{cases} \geq 0 \\ \gtrless 0 \end{cases} \quad j = 1, \dots, n$$

The data in this linear program consists of c_j *(j= 1, …., n)*, b_i *(i = 1, …., m)* and a_{ij} *(I = 1, …., m, j = 1, …., n)*, where c_j is the cost coefficient of x_j and b_i is known as the right-hand-side of equation *i*.

3.3 Techniques for managing uncertainty in optimization models

Real-world problems almost invariably include parameters, which are unknown when a decision has to be made (Shapiro et Philpott, 2007). As mentioned in the introduction to this thesis, the oil industry is subject to uncertainties due to oil pricing and demand, particularly during the COVID-19 pandemic. There has been a significant increase in the practical implementation of solutions that produce realized cost savings and take advantage of increased computational power (Marla et al., 2020). There are several techniques for managing uncertainties in optimization models, as shown in Figure 3.1.

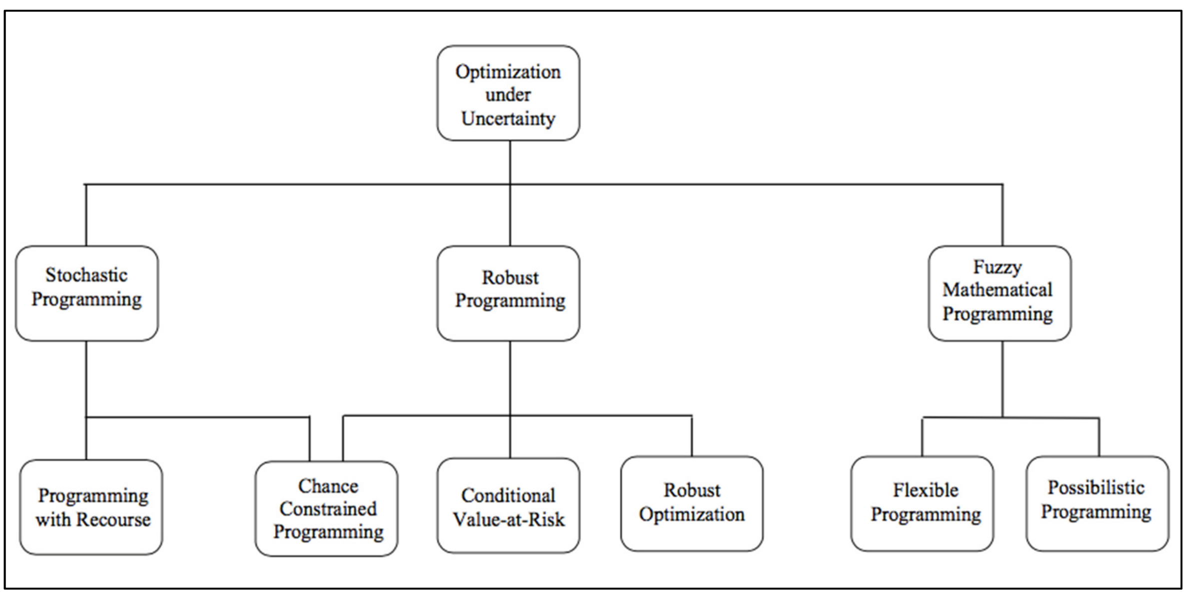


Figure 3.1 Approaches to optimization under uncertainty
Taken from Marla et al. (2020)

When the parameters are uncertain but assumed to lie in some set of possible values, a solution can be found that is feasible for all possible parameter choices and optimizes a given objective function (Shapiro et Philpott, 2007).

3.3.1 Stochastic programming

Stochastic programming models are used where probability distributions governing the data are known or can be estimated. Under the standard two-stage linear program (termed stochastic programming with recourse), the decision variables are divided into two sets; the *first stage* variables have to be decided before the actual realization of the uncertain parameters. The *second stage* variables are construed as corrective measures or recourse against any infeasibility arising from a particular completion of uncertainty once random events present themselves during the first stage. Due to uncertainty, the second stage cost is a random variable. The objective is to select stage 1 variables to minimize the total cost (stage 1 and stage 2) (Sahinidis, 2004).

3.3.2 Fuzzy mathematical programming

Fuzzy mathematical programming also addresses optimization problems under uncertainty by considering random parameters as fuzzy numbers and treating constraints as fuzzy sets (Sahinidis, 2004). There are two main types of fuzzy programming; flexible programming, which deals with uncertainties on the right-hand side of the equation, whereas possibilistic programming recognizes uncertainties in the objective function coefficients and constraint coefficients (Sahinidis, 2004).

3.3.3 Robust Programming

There are three main practical approaches employed to modeling uncertainty to obtain robust solutions; Chance Constrained Programming, Robust Optimization, and conditioned Value at Risk (Marla et al., 2020).

Chance Constrained Programming (CCP) is a type of stochastic programming approach developed in the late 1950s by Charnes and Cooper (1959). It is used to deal with uncertainty on the constraints $Ax \leq b$ in the nominal problem (Charnes et Cooper, 1957). CCP is also termed Probabilistic Stochastic Programming. In the second stage of the stochastic process, the focus is on the system's ability to meet feasibility in an uncertain environment. The system's reliability is expressed as a minimum requirement on the probability of satisfying constraints (Sahinidis, 2004).

Conditional Value at Risk (CVaR) has been developed as a risk management tool in the finance and insurance industries. Risk measures have a crucial role in optimization under uncertainty, especially in coping with the losses incurred and extending the well-known Value-at-Risk (VaR) measure (Rockafellar et Uryasev, 2002).

Robust Optimisation (RO) was first suggested by Soyster (1972) when he developed a significantly different strategy for defining the feasible region in a convex mathematical programming problem (Soyster, 1972). Others have extended it, including Ben-Tal and Nemirovski (1998; 1999) and Bertsimas and Sim (2001). Under the RO approach to solving linear optimization problems with uncertain data, a suboptimal solution is accepted for the *nominal values* of the data to ensure that solution remains feasible and near-optimal when the data changes (Bertsimas et Sim, 2004) (Bertsimas and Sim, 2001).

This study uses a stochastic approach to optimize costs post-merger of an upstream supply chain under uncertainty related to demand and shared service costs. LINGO software was used to build, verify and validate the model and run scenarios to investigate SC performance. The proposed mathematical model for the upstream COSC is divided into two parts; objective function and constraints. The objective function attempts to optimize the oil company's resources by minimizing the total costs, including shared service costs, extraction costs, processing costs, inventory costs, transportation costs, and penalty costs at the oil depot. A set of linear constraints is added to the model to account for transportation capacity, capacity constraints at the various intermediary processing facilities, and inventory balance and capacity constraints at the oil depots.

3.4 Detailed methodology

The main objective of this research is to propose a tactical planning tool for Oil &Gas supply chain that help decision-maker in the evaluation of the impact of uncertainty in cost after a merger. Consequently, we propose a four-step methodology that follows the development of different analytical models to answer the research questions introduced before.

The **first step** presented in chapter 3 investigates the literature of strategic/tactical from a modeling perspective to identify the research gaps, opportunities, modeling issues, system definition, and delimitations. A systematic literature review using qualitative and quantitative methods is developed. The main scope is for mathematical models for the strategic and tactical supply chain in the petroleum sector to capture the relevant system components by following these sub-steps: the papers were selected based on applied mathematics, management, and engineering journals also, based on chosen keywords, with a time frame of 10 years covered from 2010 to 2019 period to get a total of 158 references by using the English language. After that, we excluded the papers that did not fulfill our research to come up with 23 references.

The research methodology consists of a structured review covering sustainable supply chain planning models in petroleum industry research. It starts by identifying keywords based on which papers are selected using the citation method (Pittaway et al., 2004). SLR is a valuable tool that can help the researcher comprehend diversity regarding knowledge and historic development regarding a specific research topic. Moreover, a literature review helps the researcher identify further research opportunities by analyzing research gaps in the existing knowledge. The systematic content analysis process selected to develop the required methodology of this work consists of the following steps (Junior et Godinho Filho, 2010; Krippendorff, 1980): material collection, descriptive analysis, category selection, material evaluation. As a result of this step, we have to systematically investigate the selected papers to get the main finding. A taxonomy framework that includes the main component guides us to structure our new model (Purpose of the study, performance, Supply chain structure, decision phase, modeling approaches, horizon, applications, and environmental evaluation). Further, the selected peppers were analyzed to identify the research gaps, opportunities, modeling issues, and future research.

In the second step, a MILP model is introduced to evaluate the supply chain performance based on cost drivers linked to mergers decisions. Also, the first model focuses only on the Oil supply chain. The model was validated using a real case study from a Middle East country. The main assumptions are defined. Therefore, we add the parameters and identify the decisions, constraints, criteria, objective functions, and equations to obtain the MILP model. This step aims to obtain the **Baseline model** before the merger process. The main goal of this model is to help the decision-makers identify the decisions related to the production flow between nodes, production capacities at each level, and how to satisfy the demand. Solving and running the model with different demand and cost scenarios help to see the SC dynamic and validate the model from an economic perspective.

A second mathematical model (model 2) is proposed **in step 3** to evaluate how much the economy of scope and the economy of scale favorably impact potential mergers. Thus, as a third step to address the tactical planning of upstream Crude Oil and Gas Supply Chain subject to demand and shared services cost uncertainties, the problem is formulated as a mixed-integer linear programming (MILP) model. Also, it determines the budget and the efficient implementation of operational strategies at shared services and the production and processing of oil and gas. A real case example from the oil and gas industry in the Middle East region is used to validate the model. Three (3) cases are analyzed: merger under economies of scale, merger under economies of scope, and merger under the joint economies of scope and scale.

Finally, **in step 4,** we propose a stochastic optimization model (model 3) for tactical planning of COSC under cost uncertainty. The model formulation considers a multi-echelon supply chain with a multi-product and multi-period setup. It also incorporates backorder and inventory costs. We illustrate how our model directly applies to supply chain planning. Numerical results based on the same data for the case show the impact of cost uncertainty on supply chain planning decisions and synergy gains. We also measure the value of modeling uncertainty against deterministic planning (model 2).

3.5 Summary

This chapter represents a brief overview of the nature of the study. It starts with providing general information about the different techniques used in the methodology. Finally, a detailed methodology is presented to explain the different steps followed to answer the research questions.

CHAPTER 4

MODELLING THE UPSTREAM COSC: A MATHEMATICAL APPROACH

4.1 Mathematical formulation

In this study, a mathematical model is developed to optimize the upstream COSC total cost. The model will allow a company to understand the impact of uncertainty in demand and cost parameters after a merger. Tactical decisions are included in the model. The supply chain structure and the model development steps are described in the following subsections.

4.1.1 Problem definition

The tactical supply chain planning of the upstream supply chain in the oil and gas sector is considered in this study. The supply chain can be complicated, but for the sake of this study, we assume that the upstream COSC is composed of four (4) types of infrastructures, namely production facilities, processing plants, gathering centers, and demand terminals. Figure 4.1 depicts a schematic representation of the upstream supply chain network.

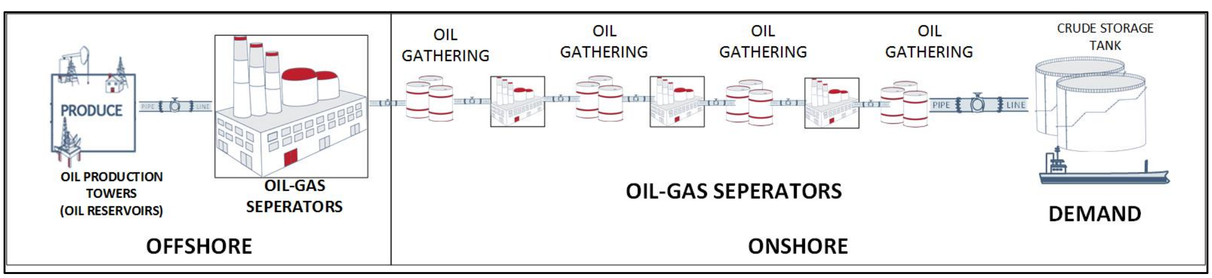


Figure 4.1 Upstream COSC supply chain structure

The supply chain of crude oil starts from offshore oil reservoirs and is connected to a set of Gas / Oil separation plants. The crude oil is then transported to the onshore oil processing plant, which comprises two further separation stages. The stabilized crude oil is then transported by pipeline to a terminal made of crude storage tanks. The crude oil is used to satisfy some local refineries' demand and satisfy the international market. Several assumptions are stated to develop the mathematical model: demand is known, and deterministic, the supply chain structure (locations of oil reservoirs, processing plant) is known and not modified after the merger decision. The capacities of all facilities are also known, the investment cost for shared services are known at each echelon but present some uncertainty after the merger process, and operational costs (processing costs) are also given. Given the data and the information related to the problem described, the objective of the MILP model is to minimize the total cost by defining the best tactical planning for oil production and transportation to deliver the demand of the local and international markets.

4.1.2 Model elements

Considering the problem described in the previous section, the MILP model involves the sets, parameters, and variables summarized as follows.

Sets/Indices

o, d: all nodes for oil processing ;

R: a set of oil reservoirs (production)

P^n : set of oil processing plants at each stage $n \in \{1,2,3\}$; H : set of oil gathering centers

S : set of spheroids plants for oil processing, E : set of strippers for oil processing

L : set of local oil depots; *T*: set of time periods

For notational convenience, denote by $O = R \cup P^n \cup H \cup S \cup E$ and $D = P^n \cup H \cup S \cup E \cup L$ the sets of possible origins destinations for crude where $n \in \{2,3\}$.

Cost, Capacity and Demand parameters

DR **:** depletion rate of crude oil

SSC_o **:** fixed cost for shared services cost at the facility $o \in O = R \cup P^n \cup H \cup S \cup E$

OEC_{tod} : extraction cost of crude oil during time period *t,* \$/MMbarrel; where $o \in R, d \in P^1$

PCO^1_{tod} : processing cost of crude oil at node *d* during period *t* where $o \in R, d \in P^1$

PCO^{n}_{tod} : processing cost of crude oil at node *d for stage n* during period *t* where $o \in H, d \in P^n$

PCO^{S}_{tod} : processing cost of crude oil at spheroids during period *t* where $o \in H, d \in S$

PCO^{E}_{tod} : processing cost of crude oil at strippers during period *t* where $o \in H, d \in E$

$\mathrm{IC}^{\mathrm{O}}_{to}$: inventory holding cost of crude oil during period *t* where $o \in H \cup L$

$\mathrm{WC}^{\mathrm{O}}_{to}$: Penalty cost for producing oil below the demand at node $o \in L$ during period *t*.

$\mathrm{TC}^{\mathrm{O}}_{tod}$: Transportation cost per unit of crude oil during time period *t* where $p \in P, q \in Q$

RO_o : amount of reserves in oil reservoir $o \in R$, MMbarrel;

C^{H}_{o} : capacity of facility $o \in O = R \cup P^n \cup H \cup S \cup E$ for the whole horizon

PO^{n}_{tod} : yield of crude oil liberated during time period t at node $o \in R \cup H$ transported to node $d \in P^n$, Percentage

PO^{S}_{tod} : yield of crude oil liberated during time period *t* at node $o \in H$ transported to node $d \in S$, Percentage

PO^{E}_{tod} : yield of crude oil liberated during time period t at node $o \in H$ transported to node $d \in E$, Percentage

CO^{n}_{td} : capacity of oil processing during period *t* at node $d \in P^n$ and $n \in \{1,2,3\}$,

CRL^{O}_{tod} : capacity of the route linking node $o \in O$ to node $d \in D$ for crude oil, MMbarrel

COG_{td} : capacity at oil gathering center $d \in H$

CO^{S}_{td} : capacity of spheroid during period *t* at node $d \in S$, MMbarrel

CO^{E}_{td} : capacity of strippers during period *t* at node $d \in S$, MMbarrel

CO^{L}_{td} : capacity of oil depot during period *t* at node $d \in S$, MMbarrel

DO_{td} : demand for oil (MMbarrel)

Decision variables

Z_o: binary variable =1 if the shared service is activated at facility $o \in O = R \cup P^n \cup H \cup S \cup E$

X_{tod} : amount of crude oil transported in time period *t* from node *o* to *node d, MMbarrel; where* $(o,d) \in (R,P^1) \cup (H,P^n) \cup (H,S) \cup (H,E)$ and $n \in \{2,3\}$.

IO_{to}: inventory of crude in time period *t* above the demand at node o, MMbarrel; where $o \in H \cup L$.

IO_o^0: initial inventory of crude in time period *t* above the demand at node o, MMbarrel; where $o \in H \cup L$

BO_{to}: amount of backorder of crude oil at node $o \in L$ during period *t*, MMbarrel .

4.1.3 Model formulation

The proposed mathematical model for upstream COSC is divided into two parts: objective function and constraints. The objective function (*Z*) attempts to optimize the petroleum organization's resources by minimizing the total cost. The following equations define the mathematical formulation of the objective function: $Z = \min\{C^O\}$ the total oil production and processing cost through the upstream supply chain until the local depots.

$$\begin{aligned}
C^O = & \underbrace{\sum_{o\in R\cup P^n \cup H\cup S\cup E} SSC_o * Z_o}_{\text{Shared services cost (oil)}} \underbrace{\sum_{t\in T,o\in R,d\in P^1} OEC_{tod} * X_{tod}}_{\textit{Extraction}\text{ cost (oil reservoir)}} + \underbrace{\sum_{t\in T,o\in R,d\in P^1} PCO^1_{tod} * X_{tod}}_{\text{Processing cost stage 1}} + \\
& \underbrace{\sum_{t\in T,o\in H,d\in P^n} PCO^n_{tod} * X_{tod}}_{\text{Processing costs at the } n \text{ stages}} + \underbrace{\sum_{t\in T,o\in H,d\in S} PCO^S{}_{tod} * X_{tod}}_{\text{Processing cost spheroid}} + \underbrace{\sum_{t\in T,o\in H,d\in P} PCO^E{}_{tod} * X_{tod}}_{\text{Processing cost : strippers}} + \\
& \underbrace{\sum_{t\in T,o\in H\cup L} IC^O{}_{to} * IO_{to}}_{\text{Inventory cost : gathering center and oil depot}} + \underbrace{\sum_{t\in T,o\in L} WC^O{}_{to} * BO_{to}}_{\text{Penality cost at oil depot}} + \underbrace{\sum_{t\in T,o\in O,d\in D} TC^O{}_{tod} * X_{tod}}_{\text{Transportation costs}}
\end{aligned} \tag{4.1}$$

A set of linear constraints are added to the model and given in the following equations. Sustainability constraints to ensure a specific lifetime for the oil reserves.

$$\sum_{t\in T,o\in R,d\in P^1} X_{tod} \le DR \times \sum_{o\in R} RO_o \quad \forall t \in T \tag{4.2}$$

The flow of oil through the existing routes should be below or equal to the transportation capacity.

$$X_{tod} \leq CRL^{O}_{tod} \quad \forall t \in T \forall o \in O \forall d \in D \tag{4.3}$$

Flow balance and capacity constraint for oil at the Gas/Oil separation center.

$$\sum_{o \in R} PO^{1}_{toj} X_{toj} = \sum_{d \in H} X_{tjd} \quad \forall t \in T \forall j \in P^{1} \tag{4.4}$$

$$\sum_{o \in R} PO^{1}_{tod} X_{tod} \leq CO^{1}_{td} \ \forall t \in T \forall d \in P^{1} \tag{4.5}$$

Inventory balance and capacity constraints at gathering center 1

$$\sum_{o \in P^{1}} X_{toj} + IO^{0}_{j} = \sum_{d \in P^{2}} X_{tjd} + IO_{tj} \quad \forall j \in H; t = 1 \tag{4.6}$$

$$\sum_{o \in P^{1}} X_{toj} + IO_{(t-1)j} = \sum_{d \in P^{2}} X_{tjd} + IO_{tj} \quad \forall j \in H; t \in T, t \neq 1 \tag{4.7}$$

$$\sum_{o \in P^{1}} X_{tod} + IO_{(t-1)d} \leq COG_{td} \quad \forall d \in H; t \in T, t \neq 1 \tag{4.8}$$

Flow balance and capacity constraint for oil at oil processing plant 2

$$\sum_{o \in H} PO^{2}_{toj} X_{toj} = \sum_{d \in H} X_{tjd} \quad \forall t \in T \forall j \in P^{2} \tag{4.9}$$

$$\sum_{o \in H} PO^{2}_{tod} X_{tod} \leq CO^{2}_{td} \ \forall t \in T \forall d \in P^{2} \tag{4.10}$$

Inventory balance and capacity constraints at gathering center 2

$$\sum_{o \in P^{2}} X_{toj} + IO^{0}_{j} = \sum_{d \in P^{3}} X_{tjd} + IO_{tj} \quad \forall j \in H; t = 1 \tag{4.11}$$

$$\sum_{o \in P^{2}} X_{toj} + IO_{(t-1)j} = \sum_{d \in P^{3}} X_{tjd} + IO_{tj} \quad \forall j \in H; t \in T, t \neq 1 \tag{4.12}$$

$$\sum_{o \in P^{2}} X_{tod} + IO_{(t-1)d} \leq COG_{td} \quad \forall d \in H; t \in T, t \neq 1 \tag{4.13}$$

Flow balance and capacity constraint for oil at oil processing plant 3

$$\sum_{o \in H} PO^{3}_{toj} X_{toj} = \sum_{d \in H} X_{tjd} \quad \forall t \in T \forall j \in P^{3} \tag{4.14}$$

$$\sum_{o \in H} PO^{3}_{tod} X_{tod} \leq CO^{3}_{td} \ \forall t \in T \forall d \in P^{3} \tag{4.15}$$

Inventory balance and capacity constraints at gathering center 3

$$\sum_{o\in P^3} X_{toj} + IO_j^0 = \sum_{d\in S} X_{tjd} + IO_{tj} \quad \forall j\in H; t=1 \tag{4.16}$$

$$\sum_{o\in P^3} X_{toj} + IO_{(t-1)j} = \sum_{d\in S} X_{tjd} + IO_{tj} \quad \forall j\in H; t\in T, t\neq 1 \tag{4.17}$$

$$\sum_{o\in P^3} X_{tod} + IO_{(t-1)d} \leq COG_{td} \quad \forall d\in H; t\in T, t\neq 1 \tag{4.18}$$

Flow balance and capacity constraint for oil Spheroid (oil processing)

$$\sum_{o\in H} PO_{toj}^S X_{toj} = \sum_{d\in H} X_{tjd} \quad \forall t\in T \forall j\in S \tag{4.19}$$

$$\sum_{o\in H} PO_{tod}^S X_{tod} \leq CO_{td}^S \quad \forall t\in T \forall d\in S \tag{4.20}$$

Inventory balance and capacity constraints at gathering center 4

$$\sum_{o\in S} X_{toj} + IO_j^0 = \sum_{d\in E} X_{tjd} + IO_{tj} \quad \forall j\in H; t=1 \tag{4.21}$$

$$\sum_{o\in S} X_{toj} + IO_{(t-1)j} = \sum_{d\in E} X_{tjd} + IO_{tj} \quad \forall j\in H; t\in T, t\neq 1 \tag{4.22}$$

$$\sum_{o\in S} X_{tod} + IO_{(t-1)d} \leq COG_{td} \quad \forall d\in H; t\in T, t\neq 1 \tag{4.23}$$

Flow balance and capacity constraint for oil Strippers (oil processing)

$$\sum_{o\in H} PO_{toj}^S X_{toj} = \sum_{d\in L} X_{tjd} \quad \forall t\in T \forall j\in E \tag{4.24}$$

$$\sum_{o\in H} PO_{tod}^S X_{tod} \leq CO_{td}^S \quad \forall t\in T \forall d\in S \tag{4.25}$$

Inventory balance and capacity constraints at oil depots

$$\sum_{o\in E} X_{tod} + IO_d^0 = DO_{td} + IO_{td} \forall d\in L; t=1 \tag{4.26}$$

$$\sum_{o\in E} X_{tod} + IO_{(t-1)d} = IO_{td} + DO_{td} - BO_{td} \quad \forall d\in L; t\in T, t\neq 1 \tag{4.27}$$

$$\sum_{o\in E} X_{tod} + IO_{(t-1)d} \leq CO_{td}^L \quad \forall d\in L; t\in T, t\neq 1 \tag{4.28}$$

Logical constraints: there is no flow if the shared service contract is not active.

$$\sum_{d\in D, t\in T} X_{tod} \leq C_o^H \times Z_o \ \forall o\in R\cup P^n \cup H\cup S\cup E \tag{4.29}$$

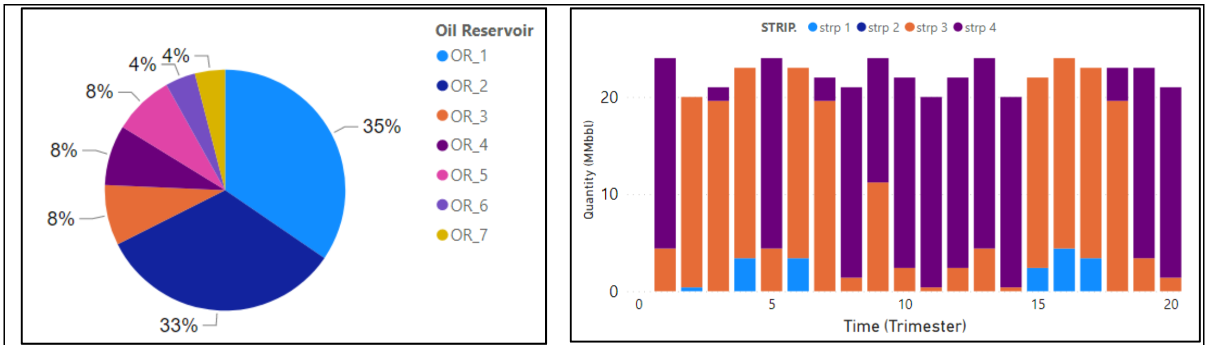
4.2 Scenario-based methodology and model validation

In this section, a real upstream COSC from a Gulf Cooperation Council (GCC) country was chosen to illustrate the utility of the proposed model, and an analysis was undertaken.

