Strategic and Tactical Crude Oil Supply Chain: Mathematical Programming Models

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Eidesstattliche Erklärung

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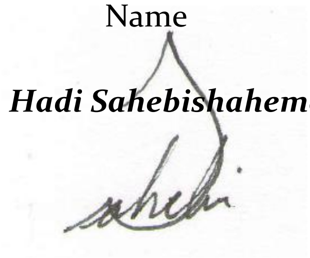

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Preface

Supply Chain Management (SCM) is the management of a complex and dynamic network of integrated companies or organizations which are involved in satisfying the final customer. Traditional managers concentrated only on their own firms. They treated supplier and customer as competitive firms. They never considered the potential for one another to cooperate as partners. In many cases, they dealt with each other very competitively, fearing to lose advantages by customers or suppliers. Beginning in the 1960s and 1970s, some firms started to consider themselves as intertwined functions in order to serve their customers. They adopted their material management structure and integrated their functions together to improve customer service. This integration formally was called "material logistics management". By intensifying the integration, they observed a better performance and a higher customer satisfaction level. As a result, in the 1980s and 1990s more companies continued to integrate. Recently there has been an increasing interesting in the performance, design, and study of the supply chain as a whole. Managan et al. (2011) illustrated the evolution and structure of the integrated supply chain (See Figure 1).

The term "Supply Chain Management" emerged in the late 1980s and then its use vastly grew in the 1990s. Formerly, other terms such as "logistics" and "operations management" were used (Hugos, 2011). Nowadays, the former term, logistics, is still being widely used in business and academies. But what are the main distinguishing features of them. To figure this out, it is worth studying these terms precisely.

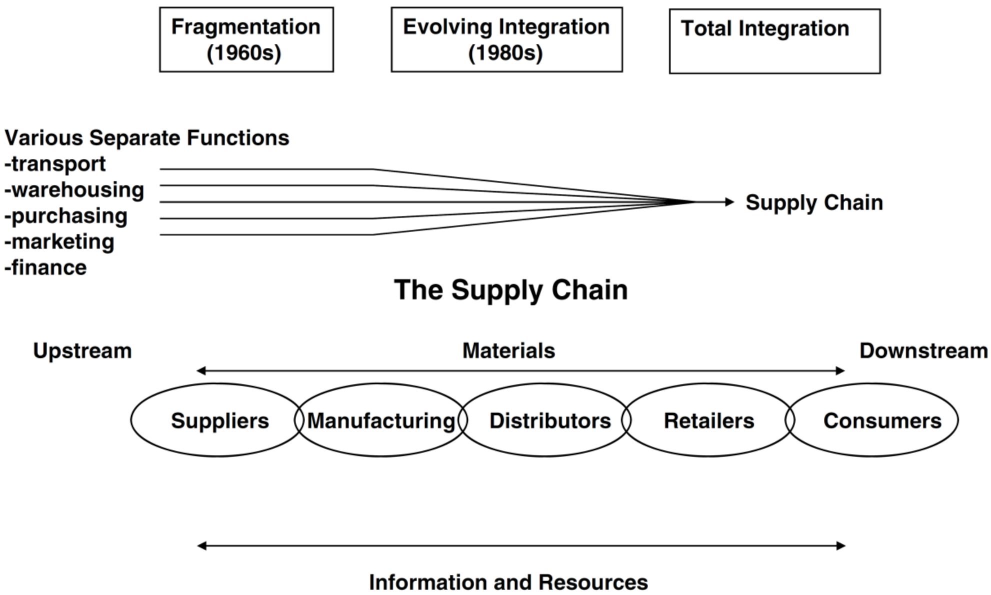

Figure 1: The evolution and structure of the integrated supply chain.
(Source: Managan et al. 2011)

LOGISTICS

The *logistics* deals with the organization, movement, and storage of material and people. This term was first employed by the military to illustrate operations associated with maintenance of fighting force in the field and, in its narrowest sense, to describe the housing of troops (Goetschalckx, 2011). Gradually the term came into business and service organizations.

The Council of Supply Chain Management Professionals (CSCMP) is a large trade association to develop the education and practice of logistics. Logistics is defined by the CSCMP (2010), as:

> "The process of planning, implementing, and controlling procedures for the efficient and effective transportation and storage of goods including services, and related information from the point of origin to the point of consumption for the purpose of conforming to customer requirements. This definition includes inbound, outbound, internal, and external movements."

In addition, as the Council of Supply Chain Management Professionals (2010) defines, the "*Logistics Management*" is:

> "That part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customers' requirements."

The CSCMP (2010) also describes the following activities as logistics management functions:

> "Logistics management activities typically include inbound and outbound transportation management, fleet management, warehousing, materials handling, order fulfillment, logistics network design, inventory management, supply/demand planning, and management of third party logistics services providers. To varying degrees, the logistics function also includes sourcing and procurement, production planning and scheduling, packaging and assembly, and customer service. It is involved in all levels of planning and execution-strategic, operational, and tactical. Logistics management is an integrating function which coordinates and optimizes all logistics activities, as well as integrates logistics activities with other functions, including marketing, sales, manufacturing, finance, and information technology."

Goetschalckx (2011) states that logistics is a mission-oriented discipline. It consists of all the required functions and integrates all of them to accomplish its mission. Hence, making time and space utility available to an organization can be a summarized description of this term. Logistics deals with three kinds of flows: financial flows, information flows, and material flows (in some definition service flows are also addressed as the forth kind of flows). The main aim of logistics is to strive to manage all of the above mentioned flows simultaneously, in order to achieve the predefined aims.

SUPPLY CHAIN

Supply chain is a very closely related concept to logistics. There is, as in many other terms, no agreement on the definition of the supply chain. This lack of a universal definition triggers off a plethora of definitions in this context. Therefore, some definitions are offered below:

- A supply chain may be defined as an **integrated process** wherein a number of various business entities (i.e. suppliers, manufacturers, distributors, and retailers) work together in an effort to: (1) acquire *raw materials*, (2) convert these raw materials into specified *final products*, and (3) deliver these final products to ***retailers*** (Beamon, 1998).

- Supply Chain: 1) Starting with unprocessed *raw materials* and ending with the final ***customer*** using the *finished goods*, the supply chain **links** many companies **together**, and 2) The material and informational interchanges in the logistical process stretching from acquisition of *raw materials* to delivery of *finished products* to the ***end user***. All vendors, service providers and customers are **links** in the supply chain (CSCMP, 2010).

- A supply chain is an **integrated** network of resources and processes that is responsible for the acquisition of *raw materials*, the transformation of these materials into intermediate and *finished products*, and the distribution of the finished products to the ***final customers*** (Goetschalckx, 2011).

- The central theme of all definitions is the **integration** of all entities and functions to convert *raw materials* to *finished goods* or *service* throughout a supply chain by adding value to deliver to the ***customer***.

It is obvious that the management of this integrated network requires extensive efforts. According to the Council of Supply Chain Management Professionals (2010), the "*Supply Chain Management*" can be defined as:

> "Supply Chain Management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies. Supply Chain Management is an integrating function with primary responsibility for linking major business functions and business processes within and across companies into a cohesive and high-performing business model. It includes all of the logistics management activities noted above, as well as manufacturing operations, and it drives coordination of processes and activities with and across marketing, sales, product design, finance, and information technology."

After definition of logistics and SCM, distinguishing between them is a significant issue to avoid confusions. This issue has led to many discussions. Larson and Halldorsson (2004) investigate these terms and their definitions, concepts, and applications. Then they address four perspectives on logistics and SCM: *traditionalist, relabeling, unionist* and *intersectionist.* According to their study, the *traditionalist* perspective introduces SCM as a subset of the Logistics. From this point of view, SCM is only a small branch of the tree of a wider concept, into logistics. Conversely, in the *unionist* perspective logistics is positioned within SCM. In this perspective, the SCM concept covers logistics. In the *relabeling* view, logistics just is renamed SCM, simply. According to this view, what was logistics is now SCM. The *intersectionist* perspective states that both of them have some overlaps, though each has separate parts. Figure 2 illustrates all these perspectives, in brief. In this work, our approach is based on the unionist perspective. It is also evidenced by all earlier definitions. In summary, supply chain management deals with all logistics functions, as well as involving some other functions such as marketing, new product development, finance, and customer service.

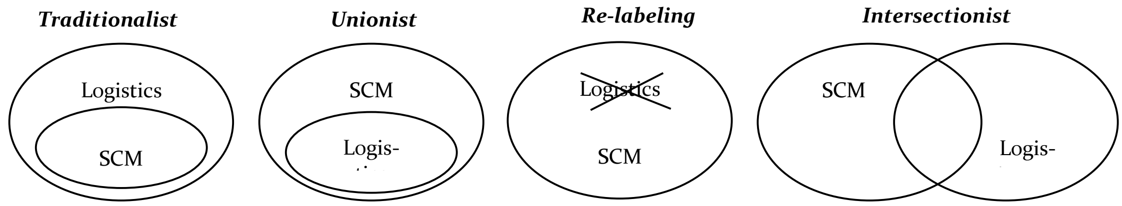

Figure 2: The four perspectives on Logistics and SCM.
(Source: Larson and Halldorsson 2004)

PURPOSE OF THIS THESIS

Crude oil industry very fast became a strategic industry. On the one hand, due to the world-wide marketplace and the extension of oil reservoirs to all parts of the world, even to the icy water of the Arctic Ocean and to the deserts of Africa, Crude Oil Supply Chain (COSC) is one of the most complex supply networks. The management of this complex system has created new challenges for oil industry managers and engineers. On the other hand, due to the vital role of this industry in the today's world business, the crude oil industry involves enormous financial flows (see Section 1.1). Then, optimization of supply chain models is essential, within the crude oil context. These necessities motivate us to investigate the applications of the SCM model within the oil industry context.

In this light, the core purpose of this thesis is twofold. The first aim is to carry out an extensive review of mathematical programming models in the COSC context, in order to identify gaps and recommend possible research directions. Once the gaps in the literature have been outlined, we point them out to establish the second aim of this thesis. This core aim is to elaborate concert mathematical programming models to formulate realistic crude oil supply chain problems.

METHODS

A systematic literature review is often aimed to enable the researcher to investigate, outline and evaluate the existing intellectual area. Based on that existing body of knowledge, the key gaps and opportunities of developments can be detected. The underlying principle is to improve and extend the existing body of knowledge further. Considering this logic, a systematic literature review on applying mathematical models for the strategic and tactical crude oil supply chain is carried out. As explained, this extensive literature review is the first core aim of this thesis. To investigate the literature in this context, we start with a search of all papers published in the scientific publishing portals e.g. Elsevier, Wiley, Taylor & Francis, or Emerald. These are selected due to their wide coverage of applied mathematics, management, and engineering journals. The following search keywords are investigated: "*supply chain management*", "*logistics*", or "*supply network*" which is separately combined with "*crude oil industry*", "*petroleum industry*", or "*refinery plants*". With a time frame of 26 years, a total of 158 references were collected from the mentioned scientific databases. Then we skimmed all to select those that are: (i) focused on the strategic and/or tactical levels of supply chain, (ii) dealt with a crude oil supply chain which to consist of at least two tiers (echelons), and (iii) taken a mathematical programming model into account. To classify and investigate the selected papers systematically, a taxonomy framework for this review is introduced. In this framework, ongoing and emerging issues which are surrounding the strategic and tactical decisions of COSC problems are investigated. As a main goal, the gaps of literature are analyzed to recommend possible research directions.

In the second part of this thesis, we aim to develop the last work and introduce a new mathematical programming model to translate the real crude oil problems best. For this purpose, we formulate three mathematical programming models, which have – to the best of our knowledge – not yet been elaborated to study the crude oil supply chain from these points of view. We attempt to apply the joint venture collaboration, integrate the oilfield development and crude oil transportation, and design the supply network of upstream crude oil industry environmentally conscious. In these cases, firstly we review the background of each context.

Afterwards, we introduce our contributed mathematical models. Finally to illustrate the applications of each model, we experiment hypothetical but realistic data of a National Oil Company which is working in the Persian Gulf waters. All models are implemented in the IBM ILOG CPLEX Optimization Studio 12.5 using CPLEX solver package.

THESIS OUTLINE

As previously mentioned, the thesis falls into two board parts which are introduction and contribution. The first part consists of Chapters 1 and 2, while the remaining chapters form the latter part.

Chapter 1 gives an introduction into crude oil industry. Thereby, we overview the essential parts and concepts which are probably needed to follow the rest of the thesis. We aim to introduce the oil industry so that the reader can follow the thesis, even if he is not a specialist in this area. In this chapter, the role of crude oil industry, the offshore and onshore platforms and the crude oil segments are described. In addition, we outline how crude oil flows through different entities and which functions are operating to recover, separate, transform, and distribute the crude oil.

Chapter 2 is devoted to the core aim of this part, literature review of the COSC mathematical models. Thereby, the focus of our review lies on the strategic and tactical decision levels. The operational models of crude oil supply chain, thus, are beyond the scope of this thesis. The reasons behind this demarcated scope are also discussed in the introduction section of this chapter. Before reviewing the selected papers in this context, we study the previous review papers briefly to show why this literature review is required. Afterwards, the carrying out of a systematic literature review characterizing an appropriate taxonomy framework is essential. The classification scheme of literature is based on this framework. We conclude the chapter with a summary of overlooked issues and recommend possible research directions.