4.2.1 Case study

The network in this case study starts with the offshore oil reservoirs to the onshore oil depots. First, a seven (7) offshore oil reservoirs network is connected to Gas/Oil separation plants. The crude oil is then transported to the onshore oil processing plant, which comprises two further stages of separation. The stabilized crude oil is then transported by pipeline to a terminal comprising 13 storage tanks. The data required to run the model include the following: gas/ oil ratio corresponding to the type of crude oil from the different reservoirs, the demand for crude based on market conditions and the Organization of the Petroleum Exporting Countries (OPEC) constraints, the capacity of the various processing plants, the capacity of interconnecting pipelines, and cost elements (shared services, production, processing, transportation, and penalty associated with exceeding or not meeting demand).

The model integrated with the data was solved with the commercial solver Lingo 17.0. The planning horizon is five years with one quarter planning period (20 periods). The model for the baseline scenario is composed of 4,025 decision variables (13 integers), 5,325 constraints, and it was solved within 10 seconds. The initial results from the baseline model show the level of production at the different reservoirs. Two (2) oil reservoirs (OR1 and OR2) are responsible for almost 68% of the quantity produced, as shown in Figure 4.2 (a). Figure 4.2 (b) illustrates the flow from the strippers to the oil depot, reflecting the production level at each period.



(a) (b)

Figure 4.2 Oil extraction and processing - Baseline scenario

The total cost is depicted in Figure 4.3. Four cost drivers represent the total cost distribution and the cost/barrel(or bbl). Shared services costs represent more than 45.11%, accounting for an average of $2.01/bbl. The processing costs account for 36.06% ($1.61/bbl). The production costs are around 12.39% ($0.55/bbl), and the logistics costs represent 6.44% ($0.29/bbl). The total cost for the baseline scenario is 1,990 M$, and the average cost per bbl is $4.46. We also ran the model to obtain the optimal result assuming that it is possible to implement flexible contracts for shared services and services and allow reservoirs' closure for some periods. Indeed, due to the inflexibility of the oil supply chain structure, adding flexibility in the shared services obtained from contractors is crucial for achieving resilience (Ivanov and Hosseini, 2019).

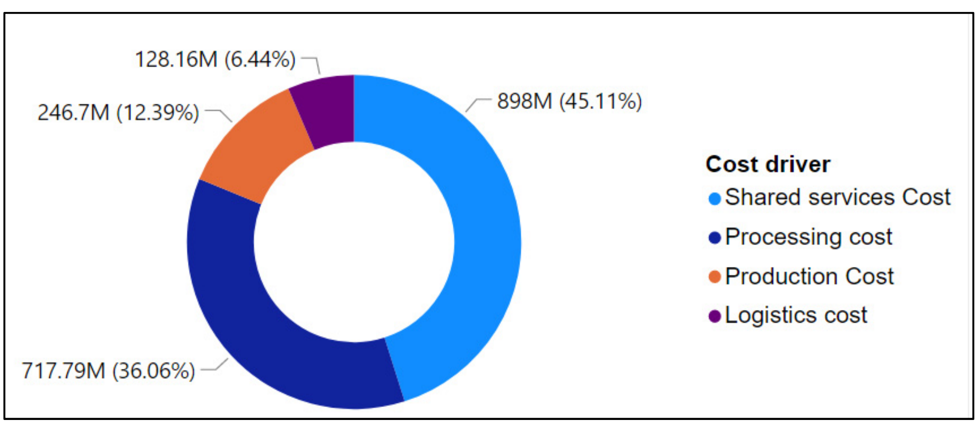


Figure 4.3 Supply chain cost drivers

We also run a sensitivity analysis related to the demand (OPEC quota) parameters. For the baseline scenario, we assume that oil reservoirs are always active. For the Optimal scenario, we assume that it is possible to deactivate the cost of the shared services (flexibility in the contract for shared services).

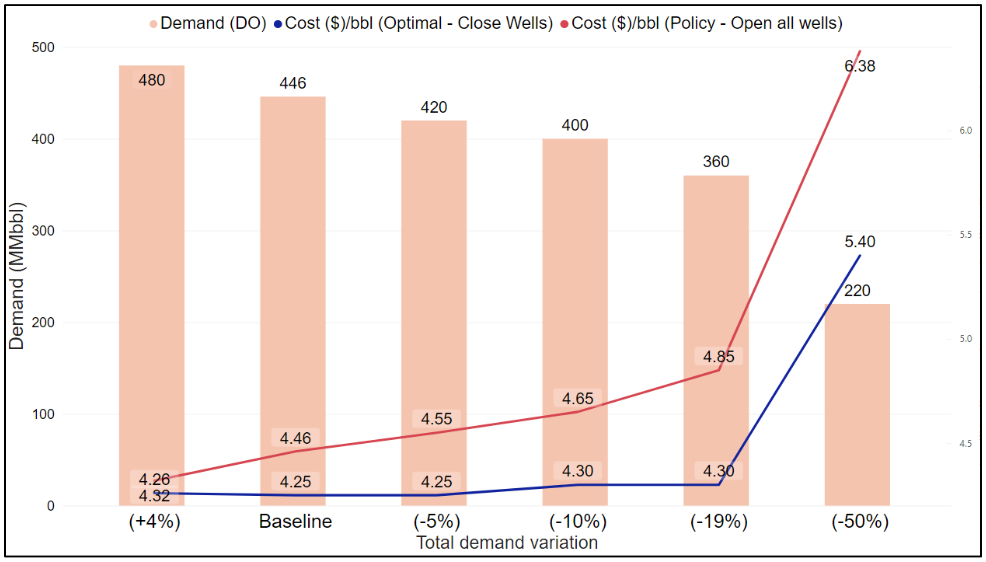


Figure 4.4 Relation between demand variation and the cost/bbl

As a result, we can observe that the cost/bbl increases when demand decreases. However, we witness that the cost increase is lower with the flexible scenario. Indeed, if flexibility is possible to implement, it offers better cost control when the demand decreases. The average cost/bbl for the optimal strategy is 4.25 and reaches $5.40 for the extreme scenario when demand decreases by 50%.

4.2.2 Post-merger integration and experimental evaluation

In this section, we will consider adding uncertainty to the model. Therefore, two sources of uncertainty are considered (Demand and Shared services cost (SSC)) since these costs are impossible to evaluate precisely after a merger. We also study two possible states for the demand (demand increase and decrease). Finally, we run the model for the baseline and the optimal cases. Table 4.1 summarizes the different states of uncertain parameters and results. It shows how the total cost (cost/bbl) is sensitive to the shared services and demand variation cost. Again, we can observe a better control of the variation for the optimal scenario.

Table 4.1 Scenario construction and initial results

Case	Scenario	Demand variation	Prob.	SSC variation	Prob.	Total Cost (M$)	Cost ($)/bbl	Avg. Cost ($)
Baseline	Scenario 1	5%	0.3	-50%	0.7	1,651	3.44	3.81
	Scenario 2	5%	0.3	-20%	0.3	1,894	3.95	
	Scenario 3	-20%	0.7	-50%	0.7	1,332	3.70	
	Scenario 4	-20%	0.7	-20%	0.3	1,574	4.37	
Optimal	Scenario 1*	5%	0.3	-50%	0.7	1,61	3.35	3.67

4.3 Conclusion

This chapter presents a mixed-integer linear program to minimize the cost of the strategic and tactical plans for the upstream sector of the oil supply chain in the GCC region. To the best of our knowledge, this study is the first to analyze upstream COSC after post-merger integration, given the uncertainty related to demand and shared services cost at wells. Uncertainty is considered through a scenario-based analysis and decision tree approach to evaluate the cost per bbl with and without flexibility in contract shared services management. The cost breakdown based on cost-drivers highlights the importance of shared services and processing costs from the model results.

The model is practical and offers an in-depth analysis of the impact of demand and SSC uncertainty on the cost/bbl. The model helps decision-makers identify the flexibility needed in shared services contracts to achieve the expected gains after mergers. For future research, three aspects should be integrated. First, the gas supply chain should be added to the model considering the close interdependency between oil and gas production. Second, instead of examining the uncertainty in the model using a scenario-based approach, a robust programming model should be formulated to account for uncertainty in other parameters.

Finally, an efficient solution technique might be formulated to handle large-scale (big-data-driven) oil and gas systems (Mulvey, Vanderbei et Zenios, 1995).

CHAPTER 5

IMPACT OF HORIZONTAL MERGERS ON SUPPLY CHAIN PERFORMANCE

5.1 Introduction

Nowadays, no country in the world can run smoothly without oil and gas, and the development of today's world would not have been possible without it. The recent COVID 19 epidemic and the dramatic reduction in demand for petroleum products have resulted in much lower oil prices and demand, which provides more significant uncertainty in future oil pricing. Oil demand is unlikely to return to its path before the pandemic, and the disconnect between supply and demand will be here for some time and will drive down returns and force transformation. This uncertainty and lower oil prices are reducing the operating margins of the Oil and Gas companies forcing them to review their organizational structures and supply chains to improve efficiencies and reduce cost as part of a continuous improvement process (Attia, Ghaithan et Duffuaa, 2019; Ben Amor et Ghorbel, 2018). As a result, the management of the Crude Oil Supply Chain (COSC) or the Hydrocarbon Supply-Chain (HCSC) as defined by Attia et al. (2019) is receiving increased importance in both a business and government context.

The oil and gas industry has complex supply chains that involve several companies supplying materials and equipment required at multiple locations (wellheads, production facilities, and refineries) and support services such as project and contract management and logistics. Attia et al. (2019) recognized that the activities of the HCSC were segmented into upstream, midstream, and downstream sectors. This research is concerned with the upstream sector's supply chain (SC) comprising several entities, including Wellhead Platform, Production Platform, and Crude Oil Terminal (Sahebi, Nickel et Ashayeri, 2014). For upstream oil companies, effective supply chain management is critical. The upstream companies heavily depend on third-party material and service providers, representing 80% of their total operating costs (Agarwal, Sharma et Alex, 2016). Supply chain decisions can occur on strategic, tactical, and operational levels (Sahebi, Nickel et Ashayeri, 2014). The three levels of decisions can be used to optimize the design and planning of the crude oil supply chain model subsystems, including field development, crude oil transportation, refinery planning, and product distribution (Shah, Li et Ierapetritou, 2011). Tactical planning of crude oil logistics in transporting the oil from the wellhead to the intermediate storage facility is critical within the crude oil supply chain (Shapiro, 2004). Companies can achieve significant savings and sustainability by utilizing strategic and tactical supply chain models and underlie the focus on research in this area (Abdussalam et al., 2021; Sahebi, Nickel et Ashayeri, 2014). Previous research has proven that collaboration and integration are key strategies frequently used by different industrial and services sectors and might lead to significant cost savings (Cedillo-Campos et al., 2020; Er Kara, Oktay Fırat et Ghadge, 2020; Long, 2018). This can be achieved through horizontal and vertical integration resulting from a merger between two or more companies or through internal re-organization and transformation (add a reference here). The transformation of operational strategies of the supply chain has particular significance as part of the merger of two or more oil companies where the new entity can take the best practices of the pre-merged companies and redesign the supply chain to take full advantage of the supply chain newly merged entity.

The prediction of the expected gains after a merger becomes even more complex due to uncertainty. Sources of uncertainty in a SC can be classified into three groups: demand, process/manufacturing, and supply (Peidro et al., 2009). For the COSC, uncertainty in supply is caused by how the suppliers [or oil producers] operate collectively within the market and may be affected by price and political factors. On the other hand, demand uncertainty is due to demand volatility (exacerbated by the current COVID-19 situation) or inexact demand forecasting (Peidro et al., 2009). Therefore, specific research studies have been proposed and incorporated in supply chain optimization tools to cope with uncertainty when planning the oil and gas supply chain. Uncertainty in supply chain optimization problems has been treated using stochastic programming, robust optimization (Govindan et Cheng, 2018), and fuzzy programming (Lima, Relvas et Barbosa-Póvoa, 2021). Stochastic programming is applicable when parameters follow known distributions. Robust optimization is applicable when the parameters are known within some bounds. The recent developments in this area show that stochastic programming is the most used approach since these studies assume that demand, prices, and supply uncertainty distribution are known using historical and statistical data (Lima, Relvas et Barbosa-Póvoa, 2018). On the other hand, few studies in the O&G supply chain used robust optimization, especially when information is not available to estimate the uncertainty distribution of parameters. We also observe that less attention has been given to the planning of the upstream supply chain under uncertainty. In addition, in the horizontal post-merger of upstream O&G supply chain, finding the information to estimate the new cost parameters after mergers is complex. Quantifying the synergy after the merger in the supply chain is a challenge since it guides the important improvement in the supply chain efficiency. In the field of supply chain management, very few studies focused on supply chain mergers. To the best of our knowledge, no in-depth quantitative models focus on the key characteristics of the upstream oil and gas supply chain after a merger and their impact on supply chain performance (synergy).

Based on this background, the main question that needs to be answered is identifying the main SC characteristics and how they affect supply chain synergy after a merger. Therefore, the main motivation of this study is to contribute to the academic and practitioner communities in solving such a problem. The study will better understand where the effort should be concentrated and each level of the supply chain to achieve the expected synergy after horizontal merger decisions under uncertainty of demand and cost parameters.

The present research contributes to the three essential subjects of the oil and gas supply chain planning area and literature. First, it addresses the supply chain cost structure and the tactical decisions related to the post-mergers supply chains for the first time. Hence, the tactical decisions in the upstream supply chain reflect the system's reality in post-merger integration efforts. Second, uncertainty consideration in the upstream COSC is a new contribution since most previous studies that include uncertainty focus on the downstream sector. Consequently, new sources of uncertainty are introduced using the scenario-based method, which limits the computational complexity. Finally, a new real-life case study is proposed using a comprehensive data collection process to validate the baseline model (before the merger) and study the different post-merger scenarios.

5.2 Supply chain planning and mergers

Although there is a plethora of literature on horizontal mergers within economics and finance, surprisingly, few studies link supply chain planning, optimization, and mergers. Most of the studies in this area try to answer the following question: can horizontal mergers be profitable? From a supply chain perspective, managers expect improved efficiency. After a merger, the real risk in a company's management is not the danger of failure but half-success. Mergers can be classified into three main types: vertical, conglomerate, and horizontal. A vertical merger is a combination of two companies that have a buyer-seller relationship. A conglomerate merger combines firms that are involved in producing unrelated products or services. They are not competitors, and they do not have a buyer-seller relationship.

A horizontal merger, which this study aims, occurs when two companies in a similar type of production, distribution, or business area are brought under one management. After a horizontal merger, competition in the market is reduced because the merged firms formerly competed for business. Costs can also be reduced because duplicated functions can now be combined (Hsu, Wright et Zhu, 2017). These improvements can be achieved from the realization of the economy of scale and the economy of scope. Indeed, with mergers, it is possible to consolidate materials requirements and centralize purchasing, resulting in substantial savings in overhead costs.

Previous studies have tried to analyze the post-merger process from a supply chain perspective, mainly in the commercial context, focusing on coordination and cooperation (Cho, 2014; Gupta et Gerchak, 2002; Lan et al., 2019). Singh et al. (2014) present a study evaluating vertical coordination's impact concerning the vegetable supply chain industry (Singh, Mishra et Mishra, 2014). Zhu et al. (2016) studied the implications of upstream and/or downstream horizontal mergers on suppliers, retailers, and consumers (Zhu, Boyaci et Ray, 2016).

A recent study focused on mergers and acquisitions in blood banking systems in the United States. The research uses supply chain network optimization models to evaluate the cost efficiency (synergy) associated with a merger or acquisition in the blood banking industry (Masoumi, Yu et Nagurney, 2017). Using a similar approach, Soylu et al. (2006) develop a mixed-integer linear programming (MILP) model to identify the synergy among different energy systems (Soylu et al., 2006). Alptekinoglu and Tang (2005) developed a convex non-linear programming problem to analyze distribution efficiency associated with mergers and acquisitions. Gupta and Gerchak (2002) proposed a model to understand the relationship between production efficiency and mergers (Gupta et Gerchak, 2002).

5.3 A mathematical framework for synergy quantification

In this chapter, a mathematical model is developed to optimize the upstream COSC total cost. The model will allow a company to understand uncertainty in demand and cost parameters after a merger. Tactical decisions are included in the model. The supply chain structure and the model development steps are described in the following subsections.

5.3.1 Problem statement and method

The strategic and tactical supply chain planning of the upstream supply chain in the oil and gas sector is considered in this research study. The supply chain can be complicated, but for the sake of this study, we assume that the upstream COSC is composed of four (4) types of echelons, named production facilities, processing plants, gathering centers, and demand terminals. An overlap exists between the two networks as the fact that crude oil contains associated gas. Figure 5-1 depicts a schematic representation of the upstream supply chain network.

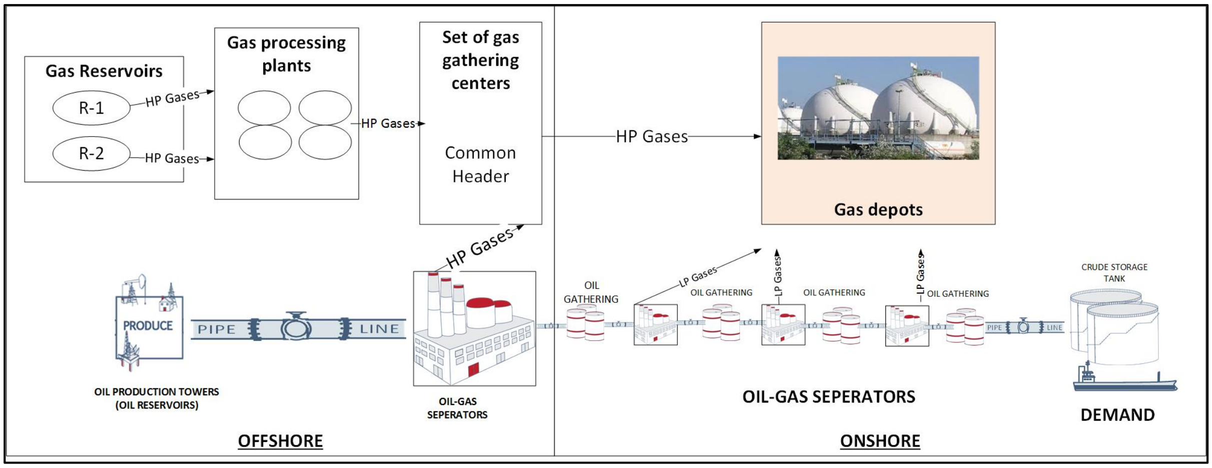


Figure 5.1 Upstream Oil and Gas supply chain structure example

The supply chain of crude oil starts from offshore oil reservoirs and is connected to a set of Gas / Oil Separation plants to separate gases and water from crude oil. These offshore Gas / Oil separation plants are the first stage of different stage separation processes to achieve maximum liquid recovery, stabilize oil & gas, and separate water. The offshore production separators operate at a pressure significantly above the atmosphere, and the high-pressure gas is sent to the offshore gas processing plants. The crude oil is then transported to the onshore oil processing plant, which comprises two further separation stages. After separating water and gas, the crude oil must be stabilized to remove light hydrocarbons to achieve the vapor pressure required for safe storage and transport and meet the required sales contract. This is achieved in a set of "stripping columns," which can achieve a stable specification product with a higher recovery (Stewart and Arnold, 2009). The stabilized crude oil is then transported by pipeline to a terminal comprising of crude storage tanks. The associated HP gases from the Gas/Oil separation plants and produced gases from gas reservoirs are transported to gas processing plants to remove impurities to meet the required product specification and then transported via pipelines to an onshore gas depot. Additional low pressure and atmospheric gases from the onshore oil processing plant are also collected, and the resulting gases are stored in gas depots. The crude oil is used to satisfy the local demand of many local refineries and satisfy international demand in line with the prevailing OPEC quota. Natural gas is again used to satisfy the demand of local petrochemical plants, industrial and domestic LPG production.

When two companies merge, a number of decisions need to be made to consolidate the constituent supply chains. For instance, executives and supply chain analysts need to understand the impact of the merger on their supply chain. There is a minimum impact on the supply structure for the oil and gas sector, given the level of inflexibility observed. Nevertheless, the synergy (known as the critical justification of a merger) can be obtained from achieving the cost efficiency of the total logistic cost. Therefore, it is also essential to obtain supply chain performance measures or estimate them before and after a merger. We develop the mixed-integer programming model to quantify pre-merger and post-merger scenarios. In both models, the objective is to minimize the total supply chain cost. The goal of the mathematical model in this section is to identify the optimal supply chain plan given the new setting after the horizontal mergers. Second, it presents a framework to quantify the merger-induced synergies and cost reductions from the joint economy of scale and economy of scope.

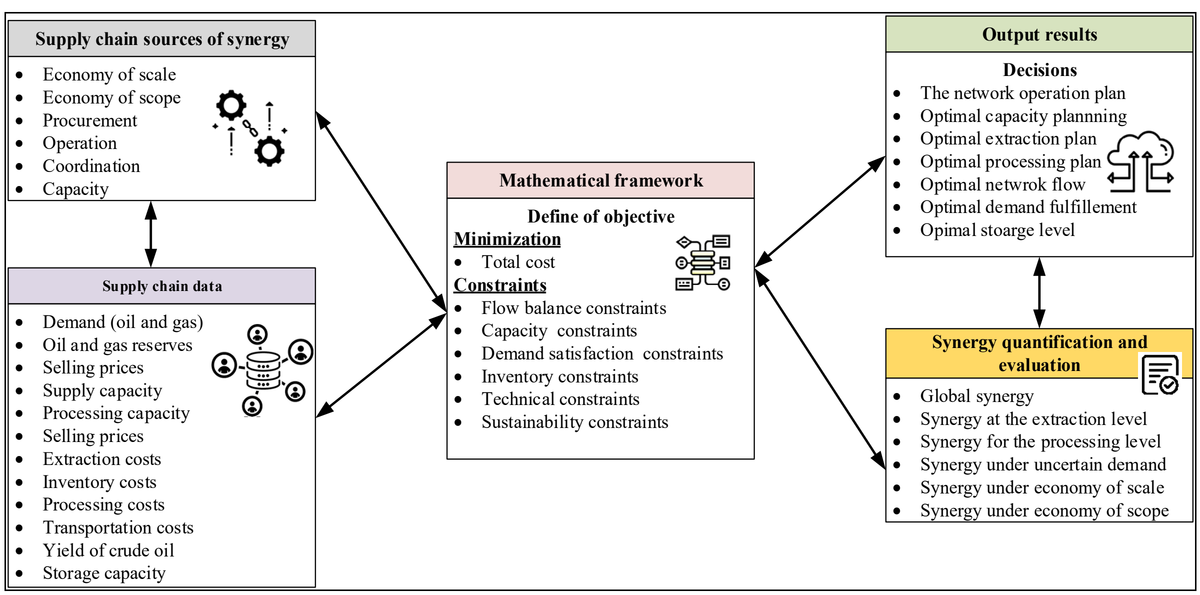


Figure 5.2 Research methodology framework

5.3.2 Model elements

Considering the problem described in the previous section, the MILP model involves the sets, parameters, and variables summarized as follows.