The second part starts with Chapter 3 in which we formulate the joint venture formation and partner selection. To foster insight into joint venture processes, especially partner selection procedures, a brief summary of the joint venture motives and its formation processes are provided. Then a goal programming model is proposed to form a joint venture and select right partners to collaborate with. A main contribution of this mathematical model is that, to the best of our knowledge, a mathematical programming model to establish a joint venture has not yet been formulated in the crude oil industry context. Another key feature of our model is that the dependency relations of activities of crude oil development projects are taken into account, which is also a novel feature in this context.

In Chapter 4, the integration of upstream functions is in the center of attention. Although a key principle in the supply chain management concept is the integration of all involved functions through the supply network, this leading feature is ignored in upstream crude oil supply chain models. In other words, most of the researchers deal with oilfield development problems and crude oil transportation issues individually. According to our literature review, no paper has yet formulated the crude oil transportation and oilfield development problems into a single mathematical model to optimize. To fill this gap, we develop an optimization model in this context. In this chapter we also present two one-factor-at-a-time sensitivity analyses to provide a better understanding of the basic concepts.

Considering environmental impacts within the supply chain is a flourishing research area, whilst it is neglected in crude oil supply chain literature. Chapter 5 is devoted to fill this gap. We give a brief introduction into environmental assessment methods and study its background in crude oil industry, first. The third formulated mathematical model in this thesis, finally, is proposed in this chapter and solved efficiently.

The thesis ends with Chapter 6, in which we give a conclusion and recommend the possible directions of future research. At the end of each chapter, short summaries give an overview of the corresponding chapter accessible for the reader. Since we formulate a new model in each chapter of the second part, the notation is mentioned at the end of each particular chapter. It is also worth pointing out that in order to make it easier for the reader to find the references of each chapter; they are provided in the last section of each chapter. In addition, having a complete bibliography is also admired in academic studies. As a consequence, we mention all references cited throughout the sections at the end of the thesis.

Chapter One

An Introduction to the Crude Oil Industry

Outline

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1.2 Crude Oil Industry's Segments 3

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This chapter gives an introduction to the crude oil industry. We provide some preliminary notions. To gain this goal, an overview on the relevant literature has been carried out. This literature consists of many documents, reports, equipment manuals, project documentations, and oil handbooks. Most of the current literature contains a plethora of details, which sound unnecessary to our aim. On the other side, some others only list functions and equipment of crude oil industry, too briefly. To fill this gap, we provide this chapter to make an introductory knowledge of crude oil industry. We recommend starting with this introduction, before considering the remaining parts of the thesis.

In the next section, a short description of crude oil role in the today's world trade is illustrated. Then, we discuss our motivation of focusing on the crude oil industry. In Section 1.2, we discuss three schools of crude oil industry classifications, and then indicate the preferred school to address in this thesis. In Section 1.3, two broad types of crude oil platforms (i.e. offshore and onshore) are presented, followed by introducing the main entities within this context. Finally, we study all functions of the crude oil industry. Note that this chapter gives the reader an overview of the entire oil industry, while still capturing the essence of the main characteristics. In the interest of overview, this chapter is by no ways a thorough illustration of the detailed features. For the same reason, many details have been skipped over.

1.1 CRUDE OIL INDUSTRY'S ROLE

Crude Oil has been used for thousands of years, yet there is no generally agree-upon the origin and formation of this natural resource of energy. Generally, oil is considered as the product of a multi-million year geological process in which dead organic material deposited and transformed to hydrocarbons in underground reservoirs.

Crude oil has been used with the aim of only lighting and heating for many centuries. However, nowadays, it plays a significant and vital role in global economy. Some pundits consider the crude oil as the lifeblood of our modern society. The development of today's world would not be imagined without it (Khan & Islam, 2007).

From several points of view, crude oil industry is a fundamental industry for current world trade and future developments. First, up to now, there has been no real rival to fossil fuel, due to the low price of this source of energy, compared with the other sources of energy. The reasonable price of this energy type caused a growing tendency among the energy consumer to demand it more. Beyond these facts, the limited amount of proved oil reservoirs and their depletions verify the sustained dominance of crude oil industry in the future.

In addition, the crude oil industry involves enormous financial flows. The World Trade Organization reports the $2348 billion as the total value of the export of fuel,

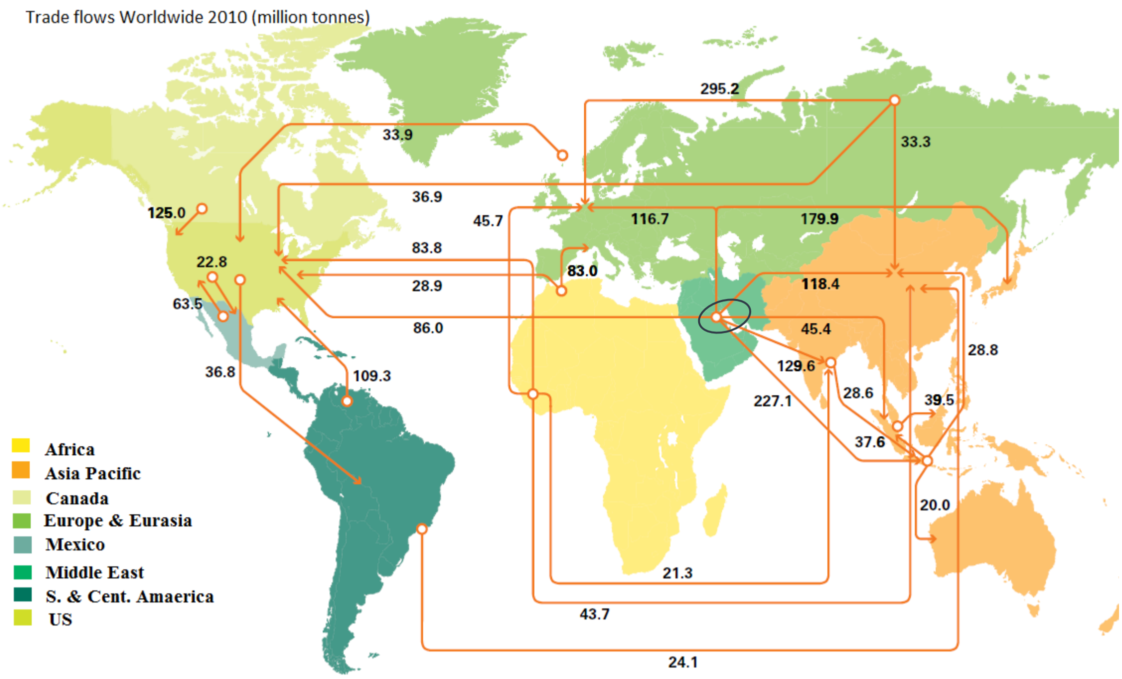

Figure 1.1: Crude oil flows. (Source: BP, 2011)

in 2010. The export of fuel account for 15.8% of world exports of primary products. According to this report, among the fuel sources, the crude oil continues to be the world's leading source of energy, by 33.6% of total energy consumption (BP, 2011). It is worth noting that the main crude oil reservoirs, at which crude oil is extracted, are placed on around of the Persian Gulf. As illustrated in Figure 1.1, the majority of crude oil, 44.17% of the world exports, comes from this regions towards the consumers countries.

As a result of these strategic issues, the oil industry is in the center of the global geopolitical and macroeconomic outlook and most of the governments intellectually take care of the evolution of the crude oil industry or even directly control the respective activities in their countries (Manzano, 2005). These prominent matters motivated us to concentrate on this industry and strive to improve its efficiency.

1.2 CRUDE OIL INDUSTRY'S SEGMENTS

All entities and functions of the crude oil industry can be classified into three different ways. First, the crude oil industry sometimes is divided between the upstream and the downstream segments. According to this classification, an upstream segment made of several entities, namely, crude oil reservoirs, oil wells, separator, storage tanks, oil tankers and oil terminals, and pipeline network. This segment is responsible for exploration and development of oilfields; and deals with the recovery, separation, storage, and transportation of crude oil. The downstream segment includes refineries, petrochemicals, depots, and customers. This segment covers the transformation of crude oil at refineries and petrochemical plants, the distribution, and the marketing activities of all the oil derived products.

According to the second classification scheme, the crude oil industry is addressed relative to three major segments: upstream, midstream and downstream. In this light, the upstream segment refers to the exploration, extraction, separation, and transportation of crude oil to refineries, as same as the first classification. Midstream segment represents the crude oil transformation at refineries and petrochemicals. Downstream segment describes functions that follow transformation, embracing storage, distribution, and marketing.

In addition, the third classification scheme applies those terms to oil industry as follows: Upstream covers exploration and production activities, Midstream deals only with transportation of crude oil and gas to terminal and storage, And downstream refers to the reminder of activities to delivery final products to customers (An, Wilhelm, & Searcy, 2011; Leiras, Ribas, Hamacher, & Elkamel, 2011; Manzano, 2005).

For the purposes of this study, we find the second classification scheme more appropriate. In a nutshell, we divided the whole industry into upstream, midstream and downstream. The first segment covers activities up to the oil terminal, the second one embraces the transformation processes, and the last segment covers the remaining activities, i.e. distribution, storage, and marketing.

1.3 OFFSHORE VS. ONSHORE

As addressed, this industry consists of a vast number of functions that are extended to all over the world, from the Persian Gulf to the Gulf of Mexico, from desert to the Arctic. Each of these functions needs a specific set of equipment to be operated by. Inspite of this wide range, many components of the functions principally are quite similar. As a result, the main characteristics of these functions, entities and equipment are fairly alike. The details will be discussed later. In the following, we distinguish between onshore and offshore facilities.

1.3.1 Onshore

An onshore well can be economically viable even for a few hundreds of barrels, to recover per day. Although, economically viable in onshore cases is the exact opposite of offshore wells. Since, the offshore facilities are much more expensive, that in onshore oilfields, structuring of them asks for more recoverable oil. Structuring, carrying, handling and removing of the onshore facilities are less challengeable than the offshore ones. Then, it can be seen small private wells with 100 barrels a day in onshore shallow fields. However some offshore large bores can produce 4000 barrels a day. To better understand of differences, given crude oil can be recovered from shallow wells (e.g. in 30 meters earth depth) to wells of 3000 meters deep in 2000 meters water depth. And also development of an onshore well requires 10.000 dollar, while investment in an offshore development needs 10 billion dollar.

1.3.2 Offshore

The first offshore well is drilled on Louisiana offshore in 1940's. Within the capabilities of current technology, the oil industry has been expanded to very deep water. In the last few decades, offshore extraction has extended extremely. The today's offshore production accounts for approximately 30 percent of world crude oil production. With the advanced technologies, an increase in the growth is expected in the future.

Offshore structures vary according to the water depth of oilfields. In shallow offshore oilfields, fixed platforms are founded. For deeper offshore oilfields, the next generation of platforms, floating production platforms, can be an excellent structure. However, recently, pure sea bed structures with pipe connections to shore facilities without any offshore topside structure are implemented. Some of the common offshore structures are summarized as following:

(i) ***Fixed Platforms:*** There exist several types of fixed platforms. The two major classes of them are presented.

- **Shallow water complex:** This complex consists of several independent platforms coupled with gangway bridges. Each of the platforms can be considered as drilling platform, wellhead platform, power generation, riser platform, processing platform, and accommodations platform. In water depths up to 100 meters, typically, these platforms can be founded.
- **Gravity Base:** A massive concrete steady structure fixed on the bottom, commonly with tank storages that rest on the sea bed. It is suitable for large fields typically in 100 - 500 meters water depth.

(ii) ***Floating Platforms:*** These are platforms which can be moored in any water depth, particularly up to 2000 meter. There are several types of floating production facilities. Some major types are: Production Semi-Submersibles, Spars, Tension Leg Platforms (TLPs), and Floating Production Storage and Offloading (FPSO) platforms, as shown in Figure 1.2. The main peculiarities of these platforms are:

- **Water Depth:** These platforms can be used almost in any water depth.
- **Installation:** Since the floating platforms are structured in advance, the installation time of these kinds of platforms are negligible.

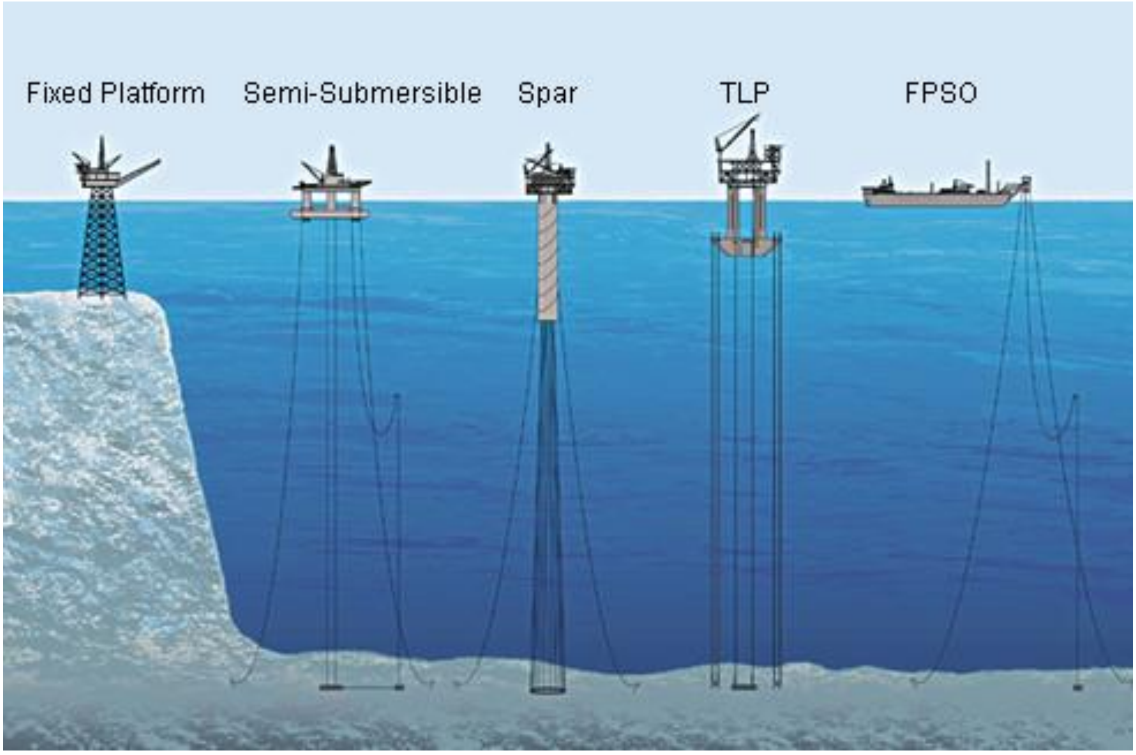

Figure 1.2: Offshore platforms. (Source: http://www.modec.com)

- **Capital Expenditure:** Only a handful of oil companies have FPSOs. In fact, leasing FPSOs is very common in this context. By leasing an FPSO, the capital expenditures will fall remarkably.
- **Moveable:** After finishing of the recovery phase, a floating platform can be moved to another oilfield, simply.
- Overall, these unique aspects of floating platforms provide a wide range of opportunities for oil companies. Although, a discussion on all of them is out of the scope.

(iii) ***Subsea Systems:*** In these cases, crude oil wells are concreted on the seabed, as opposed to at the surface. The crude oil is recovered from the wellhead, just like the floating platforms. Once the oil is recovered, it should be pumped to a production platform (floating or fixed) or can be connected to an onshore production facility. Subsea systems normally are employed in more than 2,000 meters water depths.

Since, the main offshore functions (e.g. drilling, completion, production and separation) are performed from the surface; aforementioned fixed or floating platforms are structured to provide this required stable ground. Note that the subsea systems do not have the ability to drill oil wells; they are used only in producing crude oil and pump the extracted crude oil into pipelines. In addition, a production platform can be strategically allocated to service a large number of wells over a wide area of an oilfield.

1.4 CRUDE OIL INDUSTRY'S ENTITIES

1.4.1 Reservoir

A biogenic hypothesis discusses that crude oil was created from deep carbon sediments, perchance dating back to the Earth formation (Glasby, 2006); but no words about the source of these carbon deposits. Similarly several theories are presented to illustrate the origin of crude oil and other hydrocarbons. These theories can be divided into two groups: the inorganic theory of origin, and the organic theory and (Abdel-Aal, Aggour, & Fahim, 2003). The organic theory proposes a description, which is acknowledged by most of geologists and scientists. It is evident that, millions of years ago, water covered much more of the existing land area. The Gulf of Mexico and the Persian Gulf, for instance, are two remained slices of such ancient seas. The dead body of animals and plants came into the sea by rivers. Then these dead organisms were buried under other deposits. Over thousands centuries, these organic deposits converted into oil and gas by high temperature, pressure, bacteria, and other reactions. In the high temperature circumstances, the natural gas has been formed. Whilst under the lower temperature circumstances, the crude oil has been created. The sedimentary rock in which petroleum was formed is called '*reservoir rock*'.

Naturally, in the oil reservoirs, hydrocarbon accumulations are mixtures of organic elements. The treatment of these organic compounds varies with the pressure and temperature. These hydrocarbons can be found in solid state, liquid state, gaseous state, or in various combinations of solid, liquid, and gas. This treatment of the reservoir can be determined by analyzing the geophysical properties of '*reservoir rock*'. Analyzing of the reservoir behavior and its characteristics is a main task of petroleum engineers who have to study the reservoir and determine the future development plan of the reservoir (in literature, called oilfield development) and to recover the crude oil in such way to gain the maximal of the profit.

Petroleum reservoirs broadly are divided between crude oil and gas reservoirs. These broad classes can be subdivided according to the mixture state, the initial pressure and temperature, and the surface temperature and pressure (for more information see (Ahmed, 2010)). Consequently, several classifications of the crude oil reservoirs are presented. However, scientists are categorize them depending to their drive mechanisms or geologic structure. Studying the geologic structure and classification is of interest to petroleum and drilling engineers, is of no interest to a supply chain manager. Therefore, we do not discuss about the geologic classification. Note that in reservoir engineering recovery, production, and extraction commonly are considered equivalent.

1.4.1.1 Drive mechanism

The energy that is used to recover hydrocarbons from the reservoir to the production wellhead as a drive is called the drive mechanism. Generally, drive mechanisms are divided into two groups, natural drive mechanisms and artificial drive mechanisms. The former group is also called *primary recovery* and the latter group comprises the *secondary recovery* and *tertiary recovery/ enhanced oil recovery (EOR)*.

Each drive mechanism can be specified by some typical performance attributes in terms of:

- Ultimate recovery factor
- Pressure decline rate
- Gas-oil ratio
- Water production

Table 1.1: Natural drive mechanisms and efficiency. (Source: Ahmed, 2010)

Drive Mechanism	Type	Energy Source	Recovery Efficiency
Gas-cap	-----	Gas cap expansion	20-40
Dissolved gas	Evolved gas	Evolved solution gas	18-25
	Gas expansion	and gas expansion	2-5
Water	Bottom	Aquifer expansion	20-40
	Edge		35-60
Gravity drainage	-----	Gravity	50-70
Combination	-----	Combination	20-65

Natural drive mechanisms: When a reservoir was forming, the pressure energy of the accumulated gas and water was also captured. After drilling a well, the pressure in the well is far lower than in the reservoir. It is that natural energy of the accumulated water, or gas, or both that drives the crude oil from the reservoir into the wellbore and lift it up to the wellhead, see (Abdel-Aal et al., 2003; Ahmed, 2010; Glover, 2001). This kind of crude oil recovery employs only the reservoir's natural energy as the drive mechanism is called *primary recovery*: the extraction of crude oil without running any extra procedure, for example gas or water injection, or pumping. In other words, this natural energy of the reservoir requires not to be supplemented by any other process.

The overall performance of crude oil reservoirs is determined by the nature of the energy to drive hydrocarbons to the wellbore (Ahmed, 2010). There exist five basic drive mechanisms that naturally provide the necessary energy to recover oil, and each of them has different expected range of recovery efficiency. These natural drive mechanisms are:

- Gas-cap drive,
- Dissolved gas drive,
- Water drive,

- Gravity drainage drive,
- Combination drive.

Table 1.1 shows these mechanisms, their types and energy sources, along with recovery efficiency of each. By recovery efficiency is a term that indicates the average percent of recoverable crude oil. Note that this factor is a leading factor to decide whether a reservoir is economically viable or not. Obviously, higher recovery efficiency shows higher level of recoverable crude oil, and consequently, higher expected profit for the reservoir development.

Artificial drive mechanisms: When a reservoir's natural drive mechanism has low efficiency to recover crude oil, a supplemental drive mechanism can be used to extract the remaining hydrocarbons and increase the production rate and recovery efficiency. *Secondary drive mechanisms*, as a result of human intervention, improve recovery efficiencies. This mechanism involves the injection of water or gas to the base of a reservoir. Therefore, secondary drive techniques commonly fall into these categories:

- Water injection,
- Gas injection.

According to the petroleum documents, it is observed that primary and secondary recovery methods usually only extract about 35% of the original oil in place (given Tables 1.1 and 1.2). In this situation, *tertiary drive (EOR)* methods have been intended to improve the recoverable level. Three broad categories of *EOR* methods are:

- Thermal,
- Chemical,
- Miscible gas.

Table 1.2: Secondary and tertiary drives. (Source: Ahmed, 2010)

Recovery technique	Drive Mechanism	Recovery Efficiency
Secondary drive	Water injection	5-50
	Gas injection	up to 35
Enhanced Oil Recovery	Thermal	25-60
	Chemical	25-40
	Miscible gas	up to 35

Artificial lifting facilities, to set up secondary or tertiary mechanisms, should be designed, selected, installed, and operated by production engineers. Prudent economic analyses are critical because of extreme cost of these methods. A common indicator to show the viability of running a secondary and EOR project is the incremental oil recovery factor. The factor is schematically depicted in Figure 1.3 (adopted of Sheng (2010).

1.4.2 Crude Oil Wellhead

Once a well is drilled, and analyzed that a viable recoverable amount of crude oil is present, the crude oil well should be completed (the main process will be discussed latter). A completed well can allow the flow of petroleum from the bottom of the well up to the surface. In the completion process a wellhead must be installed on the top of well. It consists of the pieces of equipment to regulate and monitor the recovery of crude oil from the reservoir. The wellhead made of three components: the 'Christmas tree', tubing head, and the casing head.

A Wellhead completion may be a Subsea or Dry. Subsea wellheads are completed on the seabed under water, whereas Dry wellheads are placed on the land. In addition, wellheads rest on the top of all actual wells (production wells and injection wells) to complete them and make recovery process available. Injection wells are those used to inject special material into reservoir as a secondary or tertiary drive mechanism.

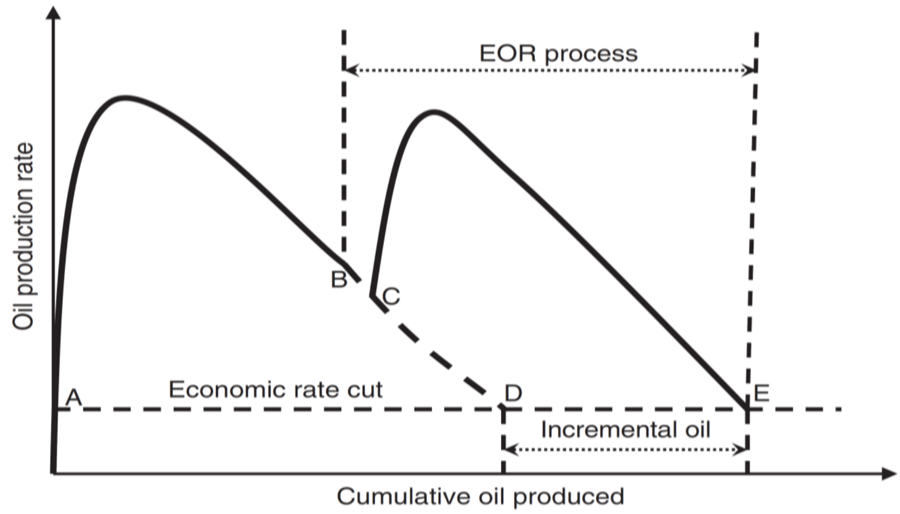

Figure 1.3: Incremental oil recovery from an EOR process. (Source: Sheng, 2010)

1.4.3 Manifold and Gathering Pipeline

A network of gathering pipes and manifolds are installed for every well, to bring the crude oil streams in to the main production facilities. Manifolds allow to set up and control production of a "well set" and utilize reservoir. Manifolds can be placed on surface, on platform or on a seabed, depending on the production system.

1.4.4 Separator

The recovered crude oil is a mixture of oil, water, gas, and various compounds which should be separated to be economically viable to transport. This process, in oil industry context, is called crude oil production, processing or separation. Separators are used to gain this purpose. The separation procedures are as following:

- Crude oil streams are fed into the separator,
- Pressure is controlled and reduced in several stages,
- After a retention time, water settle at the bottom, gas bubble out, and oil stay in the middle.

The separators come in many variants, as:

- ***Gravity separators***: Classical design of separators is the gravity separator. The main separators are gravity separators which are based on the density difference between the phases should be separated. The main body is made of cylindrical vessel up to 5m in diameter and 20m long. The gravity separators can be either two-phase, three-phase or four-phase.

- ***Centrifugal separators*:** This separator enhances the effect of gravity by spinning the fluids at a high velocity.

- ***Special separators*:** After passing the last separators, the crude oil streams can feed into a special separator. Three kinds of them are mentioned blew:

  a. **Coalescer***:* If it is needed to remove more water, the coalescer is used as a final removal of water.
  b. **Electrostatic Desalter***:* In some case, the amounts of salts, that are embraced by crude oil, are unacceptable. To remove them, the Electrostatic Desalters are in use.
  c. **Water treatment**: the high level of water cut shows that a huge amount of water is produced. This amount is unacceptable to discharge into sea and must be cleaned first. Often this water release several pollutants into the environment, and have to be capped.