Sets/Indices

Oil

o, d : all nodes for oil processing

R : set of oil reservoirs (production)

P^n : set of oil processing plants at each stage $n \in \{1,2,3\}$

H : set of oil gathering centers

S : set of spheroids plants for oil processing

E : set of strippers for oil processing

L : set of local oil depots

Gas

u, v: all gas nodes processing

G : set of gas reservoirs (production)

J: set of gas processing plants

I : set of gas gathering centers

K : set of local gas depots

T : set of time periods

For notational convenience, denote by $O = R \cup P^n \cup H \cup S \cup E$ and $D = P^n \cup H \cup S \cup E \cup L$ the sets of possible origins destinations for crude where $n \in \{2,3\}$.

For notational convenience, denote by $U = G \cup J \cup I \cup P^n$ and $V = J \cup I \cup K$ the sets of possible origins destinations for gas processing.

Cost parameters (oil)

SSC_o **:** Fixed cost for shared services at a facility $o \in O = R \cup P^n \cup H \cup S \cup E$

$VSSC_{tod}$ **:** Variable cost for shared services at period *t* from node *o* to *node d, MMbarrel; where* $(o,d) \in (R,P^1) \cup (H,P^n) \cup (H,S) \cup (H,E)$ and $n \in \{2,3\}$.

OEC_{tod} : extraction cost per unit of crude oil during time period t, \$/barrel; where $o \in R, d \in P^1$

PCO^{1}_{tod}: processing cost per unit of crude oil at node *d* during time period *t* where $o \in R, d \in P^1$

PCO^{n}_{tod}: processing cost per unit of crude oil at node *d for stage n* during time period *t* where $o \in H, d \in P^n$

PCO^{S}_{tod}: processing cost per unit of crude oil at spheroids during time period *t* where $o \in H, d \in S$

PCO^{E}_{tod}: processing cost per unit of crude oil at strippers during time period *t* where $o \in H, d \in E$

IC^{O}_{to}: inventory holding cost of crude oil during time period *t* where $o \in H \cup L$

WC^{O}_{to}: Penalty cost per unit for producing oil below the demand at node $o \in L$ during time period *t* (i.e., a penalty of filling part of the demand from the outside market), \$/MMbarrel .

TC^{O}_{tod}: Transportation cost per unit of crude oil during time period *t* where $p \in P, q \in Q$

Capacity parameters

RO_o: amount of reserves in the oil reservoir $o \in R$, MMbarrel;

C^{H}_{o} : Capacity of a facility $o \in O = R \cup P^n \cup H \cup S \cup E$ for the whole horizon

PO^{n}_{tod}: Yield of crude oil liberated during time period t at node $o \in R \cup H$ transported to node $d \in P^n$, Percentage

PO^{S}_{tod}: Yield of crude oil liberated during time period t at node $o \in H$ transported to node $d \in S$, Percentage

PO^{E}_{tod}: Yield of crude oil liberated during time period t at node $o \in H$ transported to node $d \in E$, Percentage

CO^{n}_{td}: capacity of oil processing during time period t at node $d \in P^n$ and $n \in \{1,2,3\}$,

CRL^{O}_{tod}: capacity of the route linking node $o \in O$ to node $d \in D$ for crude oil , MMbarrel

COG_{td}: capacity at oil gathering center $d \in H$

CO^{S}_{td} : capacity of spheroid during time period t at node $d \in S$, MMbarrel

CO^{E}_{td} : capacity of strippers during time period t at node $d \in S$, MMbarrel

CO^{L}_{td} : capacity of oil depot during time period t at node $d \in S$, MMbarrel

RG_{u} : amount of reserves in gas (bscft) reservoir $u \in G$;

CG_{tu} : capacity of gas processing plan (bscft) during time period t at node $u \in J$

CRL^{G}_{tuv} : capacity of the route linking node $u \in U$ to node $v \in V$ for gas , bscft

PO^{E}_{tod} : Yield of crude oil liberated during time period t at node $o \in H$ transported to node $d \in E$,

Cost parameters (gas)

GEC_{tuv} : extraction cost per unit of gas during time period t , \$/bscft; where $p \in G, q \in J$

PCG^{1}_{tuv} : processing cost per unit of gas at node d during time period t where $p \in P^{1}, q \in J$

TC^{G}_{tuv} : transportation cost per unit of gas during time period t where $u \in U, v \in V$

IC^{G}_{tu} : inventory holding cost of gas during time period t where $u \in I \cup K$

BC^{G}_{tu} : Penalty cost per unit for producing gas below the demand at node $u \in K$ during time period t (i.e., penalty of filling part of the demand from the outside market), \$/bscft.

Demand and price parameters

DO_{td} : demand for oil

DG_{td} : demand for gas

PR^{O}_{td} : selling price of crude oil (\$/MMbarrel) during time period t at demand node d ; where $d \in L$.

PR^{G}_{tv} : selling price of gas (\$/bscft) during time period t at demand node v ; where $v \in K$.

Decision variables: Oil

Z_{o} : binary variable =1 if the the shared sevice is activated at facilty $o \in O = R \cup P^{n} \cup H \cup S \cup E$

X_{tod} : amount of crude oil transported in time period t from node o to *node d, MMbarrel; where* $(o,d) \in (R,P^1) \cup (H,P^n) \cup (H,S) \cup (H,E)$ and $n \in \{2,3\}$.

IO_{to} : inventory of crude in time period t above the demand at node o, MMbarrel; where $o \in H \cup L$.

IO_o^0 : initial inventory of crude in time period t above the demand at node o, MMbarrel; where $o \in H \cup L$

BO_{to} : amount of backorder of crude oil at node $o \in L$ during time period, MMbarrel .

Decision variables: Gas

Y_{tuv}: amount of gas transported from node p to node q in time period t, bscft; where $P = G \cup J \cup I$ and $Q = J \cup I \cup K$

IG_{tu} **:** inventory of gas in time period t above the demand at node u, bscft; where $u \in I \cup K$

BG_{tu} : amount of backorder of gas at node $u \in K$ during time period, \$/MMbarrel

5.3.3 Model Assumptions

Several assumptions are stated in order to develop the mathematical model:

- Demand is known and deterministic
- The supply chain structure (locations of oil reservoirs, gas reservoirs, processing plant) is known and not modified after the merger decision, given the inflexibility
- The capacities of all facilities are also known,
- The investment cost for shared services are known of each echelon but present some uncertainty.
- Operational costs (processing costs) are also given, but they present some uncertainty.

Given the data and the information related to the problem described, the objective of the MILP model is to minimize the total cost by defining the best strategic and tactical planning for oil and gas production and transportation to deliver the demand of the local and international market. The model will decide on the production capacity of oil and gas, oil and gas processing levels, and the services needed to support the supply chain operations subject to facility, storage, and transportation capacities constraints.

5.3.4 Objective function

The proposed mathematical model for upstream COSC is divided into two parts, namely the objective function and constraints. The objective function (Z) attempts to optimize the petroleum organization's resources by minimizing the total cost. The following equations define the mathematical formulation of the objective function: $Z = \min\left\{C^O + C^G\right\}$, where C^O and C^G are total oil and gas processing costs through the O&G upstream supply chain until the local depots, respectively.

The total cost for oil (C^O) include the cost of shared services at facilities, cost of production at oil reservoirs, the processing cost at each plant, inventory cost at gathering centers and oil depots, penalty cost at oil depot in case the final demand is not satisfied, and the transportation cost through all existing routes.

$$\begin{aligned}
C^O = & \underbrace{\sum_{o \in R \cup P^n \cup H \cup S \cup E} SSC_o * Z_o}_{\text{Shared services cost (oil)}} + \underbrace{\sum_{t \in T, o \in O, d \in D} VSSC_{otd} X_{tod}}_{} \underbrace{\sum_{t \in T, o \in R, d \in P^1} OEC_{tod} * X_{tod}}_{\textit{Extraction}\text{ cost (oil reservoir)}} + \underbrace{\sum_{t \in T, o \in R, d \in P^1} PCO^1_{tod} * X_{tod}}_{\text{Processing cost stage 1}} + \\
& \underbrace{\sum_{t \in T, o \in H, d \in P^n} PCO^n_{tod} * X_{tod}}_{\text{Processing costs at the } n \text{ stages}} + \underbrace{\sum_{t \in T, o \in H, d \in S} PCO^S{}_{tod} * X_{tod}}_{\text{Processing cost spheroid}} + \underbrace{\sum_{t \in T, o \in H, d \in P} PCO^E{}_{tod} * X_{tod}}_{\text{Processing cost : strippers}} + \\
& \underbrace{\sum_{t \in T, o \in H \cup L} IC^O{}_{to} * IO_{to}}_{\text{Inventory cost : gathering center and oil depot}} + \underbrace{\sum_{t \in T, o \in L} WC^O{}_{to} * BO_{to}}_{\text{Penality cost at oil depot}} + \underbrace{\sum_{t \in T, o \in O, d \in D} TC^O{}_{tod} * X_{tod}}_{\text{Transportation costs}}
\end{aligned} \tag{5.1}$$

The total cost for gas (C^G) includes the production cost at gas reservoirs, the gas processing cost at each plant, transportation cost through all existing routes, inventory cost at gas gathering centers and gas depots, and the penalty cost in case the final demand is not satisfied.

$$C^G = \underbrace{\sum_{t\in T,u\in G,v\in J} GEC_{tuv} * Y_{tuv}}_{\textit{Extraction}\text{ cost (gas reservoir)}} + \underbrace{\sum_{t\in T,u\in P^1,v\in J} PCG^1{}_{tuv} * Y_{tuv}}_{\text{Gas processing cost (gas from stage 1 oil processing)}} + \underbrace{\sum_{t\in T,u\in P,v\in Q} TC^G{}_{tuv} * Y_{tuv}}_{\text{Transportation costs}} +$$
$$\underbrace{\sum_{t\in T,u\in I\cup K} \mathrm{IC^G}_{\mathrm{tu}} * \mathrm{IG}_{\mathrm{tu}}}_{\text{Inventory cost at gas gathering centers/gas depot}} + \underbrace{\sum_{t\in T,u\in K} BG_{tu} * BG_{tu}}_{\text{Penality cost at gas depots}} \tag{5.2}$$

5.3.5 Constraints

A set of linear constraints are added to the model and given in the following equations:

- Sustainability constraints. Where S represents the depletion rate to ensure a specific lifetime for the reserves.

$$\sum_{t\in T,o\in R,d\in P^1} X_{tod} \le S\times\sum_{o\in R} RO_o \quad \forall t\in T \tag{5.3}$$

The flow of oil through the existent routes should be low or equal to the transportation capacity.

$$X_{tod} \le CRL^O_{tod} \ \ \forall t\in T\forall o\in O\forall d\in D \tag{5.4}$$

Flow balance and capacity constraint for oil at the Gas/Oil separation center.

$$\sum_{o\in R} PO^1_{toj} X_{toj} = \sum_{d\in H} X_{tjd} \quad \forall t\in T\forall j\in P^1 \tag{5.5}$$

$$\sum_{o\in R} PO^1_{tod} X_{tod} \le CO^1_{td} \ \ \forall t\in T\forall d\in P^1 \tag{5.6}$$

Inventory balance and capacity constraints at gathering center 1

$$\sum_{o\in P^1} X_{toj} + IO^0_j = \sum_{d\in P^2} X_{tjd} + IO_{tj} \quad \forall j\in H; t=1 \tag{5.7}$$

$$\sum_{o\in P^1} X_{toj} + IO_{(t-1)j} = \sum_{d\in P^2} X_{tjd} + IO_{tj} \quad \forall j\in H; t\in T, t\ne 1 \tag{5.8}$$

$$\sum_{o\in P^1} X_{tod} + IO_{(t-1)d} \le COG_{td} \quad \forall d\in H; t\in T, t\ne 1 \tag{5.9}$$

Flow balance and capacity constraint for oil at oil processing plant 2

$$\sum_{o\in H} PO^2_{toj} X_{toj} = \sum_{d\in H} X_{tjd} \quad \forall t\in T\forall j\in P^2 \tag{5.10}$$

$$\sum_{o\in H} PO^2_{tod} X_{tod} \le CO^2_{td} \ \ \forall t\in T\forall d\in P^2 \tag{5.11}$$

Inventory balance and capacity constraints at gathering center 2

$$\sum_{o\in P^2} X_{toj} + IO_j^0 = \sum_{d\in P^3} X_{tjd} + IO_{tj} \quad \forall j \in H; t = 1 \tag{5.12}$$

$$\sum_{o\in P^2} X_{toj} + IO_{(t-1)j} = \sum_{d\in P^3} X_{tjd} + IO_{tj} \quad \forall j \in H; t \in T, t \neq 1 \tag{5.13}$$

$$\sum_{o\in P^2} X_{tod} + IO_{(t-1)d} \leq COG_{td} \quad \forall d \in H; t \in T, t \neq 1 \tag{5.14}$$

Flow balance and capacity constraint for oil at oil processing plant 3

$$\sum_{o\in H} PO_{toj}^3 X_{toj} = \sum_{d\in H} X_{tjd} \quad \forall t \in T \forall j \in P^3 \tag{5.15}$$

$$\sum_{o\in H} PO_{tod}^3 X_{tod} \leq CO_{td}^3 \ \forall t \in T \forall d \in P^3 \tag{5.16}$$

Inventory balance and capacity constraints at gathering center 3

$$\sum_{o\in P^3} X_{toj} + IO_j^0 = \sum_{d\in S} X_{tjd} + IO_{tj} \quad \forall j \in H; t = 1 \tag{5.17}$$

$$\sum_{o\in P^3} X_{toj} + IO_{(t-1)j} = \sum_{d\in S} X_{tjd} + IO_{tj} \quad \forall j \in H; t \in T, t \neq 1 \tag{5.18}$$

$$\sum_{o\in P^3} X_{tod} + IO_{(t-1)d} \leq COG_{td} \quad \forall d \in H; t \in T, t \neq 1 \tag{5.19}$$

Flow balance and capacity constraint for oil Spheroid (oil processing)

$$\sum_{o\in H} PO_{toj}^S X_{toj} = \sum_{d\in H} X_{tjd} \quad \forall t \in T \forall j \in S \tag{5.20}$$

$$\sum_{o\in H} PO_{tod}^S X_{tod} \leq CO_{td}^S \ \forall t \in T \forall d \in S \tag{5.21}$$

Inventory balance and capacity constraints at gathering center 4

$$\sum_{o\in S} X_{toj} + IO_j^0 = \sum_{d\in E} X_{tjd} + IO_{tj} \quad \forall j \in H; t = 1 \tag{5.22}$$

$$\sum_{o\in S} X_{toj} + IO_{(t-1)j} = \sum_{d\in E} X_{tjd} + IO_{tj} \quad \forall j \in H; t \in T, t \neq 1 \tag{5.23}$$

$$\sum_{o\in S} X_{tod} + IO_{(t-1)d} \leq COG_{td} \quad \forall d \in H; t \in T, t \neq 1 \tag{5.24}$$

Flow balance and capacity constraint for oil Strippers (oil processing)

$$\sum_{o\in H} PO^{S}_{toj} X_{toj} = \sum_{d\in L} X_{tjd} \quad \forall t\in T \forall j\in E \tag{5.25}$$

$$\sum_{o\in H} PO^{S}_{tod} X_{tod} \leq CO^{S}_{td} \quad \forall t\in T \forall d\in S \tag{5.26}$$

Inventory balance and capacity constraints at oil depots

$$\sum_{o\in E} X_{tod} + IO^{0}_{d} = DO_{td} + IO_{td} \forall d\in L; t=1 \tag{5.27}$$

$$\sum_{o\in E} X_{tod} + IO_{(t-1)d} = IO_{td} + DO_{td} - BO_{td} \quad \forall d\in L; t\in T, t\neq 1 \tag{5.28}$$

$$\sum_{o\in E} X_{tod} + IO_{(t-1)d} \leq CO^{L}_{td} \quad \forall d\in L; t\in T, t\neq 1 \tag{5.29}$$

Logical constraints: the is now flow if the shared service contract is not active in the plant

$$\sum_{d\in D, t\in T} X_{tod} \leq C^{H}_{o} \times \mathrm{Z}_{o} \quad \forall o\in R\cup P^{n} \cup H\cup S\cup E \tag{5.30}$$

Sustainability constraints. Where S represents the depletion rate to ensure a specific lifetime for the gas reserves.

$$\sum_{u\in G, v\in J} Y_{tuv} \leq \mathrm{S} \times \sum_{u\in G} RG_{u} \quad \forall t\in T \tag{5.31}$$

The flow of oil through the existent routes should be lower or equal to the transportation capacity.

$$Y_{tuv} \leq CRL^{g}_{tuv} \quad \forall u\in U; \forall v\in V; t\in T \tag{5.32}$$

Flow balance and capacity constraint for oil at gas processing plants

$$\sum_{u\in G} Y_{tus} = \sum_{v\in I} Y_{tsv} \quad \forall t\in T; s\in J \tag{5.33}$$

$$\sum_{u\in G} Y_{tuv} \leq CG_{vt} \quad \forall t\in T; v\in J \tag{5.34}$$

Flow balance and capacity constraints at gas gathering

$$\sum_{u\in J} Y_{tus} + IG_{0s} = \sum_{v\in K} Y_{tsv} + IG_{ts} \quad \forall t=1; s\in I \tag{5.35}$$

$$\sum_{u\in J} Y_{tus} + IG_{(t-1)s} = \sum_{v\in K} Y_{tsv} + IG_{ts} \quad \forall t\neq 1; s\in I \tag{5.36}$$

$$\sum_{u \in J} Y_{tuv} + IG_{(t-1)v} \leq CG_{tv} \quad \forall t \neq 1; v \in I \tag{5.37}$$

Flow balance for associated gas

$$\sum_{o} GOR_{tod} \times X_{tod} = Y_{tdv} \quad \forall t \in T; d \in P^n \cup S \cup E; v \in J; o \in R \cup H \cup S \tag{5.38}$$

Inventory balance and capacity constraints at gas depots

$$\sum_{u \in I \cup P^n \cup S \cup E} Y_{tuv} + IG_{0d} = IG_{0d} + DG_{td} \quad \forall t = 1; d \in K \tag{5.39}$$

$$\sum_{u \in I \cup P^n \cup S \cup E} Y_{tuv} + IG_{(t-1)d} = IG_{td} - BG_{td} + DG_{td} \quad t \in T; t \neq 1; d \in K \tag{5.40}$$

5.4 Efficiency measure associated with the merger of the oil and gas

Since the supply chain structure after the merger in the oil and gas industry will not change (highly inflexible supply chain), this study will consider the case where mergers generate cost efficiencies (synergy) via economy of scope and economy of scale.

The economy of scope concept is defined as the process of reducing the cost of resources (Human Resources or HR) and skills (Information Technology or IT) for an individual business enterprise. It is achieved by spreading the use of these resources and skills over two or more enterprises (Hofstrand, 2019). Economies of scale result from spreading fixed costs (Finance and procurement) over many units of production. Because fixed costs remain the same regardless of the number of units produced, the fixed cost per unit declines as the number of units increases. Because of declining fixed costs per unit, the total cost per unit also decreases. Examples of fixed costs include depreciation on machinery or a processing facility, administrative overhead, interest payments on real estate or capital assets, and other costs that do not change with the production level (Hofstrand, 2019).

For this study, to quantify the synergy for the supply chain after the merger, we assume that the merger will affect mainly the shared services costs (SSC). These costs affect every level of the supply chain, including HR, finance, procurement, and IT. The general equation of SSC at each node is defined as a function of the quantity (X) processed at each node. For the purpose of this study, let SSC_o^{pre} be the cost of shared services before the merger (equation 41), where SSC_o and $VSSC_o$ are the fixed and variable shared service costs respectively at node $o \in O = R \cup P^n \cup H \cup S \cup E$.

$$SSC_o^{pre}(X) = SSC_o + VSSC_o.X \text{ (before merger)} \tag{5.41}$$

Also, let CCS_o^{post} be the cost of the shared services after the merger as shown in equation 42, where $\alpha_o \in [0,1]$ represents the percentage reduction achieved through the economy of scale and $\beta_o \in [0,1]$ the percentage reduced due to the economy of scope.

$$CCS_o^{post}(X) = \alpha_o.SSC_o + \beta_o.VSSC_o.X \text{ (after merger)} \tag{5.42}$$

In this case, synergy quantification/evaluation relative to the criterion (performance measure: total SC cost) can be defined using the measured pre-and post-merger criterion. Let's define K_i^{pre} and K_i^{post} the values for this criterion before and after the merger, respectively, and σ_i are defined as the percentage variation K_i^{pre} .

$$\sigma_i = \frac{K_i^{pre} - K_i^{post}}{K_i^{pre}} \times 100\% \tag{5.43}$$

The expectation for supply chain improvements resulting from a horizontal merger is that the performance of supply chains will be enhanced by sharing resources and increased asset utilization, but such expectation is not always guaranteed in practice.

Reducing the cost per barrel (cost/bbl) is one of the primary motivations behind the oil sector merger. Therefore, the next section will use the proposed model and supply chain characteristics to elaborate on quantifying and revealing synergy in the oil and gas sector.

5.5 Impact of mergers on supply chain performance

In this section, a real upstream COSC from the GCC was chosen to elucidate the utility of the proposed model, and analyses were undertaken.

5.6 The baseline scenario for the study

The network in this case study starts with the offshore oil reservoirs to the onshore oil depots. First, a seven (7) offshore oil reservoirs network is connected to Gas/Oil separation plants. The crude oil is then transported to the onshore oil processing plant, which comprises two further stages of separation. The stabilized crude oil is then transported by pipeline to a terminal comprising 13 storage tanks. The data required to run the model include the following: gas/ oil ratio corresponding to the type of crude oil from the different reservoirs, the demand for crude based on market conditions and OPEC constraints, the capacity of the various processing plants, the capacity of interconnecting pipelines, and cost elements (shared services, production, processing, transportation, and inventory or penalty associated with exceeding or not meeting demand). The model integrated with the data was solved with the commercial solver Lingo 17.0. The planning horizon is five years with one quarter planning period (20 periods). The model for the baseline scenario is composed of 4,031 decision variables (13 integers), 5,631 constraints, and it was solved within 15 seconds.

The initial results from the baseline model show the level of production at the different reservoirs. Two (2) oil reservoirs (OR1 and OR2) are responsible for 72.45% of the quantity produced, as shown in Figure 5-3 (a). Figure 5-3 (b) illustrates the flow from the strippers to the oil depot, reflecting the net production level at each period.

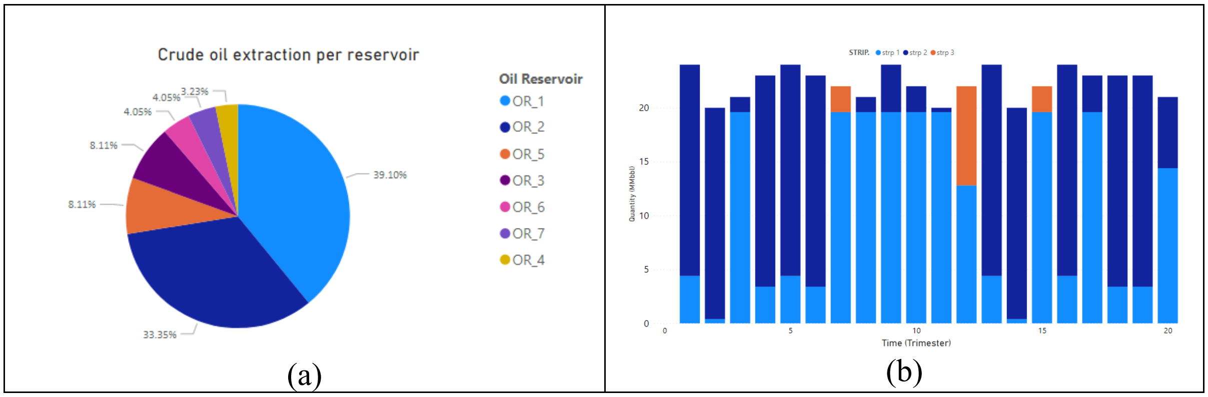


Figure 5.3 Oil extraction activity

The total cost for the 5-year horizon is equal to 2,716 million dollars (M$). Figure 5-4 shows the cost for each echelon. Oil Extraction (OE) activities at oil reservoirs represent almost 25% of the total cost. The three-stage oil processing (OP) counts for approximately 54%. The other processing steps (spheroid and strippers) represent 16%, followed by the logistics costs (transportation), which count for 5% approximately. Five (5) cost drivers are also used to analyze the cost distribution and the cost/bbl, equal to $6.09. The total shared services costs (fixed and variable) represent, in this case, 58%, which account for an average of $3.35/bbl. The processing costs account for 26% ($1.61/bbl). The extraction costs are around 11% ($0.66/bbl), and the logistics costs represents 5% ($0.29/bbl).