1.4.5 Storage Tank

The separated, ‘pure’, crude oil may be piped directly to a refinery or to a tanker terminal. On production platforms without pipeline, crude oil must be stored on onboard storage tanks, and then offloaded to the oil tankers to be transported. In addition storage tanks are needed to allow for metering oil properties, sampling, and gauging.

Table 1.3: Summary of oil storage tanks. (Source: Abdel-Aal et al., 2003)

Characteristics	Standard Storage Tanks	Conservation-Type Storage Tanks		
		I (Floating Roofs)	II (Variable-Vapor-Space)	III (Pressure Storage)
Evaporation losses	High	Significantly reduced	Significantly reduced	Prevented or eliminated
Operating conditions	Recommended for liquids whose vapor pressure is atmospheric or below at storage conditions (vented).	Allow no vapor space above the liquid; level (no venting)	Allow the air-vapor mixture to change volume at constant or variable pressure (no venting)	Allow the pressure in the vapor space to build up. Tanks are capable of withstanding the maximum pressure without venting.
Sub-classification	1. Rectangular 2. Cylinderical: a) Horizontal b) Vertical		1. Lifter roof, which is a gas holder mounted on a standard storage tank. 2. Vapor-dome	1. Low-pressure storage normally designed for 2.5–5 psig (up to 15 psig) 2. High pressure storage: 30–200 psig
Typical types	Cone-roof-vertical (cylinderical tanks)	Floating-roof, wiggins-Hidek type	Lifter roof tanks, wiggins dry seal type	Spheroids and hemispheroids for low pressure storage, spheres for high pressure storage
Applications	Heavy refinery products	Sour crude oils, light crude oils, light products.	Light refinery product and distillates	Spheriods are used to store aviation, motor, jet fuels. Spheres are used to store natural gasoline and LPG.

Storage tank normally stores up more than the production of regular cycle. For example an onboard set of storage tank must be able to store up to five weeks of crude oil productions, three weeks for normal cycle and two extra weeks for unanticipated delays such as natural disaster, bad weather, or uncertainty of transportation time. This could produce a demand of several million barrels. Abdel-Aal et al. (2003) provided an interesting summary of oil tanks (As shown in Table 1.3).

Storage tanks, in addition, are available on refineries, oil terminals, petrochemical plants, and on depots. Because of different type of oil product has to be stored in, geological conditions, and environmental constraints, design and selection of a storage tank are complex problems. To solve it we require careful consideration of the economic and environmental factors. Each type has specific features like expenditure, capacity, evaporation loss, operation condition, and etc. Table 1.3 shows a summary of storage tanks and their characteristics. These economic and environmental characteristics should be studied very prudently.

It would be ideal to design high pressure storage tanks such that the pressures is high enough to control evaporation; resulting in minimizing emissions. Nevertheless, this way could not be economical; also, refiners demand crude oil to meet maximum vapor pressure specifications (Abdel-Aal et al., 2003). These generated vapors from storage and other sources can be recovered by various methods like absorption, condensation, simple cooling, adsorption, or a combination of them. This process needs its own special facilities that we skip a detail description.

In addition to handling the vapors, another difficulty arises when an oil terminal have to service several production sites. In this situation, various qualities and blending challenges must also be managed.

1.4.6 Pipeline

There exists pipeline everywhere in a production system, in a utility system, and in an agriculture system. A large variety of pipeline is used in petroleum industry. Pipes' diameters can vary from 6" to 48" and even more. As mentioned, small diameter pipelines are employed to gather crude oil from each separate wellhead, and then converge on a collecting center. In offshore, this collection center is called well platform. Then oil is pumped through pipelines to the gas–oil separating plant. In this level, the diameter is enlarged to convey more amounts of crude oils. Due to oil and gas properties and harsh environment, production pipeline has special construction and design.

1.4.7 Oil Tanker

In many occasions, it is impractical to transport crude oil by pipeline. For instance, there exists a huge discovery in Africa but no market. For another example, Japan has considerable need for energy and very small supplies within suitable distances for pipelines. In those instances, crude oil should be carried by oil tankers. An oil company may own or lease a charter contract to deliver crude oil to customers. Crude oil tankers usually transport crude oil from the production platforms to the oil terminals, and infrequently from terminals to terminals. Crude oil tankers are commonly categorized depending on their capacity. To this purpose, the Dead Weight Tonnage (DWT) is a metric unit, i.e. the total weight that an oil tanker can carry safely. This total weight is the sum of the weights of crew, passengers, provisions, fresh water, fuel, and cargo. All around the world, there are several groups of large oil tankers those can transport millions of gallons of crude oil to refineries.

Generally, two groups of oil tankers deliver crude to a refinery; small vessels carrying just single parcel of crude oil, and very large crude carriers (VLCCs) that are able to carry several different parcels of crudes.

1.4.8 Sea Port Terminal

In most exporting countries, the oil should be transported by pipeline to the sea port terminal. At terminal, there exists loading/ unloading systems to load/ unload crude oil into/ from oil tankers to export. This system also has several complexity must to be handled, i.e. tanker lightering problem, loading/ unloading scheduling, and jetties scheduling.

1.4.9 Refinery

The refineries are considered as the heart points of the crude oil industry. The goal of typical crude oil refinery is to convert as much of the barrel of crude oil into profitable products (Gary & Handwerk, 2001). A refinery normally transform the crude oil into a wide range of products such as asphalt, fuel oil, diesel oil, kerosene, jet fuels, aviation and motor gasoline, liquefied petroleum gases, and fuel gases. Refinery procedures broadly fall into three basic chemical processes: (1) Distillation, (2) Molecular structure alteration (Thermal Cracking, Reforming, Catalytic Cracking, Catalytic Reforming, Polymerization, Alkylation, etc.), and (3) Purification. A typical refinery unit is shown in Figure 1.4. As illustrated in Figure 1.4, refining the crude oil is an enormous chemical complex.

1.4.10 Petrochemical Plant

In many cases, refineries are integrated with nearby petrochemicals plants. This integration allows both plants to exchange streams: the petrochemical facility receives streams of raw materials from the oil refinery and the refinery receives back streams from the petrochemical plant that can be used again for petroleum products (e.g., gasoline blending). The petrochemicals plants produce high value products like ethylene, propylene, styrene, butadiene and benzene. Furthermore, these so-called base petrochemicals can be transformed again into other products like high density polymers (plastics, PVC, polystyrene, polyethylene, and polypropylene), elastomers and aromatics-based products.

1.4.11 Customer

The oil derived products are transported to customers by pipeline, tanker, truck, rail or barge. The quantities transported are smaller (typically 10 to 50,000 tons) than in the case of crude oil (generally over 100,000 tons) and therefore the economies of scale are less important than in the case of bigger crude oil tankers. Commonly, the oil industry serves two types of customers:

- **Wholesale customers**, such as big fuel consumers (airlines, shipping companies), power plants and other industrial customers.
- **Retail customers**, for example who use petrochemical products and the fuels essentially for transportation and domestic heating.

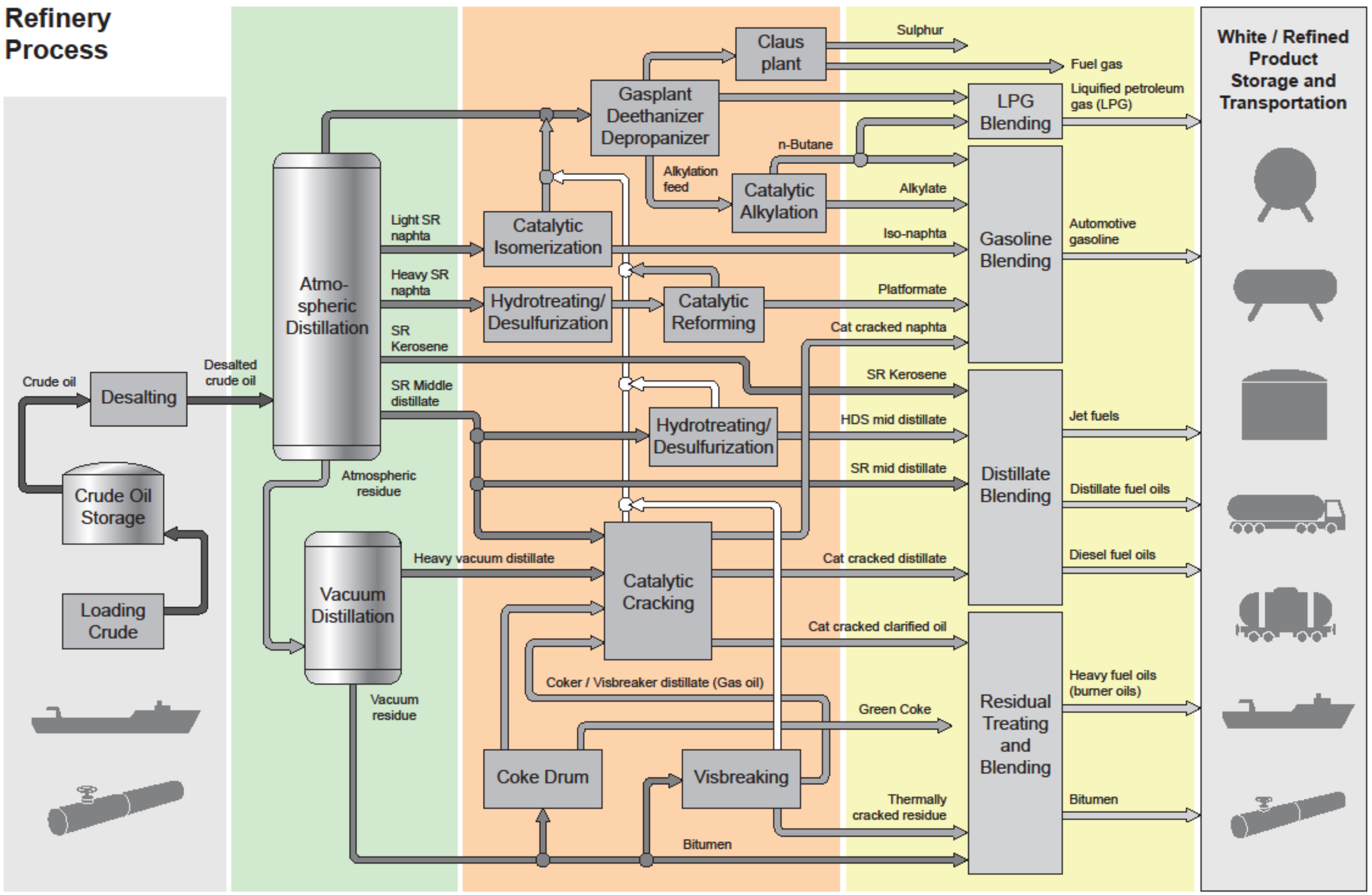

Figure 1.4: A typical refinery process. (Source: http://www.endress.com)

1.5 CRUDE OIL INDUSTRY'S FUNCTIONS

As illustrated, oil industry is divided into upstream, midstream and downstream. The main processes in the upstream section are exploration, discovery or appraisal, drilling and completion, recovery, gathering, processing, transportation and storage. The end point of this section is an oil terminal (Khan & Islam, 2007; Satter & Thankur, 1994). At this point it is worth pointing that a reservoir's life begins with exploration that results in discovery of a reservoir. To approve a crude oil reservoir, appraisal of the reservoir is necessary. An approved reservoir should be completed and made ready for production through oilfield development function (i.e. drilling wells, installation of platforms, and interconnection of them). As said before, a reservoir can produce crude oil by primary, secondary, and tertiary mechanisms. The reservoir's life ends with the abandonment procedure (see Figure 1.5). Throughout a reservoir's life, integrated reservoir management is the key to operate a successful function (Satter & Thankur, 1994). In summary, upstream functions can be fallen into exploration and production. As a result, a crude oil upstream segment is also known as the exploration and production (E&P) sector.

As mentioned earlier, the hear points of downstream are refineries. Crude oil, with different qualities, has been conveyed to a refinery from oil storage terminal. And refineries convert crude oil into more useful and profitable products. These products are demanded by petrochemical plants, airport as fuel for airplanes, production industries as a source of energy, or even to a driver to fire his car. In the following, an overview of above functions is provided.

1.5.1 Exploration

Oil reservoirs, except shallow ones, are covered up with a huge amount of rock. It is clear that determining the location of them is a challenging task and needs a scientific exploration. According to reports, the first modern exploration dates back to the early 1910s, when geologists were working on the discovery of the Cushing Field in Oklahoma, US.

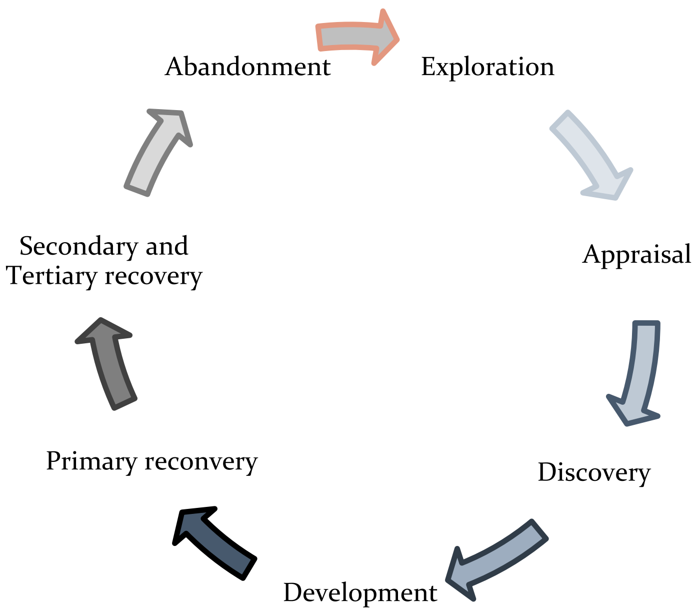

Figure 1.5: Petroleum reservoir's life.