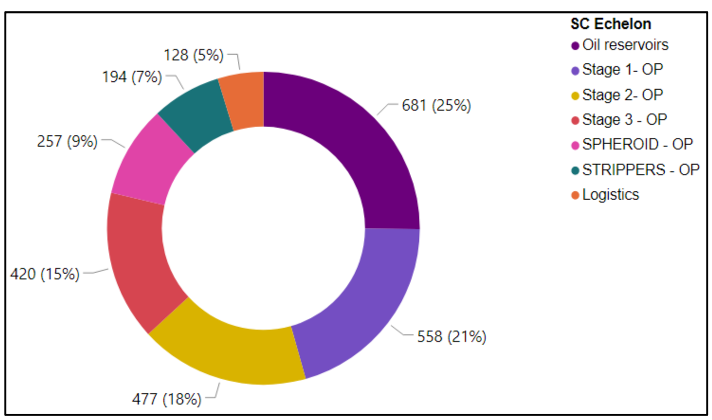


Figure 5.4 Total cost per SC echelon (M$)

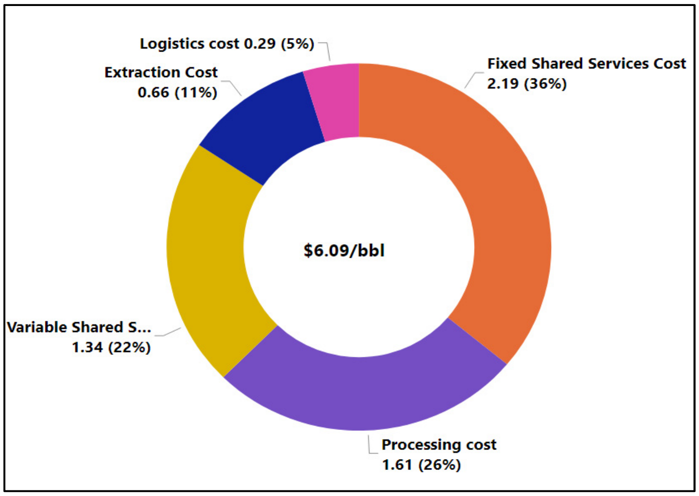


Figure 5.5 Cost/bbl ($) relative to cost drivers

We also run a sensitivity analysis related to the demand (OPEC quota) parameter. Based on the recent International Energy Agency (IEA) report, the COVID-19 pandemic cuts growth forecast for oil demand. Between 2019 and 2030, the growth is expected to reach nine percent (9%). With market instability and all efforts to reach climate goals, the demand might decrease in the future. Thus, to consider the impact of demand uncertainty, we design ten (10) different scenarios where the average demand can increase or decrease. The experimental results for each scenario are shown in Table 5.1. Figure 5.7 reports the total SC cost and the cost/bbl for each scenario. In case of an increase in the demand, we observe that cost/bbl decreases until the demand increase reaches 13%. When the demand increases by 14%, the cost/bbl rises to $6.43; the supply chain reaches the capacity for this case. The company starts paying penalties because it is impossible to fulfill the total demand (see Figure 5.7). The decrease in demand generates higher costs since the marginal cost increases, and the fixed cost remains constant.

Table 5.1 Scenarios for demand variation

Demand variation	-25%	-20%	-15%	-10%	-5%	Baseline	+5%	+10%	+12%	+13%	+14%
Total Cost (M$)	2,241	2,338	2,420	2,524	2,610	2,716	2,809	2,883	2,926	2,950	3,255
Cost/ bbl ($)	6.71	6.51	6.37	6.31	6.18	6.09	5.98	5.90	5.85	5.83	6.43

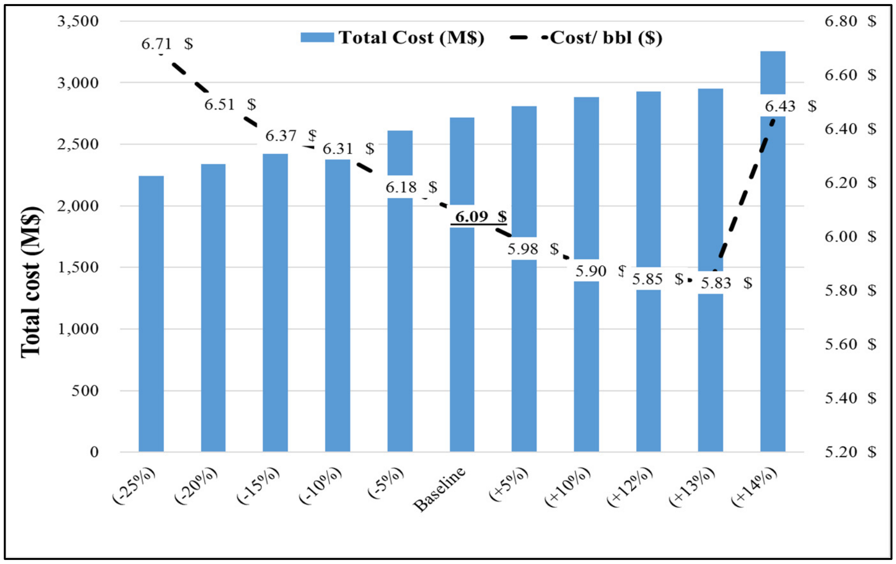


Figure 5.6 Cost variation under uncertain demand

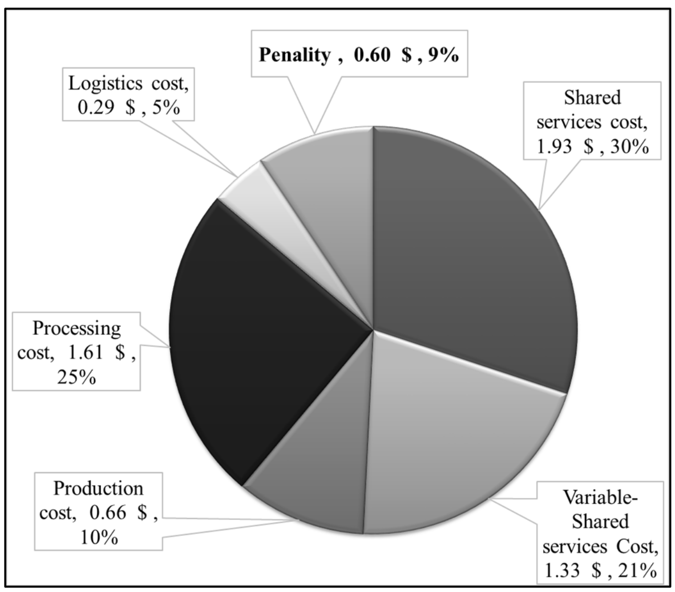


Figure 5.7 Cost structure for demand increase by +14%

5.7 Design of computations and analysis

This section investigates the potential supply chain synergetic improvements brought by a merger using mathematical modeling. The proposed model is used to evaluate how much the economy of scale and economy of scope will impact after merger success. The experimentation examines three different cases: 1) merger with the economy of scale, 2) merger with the economy of scope, and 3) joint economy of scope and scale.

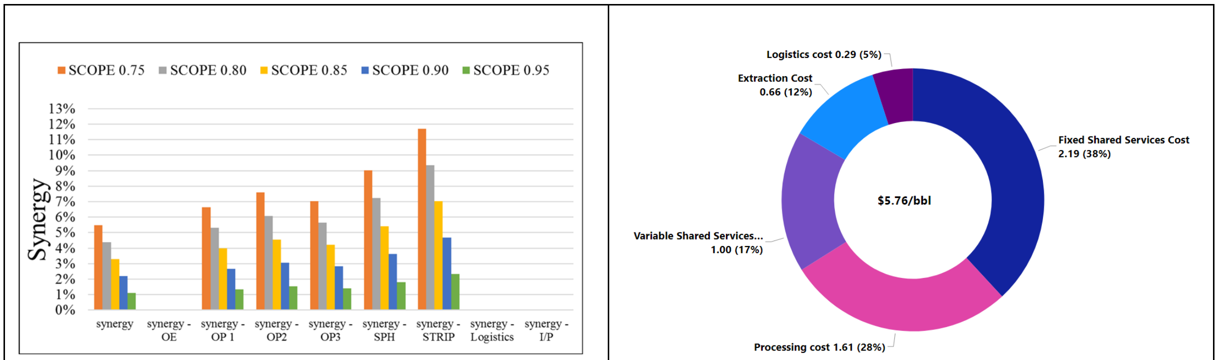
5.7.1 Merger with an economy of scope

To reveal the synergy gains relative to economy of scope, a computational study is designed varying β_o from *1* to *0.75*. When $\beta_o = 0.75$, it means that it is possible to reduce the variable shared services cost at each SC echelon by 25% after the merger. Table 5.2 reports the total cost, the total synergy, and the expected cost/bbl for different values of β_o. For instance, the total synergy that can be achieved when $\beta_o = 0.75$ is 5%. For this specific scenario, the cost/bbl is equal to $5.76. Thus, if the company targets a cost/bbl of $5 after a merger, reducing variable shared services cost by 25% is not enough to achieve this target.

Table 5.2 Synergy with the economy of scale

Instance	BETA	Demand	Supply Chain (all echelons)		Cost / bbl	
			Total Cost (M$)	Total synergy	Target	Result
SCOPE 0.75	0.75	Stable	2567	5%	$ 5	$ 5.76
SCOPE 0.80	0.8	Stable	2597	4%	$ 5	$ 5.82
SCOPE 0.85	0.85	Stable	2627	3%	$ 5	$ 5.89
SCOPE 0.90	0.9	Stable	2656	2%	$ 5	$ 5.96
SCOPE 0.95	0.95	Stable	2686	1%	$ 5	$ 6.02
Baseline	1	Stable	2716		$ 5	**$ 6.09**

Moreover, Figure 5.8 (a) demonstrates that the synergy is achieved throughout the cost reduction at the different oil processing stages since most oil extraction costs are fixed. Also, it is essential to mention that there is no synergy for transportation since the transportation infrastructure remains the same after the merger process. Figure 5.8 (b) illustrates the cost structure for each bbl where the fixed cost for shared services remains the most important with 38%.



a) Synergy by supply echelons

b) Cost structure per bbl

Figure 5.8 Synergy with the economy of scope ($\beta_o = 0.75$)

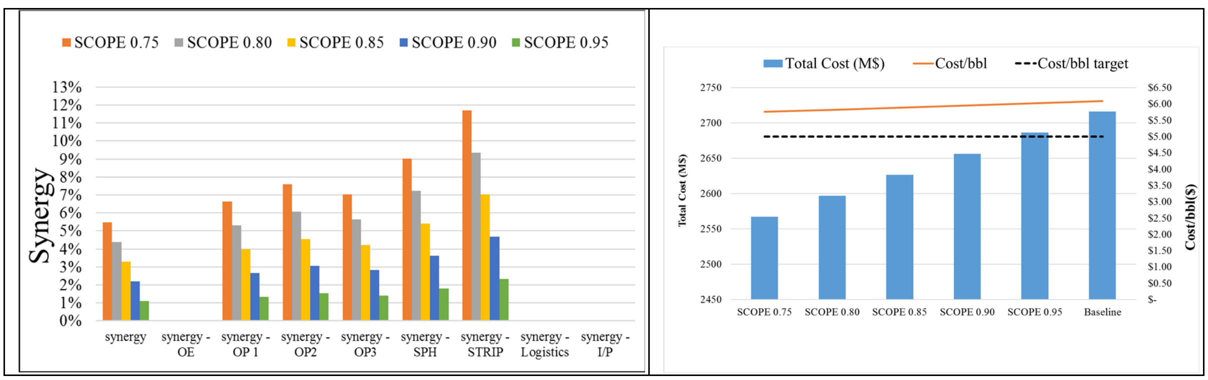


Figure 5.9 Synergy results with the economy of scope

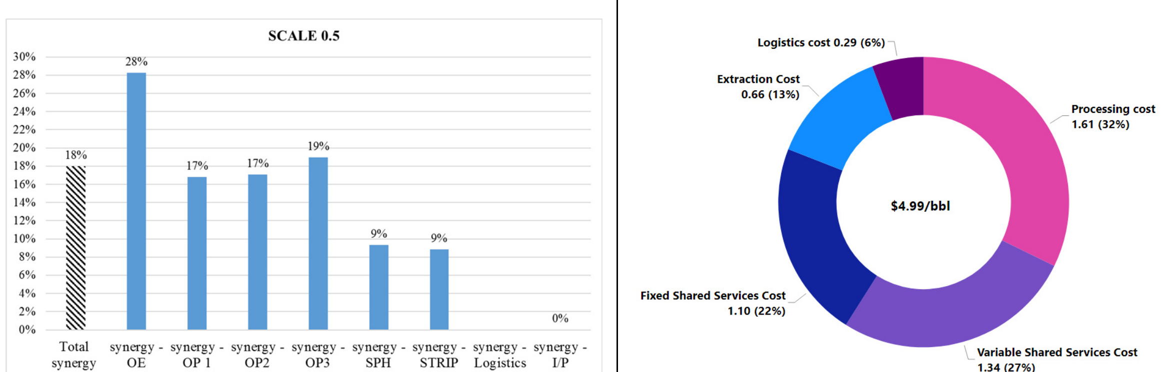
5.7.2 Merger with the economy of scale

In order to reveal the potential synergy gains relative to the economy of scale, a computational study is designed with varying α_o from one to 0.5. When $\alpha_o = 0.5$, it means that it is possible to reduce the fixed shared services cost at each SC echelon by 50% after the merger for this scenario (named SCALE 0.5). For this specific scenario, where demand is stable (same as baseline scenario) is possible to achieve a total synergy of 18% for the supply chain. For this specific scenario, the expected cost/bbl is $4.99, and it is possible to achieve the targeted cost/bbl after the merger in this case.

Table 5.3 Synergy with the economy of scale

			Demand	Supply Chain (all echelons)		Cost / bbl	
Instance	Alpha	Beta		Total Cost (M$)	Total synergy	Target	Cost / bbl
SCALE 0.5	0.5	1	Stable	2227	18%	$5	$ 4.99
SCALE 0.6	0.6	1	Stable	2325	14%	$5	$ 5.21
SCALE 0.7	0.7	1	Stable	2422	11%	$5	$ 5.43
SCALE 0.8	0.8	1	Stable	2520	7%	$5	$ 5.65
SCALE 0.9	0.9	1	Stable	2618	4%	$5	$ 5.87
Baseline	1	1	Stable	2716	n-a	$5	$ 6.09

Moreover, Figure 5.10 (a) demonstrates that the synergy is achieved throughout the cost reduction at the different oil processing stages. Also, it is essential to mention that there most important synergy is observed at the oil exploration stage with 28%. Figure 5.10(b) illustrates the cost structure for each bbl where the processing cost becomes the most important with 32%, followed by the variable shared services cost, which represents 27%. In this scenario, the fixed shared services cost counts for 22%.



a) Synergy by supply echelons

b) Cost structure per bbl

Figure 5.10 Synergy with the economy of scale ($\alpha_o = 0.5$)

Based on the different computational scenarios for this case example, we study the effect of a horizontal merger. The experimentation revealed that with only the economy of scope, it is not possible to achieve the targeted cost/bbl of $5 (see Figure 5.9). With the economy of scale, it is possible to reach the targeted cost/bbl only when $\alpha_o = 0.5$ (see Figure 5.11).

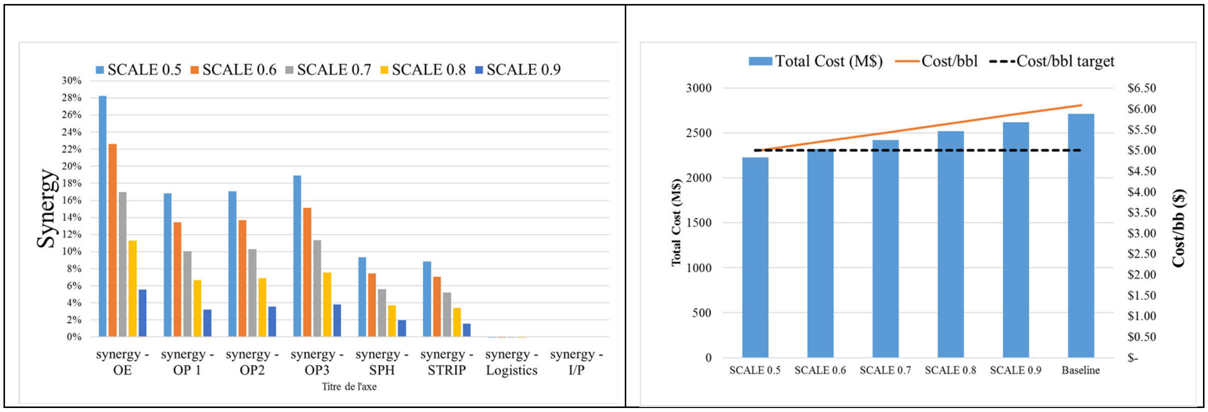


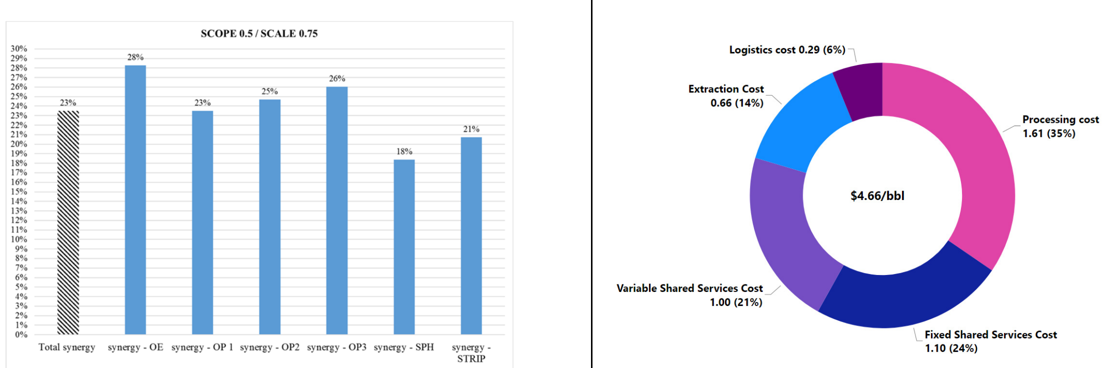
Figure 5.11 Synergy results with the economy of scale

Therefore, it is crucial to evaluate precisely the potential cost reduction at each SC level. In addition, these results give a specific platform to negotiate new contracts with the service providers to guarantee potential synergies after the merger process. Synergetic gain due to oil exploration activities has an essential impact on the supply chain performance after the merger, and it is considered the more significant contributor in our study.

5.7.3 Merger with an economy of scale and scope

In the previous sections, impacts of the economy of scale and economy of scope are analyzed separately. In practice, it is possible to achieve economy of scope and economy of scale after the horizontal merger. Thus, the goal in the section is to reveal the impact of different scenarios of the joint economy of scope and scale on resulting supply chain synergies. The insight gained from these experiments will improve the prediction of potential supply synergy in the upstream Oil and Gas Industry after a horizontal merger. To achieve this goal, experiments are designed for different combinations of values of α_o and β_o, where $\alpha_o \in \{1; 0.9; 0.8; 0.7; 0.6; 0.5\}$ and $\beta_o \in \{1; 0.95; 0.9; 0.85; 0.8; 0.75\}$. In total, 26 mergers scenarios are obtained and reflect the possible cost reduction under the joint economy of scale and scope policies.

For each scenario, the mathematical model is solved, and the results are reported in ANNEX II. Figure 5.12 (a) demonstrates the synergy achieved throughout the cost reduction at the different oil processing stages for the specific scenario with $\alpha_o = 0.5$ and $\beta_o = 0.75$. The total synergy achieved is 23%, which reduces the cost/bbl to \$4.66, which is lower than the targeted cost of \$5. Most of the synergy is observed for the oil extraction stage, with a synergy of 28%. Figure 5.12 (b) illustrates the cost structure for each bbl., where the processing cost counts for 35%.



a) Synergy by supply echelons

b) Cost structure per bbl

Figure 5.12 Synergy with a joint economy of scope and scale ($\alpha_o = 0.5$; $\beta_o = 0.75$)

Figure 5.13 shows that it is impossible to achieve the targeted cost/bbl of \$5 if $\alpha_o > 0.7$. When $\alpha_o \leq 0.6$, it is possible to reduce the cost/bbl and achieve the targeted value of \$5. For instance, when $\alpha_o = 0.6$ and $\beta_o = 0.8$, the cost/bbl is equal to \$4.95. In this specific scenario, the total synergy is 19% (see ANNEX II). Therefore, based on the different results, it is now possible to characterize potential synergy after a merger and conditional to realizing specific levels of economies of scale and scope at each supply chain echelon and processing oil processing stage.

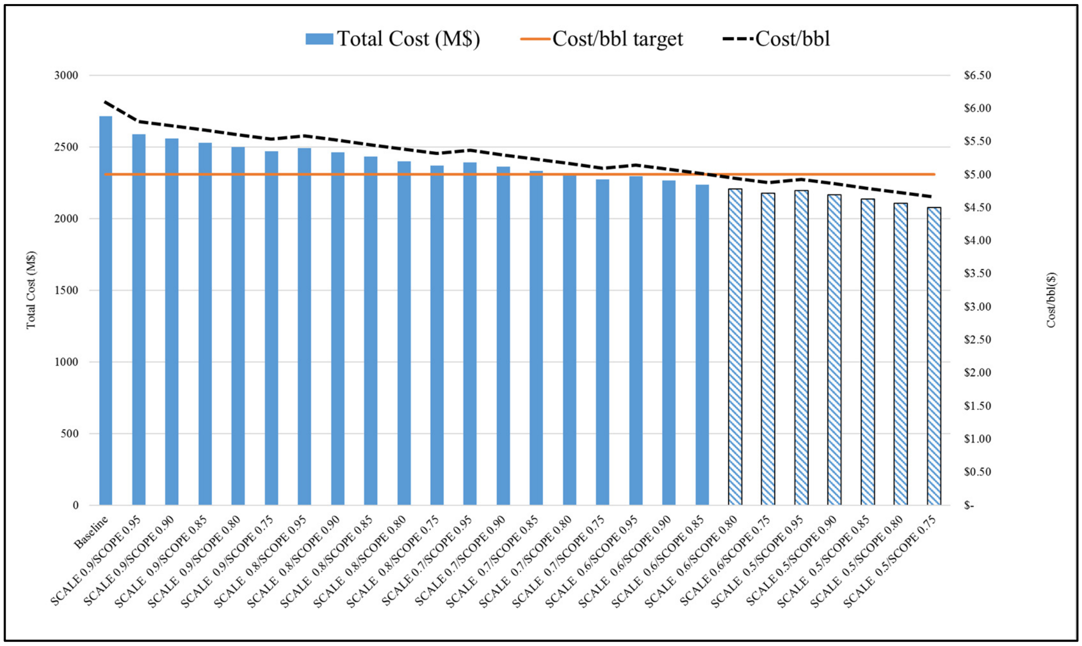


Figure 5.13 Synergy with a joint economy of scope and scale

5.8 Findings and managerial insights

This study examined the synergy gain in oil and gas supply chain performance after a horizontal merger for a real upstream COSC from the GCC. Two operational strategies are investigated to predict the impact on supply chain performance. First, suppose the synergy comes only from the economy of scale and reduces the operating costs of the supply chain. In that case, we find that the horizontal merger will not achieve the targeted cost/bbl. For the second case, we assume that synergy comes because of the economy of scope. In a horizontal merger, we show that the company will lower the fixed shared services costs and achieve the targeted value for the cost/bbl. Finally, if the synergy comes from economies of scope and scale, it is possible to significantly reduce the cost/bbl and achieve the intended outcome from the horizontal merger.

Although a merger is a strategic decision, the previous results establish the close relationship between mergers and operational strategies. In many cases, mergers are often decided based on a financial perspective and ignore the impact on supply chain performance and operational strategies, leading to a significant percentage of failure. Therefore, this study demonstrates the importance of supply chain performance evaluation before and after the merger and predicts the synergy gain using supply chain models before the final merger decision.

Interestingly, although the solid real-life proof in the oil and gas sector that mergers have a major impact on supply chain elements (i.e. shared services), as well as the fact that they contribute significantly to the motivational ground for mergers and their eventual success/failure, the relationship has been widely unexplored. Using the proposed model, it is now possible to evaluate the feasibility of different operational strategies and their impact on supply chain performance if the merger happens.

5.9 Conclusion

This chapter draws elements from supply chain modeling and optimization to examine synergy gain in supply chain performance after a merger in the oil and gas industry. Reducing the cost/bbl by supply chain consolidation had been a significant motivation behind the recent wave of horizontal mergers in the petroleum sector. Nevertheless, such a goal has proven to be elusive in practice. Therefore, in-depth experimentation using data from a real case company have been carried out to quantify synergy in supply chain mergers that lead to economies of scope and scale at different supply chain echelons. To the best of our knowledge, this is the first study to appear in the literature and use supply chain modeling in the upstream oil and gas sector to compute synergy after a horizontal merger. The different scenarios studied in this research identified the key characteristics and conditions of the new operational strategies that affect supply chain synergy. We first studied the impact of economies of scale on different supply chain activities. We also studied the effect of economies of scope. Finally, we investigated the effect of joint economies of scope and scale. Supply chain managers could use the tool to initiate the negotiation platform with shared services providers and transform the procurement process after mergers.

CHAPTER 6

SUPPLY CHAIN SYNERGY UNDER UNCERTAINTY

6.1 Introduction

In previous chapters, we established that the synergy gain in oil and gas supply chain performance after a horizontal merger for COSC is very sensitive to the uncertainty related to the demand and shared services costs. The potential reduction of these costs through economy of scale and economy of scope might impact different supply chain decisions. However, to the best of our knowledge, no stochastic model addresses the COSC supply chain planning problem considering these uncertainties in the context of mergers, which is essential in this case given the direct impact on the cost/bbl. By developing the proposed quantitative model, we aim to answer the following research questions:

- What is the optimal COSC plan under the uncertainties shared services cost parameters after a merger?
- How to evaluate the synergy COSC after a merger under uncertainties?

Under uncertainty, supply chain planning is a very active research area (Govindan, Fattahi et Keyvanshokooh, 2017; Grossmann et al., 2016; Papageorgiou, 2009; Simangunsong, Hendry et Stevenson, 2012). Peidro et al. (2009) propose a classification of the literature related to this subject according to the problem type, source of uncertainty, and modeling approach. Sources of uncertainties included supply, demand, and process/manufacturing (Peidro et al., 2009). Four modeling approaches were discussed: analytical models, models based on artificial intelligence, simulation models, and some hybrid modeling. Also, Tordecilla et al. (2021) have recently reviewed 93 papers on using simulation and optimization methods in the design of SC networks. They show that most papers use stochastic programming and mixed-integer linear programming (MILP) modeling tools for the supply chain. Other studies use Monte-Carlo simulation to generate test scenarios (Tordecilla et al., 2021). In this chapter, we will use stochastic programming and thus fits in the category of analytical models. Next, the focus will be on the review of supply chain planning models with uncertainty considerations.

Supply chain planning and optimization models that include demand uncertainty are the most studied literature (Tordecilla et al., 2021). A recent study by (Zahiri, Suresh et de Jong, 2020) proposes a new bi-objective mathematical model for hazardous materials transportation design considering resiliency and perishability. To deal with uncertainties in the model, a multi-stage stochastic programming approach is proposed. Sabouhi, Pishvaee, et Jabalameli (2018) present a two-stage possibilistic-stochastic programming model for supplier selection and supply chain design under disruption and operational risks. A pharmaceutical company is used as a case study to investigate the applicability of the proposed model and analyze the solution results. (Ni, Howell et Sharkey, 2018) build a two-stage stochastic programming model to increase the resiliency of single-product, single-echelon supply chain systems that include the cost of lost customers. (Li et Zhang, 2018) investigate a supply chain network design problem with facility disruptions and propose a sample average approximation (SAA) algorithm. They formulate a stochastic programming model and an explicit scenario-based model. Computational results are developed to evaluate the performance of the SAA algorithm. Studies related to facility capacity and uncertainty is another topic where different approaches had been proposed (Jabbarzadeh, Haughton et Khosrojerdi, 2018; Ni, Howell et Sharkey, 2018; Zhao et You, 2019). Some studies also focus on uncertainties related to supply, lead-time, processing time, and transportation time (Tordecilla et al., 2021).

Escudero et al. (1999) developed a stochastic programming modeling framework to optimize a multi-period multi-product multi-level supply chain planning problem under demand and supply uncertainties (Escudero et al., 1999). Suppl uncertainties include the unit cost of raw material, supply capacity, and raw material shipment capacity. The model was applied in the automotive sector. Alonso-Ayuso et al. (2003) presented uncertainty of the cost of raw materials (Alonso-Ayuso et al., 2003). Mohammadi Bidhandi and Mohd

Yusuff (2011) considered a stochastic model with uncertainties at the strategic and tactical planning decisions. Uncertainties are mainly related to supply costs and capacities (Mohammadi Bidhandi et Mohd Yusuff, 2011). Mirzapour Al-E-Hashem et al. (2011) used a robust optimization model for supply chain planning with multiple suppliers, manufacturers, and customers. The model incorporated uncertainty of raw materials and transportation costs from suppliers (Mirzapour Al-e-hashem, Malekly et Aryanezhad, 2011).

Due to the application that inspired this study (post-merger oil and gas tactical supply chain planning), this chapter focuses on shared service cost and demand uncertainties. However, the proposed model can handle additional sources of uncertainty, such as capacity. The structure of this chapter is as follows. Section 6.2 explains the problem under study, the stochastic model's general formulation, and the solution procedure. Section 6.3 shows the significant modification of the deterministic model presented in chapter 5. Section 6.4 focuses on the presentation of computational experiments and results. It also provides some theoretical and managerial insights based on detailed sensitivity analyses.

6.2 Methodology and solution procedure

Uncertain parameters follow continuous distributions and generate large models that are difficult to solve. Thus, performing a Sampling Average Approximation (SAA) procedure could be an effective way to consider many scenarios to approximate the optimal solution. The methodology has been applied to different supply chain planning problems with success (Tordecilla et al., 2021). Using this technique based on Monte Carlo simulations (Homem-de-Mello et Bayraksan, 2014), the aim is to approximate the expected objective function of the stochastic problem by an SAA derived from a random sample. After that, the modified model is solved repeatedly using different samples to obtain a statistical estimate of the optimality gaps (Santoso et al. 2005).

The sampling average approximation procedure

The following equation is the general formulation of the compact stochastic optimization problem in the context of supply chain planning:

$$\boldsymbol{min\, f}(\boldsymbol{y}) = \mathbb{E}\ [\boldsymbol{Q}(\boldsymbol{y}, \boldsymbol{\xi})] \tag{6.1}$$

Where $\xi\ (q, d, s, M)$ is a random cost vector, and $Q(y, \xi)$ is the optimal value of the following problem:

$$min\, q^T x + h^T z \tag{6.2}$$

$$s.t.\ \ Nx = 0, \tag{6.3}$$

$$Dx + z \geq d, \tag{6.4}$$

$$Sx \leq s, \tag{6.5}$$

$$Rx \leq My, \tag{6.6}$$

$$x \in \mathbb{R}^{+}, \tag{6.7}$$

Vector q corresponds to the model's processing, inventory, and transportation costs, and x to the flow in the supply chain network. Equations (6.3), (6.4), and (6.5) represent the classical flow conservation, demand, and supply capacity constraints. Equation (6.6) defines each node's processing requirements, while M is the matrix setting the nodes' capacities. Any particular realization of the random vector $\xi\ (q, d, s, M)$ is called a scenario where the probability distribution of ξ is known. Thus, (6-1)- (6-7) is a typical compact stochastic formulation to minimize the expected cost defined by $\mathbb{E}\ [Q(y, \xi)]$. It is well known that $\mathbb{E}\ [Q(y, \xi)]$ is a convex non-linear function of y (Santoso et al. 2005). The problem considered in (6-1) is challenging to solve, especially if $Q(y, \xi)$ follows a continuous distribution. With a generated sample of $\xi^1, \ldots, \xi^N$, SAA methodology evaluates $\mathbb{E}\ [Q(y, \xi)]$ by generating N scenarios to build an approximation of the following function:

$$\frac{1}{N}\sum_{n=1}^{N} Q(y,\xi^n) \tag{6.8}$$

Thus, that means the problem: $min\, f(y) = \mathbb{E}\ [Q(y,\xi)]$ will be approximated by the following one:

$$min_y \left\{ \hat{f}_N(y) = \frac{1}{N}\sum_{n=1}^{N} Q(y,\xi^n) \right\} \tag{6.9}$$

Finally, we need to solve the problem (6.9) multiple times by generating multiple replications to reach this goal. The detailed algorithm is explained in ANNEX III.

6.3 Model development

The following section will present the model formulation, including the notations such as the sets, parameters, objective function, and the model's constraints. For uncertainty, we consider $\alpha_o \in [0,1]$ representing the percentage reduction achieved through the economy of scale and $\beta_o \in [0,1]$ the percentage reduced due to the economy of scope. These are uncertain parameters that follow a known probability distribution. Their uncertainty should be considered to ensure realistic supply chain planning optimization and synergy estimation after mergers.

6.3.1 Model notations

Oil and Gas sets

o, d : all nodes for oil processing

R : set of oil reservoirs (production)

P^n : set of oil processing plants at each stage $n \in \{1,2,3\}$

H : set of oil gathering centers

S : set of spheroids plants for oil processing

E : set of strippers for oil processing

L : set of local oil depots

Z : set of scenarios

u, v: all gas nodes processing

G: set of gas reservoirs (production)

J: set of gas processing plants

I : set of gas gathering centers

K : set of local gas depots

T : set of time periods

Cost parameters (oil)

SSC_{oz}**:** fixed cost for shared services at facility $o \in O$ in scenario $z \in Z$

$VSSC_{todz}$**:** variable cost for shared services at period $t \in T$ from node $o \in O$ to *node* $d \in D$ in scenario $z \in Z$

We can calculate the shared services costs under each scenario as explained in section 5.3.

$$\forall s \in S, \qquad SSC_{oz}^{pre}(X) = SSC_{oz} + VSSC_{oz}.X \text{ (before merger)}$$
$$CCS_{oz}^{post}(X) = \alpha_{oz}.SSC_{oz} + \beta_{oz}.VSSC_{oz}.X \text{ (after merger)}$$

With α_{oz} and β_{oz} the economies of scale and scope at node $o \in O$ under each scenario $z \in Z$ respectively.

OEC_{tod}: extraction cost per unit of crude oil during time period t , \$/barrel; where $o \in R, d \in P^1$

PCO_{tod}^1: processing cost per unit of crude oil at node d during time period t where $o \in R, d \in P^1$

PCO_{tod}^n: processing cost per unit of crude oil at node *d for stage n* during period t where $o \in H, d \in P^n$

PCO_{tod}^S: processing cost per unit of crude oil at spheroids during time period t where $o \in H, d \in S$

PCO_{tod}^E: processing cost per unit of crude oil at strippers during time period t where $o \in H, d \in E$

$IC^O{}_{to}$: inventory holding cost of crude oil during time period t where $o \in H \cup L$

$WC^{O}{}_{to}$: penalty cost per unit for producing oil below the demand at node $o \in L$ during time period t (i.e., penalty of filling part of the demand from the outside market), \$/MMbarrel .

$TC^{O}{}_{tod}$: transportation cost per unit of crude oil during time period t where $p \in P, q \in Q$

Capacity parameters

RO_o: amount of reserves in oil reservoir $o \in R$, MMbarrel;

C_o^H: capacity of facility $o \in O = R \cup P^n \cup H \cup S \cup E$ for the whole horizon

PO_{tod}^n: yield of crude oil liberated during time period t at node $o \in R \cup H$ transported to node $d \in P^n$

PO_{tod}^S: yield of crude oil liberated during period t at node $o \in H$ transported to node $d \in S$

PO_{tod}^E: yield of crude oil liberated during period t at node $o \in H$ transported to node $d \in E$

CO_{td}^n: capacity of oil processing during period t at node $d \in P^n$ and $n \in \{1,2,3\}$,

CRL_{tod}^O: capacity of the route linking node $o \in O$ to node $d \in D$ for crude oil , MMbarrel

COG_{td}: capacity at oil gathering center $d \in H$

CO_{td}^S: capacity of spheroid during period t at node $d \in S$, MMbarrel

CO_{td}^E: capacity of strippers during period t at node $d \in S$, MMbarrel

CO_{td}^L: capacity of oil depot during period t at node $d \in S$, MMbarrel

RG_u: amount of reserves in gas (bscft) reservoir $u \in G$;

CG_{tu}: capacity of gas processing plan (bscft) during time period t at node $u \in J$

CRL_{tuv}^G: capacity of the route linking node $u \in U$ to node $v \in V$ for gas , bscft

PO_{tod}^E: yield of crude oil liberated during time period t at node $o \in H$ transported to node $d \in E$

Cost parameters (gas)

GEC_{tuv} : extraction cost per unit of gas during time period t , \$/bscft; where $p \in G, q \in J$

$PCG^1{}_{tuv}$: processing cost per unit of gas at node d during time period t where $p \in P^1, q \in J$

$TC^G{}_{tuv}$: transportation cost per unit of gas during time period t where$u \in U, v \in V$

$IC^G{}_{tu}$: inventory holding cost of gas during time period t where $u \in I \cup K$

$BC^G{}_{tu}$: penalty cost per unit for producing gas below the demand at node $u \in K$ during time period t (i.e., penalty of filling part of the demand from the outside market), \$/bscft.

Demand and price parameters

DO_{tdz}: demand for oil in period $t \in T$ at node $d \in D$ in scenario $z \in Z$

DG_{tdz}: demand for gas in period $t \in T$ at node $d \in D$ in scenario $z \in Z$

${PR^O}_{td}$: selling price of crude oil ($/MMbarrel) during time period $t \in T$ at demand node d ; where $d \in L$.

${PR^G}_{tv}$: selling price of gas ($/bscft) during time period $t \in T$ at demand node v ; where $v \in K$

Decision variables: Oil

Z_{oz}: binary variable =1 if the the shared sevice is activated at facilty $o \in O$ in scenario $z \in Z$

X_{todz} : amount of crude oil transported in time period $t \in T$ from node $o \in O$ to node d in scenario $z \in Z$

IO_{toz}: inventory of crude in time period $t \in T$ above the demand at node $o \in O$ in scenario $z \in Z$

IO^0_{oz}: initial inventory of crude in time period $t \in T$ above the demand at node $o \in O$ in scenario $z \in Z$

BO_{toz}: amount of backorder of crude oil at node $o \in O$ during time period $t \in T$ in scenario $z \in Z$

Decision variables: Gas

Y_{tuvz}: amount of gas transported from node p to node q in time period $t \in T$ in scenario $z \in Z$

IG_{tuz}: inventory of gas in time period $t \in T$ above the demand at node $u \in U$ in scenario $z \in Z$

BG_{tuz}: amount of backorder of gas at node $u \in K$ during time period $t \in T$ in scenario $z \in Z$

6.3.2 Objective function

The following equations define the mathematical formulation of the objective function: $Z = \min\left\{C^O + C^G\right\}$, where C^O and C^G are total oil and gas processing costs through the O&G upstream supply chain until the local depots, respectively.

$$\boldsymbol{C^O} = \sum_{z\in Z} P_z \Bigg[\underbrace{\sum_{o\in R\cup P^n\cup H\cup S\cup E} SSC_{oz} * Z_{oz}}_{\text{Shared services costs (fixed)}} \tag{6.10}$$

$$+ \underbrace{\sum_{t\in T,o\in O,d\in D} VSSC_{otdz}\, X_{todz}}_{\text{Shared services costs (variable)}} + \underbrace{\sum_{t\in T,o\in R,d\in P^1} OEC_{tod} * X_{todz}}_{\textit{Extraction}\text{ costs (oil reservoir)}}$$

$$+ \underbrace{\sum_{t\in T,o\in R,d\in P^1} PCO^1_{tod} * X_{todz}}_{\text{Processing cost stage 1}} + \underbrace{\sum_{t\in T,o\in H,d\in P^n} PCO^n_{tod} * X_{tijz}}_{\text{Processing costs at the } n \text{ stages}}$$

$$+ \underbrace{\sum_{t\in T,o\in H,d\in S} PCO^S{}_{tij} * X_{tijz}}_{\text{Processing costs spheroid}} + \underbrace{\sum_{t\in T,o\in H,d\in P} PCO^E{}_{tij} * X_{tijz}}_{\text{Processing costs : strippers}}$$

$$+ \underbrace{\sum_{t\in T,o\in H\cup L} IC^O{}_{to} * IO_{toz}}_{\text{Inventory costs : gathering center and oil depot}} + \underbrace{\sum_{t\in T,o\in L} WC^O{}_{to} * BO_{toz}}_{\text{Penality costs at oil depot}}$$

$$+ \underbrace{\sum_{t\in T,o\in O,d\in D} TC^O{}_{tod} * X_{todz}}_{\text{Transportation costs}} \Bigg]$$

$$\boldsymbol{C^G} = \sum_{z\in Z} P_z \Bigg[\underbrace{\sum_{t\in T,u\in G,v\in J} GEC_{tuv} * Y_{tuvz}}_{\textit{Extraction}\text{ costs (gas reservoir)}} + \underbrace{\sum_{t\in T,u\in P^1,v\in J} PCG^1{}_{tuv} * Y_{tuvz}}_{\text{Gas processing costs (gas from stage 1 oil processing)}} \tag{6.11}$$

$$+ \underbrace{\sum_{t\in T,u\in P,v\in Q} TC^G{}_{tuv} * Y_{tuvz}}_{\text{Transportation costs}} + \underbrace{\sum_{t\in T,u\in I\cup K} IC^G{}_{tu} * IG_{tuz}}_{\text{Inventory costs at gas gathering centers/gas depot}}$$

$$+ \underbrace{\sum_{t\in T,u\in K} BC^G{}_{tu} * BG_{tuz}}_{\text{Penality costs at gas depots}} \Bigg]$$

6.3.3 Model constraints

A set of linear constraints are added to the model and given in the following equations.

Sustainability constraints. Where S represents the depletion rate to ensure a specific lifetime for the reserves.

$$\sum_{o\in R,d\in P^1} X_{todz} \leq S \times \sum_{o\in R} RO_o \quad \forall t\in T\ \forall z\in Z \tag{6.12}$$

The flow of oil through the existent routes should be below or equal to the transportation capacity.

$$X_{todz} \leq CRL_{tod}^{O}\ \ \forall t\in T\ \ \forall o\in O\ \ \forall d\in D\ \ \forall z\in Z \tag{6.13}$$

Flow balance and capacity constraint for oil at the Gas/Oil separation center.

$$\sum_{o\in R} PO_{toj}^{1} X_{tojz} = \sum_{d\in H} X_{tjdz} \quad \forall t\in T \forall j\in P^1\ \forall z\in Z \tag{6.14}$$

$$\sum_{o\in R} PO_{tod}^{1} X_{todz} \leq CO_{td}^{1}\ \forall t\in T \forall d\in P^1\ \forall z\in Z \tag{6.15}$$

Inventory balance and capacity constraints at gathering center 1

$$\sum_{o\in P^1} X_{tojz} + IO_{jz}^{0} = \sum_{d\in P^2} X_{tjdz} + IO_{tjz} \quad \forall j\in H; t=1, \forall z\in Z \tag{6.16}$$

$$\sum_{o\in P^1} X_{tojz} + IO_{(t-1)jz} = \sum_{d\in P^2} X_{tjdz} + IO_{tjz} \quad \forall j\in H; t\in T, t\neq 1, \forall z\in Z \tag{6.17}$$

$$\sum_{o\in P^1} X_{todz} + IO_{(t-1)dz} \leq COG_{td} \quad \forall d\in H; t\in T, t\neq 1, \forall z\in Z \tag{6.18}$$

Flow balance and capacity constraint for oil at oil processing plant 2

$$\sum_{o\in H} PO_{toj}^{2} X_{tojz} = \sum_{d\in H} X_{tjdz} \quad \forall t\in T \forall j\in P^2, \forall z\in Z \tag{6.19}$$

$$\sum_{o\in H} PO_{tod}^{2} X_{todz} \leq CO_{td}^{2} \qquad \forall t\in T\ \forall d\in P^2, \forall z\in Z \tag{6.20}$$

Inventory balance and capacity constraints at gathering center 2

$$\sum_{o\in P^2} X_{tojz} + IO_{jz}^{0} = \sum_{d\in P^3} X_{tjdz} + IO_{tjz} \quad \forall j\in H; t=1, \forall z\in Z \tag{6.21}$$

$$\sum_{o\in P^2} X_{tojz} + IO_{(t-1)jz} = \sum_{d\in P^3} X_{tjdz} + IO_{tjz} \quad \forall j\in H; t\in T, t\neq 1, \forall z\in Z \tag{6.22}$$

$$\sum_{o \in P^2} X_{todz} + IO_{(t-1)dz} \leq COG_{td} \quad \forall d \in H; t \in T, t \neq 1, \forall z \in Z \tag{6.23}$$

Flow balance and capacity constraint for oil at oil processing plant 3

$$\sum_{o \in H} PO^3_{toj} X_{tojz} = \sum_{d \in H} X_{tjdz} \quad \forall t \in T \forall j \in P^3, \forall z \in Z \tag{6.24}$$

$$\sum_{o \in H} PO^3_{tod} X_{todz} \leq CO^3_{td} \; \forall t \in T, \forall d \in P^3, \forall z \in Z \tag{6.25}$$

Inventory balance and capacity constraints at gathering center 3

$$\sum_{o \in P^3} X_{tojz} + IO^0_{jz} = \sum_{d \in S} X_{tjdz} + IO_{tjz} \quad \forall j \in H; t = 1, \forall z \in Z \tag{6.26}$$

$$\sum_{o \in P^3} X_{tojz} + IO_{(t-1)jz} = \sum_{d \in S} X_{tjdz} + IO_{tjz} \quad \forall j \in H; t \in T, t \neq 1, \forall z \in Z \tag{6.27}$$

$$\sum_{o \in P^3} X_{todz} + IO_{(t-1)dz} \leq COG_{td} \quad \forall d \in H; t \in T, t \neq 1, \forall z \in Z \tag{6.28}$$

Flow balance and capacity constraint for oil Spheroid (oil processing)

$$\sum_{o \in H} PO^S_{toj} X_{tojz} = \sum_{d \in H} X_{tjdz} \quad \forall t \in T \forall j \in S, \forall z \in Z \tag{6.29}$$

$$\sum_{o \in H} PO^S_{tod} X_{todz} \leq CO^S_{td} \quad \forall t \in T, \forall d \in S, \forall z \in Z \tag{6.30}$$

Inventory balance and capacity constraints at gathering center 4

$$\sum_{o \in S} X_{tojz} + IO^0_{jz} = \sum_{d \in E} X_{tjdz} + IO_{tjz} \quad \forall j \in H; t = 1, \forall z \in Z \tag{6.31}$$

$$\sum_{o \in S} X_{tojz} + IO_{(t-1)jz} = \sum_{d \in E} X_{tjdz} + IO_{tjz} \quad \forall j \in H; t \in T, t \neq 1, \forall z \in Z \tag{6.32}$$

$$\sum_{o \in S} X_{todz} + IO_{(t-1)dz} \leq COG_{td} \quad \forall d \in H; t \in T, t \neq 1, \forall z \in Z \tag{6.33}$$

Flow balance and capacity constraint for oil Strippers (oil processing)

$$\sum_{o \in H} PO^S_{toj} X_{tojz} = \sum_{d \in L} X_{tjdz} \quad \forall t \in T \forall j \in E, \forall z \in Z \tag{6.34}$$

$$\sum_{o \in H} PO^S_{tod} X_{todz} \leq CO^S_{td} \qquad \forall t \in T \forall d \in S, \forall z \in Z \tag{6.35}$$

Inventory balance and capacity constraints at oil depots

$$\sum_{o \in E} X_{todz} + IO_{dz}^{0} = DO_{tdz} + IO_{tdz} \quad \forall d \in L; t = 1, \forall z \in Z \tag{6.36}$$

$$\sum_{o \in E} X_{todz} + IO_{(t-1)dz} = IO_{tdz} + DO_{tdz} - BO_{tdz} \quad \forall d \in L; t \in T, t \neq 1, \forall z \in Z \tag{6.37}$$

$$\sum_{o \in E} X_{todz} + IO_{(t-1)dz} \leq \ CO_{td}^{L} \ \ \forall d \in L; t \in T, t \neq 1, \forall z \in Z \tag{6.38}$$

Logical constraints related to shared services contracts activation in the plants

$$\sum_{d \in D, t \in T} X_{todz} \leq \ C_{o}^{H} \times Z_{oz} \ \forall o \in R \cup P^{n} \cup H \cup S \cup E, \forall z \in Z \tag{6.39}$$

Sustainability constraints. Where *S* represents the depletion rate to ensure a specific lifetime for the gas reserves.

$$\sum_{u \in G, v \in J} Y_{tuvz} \leq S \times \sum_{u \in G} RG_{u} \qquad \forall t \in T, \forall z \in Z \tag{6.40}$$

The flow of gas through the existent routes should be lower or equal to the transportation capacity

$$Y_{tuvz} \leq \ CRL_{tuv}^{g} \qquad \forall u \in U; \forall v \in V; t \in T, \forall z \in Z \tag{6.41}$$

Flow balance and capacity constraint at gas processing plants

$$\sum_{u \in G} Y_{tusz} = \sum_{v \in I} Y_{tsvz} \quad \forall t \in T; s \in J, \forall z \in Z \tag{6.42}$$

$$\sum_{u \in G} Y_{tuvz} \leq CG_{vt} \qquad \forall t \in T; v \in J, \forall z \in Z \tag{6.43}$$

Flow balance and capacity constraints at gas gathering

$$\sum_{u \in J} Y_{tusz} + IG_{0sz} = \sum_{v \in K} Y_{tsvz} + IG_{tsz} \qquad \forall t = 1; s \in I, \forall z \in Z \tag{6.44}$$

$$\sum_{u \in J} Y_{tusz} + IG_{(t-1)sz} = \sum_{v \in K} Y_{tsvz} + IG_{tsz} \quad \forall t \neq 1; s \in I, \forall z \in Z \tag{6.45}$$

$$\sum_{u \in J} Y_{tuvz} + IG_{(t-1)vz} \leq CG_{tv} \qquad \forall t \neq 1; v \in I, \forall z \in Z \tag{6.46}$$

Flow balance for associated gas

$$\sum_{o} GOR_{tod} \, X_{todz} = \ Y_{tdvz} \qquad \forall t \in T; d \in P^{n} \cup S \cup E; v \in J; o \in R \cup H \cup S, \forall z \in Z \tag{6.47}$$

Inventory balance and capacity constraints at gas depots

$$\sum_{u \in I \cup P^n \cup S \cup E} Y_{tuvz} + IG_{0dz} = IG_{0dz} + DG_{tdz} \qquad \forall t = 1; d \in K, \forall z \in Z \tag{6.48}$$

$$\sum_{u \in I \cup P^n \cup S \cup E} Y_{tuvz} + IG_{(t-1)dz} = IG_{tdz} - BG_{tdz} + DG_{tdz} \quad \forall t \in T; t \neq 1; d \in K, \forall z \in Z \tag{6.49}$$

The following section will present the main findings of this research by applying the SAA to the stochastic model.