The principles remain the same, although advanced technology and have dramatically developed efficiency and safety. In the following the principal steps of an oil exploration are briefly discussed.

1.5.1.1 Geologic Survey

First and oldest method to search for hydrocarbon rock formations is geologic survey. In this approach, geological maps are analyzed to identify principal sedimentary basins. Additionally, an aerial photography can be reviewed in the desk studies. Examination of the surface rock samples is a key study in this survey. All collected data is considered and compared with geologic theories to identify if crude oil is present in place. This method can only result in offering a possibility of existence of crude oil. The historical *rate of success* of finding crude oil reservoirs only by exercising the geologic survey is very low. Since, this approach commonly followed by the other surveys to improve the rate of success.

1.5.1.2 Geophysical Surveys

As going, to increase the probability of finding, more survey methods are essential such as geophysical surveys. Geophysical survey methods, commonly after carrying out the geologic surveys, are in use to increase the rate of success of finding reservoirs. These methods are found in four types: gravity survey, magnetic survey, seismic survey, and remote sensing.

1.5.1.3 Exploration drilling

Once the results of geologic and geophysical surveys have identified a promising geological structure, to approve the presence of crude oil there exists the only way of exploration drilling. An exploratory well has to be drilled and tested to give definite answers to the presence of hydrocarbons, the thickness of reservoir rock, the internal pressure of a reservoir, and etc. These variant of wells are known by drillers as 'wildcat' wells.

1.5.2 Appraisal

When an exploratory well is successful, additional wildcat wells may be demanded to find better prediction of the characteristics of the new crude oil reservoir. In other words, the appraisal stage attempts to estimate the nature of the reservoir (i.e. size, pressures, recoverable amounts of crude oil, 'grade' of the crude oil, etc.). Obviously, every exploratory drilling will not lead to a discovery. Exploratory wells may find nothing and may prove the reservoir not to be a commercial development.

1.5.3 Discovery

The collected information up to this step will be adequate to evaluate the quantity and quality of crude oil reserve. If the data prove that the development of the reservoir is commercially viable, then the crude oil reservoir will be known as a 'proved reservoir' and the exploration and appraisal results in a discovery.

1.5.4 Reservoir Development

In the recent years, to develop oilfields the oil companies have implemented what is known as the *multidisciplinary team approach*. In this approach, a panel of experts comprising scientists, specialists, and engineers covering all required disciplines are gathered together as a team. All members of the team cooperate to conclude the oilfield development stage (Abdel-Aal et al., 2003). The oilfield development necessitates the collaborative works and experience of many disciplines, i.e.

geologists, geophysicists, reservoir engineers, drilling engineers, and petroleum engineers. They are needed to assess, explain, and characterize the reservoir behavior and development operation. An oilfield development includes drilling and well completing functions.

1.5.4.1 *Drilling*

As mentioned before, drilling has a key role in the exploration as well as in the development. It is the most expensive function in the long journey of crude oil recovery. Its role in exploration is to make sure that an economical amount of oil can be recovered from the discovered oil reservoir as well as in development to provide sufficient wells to recovery oil. After accomplishment of appraisal phase, drilling engineers are involved. They are responsible for indicating the potential locations of the oil wells in the field, and designing the well completions according to the production strategy. Advanced drilling technology has developed in order to get at the harder to find oil, and in a more environmentally friendly manner. Different techniques of drilling include:

- Vertical drilling,
- Horizontal drilling,
- Slant drilling.

Oil well drilling facilities commonly are drill rigs, pumping equipment, waste and evaporation pits, and storage tanks. Among them drill rigs is most expensive and need to be handled very carefully. Finishing the operation one day sooner and returning the rig can save a huge amount of money for the *Operator Company*.

1.5.4.2 *Well completion*

The subsurface mechanical configuration of the crude oil well is called well completion. This function creates a passageway for the recovered streams from the reservoir to the wellhead at the surface (See Abdel-Aal et al., 2003). A number of completion’s types exist, including: open hole completion, conventional perforated completion, sand exclusion completion, permanent completion, multiple zone completion, and drain hole completion.

1.5.5 Production

The other highly costly and risk involving function, in addition to the drilling operation, is the production function (Khan & Islam, 2007). A production well refers to a completed crude oil well that is bringing the streams that derived from the reservoir into the bottom of the well, and from the borehole to the surface, wellhead. As mentioned before, historically, three distinct phases in production life of a reservoir are identified as primary, secondary, and tertiary or enhanced recovery. Herein, a brief study of them is illustrated, to have a complete list of crude oil life's functions. At this point of the introduction, to understand the exploration and production function clearly, it is worth taking a look at Figure 1.6. This figure depicts these functions briefly.

1.5.5.1 Primary recovery

Recovering crude oil naturally by drive mechanisms of the reservoir is called *Primary recovery*. As previous discussed the gas-cap drive, water drive, solution gas expansion, or simply gravity drainage maybe the origin of such natural drives. These drives mechanisms drive the crude oil into the wellbore, and to bring the streams to the surface may combine with artificial lift techniques, such as pumps. Commonly, the recoverable crude oil through primary recovery is about 10% of the original oil in place (Khan & Islam, 2007).

1.5.5.2 Secondary recovery

To increase the recoverable amount of crude oil, the *Secondary recovery* techniques are in use. In these recovery techniques, to maintain the reservoir pressure high enough, water or gas is injected into the crude oil reservoirs. This injection, in general, displaces crude oil and drives it to the wellbore. General estimates show that the recoverable amount in the secondary recovery is 20 to 40% of the original crude oil of the reservoir (Khan & Islam, 2007).

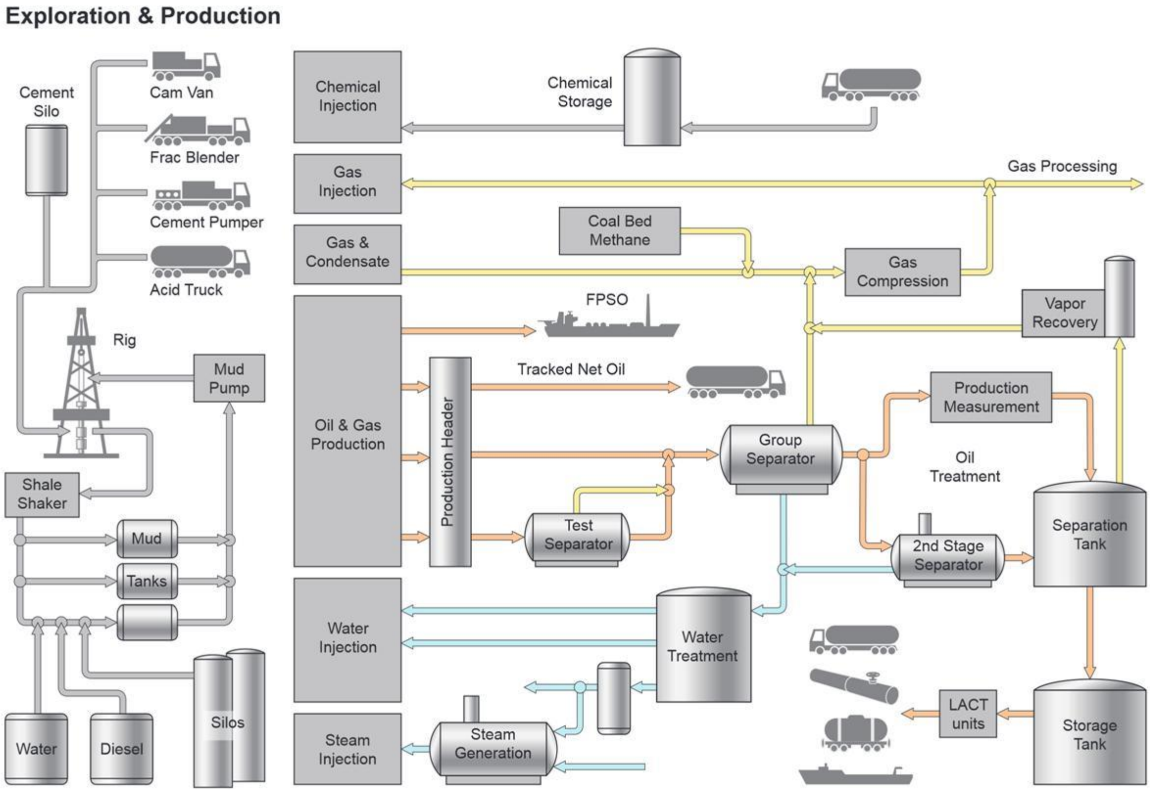

Figure 1.6: Typical exploration and production functions. (Source: http://www.endress.com)

1.5.5.3 *Tertiary recovery*

Tertiary recovery techniques, just like the *secondary recovery* techniques, refers oil recovery techniques which maintain the reservoir pressure high enough commonly by injection. The difference is that in the *tertiary recovery* techniques chemical fluids are injected into the reservoir instead of water or gas that are required in the *secondary recovery* techniques. Note that by applying the *tertiary recovery* techniques, the recoverable amount may be improved up to 60% of the original crude oil in place (see again Table 1.2)

1.5.6 Abandonment

Abandonment or *decommissioning* of oil structures is an issue that has gained a great deal of attention. It is the terminal phase of an oil reservoir or oil operations that includes unplugging and abandoning the well, removing the infrastructure, doing remediation work, and clearing debris from the project site. The offshore structures are the most difficult ones among all decommissioning. Khan and Islam (Khan & Islam, 2007) pointed that the indications point to the peak years of offshore platform decommissioning occurring before 2010.

1.5.7 Separation

The fluid recovered from the wellhead comprises usually gas, oil, free water, and emulsified water (water–oil emulsion). Before oil transporting to a local refinery or exporting, in order to reduce transportation costs and satisfy customers' demand, the oil company must first eliminate the gas and water from the well fluids. In order to improve the quality of crude oil and reduce the volume of the transporting fluids this separation is of the essence. As discussed before, separation operation includes several stages. Normally, more stages result in more qualitative crude oil. Design of a separation site needs an intellectual consideration of trade of between the separation facilities costs, capacity and rate of processing of each one, quality of crude oil, customer demands, and etc.

1.5.8 Transportation

Recovered crude oil and natural gas are mostly transported through pipelines, because it is the most economical way. As a result, the petroleum industry has the most complex piping system in the world to transport and distribute its products. In this industry, there are three main transportation networks:

- ***Gathering system:*** This system gathers recovered fluids from production wellheads and sends it to collecting centers at well platforms. And then it transports the fluid to processing centers at production platforms. This system usually transports fluids through pipeline. However, in very small onshore production well cases, it may be seen that the fluids are stored in oil storage tanks and then transported by rail tankers, even oil trackers, to a production site.

- ***Transportation of crude oil:*** This phase refers to the transportation of separated crude oil from production sites to refineries or to oil terminals.

- ***Transportation of refined oil and other oil products:*** The last phase is the distribution of refined products (at refineries or petrochemicals) to end users.

In the offshore cases, oil is transported by pipeline and oil tankers considering distances, volume of oil, loyalty of the relation between two sides, etc. If the volume of oil produced is substantial and the fence between origin and sink nodes is stable, the pipeline is the more cost-effective option. However, there are cases in which piping is not practicable. In onshore instances, petroleum products can be transported by pipeline, road, rail, and even air, for feeding an airplane which is flying. As it is observed, a significant difficulty in crude oil logistics problems is selecting suitable transportation means with respect to various numbers of quantitative and qualitative factors.

1.5.9 Storing

Storage activities are demanded throughout of the oil industry. For example, storages can be found at the production wellheads, production sites, oil terminals, refineries, petrochemical plants, etc. Figure 1.7 shows a typical storage and transportation activities in the petroleum industry.

1.5.10 Metering

To export oil from the production installations, oil volume has to be metered. Metering stations monitor and manage the amounts of crude oil. In other words, metering function employs standard meters to measure the oil volume while it is streaming through the pipelines, without hindering its movement. Devold (2009) addresses that this metric volume show the ownership transferring from a producer to a customer (or another division within the company). He, thus, denotes this function as *Custody Transfer Metering.* The metering found a basis to invoice the sold crude oil, and also is necessary to declare production taxes, revenue sharing between partners, and accuracy requirements.