6.4 Computational experiments

The model is coded using Lingo. We also developed a Microsoft Excel database containing the same input data from the case study presented in chapter 5. The choice of the sample size (N) and the number of replication (M) is an important question. In many cases, it is not easy to estimate. We observed an increase in the computational complexity of solving the SAA problem when the sample size N increases. In this study, different instances of our case study (20 scenarios for the uncertainty) take an average of 5 minutes to obtain the solution with an acceptable gap (less than 0.4% on average). Thus, it may be more efficient to choose a smaller sample size N and to generate and solve several SAA problems with independent and identically distributed (i.i.d) samples, that is, to replicate generating and solving SAA problems. This procedure is called Multiple Replications Procedure (MRP) estimators. MRP was developed by Mak, Morton, and Wood (Mak, Morton et Wood, 1999).

Thus, we proceeded with 50 different replications during the initial experiments, and we observed that the solution did not change significantly as shown in Figures 6.1 and 6.2.

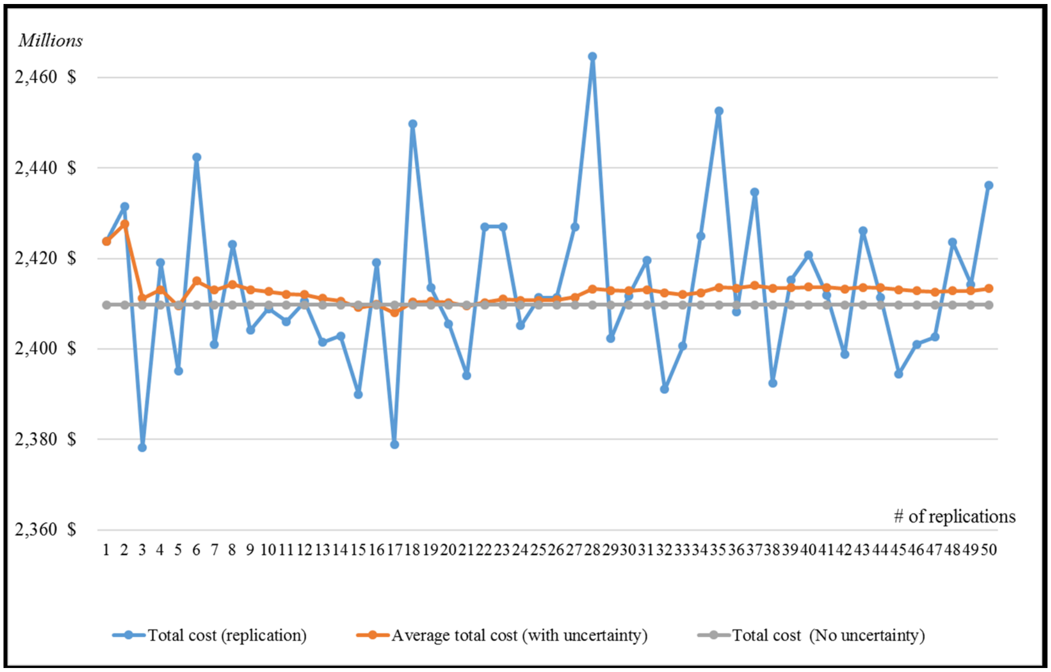


Figure 6.1 Total cost (M$) for multiple replications

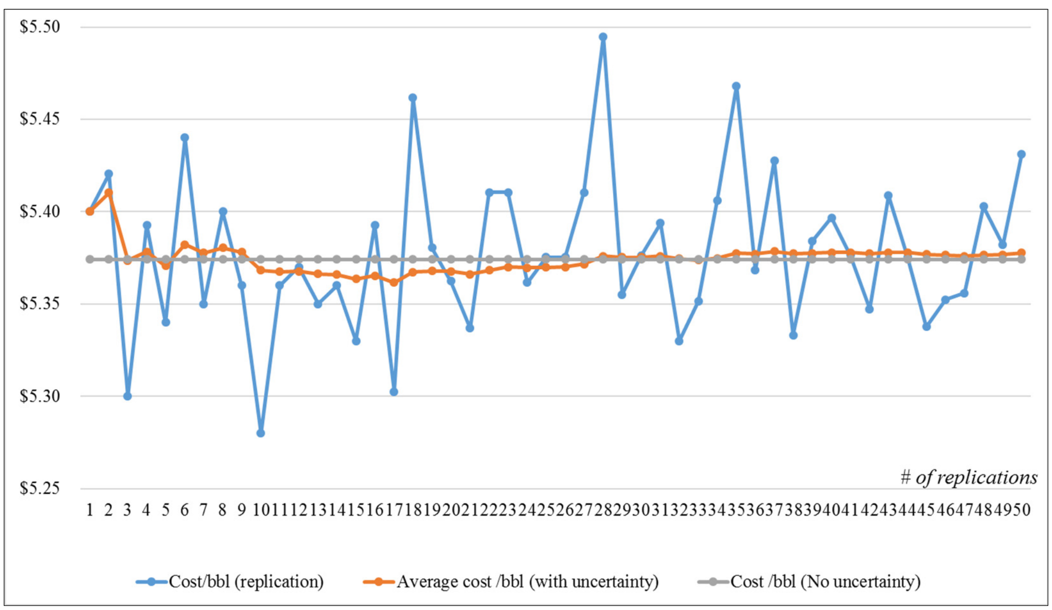


Figure 6.2 Cost/bbl ($) for multiple replications

Since our model is linear, we solve the deterministic equivalent model using the Lingo solver. We do not use any decompositions or special stochastic programming solution algorithms since the solution time is relatively short.

6.4.1 Experimentation

Since uncertainties influence the optimal supply chain plan after the merger process, this section describes the results obtained with different scenarios (N=20). With this choice, the model scale and time for solving the mathematical model to optimality is relatively acceptable (see Table 6.1 for models' statistics). To find the solution to the stochastic problem, we consider a batch size of 30 replications (M=30). It means we solved the previous model with N=20 and thirty i.i.d replications with random "alpha" and "beta." α_{oz} and β_{oz} follow uniform distributions such as $\alpha_{oz} \in [0.5; 1]$ and $\beta_{oz} \in [0.75; 1]$.

Table 6.1 Computation scale and solution time

Model	Total variables	Integers	#of constraints	CPU time (s)	Gap (%)
without uncertainty	4,031	13	5,631	10	0
with uncertainty	71,213	260	111556	470	0.39

The proposed optimization model is used with this case example to develop new theoretical and managerial insights about the following specific questions:

- How to obtain the optimal tactical plan in the case of O&G at the upstream level with multiple cost uncertainties?
- What are potential supply chain improvements reached by better estimating the synergy after a merger?
- What are the impacts of different levels of change in Oil demand?

6.4.2 Initial results

To evaluate the impact of uncertainty, we propose to analyze four cases :

- Case 1: the first case is the baseline scenario without merger (chapter 5).
- Case 2: in case 2, we consider the merger but without uncertainty. In this case, we assume the realization of the expected mean value (EMV) with $\alpha_{oz} = 0.75$ and $\beta_{oz} = 0.875$.
- Case 3: in this case, we assume that it is possible to achieve the best reduction in terms of shared services cost through the economy of scale and scope with $\alpha_{oz} = 0.5$ and $\beta_{oz} = 0.75$.
- Case 4 represents the results of the stochastic model given the uncertainty realization.

Experimental results are shown for the different cases in Table 6.2. The solution obtained by the discrete stochastic model applies to all scenarios involving uncertain parameters. Table 6.3 summarize the total synergy obtained for each case and the average cost/bbl. We can observe that the cost/bbl for cases 2 and 4 is almost the same (see Figure 6.3 c) and d)). Due to the various supply chain solutions, the approximated total cost involving uncertainty in shared services cost (Case 4) is higher than the solution that ignores uncertainty (Case 2). These results can be explained by the fact that uncertainty in shared services costs has a low impact on the planning process since the costs are very similar for the same same supply chain level.

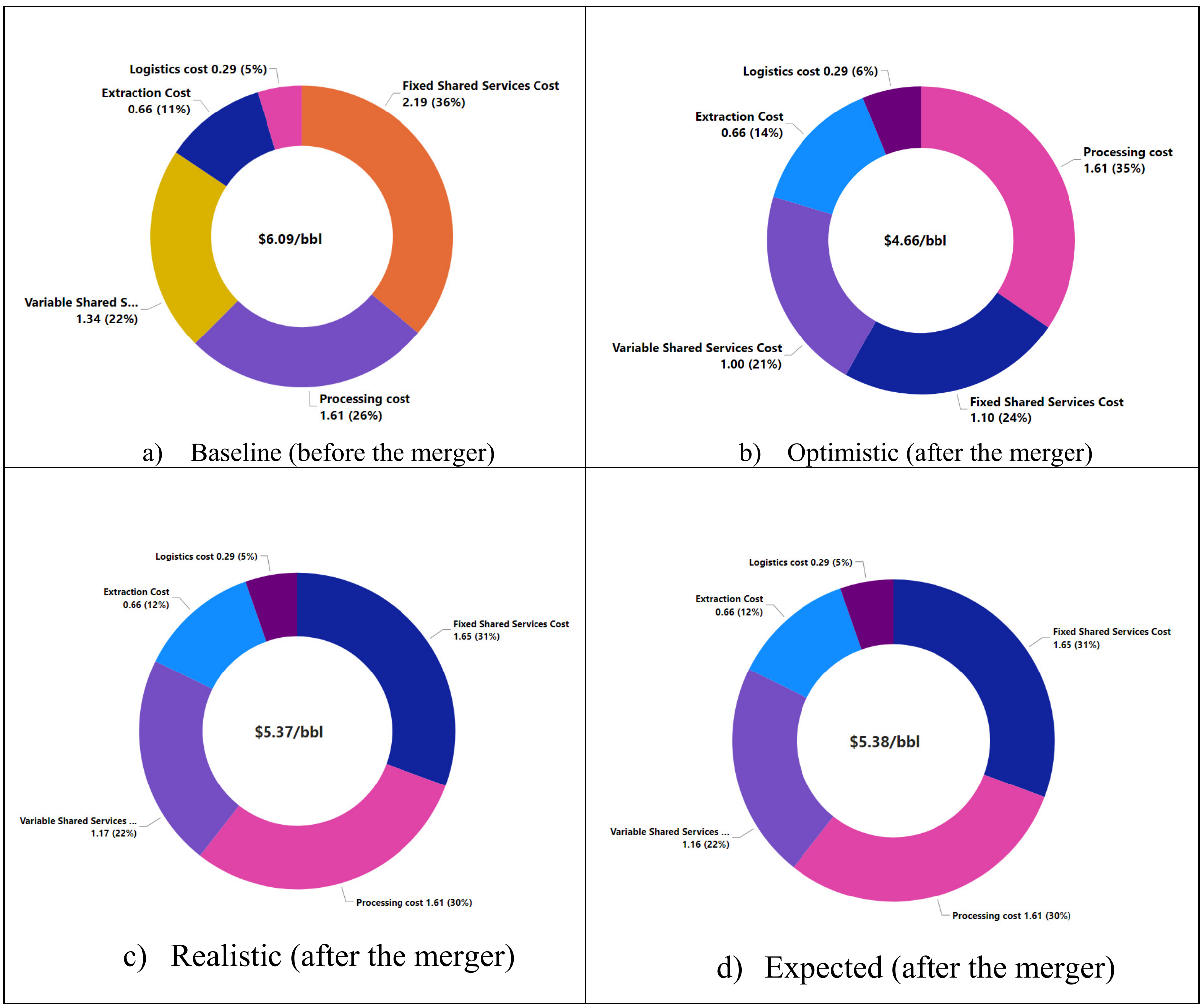
Table 6.2 Supply chain cost and synergy under cost uncertainty

Supply chain level cost (M$)	Case 1 Baseline (before merger)	Case 2 Realistic (after merger)	Synergy	Case 3 Optimistic (after merger)	Synergy	Case 4 Expected LB (after merger)	Synergy
Oil reservoirs	681.04	584.79	14.13%	488.54	28.27%	587.16	13.78%
Stage 1- OP	558.42	492.83	11.75%	427.23	23.49%	498.27	10.77%
Stage 2- OP	476.61	417.90	12.32%	359.19	24.64%	419.62	11.96%
Stage 3 - OP	420.32	365.59	13.02%	310.85	26.04%	360.76	14.17%
SPHEROID - OP	257.05	233.42	9.19%	209.79	18.38%	231.77	9.83%
STRIPPERS - OP	194.38	174.23	10.37%	154.08	20.73%	171.68	11.68%
Logistics	128.16	128.16	0.00%	128.16	0.00%	128.16	0%
Gas processing	13.90	13.90	0.00%	13.90	0.00%	13.90	0%

The stochastic solution shows that it is possible to achieve a total synergy of 11.67% for all scenarios. This result is very close to the synergy obtained for the realistic case.

Table 6.3 Synergy and cost /bbl

Supply chain level total cost (M$)	Case 1 Baseline (before merger)	Case 2 Realistic (after merger)	Case 3 Optimistic (after merger)	Case 4 Expected LB (after merger)
Total cost (O&G)	2,729.89	2,410.82	2,091.75	2,411.33
Total Synergy	-	11.69%	23.38%	11.67%
Cost/bbl ($)	6.09	5.37	4.66	5.38



a) Baseline (before the merger)
b) Optimistic (after the merger)
c) Realistic (after the merger)
d) Expected (after the merger)

Figure 6.3 Cost/bbl ($) of oil relative to cost drivers

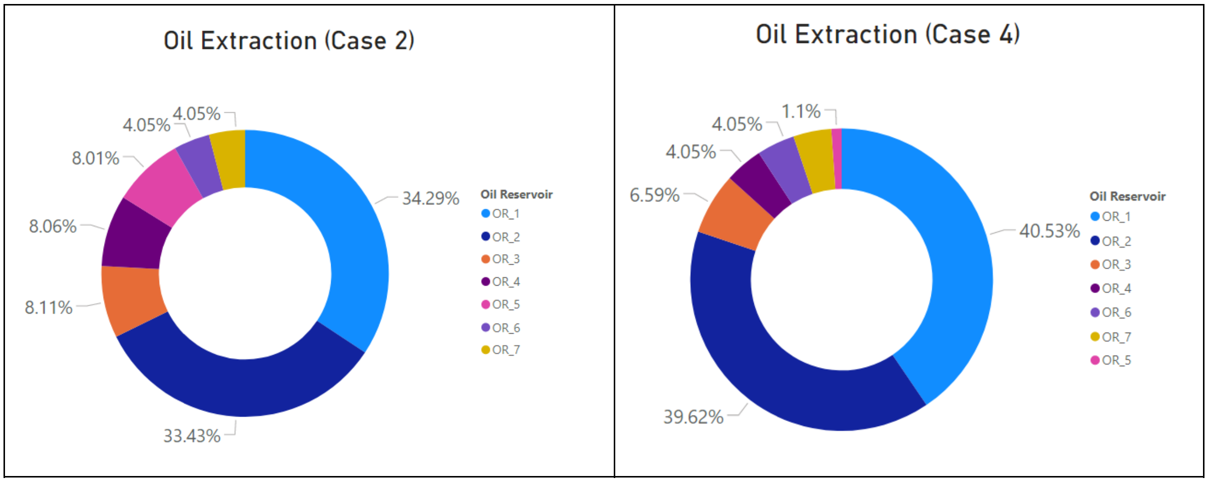


Figure 6.4 Oil extraction activity comparison between Case 2 and Case 4

6.4.3 Impact of demand uncertainty

To verify the impact of additional uncertain parameters on the total cost (cost/bbl), we consider demand uncertainty in this section. Indeed, based on the results from sensitivity analysis in chapter 5, demand uncertainty has a clear impact on supply chain planning (inventory/ penalty). Previous experimentations were executed using the deterministic demand obtained during the data collection process. Therefore, in this section, the demand for oil is assumed to follow a normal distribution as $DO_{tdz} \sim N(\mu, \sigma)$. Again, we use the discrete stochastic model to run multiple replications and obtain a new estimation of the average cost. Next, we will present the results that compare two additional cases.

- Case 5 is the deterministic scenario (no uncertainty) after merger with an average demand (μ= 23 MMbbl/period) and average shared services cost values $\alpha_{oz} = 0.75$ and $\beta_{oz} = 0.875$.
- Case 6 is the stochastic scenario with uncertain demand of Oil that follows a normal $(DO_{tdz} \sim N(23,5))$ and uncertain shared services costs α_{oz} and β_{oz} that follow uniform distributions such as $\alpha_{oz} \in [0.5; 1]$ and $\beta_{oz} \in [0.75; 1]$.

The total cost achieves a stable value after almost 40 replications with an average of M$ 2,855.33 for the discrete stochastic model (see Figure 6.5). As explained in ANNEX III, the average total cost represents a lower bound of the solution (LB) to the stochastic model.

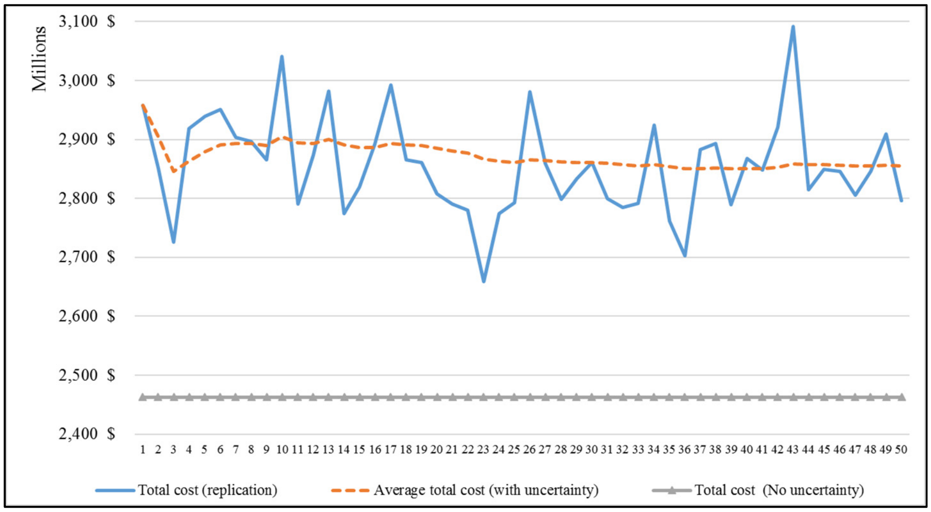


Figure 6.5 Total cost (M$) under demand uncertainty
for multiple replications

The cost/bbl achieves a stable value after almost 40 replications with an expected average of \$6.09 for the discrete stochastic model (see Figure 6.6).

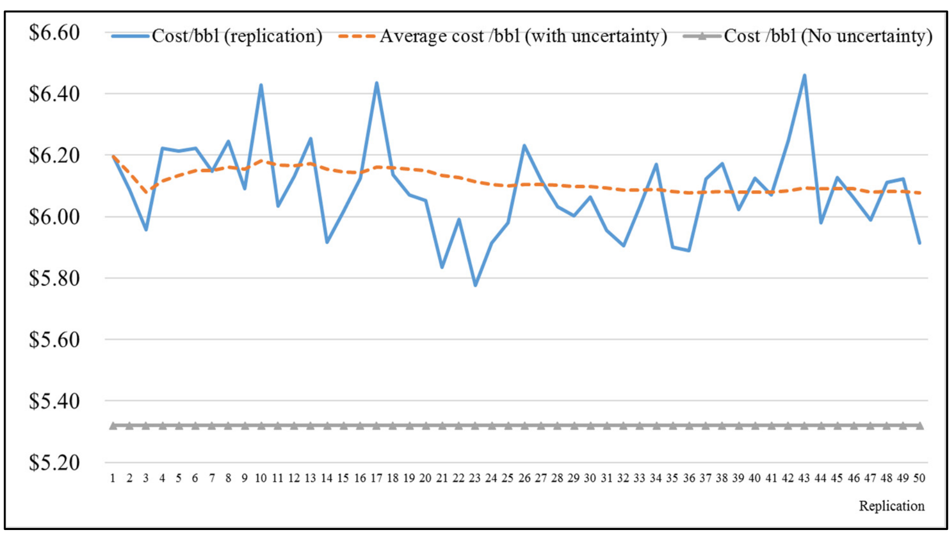


Figure 6.6 Cost/bbl (\$) under demand uncertainty
for multiple replications

The service level achieves a stable value after almost 30 replications with an expected average of 99.01% for the discrete stochastic model (see Figure 6.7).

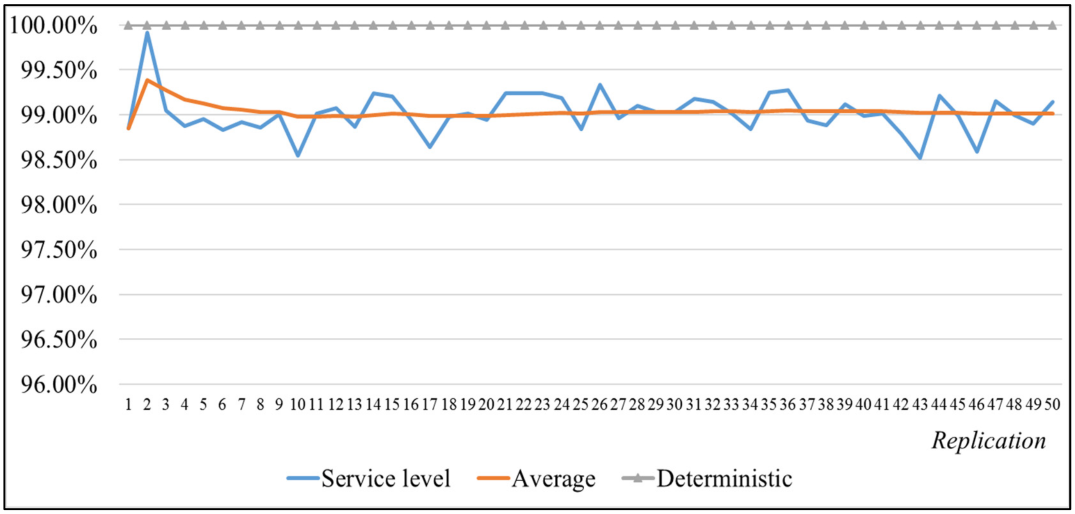


Figure 6.7 Service level under demand uncertainty for multiple replications

To compare the synergy gain at the different supply chain levels between the other cases (case 1, 5, and 6), Table 6.4 shows three solutions' detailed costs. For case 6, we use one of the replication solutions where the cost/bbl and the total cost are very close to the lower bound. It shows mainly that the synergy for this specific solution is negative with (-4.77%). The high increase in costs related to inventory and penalties impacts the supply chain performance negatively (see Figure 6.6).

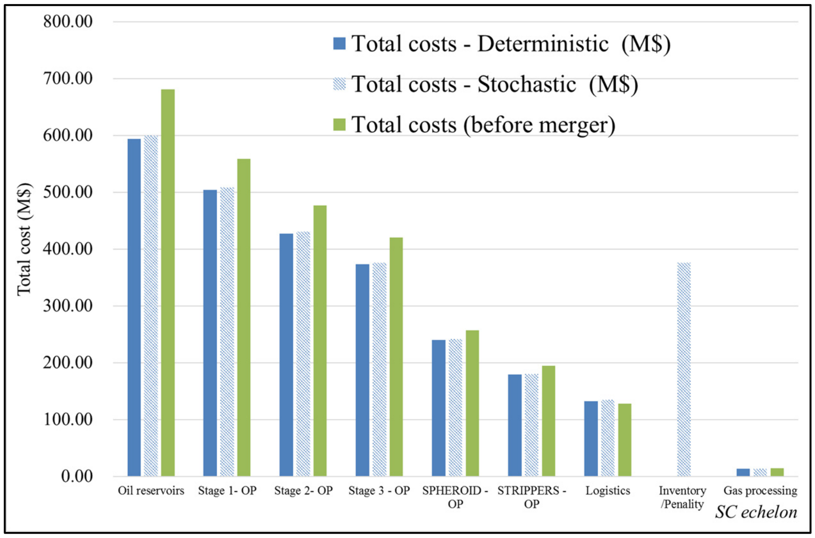


Figure 6.8 Impact of shared services costs and demand uncertainties on supply chain performance

Table 6.4 Supply chain cost (M$) and synergy under cost and demand uncertainties

Supply chain level cost (M$)	Case 1 Baseline (before merger)	Case 5 Deterministic (after a merger)	Synergy	Case 6 Stochastic solution (LB)	Synergy
Oil reservoirs	681.04	594.09	12.77%	599.67	11.95%
Stage 1- OP	558.42	503.86	9.77%	510.49	9.02%
Stage 2- OP	476.61	427.20	10.37%	432.78	9.70%
Stage 3 - OP	420.32	373.30	11.19%	377.94	10.55%
SPHEROID - OP	257.05	239.62	6.78%	243.34	5.93%
STRIPPERS - OP	194.38	178.87	7.98%	181.66	7.32%
Logistics	128.16	132.18	-3.14%	134.60	-5.02%
Inventory / Penalty	0	0		375.71	
Gas processing	13.90	13.84	0.40%	13.81	0.65%
Total cost	2,729.89	2,462.96	9.78%	2,869.99	**-4.77%**
Cost /bbl	6.09	5.32	12.64%	6.09	0%

Table 6.5 Service level analysis under cost and demand uncertainties

Supply chain performance	Case 1 Baseline (before merger)	Case 5 Deterministic (after a merger)	Case 6 Stochastic (LB)
Cost /bbl	6.09	5.32	6.09
Total Average Production (MM bbl)	9,200	9,200	9368.20
Total Average Demand (MM bbl)	9,200	9,200	9462.00
Service level	100%	100%	99.01%

Figure 10 presents the expected cost/bbl variations using the different replications for the two states: "cost uncertain" and "both cost and demand uncertain". Using these results, it is now possible to characterize the potential reduction after a merger under uncertainty.

Table 6.6 Cost/bbl estimation with variance and 95% confidence interval computation

Instance	Cost/bbl ($)			
	Mean	95% confidence interval for Mean	St. Dev.	95% confidence interval for St. Dev.
Cost uncertain	5.378	(5.365; 5.389)	0.042	(0.035 ; 0;52)
Cost and demand uncertain	6.085	(6.044; 6.126)	0.145	(0.121; 0.181)

As an interesting observation, Figure 6.9 demonstrates that the chance to obtain a cost/bbl lower than 5$ (which might be the cost/bbl target after the merger process) is somehow impossible even if we have only uncertainty in shared service costs. With the additional uncertainty in demand, it is obvious to see the cost/bbl increases. Moreover, our findings indicate that the price of Oil will impact the cost/bbl. Indeed, the penalty cost is linked to the loss of profit generated by not fulfilling the demand. It means, if the price of Oil is high, the penalty will be higher and impact the cost/bbl, especially if the service level is less than 100%.

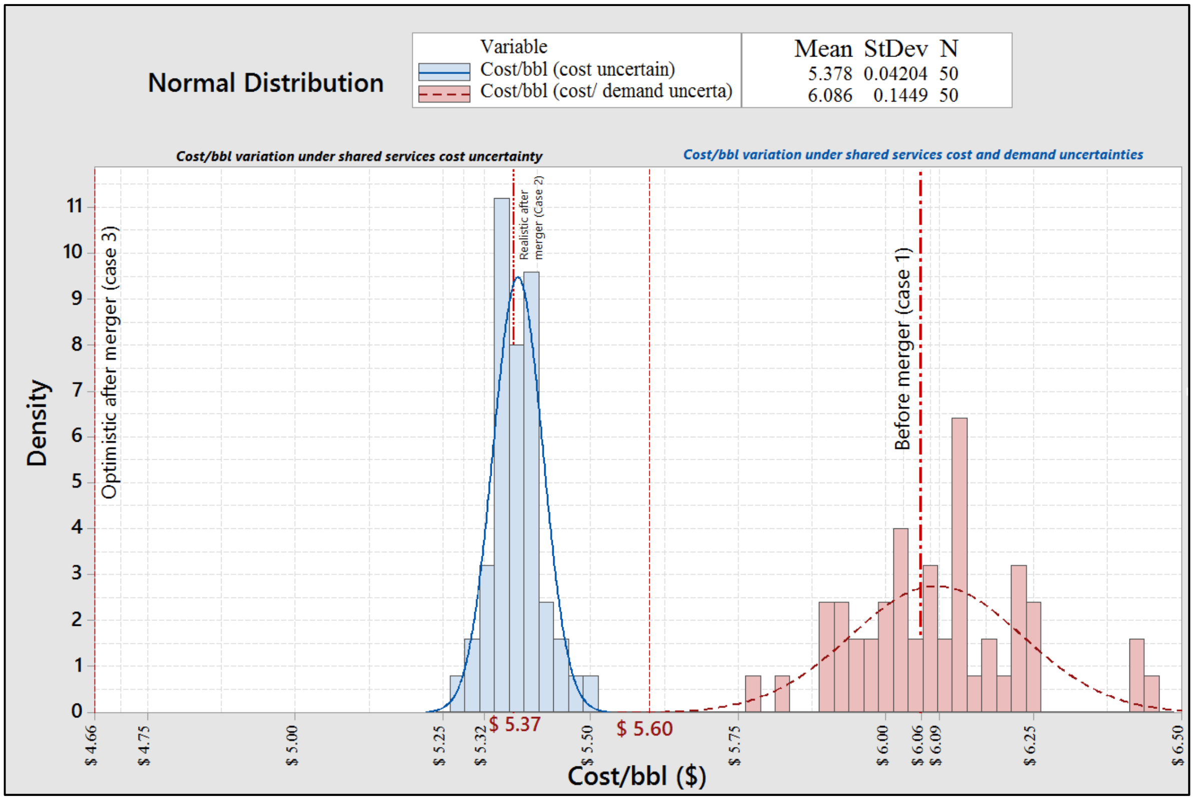


Figure 6.9 Impact of demand and SCC uncertainty on cost/bbl

6.5 Findings and managerial insights

The computational results in this chapter reveal that demand uncertainty significantly impacts the possible post-merger synergy and supply chain performance. The post-merger synergy gain is negligible with integrating the demand and shared services cost uncertainties (case 6). The increase in inventory and penalty costs negatively balances the synergetic gains from economies of scale and scope. Also, this relationship demonstrates the importance of reducing forecasting errors of demand of oil and gas, which contribute to lowering the cost/bbl and obtaining the full benefit of mergers decisions.

The paper also highlights a real need to develop supply chain decision models to support post-merger management of the upstream supply chain to maximize its efficiency under uncertainty of shared services costs (economies of scale and scope). It has identified and provided an understanding of the inter-dependencies between merger decisions and oil cost, which are crucial as a pre-cursor to identifying the strengths and weaknesses of the upstream supply chain planning model.

This research is one of the first studies that address the specific problem of tactical supply chain planning during the merger of two upstream oil companies under uncertainty of shared services cost and demand. The study has enhanced the understanding of the potential efficiencies that can be achieved in the O&G upstream supply chain after merger decisions. The research could benefit decision-makers in evaluating the expected impact of the supply chain operations by providing them the tools to assess the critical resources, expected costs, and development opportunities during and after the merger process.

6.6 Conclusion

Uncertainty in shared services costs after a merger is mainly caused by ambiguity in the economy of scale and scope efficiency. Inspired by a real-world application in the oil and gas industry, this chapter developed a stochastic programming model for tactical supply chain planning under uncertainty after a merger. The model deals with multi-product, multi-echelon supply chains in a multi-period horizon. We described a case study of our model in the oil and gas industry in the Middle East region. Based on computational, experimental results that used realistic data, the model provides the optimal oil and gas production and processing plans through the different supply chain echelons. They also showed that optimal solutions for the stochastic problem are higher than that of the corresponding case without uncertainty.

CONCLUSION

In this research, different decision-making models are introduced to minimize the cost of the tactical plans for the upstream sector of the oil supply chain in the GCC region. To the best of our knowledge, this study is the first to analyze upstream COSC after post-merger integration, given the uncertainty related to demand and shared services cost at wells.

Chapter 2 identified a significant body of research related to SCM in general and within the context of the O&G and petroleum industries. A large amount of the study deals with the downstream sector focusing on refinery-wide optimization (Khor and Varvarezos, 2017). Chapter 2 also looked at mergers within the industry, where recent research by Barrows (2017) concluded that oil industry mergers are becoming less profitable. The use of models to optimize supply chains may be a way to increase profitability. Decision-making models can be applied at both the strategic and tactical levels of design and optimization of the SC; considering the location and capacity of facilities, the use of technology with the SC, and whether to outsource parts of the SC at the strategic level or production planning, inventory management and logistics at the tactical level. Finally, Chapter 2 looked at how uncertainty is handled in these models and concluded that research literature in this area is limited. There is an opportunity to develop more advanced models that deal with uncertainties in the COSC more effectively. Chapter 3 reviewed the different techniques for managing uncertainty in the various optimization models.

Chapter 4 introduced the upstream COSC supply chain along with the formulation used to model the SC. It further details how the proposed model was validated using a real case study. The model was initially used to determine the level of production at the different reservoirs. Several different scenarios are then performed based on changing demand and flexibility in the contract for shared services. Finally, uncertainty was introduced to both demand and shared service costs to see the impact on the total cost of production. The model behaved as expected with the cost per barrel increasing, the demand decreased.

First, uncertainty is considered through a scenario-based analysis and decision tree approach to evaluate the cost/ bbl with and without flexibility in contract shared services management. The cost breakdown based on cost-drivers highlights the importance of shared services and processing costs from the model results. The model is practical and offers an in-depth analysis of the impact of demand and SSC uncertainty on the cost/bbl. The model helps decision-makers identify the flexibility needed in shared services contracts to achieve the expected gains after mergers.

The model was then used to look at the impact of horizontal mergers on SC performance, described in Chapter 5. The impact on the supply structure following a merger is minimal, given the level of inflexibility observed. However, optimizing the supply chain to obtain cost efficiencies via economies of scope and scale can generate synergies from the merger. Economies of scope result from reducing resources in areas such as HR and IT in the combined company. Economies of scale result from spreading fixed costs over a greater production from the merged entity. The model showed that it is possible to significantly reduce the cost per barrel if both economies of scope and scale are achieved through the merger. In chapter 5, it was shown that the synergy gain in oil and gas supply chain performance after a horizontal merger for COSC is very sensitive to the uncertainty related to the demand and shared services costs.

Chapter 6 investigated the impact of uncertainty in the economies of scope and scale on the SC efficiency obtained during a merger. A stochastic model was proposed for post-merger supply chain planning under uncertainty and applied to a real-world problem in oil and gas. The model deals with multi-period and multi-echelon upstream oil and gas supply chains. Uncertainties in shared services costs and demand after a merger are considered. A Sample Average Approximation (SAA) procedure with Multiple Replications Procedure (MRP) is developed to solve the stochastic model. We illustrated how our model directly applies to supply chain planning. We presented numerical results that show the impact of cost uncertainty on supply chain planning decisions and synergy gains. We also measure the value of modeling uncertainty against deterministic planning and characterize the cost per barrel (cots/bbl) after a merger under shared services cost and demand uncertainty.

7.1 Main contributions

The thesis highlights a real need to develop supply chain decision models to support the management post-merger in the upstream supply chain to maximize profit under the uncertainty of shared services costs (economies of scale and scope). It has identified and provided an understanding of the inter-dependencies between merger decisions and oil prices, which are crucial as a pre-cursor to identifying the strengths and weaknesses of the upstream supply chain planning model.

The research has helped develop a model to optimize the tactical plan for the upstream supply chain after a merger and under demand and cost uncertainties. In the case of joint mergers between two upstream O&G companies (or similar companies in other sectors), the model can be used in tactical supply chain planning decisions and might potentially reduce the impact of risky situations (cost increase, capacity problems, etc.).

The thesis has enhanced the understanding of the potential efficiencies that can be achieved in the O&G upstream supply chain after merger decisions. This research is one of the first studies that address the specific problem of tactical supply chain planning during the merger of two upstream oil companies under uncertainty of shared services cost and demand. The research is beneficial for decision-makers in evaluating the expected impact of the supply chain operations. It gives the decision-maker the tools to assess the critical resources, expected costs, and development opportunities during and after the merger process.

7.2 Limitations and future work

After the merger of two companies, different decisions need to be made to consolidate the two supply chains. In the context of oil and gas, due to the lack of flexibility regarding the supply chain reconfiguration, we have assumed that only operational strategies are subject to change by optimizing shared services costs. Future extensions of this research might take several directions.

This research has used a case example from the oil and gas sector. The same methodology could be used in other sectors where other operational and supply strategies are evaluated, such as supply chain design, product characteristics, and temporal factors. Finally, to quantify the synergy for the supply chain after the merger, we have assumed that the merger mainly affects the shared services costs (fixed and variable costs) defined as a linear function of the quantity processed at each node. A non-linear function could be considered to model the scope and scale effects on costs as an extension. In this case, other resolution methods should be investigated to solve the non-linear supply chain optimization model. Also, as an extension of this research, one can consider that other uncertain parameter that influences the cost/bbl, such as Oil price and additional operational costs.

Finally, one extension would be adding the issue of shared services providers' selection with their contractual costs. This extension increases the number of integer variables and model complexity, and the resolution method might be more challenging. The use of resolution techniques such as Benders decomposition (a primal decomposition method) may be necessary. Another extension of this model could include modeling the economy of scale and scope with an operational perspective (Zhu, 2012), leading to an integrated model with a tactical and operational decision.

ANNEX I

LIST OF REVIEWED PAPERS IN CHAPTER 2

Table-A I-1 List of reviewed papers

	Author	**Year**	**Title**	**Publication**
1	Ye et al.	2017	A mixed-integer linear programming-based scheduling model for refined-oil shipping	Computers and Chemical Engineering
2	Attia et al.	2019	A multi-objective optimisation model for tactical planning of upsytream oil & gas supply chains	Computers and Chemical Engineering
3	Zhang et al.	2018	Mixed-time mixed-integer linear programming for optimal detailed scheduling of a crude oil port depot.	Chemical Engineering Research and Design
4	Gulpinar et al.	2014	Robust investment decisions under supply disruption in petroleum markets	Computers & Operations Research
5	Oliveira et al.	2014	Accelerated Benders stochastic decomposition for the optimization under uncertainty of the petroleum product supply chain	Computers & Operations Research
6	Kirschstein	2018	Planning of multi-product pipelines by economic lot scheduling models	European Journal of Operational Research
7	Azadeh et al.	2017	Evolutionary multi-objective optimization of environmental indicators of integrated crude oil supply chain under uncertainty	Journal of Cleaner Production
8	Moradinasab et al.	2018	Competition and cooperation betwee supply chains in multi-objective petroleum green supply chain: A game theoretic approach	Journal of Cleaner Production
9	Norlund and Gribkovskaia	2015	Modal split in offshore supply network under the objective emmissions minimization	Transportation Research Part D
10	de Assis et al.	2016	A MILP model for planning the trips of dynamic positioned tankers with variable travel time	Transportation Research Part E
11	Saad et al.	2018	Planning and optimising petroleum supply chain	Procedia Manufacturing
12	Khorramshahgol et al.	2014	Application of Goal Programming to Swap Analysis in Oil Industry	Journal of Information and Optimization Sciences
13	Chan et al.	2014	Dynamic scheduling of oil tankers with splitting of cargo at pickup and delivery locations: a Multi-objective Ant Colony-based approach	International Journal of Production Research
14	Fiorencio et al.	2015	Investment Planning in the petroleum downstream infrastructure	International Transactions in Operational Research
15	Guo et al.	2016	Combining a continuous location model and Heurisic techniques to determine oilfield warehouse locations under future oil well location uncertainty	Soft Computing
16	Kesharwani et al.	2019	Moving second generation biofuel manufacturing forward: Investigating economic viability and environmental sustainability considering two strategies for supply chain restructuring	Applied Energy
17	Tan et al.	2017	Optimal shale oil and gas investments in the United States	Energy

	Author	Year	Title	Publication
18	Farahani & Rahmani	2017	Production and distribution planning in petroleum supply chains regarding the impacts of gas injection and swap	Energy
19	Ghaithan et al.	2017	Multi-objective optimization model for a dowstream oil and gas supply chain	Applied Mathematical Modelling
20	de Assis et al.	2017	A piecewise McCormick relaxation-based strategy for scheduling operations in a crude oil terminal	Computers and Chemical Engineering
21	Lima et al.	2018	Stochastic programming approach for the optimal tactical planning of the downstream oil supply chain	Computers and Chemical Engineering
22	Dimas et al.	2018	Multiproduct pipeline scheduling integrating for inbound and outbound inventory management	Computers and Chemical Engineering
23	Assis et al.	2019	An MINLP formulation for integrating the operational management of crude oil supply.	Computers and Chemical Engineering
24	Liu et al.	2016	A mixed integer linear programming model for optimal operation of a network of gas oil separation plants	Chemical Engineering Research and Design
25	Azadeh et al.	2017	Optimum Integrated Design of Crude Oil Supply Chain by Unique Mixed Integer Nonlinear Programming Model	Industrial & Engineering Chemistry Research
26	Beiranvand et al.	2018	A robust crude oil supply chain design under uncertain demand and market price: A case study	Oil & Gas Science & Technology
27	Al-Sharrah et al.	2016	Planning a Supply Chain with Risk and Environmental Objectives	International Journal of Social, Behavoral, Educational, Economic, Business and Industrial Engineering
28	Sahebi et al.	2014	Environmentally Conscious Design of Upstream Crude Oil Supply Chain	Industrial & Engineering Chemistry Research
29	Zhao et al.	2014	Multiperiod Planning Model for Integrated Optimization of a Refinery Production and Utility System	Industrial & Engineering Chemistry Research
30	Alfares et al.	2019	Applications of Clustering Models in Offshore Drilling for Crude Oil and Natural Gas	Industrial Engineering & Management Systems
31	Zhang et al.	2019	A Stochastic Linear Programming Method for the Reliable Oil Products Supply Chain System with Hub Distribution	IEEE Access

ANNEX II

SUPPLY CHAIN SYNERGY GAINS IN MERGERS

Table-A II-1 Synergy gains under the economy of scale (beta =1)

		Oil Extraction		Oil Processing - Stage 1		Oil Processing - Stage 2		Oil Processing - Stage3	
Instance	Alpha	OE Cost (M$)	synergy - OE	OP1 - Cost (M$)	synergy - OP 1	OP2 - Cost (M$)	synergy - OP2	OP3- Cost (M$)	synergy - OP3
SCALE 0.5	0.5	489	28%	464	17%	395	17%	340	19%
SCALE 0.6	0.6	527	23%	483	13%	412	14%	356	15%
SCALE 0.7	0.7	566	17%	502	10%	428	10%	372	11%
SCALE 0.8	0.8	604	11%	521	7%	444	7%	388	8%
SCALE 0.9	0.9	643	6%	540	3%	460	4%	404	4%
Baseline	1	681		558		477		420	
		SPHEROID - OP		STRIPPERS - OP		Transportation		Inventory / Penalty	
Instance	Alpha	SPH OP Cost (M$)	synergy - SPH	STRP OP cost (M$)	synergy - STRIP	Logistics Cost (M$)	synergy - Logistics	Total Cost (M$)	synergy
SCALE 0.5	0.5	233	9%	177	9%	128	0%	0	0%
SCALE 0.6	0.6	238	7%	180	7%	128	0%	0	0%
SCALE 0.7	0.7	243	6%	184	5%	128	0%	0	0%
SCALE 0.8	0.8	247	4%	187	3%	128	0%	0	0%
SCALE 0.9	0.9	252	2%	191	2%	128	0%	0	0%
Baseline	1	257		194		128		0	

Table-A II-2 Synergy gains under the economy of scope (alpha = 1)

		Oil Extraction		Oil Processing - Stage 1		Oil Processing - Stage 2		Oil Processing - Stage3	
Instance	BETA	OE Cost (M$)	synergy - OE	OP1 - Cost (M$)	synergy - OP 1	OP2 - Cost (M$)	synergy - OP2	OP3- Cost (M$)	synergy - OP3
SCOPE 0.75	0.75	681	0%	521	7%	440	8%	391	7%
SCOPE 0.80	0.8	681	0%	529	5%	448	6%	397	6%
SCOPE 0.85	0.85	681	0%	536	4%	455	5%	403	4%
SCOPE 0.90	0.9	681	0%	544	3%	462	3%	408	3%
SCOPE 0.95	0.95	681	0%	551	1%	469	2%	414	1%
Baseline	1	681		558		477		420	
		SPHEROID - OP		STRIPPERS - OP		Transportation		Inventory / Penalty	
Instance	BETA	SPH OP Cost (M$)	synergy - SPH	STRP OP cost (M$)	synergy - STRIP	Logistics Cost (M$)	synergy - Logistics	Total Cost (M$)	synergy - I/P
SCOPE 0.75	0.75	234	9%	172	12%	128	0%	0	0%
SCOPE 0.80	0.8	238	7%	176	9%	128	0%	0	0%
SCOPE 0.85	0.85	243	5%	181	7%	128	0%	0	0%
SCOPE 0.90	0.9	248	4%	185	5%	128	0%	0	0%
SCOPE 0.95	0.95	252	2%	190	2%	128	0%	0	0%
Baseline	1	257		194		128		0	