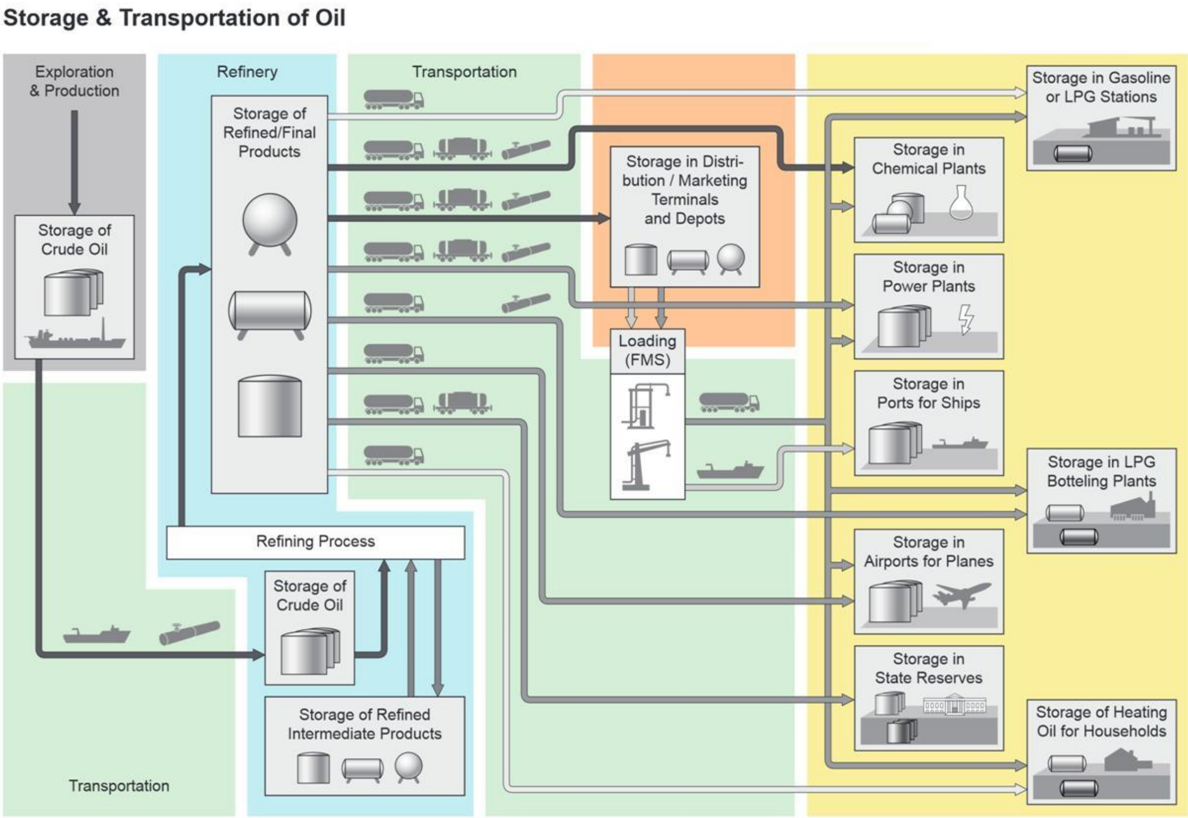

Figure 1.7: Storage and transportation throughout the crude oil industry. (Source: http://www.endress.com)

1.5.11 Transformation

The oil refining industry is the largest source of fuel production in the world. For example it is supporting about 39% of total U.S. energy demand and 97% of transportation fuels (Shah, Li, & Ierapetritou, 2010). Oil refineries are enormous complex processes, as illustrated before in Figure 1.4. Transformation involves procedures to refine and sometimes alter the crude oil. It relies on the basic difference between the boiling points of chemicals (Khan & Islam, 2007). Crude oil transformation purifies the crude oil and produces asphalt, fuel oil, diesel oil, kerosene, jet fuels, and gasoline. These products and the other products of refineries can be used as either feedstock or energy source in chemical process industry (As Figure 1.4 shows).

1.5.12 Distribution

Refineries are origins of refined products to transport along the logistics chain. Products are transported along the first stage of the chain by using 'primary transport'. Sear (1993) describes that primary transport represents the bulk carriage of products to depots, in which 'break bulk' occurs before final transport to customers. Primary transportation means comprise pipeline, marine transportation, and railcar. The final leg of the chain entitled 'secondary transport'. The secondary transportation network goes from the distribution center to retailers or customers, such as gas stations, airports, or other types of retailers. Secondary transport is typically road vehicle, but in some cases includes other modes such as railcar. In this work, we label the primary transportation, storage at depots and distribution centers, and secondary transportation as a 'distribution' problem.

1.6 SUMMARY

This chapter aimed at providing an introduction to the oil industry. Thereby, we focused on the concepts, parts and functions of this industry that are principal to configure the crude oil supply chain. The introduction started with a discussion of the leading role of the crude oil in the today's geopolitical and macroeconomic panorama, which is the rationality behind our motivation. In Section 1.2, the crude oil industry is divided into three segments and we explicitly distinguished between them. In the following section, the two varieties of facilities are illustrated. Offshore platforms and surrounding challenges are presented in this section. After clarifying the specifications of offshore and onshore crude oil production, in Section 1.4 an overview of the related entities are given, which is followed by the overview of the main functions of crude oil industry. This introduction is provided to give the reader an introductory understanding of the crude oil industry, which is fundamental for the remaining chapters of this thesis.

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Chapter Two

Strategic and Tactical Crude Oil Supply Chain Models - A Literature Review

Outline

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In today's highly competitive business world, there exists a growing recognition that companies, especially international companies, have to gain advantages of any improvement opportunity. In this light, the management of Supply Chain (SC) is receiving increased prominence in the business context. There is no agreement upon the definition of the supply chain. Therefore, numerous definitions are offered for this term. Goetschalckx (2011) proposes a distillation of several definitions in the following definition: "A supply chain is an integrated network of resources and processes that is responsible for the acquisition of raw materials, the transformation of these materials into intermediate and finished products, and the distribution of the finished products to the final customers." The underlying thread of all definitions is the integration of processes throughout the supply chain, from raw materials to final customers, for adding value to the customer. Supply Chain Management, thus, is the management of a complex and dynamic network of integrated companies or organizations which are involved in satisfying the final customer. Developing strategic and tactical decision levels of supply chain models is acknowledged by the industry (Shapiro, 2004). Companies can achieve a dramatic saving (in the 5-10% range) by applying the strategic and tactical supply chain models (Goetschalckx, Vidal, & Dogan, 2002). These facts prove the leading role of strategic and tactical models for supply chain management models. This rationality motivates us to limit the scope of this thesis into the strategic and tactical supply chain models.

In Section 1.1, we briefly discussed the key role of the crude oil in the today's world business. Crude oil industry shortly became a strategic industry, and nowadays, is the heart of our modern societies, to stream fossil fuels and supply required energy of industries all around the world. Due to world-wide marketplaces and the extension of oil reservoirs to everywhere, Crude Oil Supply Chain (COSC) is one of the most complex networks. Optimization of this complex supply chain has created new challenges for oil industry managers, and has encouraged both academic and practitioner interest in this area. Since systematic literature review takes a significant role in evidence based practices (Tranfield, Denyer, & Smart, 2003) and to gain a better appreciation of the COSC challenges, we provide this review chapter. The chapter reviews the literature on the application of mathematical programming models within the strategic and tactical COSC context.

To achieve this purpose, we start with a short overview of the previous review papers, in Section 2.1. In this section, we study three classes of previous reviews papers that overview the literature on strategic and tactical supply chain, global supply chain, and crude oil supply chain management. This section describes facts that motivate us to carry out an overview on the mathematical programming models that are applied to formulate the strategic and tactical crude oil supply chain problems. Our purpose is to foster insight into these issues and point out possible research directions.

In the following section, we describe the systematic methodology of this literature review. For this purpose, the importance and role of systematic literature reviews are explained. Afterwards, we discuss the procedures of this methodology. In brief, the selected papers will be skimmed to filter out those that: (i) dealt with single entity, (ii) involved only in operational decisions rather than strategic and/or tactical decisions, and (iii) implement simulation approaches instead of mathematical programming models.

Afterwards, we introduce an adapted taxonomy which is used as a framework to base our systematic literature review on it. This framework discusses the criteria that are employed to classify the papers reviewed. Providing such classification scheme in a systematic literature review is essential. We study the selected papers with respect to each criterion of this taxonomy framework sequentially, in Sections 2.4 – 2.12. At the end of each section, we recommend possible research directions. Finally, in Section 2.13 we give a summary of this review and highlight gaps in the literature. Afterwards this chapter ends with pointing out the proposed research directions in this thesis.

2.1 PREVIOUS REVIEW WORKS

A great deal of review research undertakes the relevant literature. To study them, firstly, 21 review researches have been opted in the current context date from 2003 to 2013. Secondly, we picked and chosen 11 papers of them, which put the focus on the mathematical programming models of the SCM, study global SCM challenges, overview the COSC and are more comprehensive. Finally, the articles fall into three following groups, and overviewed.

2.1.1 Strategic and Tactical Supply Chain Reviews

Shapiro (2004) carries out a survey on the supply chain literature associated with strategic optimization models. He discusses the new challenges surrounding the strategic supply chain management and its natural extensions to fact-based enterprise management. Moreover, Papageorgiou (2009) presents an overview on mathematical programming models of supply chain problems at strategic and tactical level in the process industry context. Some of his conclusions are (i) the treatment of uncertainty demands more efforts to take more uncertain features into account, (ii) two-stage problems are used in the most of the existing stochastic models, while to form suitable supply chain model multi-stage problem is a need, (iii) the numerical solution of large-scale problems, especially for multi-stage stochastic problems, requires further research, and (iv) an emerging stream within supply chain management context is considering environmental impact indicators, that encourages the improvement of multi-objective optimization approaches. While, Melo et al. (2009) review the recent literature on facility location, which a popular strategic problem within the context of supply chain management. They discuss the features that a facility location model should have to effectively illustrate supply chain design needs. They focus on the relation between facility location and SCM, the features of mathematical programming models, and solution methods as well as applications. Melo et al. (2009) conclude that some research directions still require more attention in future researches such as: stochasticity in SCM (i.e. combining more uncertain parameters, in particular within the complicated structures of the supply chain not only within very simplified structures), full integration of reverse and forward functions, more comprehensive models are increasingly needed, etc.

The most recent review paper is of Mula et al. (2010). They center their attention upon the tactical decision level, i.e. production and transportation planning models within supply chain context. This field is analyzed within a systematic review which based on a taxonomy framework. Their taxonomy framework is modified of Huang et al. (2003) which includes following components: the structure of supply chain, decision level, modeling approach, purpose, shared information, limitations, novelty and application. Note we also adapted this taxonomy framework with respect to the nature of crude oil supply chain, and based our systematic literature review on this framework. Additionally, we expand the framework considering a number of important elements, those are critical in the crude oil supply chain. The added elements are the solution techniques, uncertain features, environmental impacts, and global issues of the mathematical programming models within the crude oil supply chain, those are respectively presented in Sections 2.8, 2.10, 2.11, and 2.12.

2.1.2 Global Supply Chain Reviews

The two last decades observed a significant expansion of SCs into international environment, more specifically in the oil industry. This increasing growth in globalization of the oil industry, and the other international challenges it causes for oil companies, has motivated the authors' interest in global SCM literature. Herein, we study previous review papers related to global supply chain design and concentrate on the logistics of the global SCs. Schmidt and Wilhelm (2000) present an early review of the multinational logistics networks' literature. They discuss relevant mathematical programming issues that involve strategic, tactical and operational decisions. They distinguish global supply chains from domestic systems in two ways which are: (i) on a global scale, some specific values might be zone-dependent and, thus, more challenging to forecast, and (ii) the duty drawbacks, different income tax rates and duties, export taxes, import tariffs, and transfer prices must be taken into account within the global supply chain design and planning. As a result, a number of issues are encountered in a global logistics network, while a domestic system does not involve them. Due to this complexity of the global supply chains, to solve actual, large-scale, uncertain problems efficiently it is requested to develop the current solution algorithms, in this context.

Goetschalckx et al. (2002) also analyze modeling and design of global logistics networks. They focus on the strategic and tactical levels of the global supply chain models. They claim that the international factors such as the nonlinear effects of international taxation, the explicit inclusion of suppliers, the inclusion of inventory costs as part of the decision problem, the allocation of transportation cost among subsidiaries, transportation mode selection, are ignored by much of researchers. For this purpose, finally, they consider the transfer price as the key international tax factor, and present a model for these kinds of problems. In addition, Meixell and Gargeya (2005) review analytical models of the global SC design, and investigate the matching of the practical issues and the research literature of the global supply chain. Their investigation is based on the four review dimensions which are: (1) decision levels of the model, (2) performance metrics, (3) the integration degree of decision processes, and (4) globalization features. In conclusion, they claim that although difficult globalization features are resolved in the most reviewed models; few models translate an actual design problem within its entirety global supply chain.

2.1.3 Crude Oil Supply Chain Management

There exist a few literature review works in the crude oil supply chain. Some of them are like a discussion and critique rather than a systematic literature review. To the best of our knowledge, only three studies can be found which carries out a systematic investigation of the mathematical models for the crude oil supply chain problems. Bengtsson and Nonås (2010) present an overview of the midstream section of the COSC, i.e. refinery planning and scheduling activities. They treat three schools of functions: planning and scheduling of crude oil unloading and blending, production planning and process scheduling, and product blending and recipe optimization. They claim that due the complexity of the refinery planning and scheduling models, the presented researches, up till now, relax most of the nonlinear relations. This gap should be bridged within future works. In addition, they address that more research necessitated on developing of the solution techniques to consider the environmental impacts of refinery's activities.

Following the COSC review papers, Shah et al. (2010) undertake a very similar review on the refinery operations literature. Their novelty is that they overview some works of the crude oil supply chain design and planning, as well. The importance of the capturing nonlinearity and developing of the solution approaches are also addressed in their conclusions. They also mention that the integration of multisite production planning and the crude oil supply chain design are not adequately explored. Leiras et al. (2011) survey the existing literature in the field of refinery planning models. They emphasizes on the solution techniques used to optimize the model under uncertainty, and classified them. According to this review, the robust optimization method is the most common technique used to take uncertainty into account in refinery planning. They claim that the integration of different decision levels in the crude oil supply chain is rarely tackled. The main drawback of these reviews is that they only focus on the refinery operations instead of the integrated crude oil supply chain.

Overall, a large number of papers has been undertaken the investigation of relevant literature. As can be easily seen from the previous paragraphs, a systematic literature review on the mathematical models of the strategic and tactical COSC is an important area that has received no attention so far. The previous reviews on the COSC undertake research, only, into midstream segment, but not into the upstream and downstream segment (different segment of the typical structure of crude oil supply chain is illustrated in Section 2.4). This fact motivates the authors to devote this paper to a review of the mathematical programming models for the strategic and tactical crude oil supply chain problems. Our purpose is to foster insight into issues pertinent to the current field and light the future research directions.

2.2 REVIEW METHODOLOGY

Tranfield et al. (2003) describe that a literature review is often aimed to enable the researcher to scan, map, and evaluate the existing intellectual territory. Based on that existing body of knowledge, the key gaps and opportunities of developments can be detected. The underlying principle is to improve and extend the existing body of knowledge further. Considering this logic, a systematic literature review on applying of mathematical models for the strategic and tactical crude oil supply chain is carried out in the current work.

As explained, the aim of this chapter is to review the literature on the application of the mathematical models in the oil supply chain context. Following the search process, the study carried out a search of all articles published in the scientific publishing portals e.g. Elsevier, Wiley, Taylor & Francis, or Emerald. These are selected due to their wide coverage of applied mathematics, management, and engineering journals. The following search keywords were conducted: “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 which are cited the studied papers have served as a secondary source to search relevant literature. With a time frame of 26 years, a total of 158 references were collected from the mentioned scientific databases. Two groups of the identified papers can be distinguished; articles that used simulation approaches, and articles that proposed mathematical programming models. Since the former group is out of our review scope, those of Julka et al. (2002a; 2002b), Srinivasan et al. (2006), Koo et al. (2008), Pitty et al. (2008), Naraharisetti et al. (2009), and Sinha et al. (2009) are ruled out. Of the latter group, we wrote off those papers whose decisions focused exclusively on the operational level (i.e. themes such as the scheduling of loading and unloading (Saharidis & Ierapetritou, 2009), the crude oil tanker routing and scheduling (Hennig, Nygreen, Furman, Song, & Kocis, 2011; Nishi, Yin, & Izuno, 2011), the crude oil tanker lightering (Lin, Chajakis, & Floudas, 2003), the well scheduling (Kosmidis, Perkins, & Pistikopoulos, 2005), the crude oil scheduling (Shah, 1996), the pipeline scheduling (Boschetto et al., 2008; Herrán, de la Cruz, & de Andrés, 2010), etc.

Additionally, those papers studying only one entity are also filtered out. In this light, papers addressing crude oil supply chain design and/or planning mathematical models, those that present multi entities supply chain, were considered. As of July 31, 2013, a total of 53 references were selected. These papers were published in journals (92.45%) and presented at congresses (7.55%). Four of these journals represented 73.58% of all references. Figures 2.1 and 2.2 display the distribution of the reviewed papers by journals and by years, respectively. Note, the distribution of references over 2008, 2009, and 2010 are represented individually, since the number of the references in these years are significant.

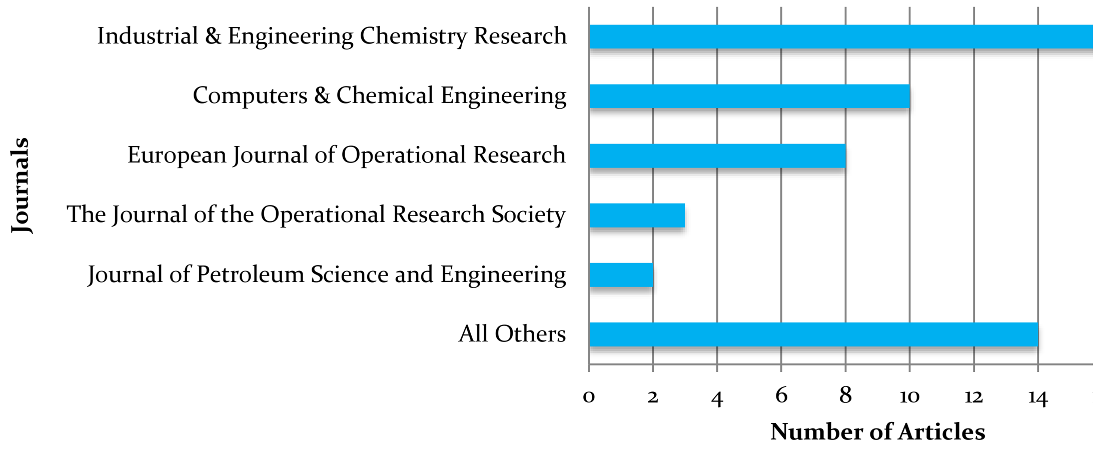

Figure 2.1: Distribution of the reviewed papers on journals.

2.3 TAXONOMY FRAMEWORK

This taxonomy is intended to be founded toward detecting the key criteria to study when formulating a COSC problem, rather than to be exhaustive. In other words, special emphasis is centered on the taxonomies of various SC models in oil industry.

Huang et al. (2003) reviewed the relevant literature to survey the impacts of information sharing on the supply chain. To gain this goal, four classification criteria are applied by them that are: supply chain structure, decision level, modeling approach, and shared information. Mula et al. (2010) have developed Huang's taxonomy by considering two more criteria which are: purpose and limitations. They also studied the novelty and practical application of each model in their review study.

To have a better appreciation of the COSC, we adapt their criteria for oil industry, and expand this taxonomy framework by taking four additional criteria into account: solution techniques, uncertain features, environmental impacts, and global issues of the reviewed papers. The adapted elements of the framework, in brief, are presented below:

- *Supply Chain Structure:* It represents the pattern that a number of enterprises are integrated and how they linked to each other to configure the supply chain.

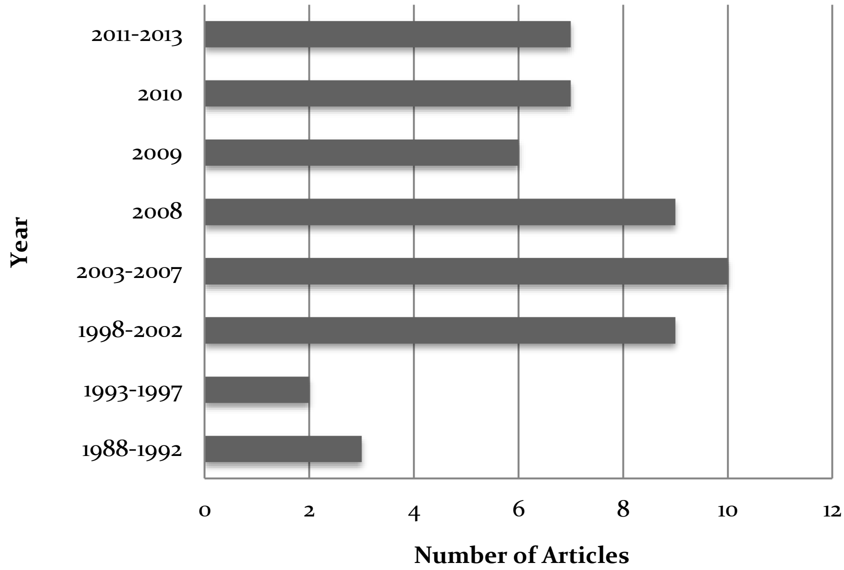

Figure 2.2: Distribution of the reviewed papers over time.

- *Decision Level:* According to planning horizon, three decision levels are distinguished; strategic, tactical and operational, and their corresponding periods are long-term, mid-term and short-term, respectively. In this work, as mentioned before, our concentration is placed on the strategic and tactical decision levels.

- *Modeling Approach:* The nature of the input parameters, decision variables, constraints, and objective functions of a model explicate the 'modeling approach'.

- *Purpose:* The objective(s) of mathematical models are defined as performance measurement(s) (Beamon, 1998) or purpose(s) (Mula et al., 2010).

- *Shared Information:* This interprets the amounts of information shared within a supply chain, and between each entities of it.

Additionally, we review the selected papers in several new respects:

- *Solution Technique:* This studies the ways that are used to achieve the optimal solution of analytical models.

- *Uncertainty Features:* The mathematical models include some forecasted parameters. Owning to this fact, considering that all the parameters and variables of a mathematical model are deterministic is not rational, especially in the strategic level of a SC problem in which parameters are forecasted for a long frame of time.

- *Environmental Impacts:* Thereby, we detect the main environmental aspects those are applied in the COSC models.

- *Global Issues:* Investigation of those characteristics which are used in a COSC model to be a realistic global supply network.

2.4 SUPPLY CHAIN STRUCTURE

The supply chain, sometimes is also called the logistics network, connotes an integrated chain in which all entities work together to supply products (or services). The supply chain structure arises from the configuration of this integrated network. A given supply chain commonly is divided into tiers (or stages, or echelons). Each of them comprises entities (or units, or facilities) with the same general functionality. Care should be taken to treat with the concept of tier. however, as distinguishing between tiers is often fuzzy and units can be a member of various tiers (Chandra & Grabis, 2007). As discussed in Section 1.2, the crude oil industry is often discussed relative to three major segments; upstream, midstream, and downstream. Upstream segment refers to exploration, production (i.e. recovery and separation), and transportation to refineries. Midstream segment describes crude oil transformation and production of oil products through refineries and petrochemicals. Downstream segment represents processes that follow transformation, including storage and distribution to customers. In each segment, there exist several kinds of the entities:

- Upstream segment: wellhead (WH), Well Platform (WP), Production Platform (PP), and Crude oil Terminal (CT);

- Midstream segment: Refinery planet (RF), and Petrochemical planet (PC);

- Downstream segment: Distribution Center/Depot (DC), Market (M), Customer (C).

In the crude oil supply chain, like other supply chains, there exist some links between entities. These links represent the flow of materials (i.e. crude oil, refinery' (semi-) finished products), services, cash, and information that make possible the functions of exploration, production, refining, storage, and distribution.

There exists various classification of the SC structure. Beamon and Chen (2001) divide the SC structure into four main classes:

- Convergent (CV) or Assembly: each entity (node or facility) in the chain has at most one successor, but may have several predecessors.
- Divergent (DV) or Arborescent: each entity has at most one predecessor, but several successors.
- Conjoined (CJ): a combination of each divergent and one convergent structure.
- Network (NW): this cannot fall into any of the three above structural classes.

In the other way, Huang et al. (2003) identified that, in general, five classes of supply chain structure can be introduced: network, convergent, divergent, serial, and dyadic.

- A dyadic (DD) supply network comprises two business entities (e.g. buyer and vendor).
- The serial (SR) structure is configured by joining several dyadic structures.

They defined divergent, convergent, and network structures as same as Beamon and Chen (2001). The structures of the reviewed papers are classified according to these six structural classes, as shown in Table 2.1. (For the sake of simplification, we use a sequential numbering to represent the paper reviewed. The corresponding references are illustrated in Table 2.3).

According to the reviewed papers, network-like and convergent-like structures are more popular. The network models usually combine the presence of midstream entities (refinery and/or petrochemical) and markets, and sometimes consider crude oil suppliers and/or distribution centers as supply chain nodes. The convergent like structures mainly cover only upstream entities and sometimes add customers and/or markets as supply chain links. Meanwhile, some other papers focused on midstream and attempted to deal with crude oil supply and distribution simultaneously. This fact commonly result in a conjoined like structure.

Figure 2.3 depicts the three typical structures of surveyed papers. In summary, it is observed that

(i) Considering only upstream usually results in a convergent structure;

(ii) Studying refinery (and petrochemical) and downstream shapes a divergent SC;

(iii) Pondering a refinery as well as suppliers, DCs, and customers configures a conjoined SC;

(iv) Dealing with the processing units of refinery and interaction of them establish a network like structure.