Table-A II-3 Synergy gains under the economy of scale and scope

	SCALE	SCOPE	Oil Extraction		Oil Processing - Stage 1		Oil Processing - Stage 2		Oil Processing - Stage3	
Instance	ALPHA	BETA	OE Cost (M$)	synergy – OE	OP1 - Cost (M$)	synergy - OP 1	OP2 - Cost (M$)	synergy - OP2	OP3- Cost (M$)	synergy - OP3
Baseline	**1**	**1**	**681**		**558**		**477**		**420**	
SCALE 0.9/SCOPE 0.95	0.9	0.95	643	6%	532	5%	453	5%	398	5%
SCALE 0.9/SCOPE 0.90	0.9	0.9	643	6%	525	6%	446	7%	393	7%
SCALE 0.9/SCOPE 0.85	0.9	0.85	643	6%	517	7%	439	8%	387	8%
SCALE 0.9/SCOPE 0.80	0.9	0.8	643	6%	510	9%	431	10%	381	9%
SCALE 0.9/SCOPE 0.75	0.9	0.75	643	6%	503	10%	424	11%	375	11%
SCALE 0.8/SCOPE 0.95	0.8	0.95	604	11%	513	8%	437	8%	382	9%
SCALE 0.8/SCOPE 0.90	0.8	0.9	604	11%	506	9%	430	10%	377	10%
SCALE 0.8/SCOPE 0.85	0.8	0.85	604	11%	499	11%	422	11%	371	12%
SCALE 0.8/SCOPE 0.80	0.8	0.8	604	11%	491	12%	415	13%	365	13%
SCALE 0.8/SCOPE 0.75	0.8	0.75	604	11%	484	13%	408	14%	359	15%
SCALE 0.7/SCOPE 0.95	0.7	0.95	566	17%	495	11%	421	12%	366	13%
SCALE 0.7/SCOPE 0.90	0.7	0.9	566	17%	487	13%	413	13%	361	14%
SCALE 0.7/SCOPE 0.85	0.7	0.85	566	17%	480	14%	406	15%	355	16%
SCALE 0.7/SCOPE 0.80	0.7	0.8	566	17%	472	15%	399	16%	349	17%
SCALE 0.7/SCOPE 0.75	0.7	0.75	566	17%	465	17%	392	18%	343	18%
SCALE 0.6/SCOPE 0.95	0.6	0.95	527	23%	476	15%	404	15%	351	17%
SCALE 0.6/SCOPE 0.90	0.6	0.9	527	23%	468	16%	397	17%	345	18%
SCALE 0.6/SCOPE 0.85	0.6	0.85	527	23%	461	17%	390	18%	339	19%
SCALE 0.6/SCOPE 0.80	0.6	0.8	527	23%	453	19%	383	20%	333	21%
SCALE 0.6/SCOPE 0.75	0.6	0.75	527	23%	446	20%	375	21%	327	22%
SCALE 0.5/SCOPE 0.95	0.5	0.95	489	28%	457	18%	388	19%	335	20%
SCALE 0.5/SCOPE 0.90	0.5	0.9	489	28%	449	20%	381	20%	329	22%
SCALE 0.5/SCOPE 0.85	0.5	0.85	489	28%	442	21%	374	22%	323	23%
SCALE 0.5/SCOPE 0.80	0.5	0.8	489	28%	435	22%	366	23%	317	25%
SCALE 0.5/SCOPE 0.75	0.5	0.75	489	28%	427	23%	359	25%	311	26%

ANNEX III

SAMPLE AVERAGE APPROXIMATION ALGORITHM

This annex presents the proposed algorithm for the SAA stochastic discrete optimization formulation:

1. **1.** Choose M independent samples of size N ($\xi_1^1, \dots, \xi_M^N$), and solve the SAA problem for each sample. Let's define υ^* the optimal value the objective function and υ_N^m and $\hat{y}_N^m$ (with m = 1,…, M) the optimal objective value and the optimal solution, respectively.
2. **2.** Next, we estimate with the following equation**:**

$$\bar{\upsilon}_{N,M} = \frac{1}{M}\sum_{m=1}^{M}\upsilon_N^m \text{ and } \sigma^2_{\bar{\upsilon}_{N,M}} = \frac{1}{(M-1)M}\sum_{m=1}^{M}(\upsilon_N^m - \bar{\upsilon}_{N,M})^2 \quad \text{(AIII-1)}$$

It is proved that $\mathbb{E}[\,\upsilon_N] \leq \upsilon^*$ (Mak, Morton et Wood, 1999; Norkin, Pflug et Ruszczyński, 1998)($\mathbb{E}[\,\upsilon_N]$ is the expected value of υ_N (Norkin et al., 1998; Mak et al., 1999). Therefore, we have also $\mathbb{E}\left[\bar{\upsilon}_{N,M}\,\right] \leq \upsilon^*$ which indicates that $\bar{\upsilon}_{N,M}$ is an estimator for lower bound (LB) of the optimal value υ^* and $\sigma^2_{\bar{\upsilon}_{N,M}}$ is the estimated variance.

3. **3.** We select a feasible solution (probably suboptimal) of the initial problem in (6-9) that is defined as $\bar{y}$. Then, the solution to estimate the value of the objective function $f(\bar{y})$ as follow:

$$\widetilde{f_{N\prime}}(\bar{y}) = \frac{1}{N\prime}\sum_{n=1}^{N\prime} Q(\bar{y}, \xi^n) \quad \text{(AIII-2)}$$

The random sample $(\xi^1, \dots, \xi^{N'})$ of size N' is independent sample from the initial sample used to find the solution $\bar{y}$. Typically the SAA procedure suggests that N' >> N. Mak, Morton et Wood (1999) proved that $\bar{y}$ being a feasible solution of (6-9) respect this condition: $f(\bar{y}) \geq \upsilon^*$ (Santoso et al. 2005). Therefore, $\widetilde{f_{N\prime}}(\bar{y})$ represents an upper bound (UB) of the optimal solution υ^* and the variance can be estimated by the following equation :

$$\sigma^2_{N'}(\bar{y}) = \frac{1}{(N\prime-1)N\prime}\sum_{n=1}^{N\prime}\left(Q(\bar{y}, \xi^n) - \widetilde{f_{N\prime}}(\bar{y})\right)^2 \quad \text{(AIII-3)}$$

4. Using steps 2 and 3, we can compute an estimate of the optimality gap (OG) of solution $\bar{y}$ using the following equation :

$$OG_{N,M,N'}(\bar{y}) = \widetilde{f_{N'}}(\bar{y}) - \bar{v}_{N,M} \tag{AIII-4}$$

The variance of this gap by is estimated by the following equation:

$$\sigma_{gap}^2 = \sigma_{N'}^2(\bar{y}) + \sigma_{\bar{v}_{N,M}}^2 \tag{AIII-5}$$

Finally, assuming that $z_\alpha = (1 - \alpha)\Phi^{-1}$ represents the cumulative distribution of the standard normal distribution; we calculate the confidence interval for the OG as follows:

$$\widetilde{f_{N'}}(\bar{y}) - \bar{v}_{N,M} + z_\alpha\sqrt{\sigma_{N'}^2(\bar{y}) + \sigma_{\bar{v}_{N,M}}^2} \tag{AIII-6}$$

This procedure is replicated by increasing the sample size *N* until the estimation of OG is acceptable.

ANNEX IV

GRAPHICAL SUMMARY UNDER COST AND DEMAND UNCERTAINTIES

Figure-A IV-1 Graphical summary of cost/bbl under cost uncertainty

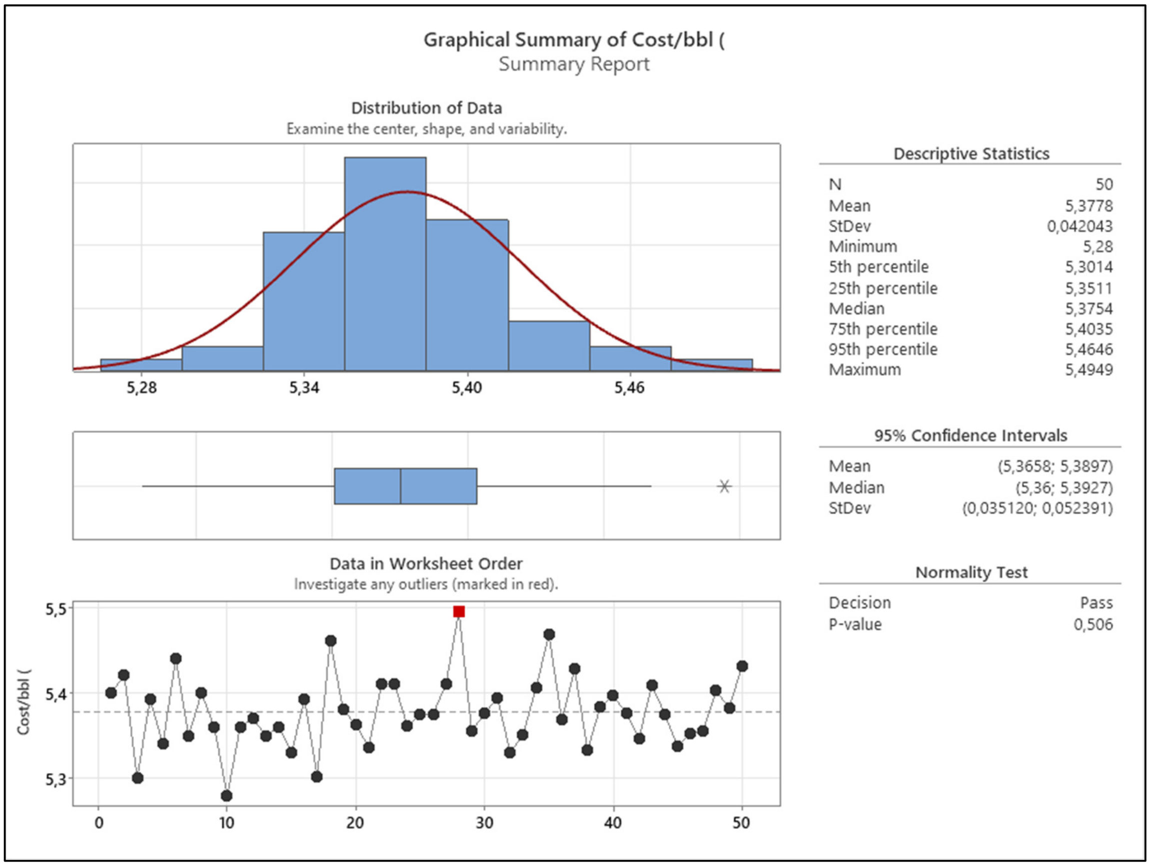


Figure-A IV-2 Graphical summary of the total cost under cost uncertainty

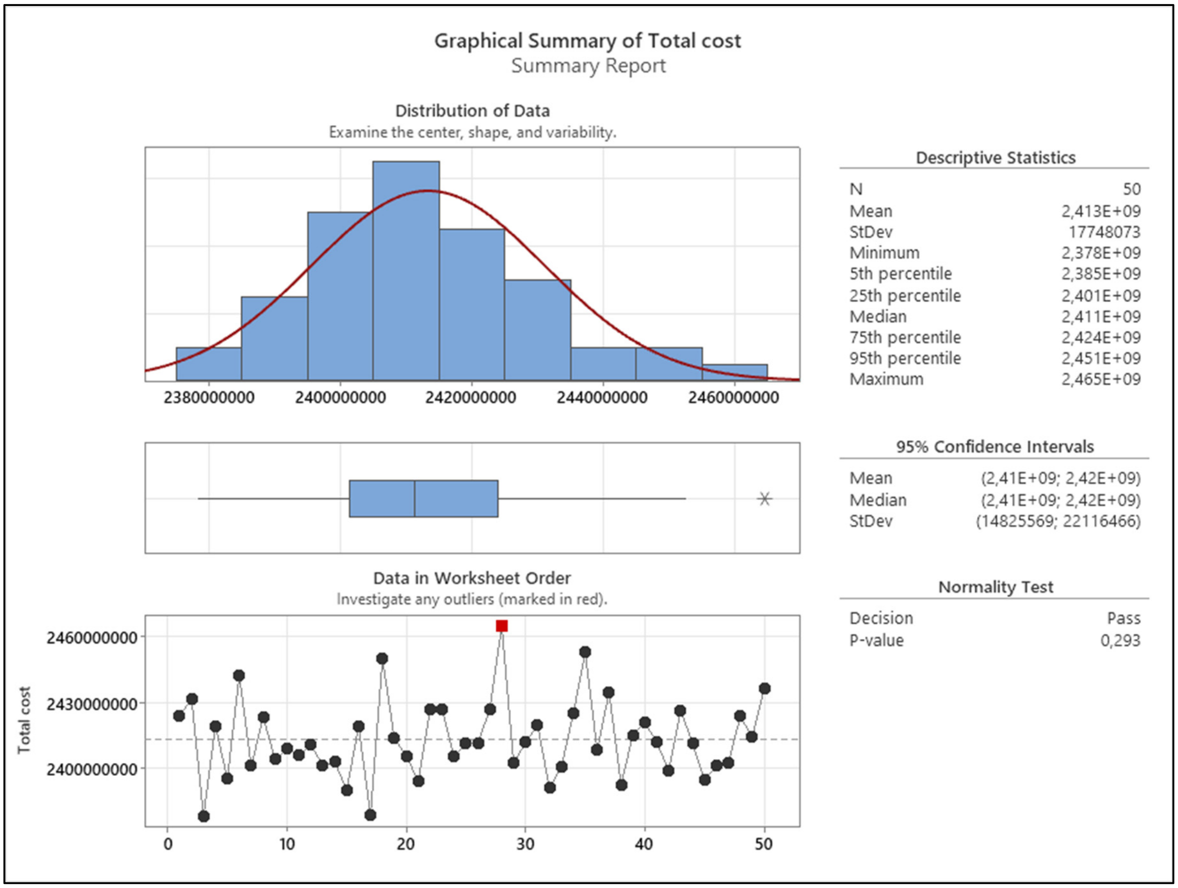


Figure-A IV-3 Graphical summary of cost/bbl under cost and demand uncertainty

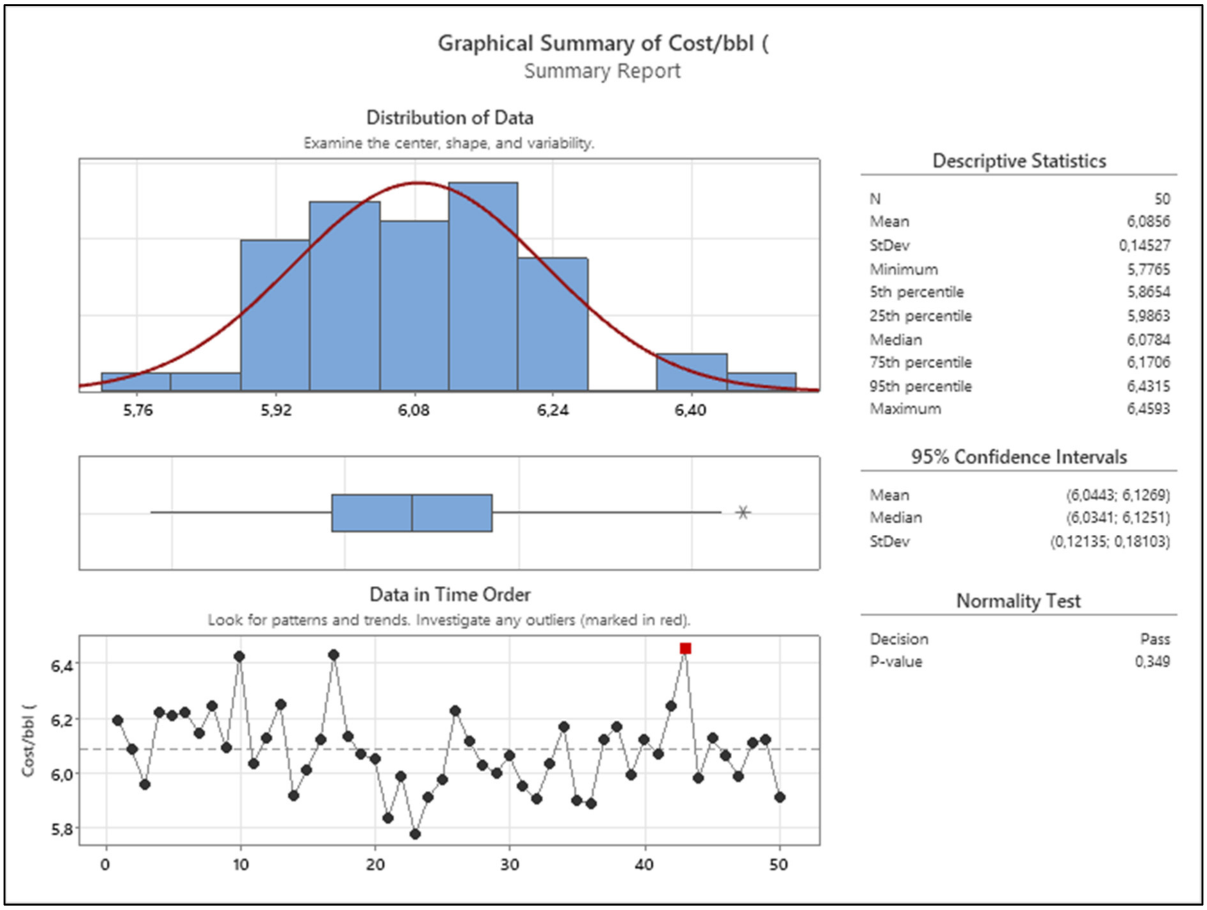


Figure-A IV-4 Graphical summary of Total cost under cost and demand uncertainty

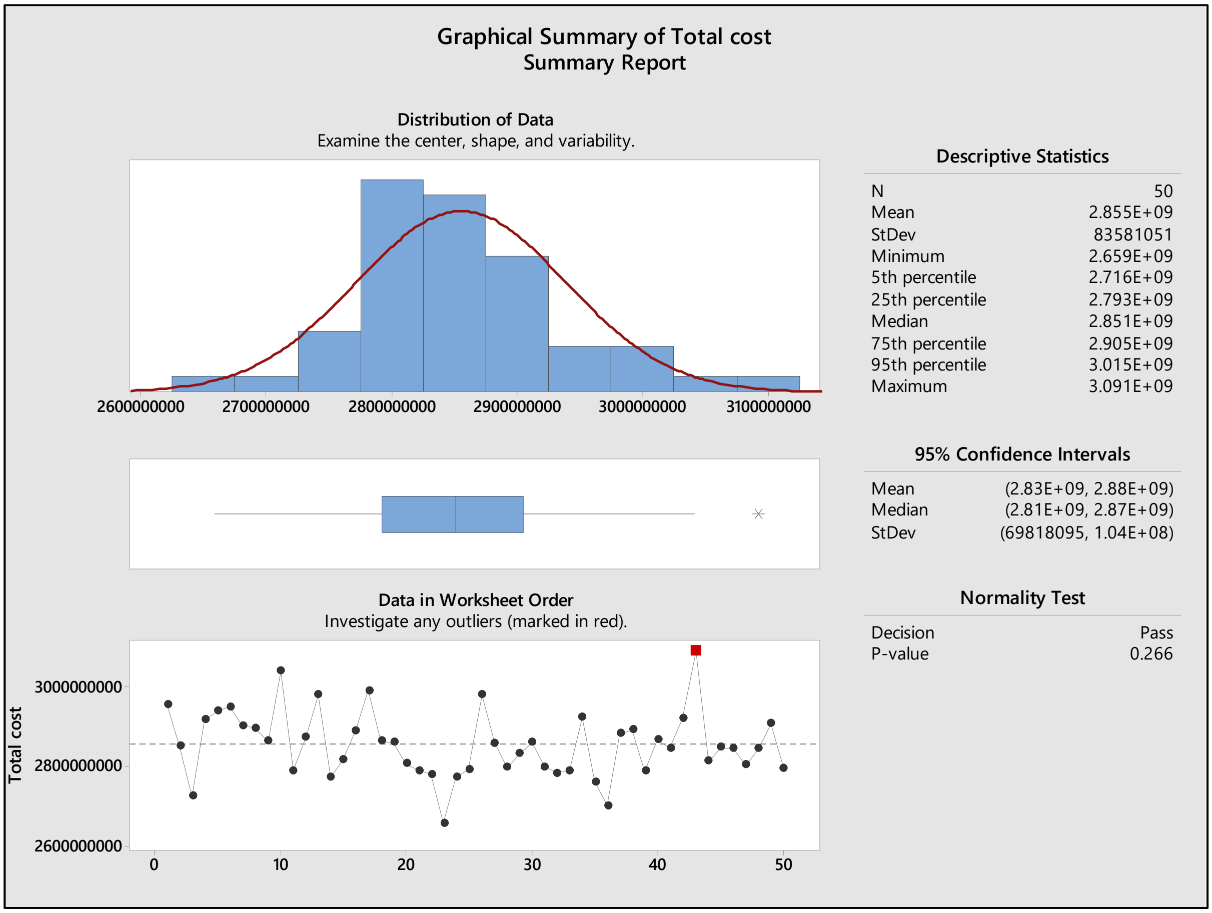
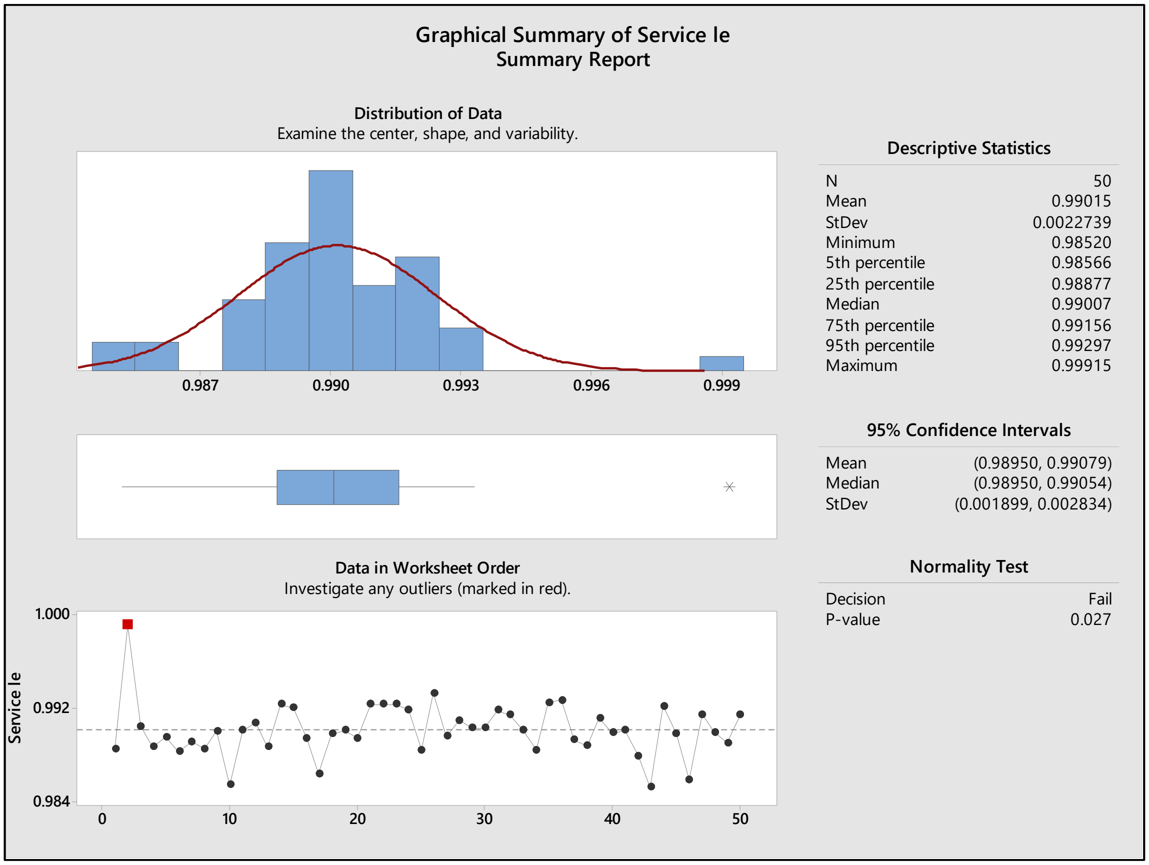


Figure-A IV-4 Graphical summary of service level under cost and demand uncertainty



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