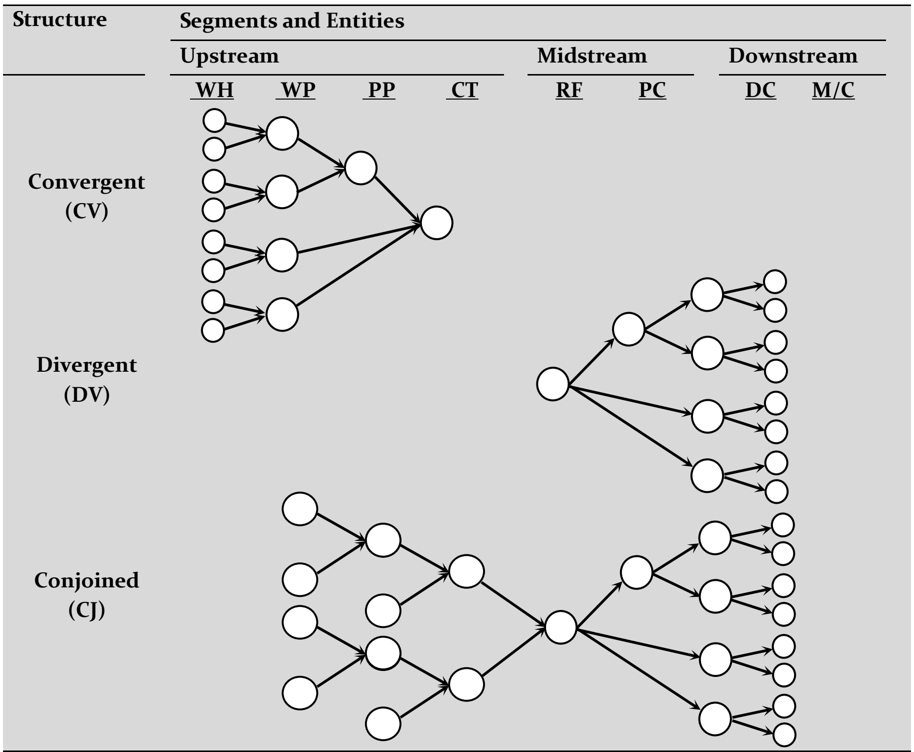

Figure 2.3: Typical structures of crude oil supply chain models.

Table 2.1: The structures of the reviewed papers.

Ref.	Structure						Segments and Entities							
							Upstream				Midstrea		Downstrea	
	DD	SR	CV	DV	CJ	NW	WH	WP	PP	CT	RF	PC	DC	M/C
[1]			✓				✓		✓					
[2]		✓					✓			✓				✓
[3]	✓							✓						✓
[4]				✓							✓		✓	✓
[5]			✓					✓						✓
[6]			✓				✓	✓	✓	✓				✓
[7]			✓				✓	✓	✓					
[8]			✓					✓	✓	✓				✓
[9]	✓									✓	✓			
[10]						✓				✓	✓			✓
[11]			✓				✓	✓	✓					✓
[12]			✓				✓	✓	✓					✓
[13]	✓									✓				✓
[14]			✓				✓	✓	✓	✓				
[15]			✓				✓	✓	✓					✓
[16]			✓					✓	✓					
[17]						✓					✓	✓		✓
[18]						✓				✓	✓		✓	✓
[19]						✓					✓			✓
[20]	✓										✓		✓	
[21]			✓				✓	✓						
[22]			✓				✓	✓						
[23]			✓					✓	✓					
[24]						✓		✓	✓	✓				✓
[25]					✓				✓	✓	✓	✓	✓	✓
[26]						✓				✓	✓			✓
[27]						✓				✓		✓		✓
[28]						✓					✓			✓
[29]						✓					✓			✓
[30]					✓						✓		✓	✓
[31]						✓				✓	✓		✓	✓
[32]						✓				✓	✓	✓	✓	✓
[33]				✓							✓		✓	✓
[34]						✓				✓	✓		✓	✓
[35]						✓					✓	✓		✓
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[40]						✓					✓			✓
[41]					✓				✓	✓	✓	✓	✓	✓
[42]						✓				✓			✓	
[43]					✓					✓	✓	✓	✓	✓
[44]						✓					✓			✓
[45]					✓				✓	✓	✓	✓	✓	✓
[46]						✓					✓			
[47]				✓							✓		✓	✓
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[49]						✓				✓	✓		✓	✓
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[51]			✓				✓	✓	✓					
[52]		✓								✓			✓	✓
[53]			✓				✓	✓	✓	✓				✓
Total #	4	2	16	4	7	20	13	17	18	26	30	8	20	39
Total %	7.5	3.8	30.2	7.5	13.2	37.7	24.5	32.1	34	49.1	56.6	15.1	37.7	73.6

Huang et al. (2003) analyzes the structure of supply chain models and conclude that the dyadic-like structures are usually formulated by an analytical model, since the simplicity of this structural class allows effective mathematical analysis. The authors claim that the complex structures (e.g. the network and conjoined structures) are usually studied by using the simulation approach. Consequently, it is apparent that the modeling approach and solution methods are very closely associated with the complexity of the supply chain structure. It can be observed in this work, by comparing Tables 2.1 and 2.6. In addition, within developing solution techniques and enhancing of the capability of modern computing technologies over the last years, researchers deal with more complicated crude oil supply chain structures. From the data in Table 2.1, 23 papers of the 29 reviewed papers have presented the complex structures (i.e. network-like or conjoined-like structure) since 2008. Meanwhile, only five articles had focused on these complex supply chains before that time (the interested readers can also see the review works of (Huang et al., 2003; Mula et al., 2010)).

2.5 LEVEL OF DECISIONS

Decisions made at the supply chain differ mainly in the range of activities coordinated through the supply network (i.e. horizontal or spatial integration) and in terms of time scales (i.e. vertical or temporal integration). In other words, the horizontal focus describes the supply chain structure; meanwhile the vertical focus explains the decision levels.

As same a lot of terms, there is also no agreement upon the classification of decision level. Traditionally, decisions in a supply chain fall into three hierarchical levels: strategic, tactical and operational decisions. The distinction between the decision levels founds on their planning horizon. The strategic level involves a relatively long planning horizon of, perhaps, in the COSC 5 to 20 years, the tactical level may deal with the time horizon of 6-24 months, and the operational level makes weekly and/or daily decisions. Papageorgiou (2009) states that key management activities in the supply chain are (i) supply-chain design, (ii) supply-chain planning and scheduling, and (iii) supply-chain control (real-time management). According to the traditional decision levels, supply-chain design (or configuration) refers to a strategic (long-term) decision level to establish the optimal network (e.g. infrastructure and assets).

Whereas planning, herein, presents a tactical decision level to reveal the best flow of materials, and scheduling is an operational level decision.

As previously discussed, Goetschalckx et al. (2002) review the literature on the global supply chain. They addressed that long-range survival, in today's global business world, will be unachievable without perfectly optimized strategic and tactical global supply chain. Employment of the strategic and tactical supply chain models will result in savings in the 5–10% range. Hence, strategic and tactical models are dramatically profitable in the global supply chain context. Since a crude oil supply chain is obviously a global supply chain, these models can definitely improve the profits of oil companies. In consequence, the current thesis, as argued before, concentrates only on application of the mathematical programming models in the strategic and tactical levels of crude oil supply chains.

2.5.1 Strategic Decisions

Schmit and Wilhelm (2000) propose that the strategic decision level identifies a set of locations at which entities are to be structured (i.e. 'facility location'), which technologies to be applied at each facility (i.e. 'technology selection'), and the capacity of each facility and technology. From their point of view, the strategic decisions configure the structure of supply chain, and thereby provide the network in which tactical and operational levels must employ. At strategic level, Huang et al. (2003) make more additional decisions such as facility allocation and outsourcing. Hammami et al. (2009), on the other hand, show that strategic models should take into account the technology selection, supplier selection factors as well as activity location. As discussed in Section 2.1.1, Melo et al. (2009) carried out a comprehensive survey over supply chain management and facility location. They address that due to the huge budgets investing in strategic levels, stability of them is massively desirable. Nonetheless, in some cases, the possibility of making gradual adjustments in the capacities of the facilities and/or in the structure of SCs may be important to consider. In consequence, in this work, the facility relocation problems are also considered as strategic decisions, which include the facility replacement, the facility removing, as well as the capacity expansions (see Table 2.2).

Table 2.2: Classification of crude oil supply chain decisions on different level.

Decision Level	Decision Type	Code
Strategic	Investment (Project Selection)	IVM
	Facility Location	FL
	– Capacity Determination	– CPD
	Facility Allocation	FAL
	Facility Relocation	FRL
	– Capacity Expansion	– CPE
	Technology	TCH
	– Selection, Upgrading, Downgrading	
	Outsourcing	OS
Tactical	Project Planning	PJP
	Production Planning	
	– Oil Field Production Planning	– OFPP
	– Refinery Production Planning	– RFPP
	Inventory Management	INM
	Distribution	DB

In summary, "strategic" level connotes network design. These decisions comprise the investment, facility location, facility relocation (e.g. capacity expansion and reduction), facility allocation, technology selection, upgrading, downgrading, and outsourcing, as shown in Table 2.2.

2.5.2 Tactical Decisions

Tactical planning is the process of determination of intermediate activities required to achieve strategic objectives. At the tactical level, the predetermined strategic decisions will be refined; since demands, price, political environment, exchange rates, and other uncertain factors become more accurate (Schmit & Wilhelm, 2000). Huang et al. (2003) addressed the production and distribution planning as regular tactical decisions. Additionally, they claim that three more tactical decisions—safety stock placement, inventory allocation, and capacity allocation (to production entities)—are recognizable within this background. This traditional classification of decision level is adapted for the oil industry and summarized in Table 2.2 (for more information see (Beamon, 2005; Hammami et al., 2009; Huang et al., 2003; Mula et al., 2010; Schmidt & Wilhelm, 2000)). According to Table 2.2 the papers are reviewed, classified, and summarized in Table 2.3.

Table 2.3: The decision levels of the reviewed papers.

Ref.	Author (Year)	Strategic						Tactical				
		IVM	FL	AL	FRL	TC	OS	PJP	OFPP	RFP	IN	DB
[1]	(Haugland et al. 1988)		CPD	✓				✓	✓			
[2]	(Aboudi et al. 1989)	✓	✓	✓				✓	✓			
[3]	(Jørnsten 1992)	✓		✓				✓	✓			
[4]	(Sear 1993)			✓							✓	✓
[5]	(Haugen 1996)	✓		✓				✓	✓			
[6]	(Iyer et al. 1998)	✓	CPD	✓				✓	✓			
[7]	(Jonsbråten 1998)		CPD	✓				✓	✓			
[8]	(Nygreen et al. 1998)	✓		✓				✓	✓			
[9]	(Escudero et al. 1999)									✓	✓	✓
[10]	(Dempster et al. 2000)									✓	✓	✓
[11]	(van den Heever and Grossmann 2000)		CPD	✓				✓	✓			
[12]	(van den Heever et al. 2000)		CPD	✓				✓	✓			
[13]	(Iakovou 2001)											✓
[14]	(van den Heever et al. 2001)		✓	✓	CPE			✓	✓			
[15]	(Aseeri et al. 2004)		✓	✓				✓				
[16]	(Goel and Grossmann 2004)		CPD	✓				✓	✓			
[17]	(Li et al. 2004)									✓	✓	
[18]	(Neiro and Pinto 2004)									✓	✓	✓
[19]	(Neiro and Pinto 2005)									✓	✓	✓
[20]	(Persson and Göthe-Lundgren 2005)									✓	✓	✓
[21]	(Carvalho and Pinto 2006a)		✓	✓				✓	✓			
[22]	(Carvalho and Pinto 2006b)		✓	✓				✓	✓			
[23]	(Goel et al. 2006)		✓	✓	CPE			✓	✓			
[24]	(Ulstein et al. 2007)								✓			
[25]	(Al-Othman et al. 2008)									✓	✓	✓
[26]	(Al-Qahtani and Elkamel 2008)			✓	CPE			✓		✓		✓
[27]	(Al-Qahtani et al. 2008)			✓						✓		✓
[28]	(Elkamel et al. 2008)		✓			✓				✓		
[29]	(Khor et al. 2008)				CPE		✓			✓	✓	
[30]	(Kim et al. 2008)			✓	✓					✓	✓	✓
[31]	(Kuo and Chang 2008b)									✓	✓	✓
[32]	(Kuo and Chang 2008a)						✓			✓	✓	✓
[33]	(MirHassani 2008)			✓						✓	✓	✓
[34]	(Alabi and Castro 2009)						✓			✓	✓	✓
[35]	(Al-Qahtani and Elkamel 2009)				CPE			✓		✓		
[36]	(Ghatee and Hashemi 2009)		✓		CPE					✓	✓	✓
[37]	(Guyonnet et al. 2009)									✓	✓	✓
[38]	(Rocha et al. 2009)			✓			✓			✓	✓	
[39]	(Tarhan et al. 2009)		✓	✓				✓	✓			
[40]	(Al-Qahtani and Elkamel 2010)			✓	CPE			✓		✓		
[41]	(Carneiro et al. 2010)		✓	✓	CPE				✓	✓		✓
[42]	(Chen et al. 2010)			✓								✓
[43]	(Jian-ling et al. 2010)			✓						✓	✓	✓
[44]	(Leiras et al. 2010)			✓	CPE			✓		✓		
[45]	(Ribas et al. 2010)		✓	✓	CPE					✓		✓
[46]	(Yang et al. 2010)									✓	✓	
[47]	(Fernandes et al. 2011)		✓	✓	✓					✓	✓	✓
[48]	(MirHassani and Noori 2011)				CPE						✓	✓
[49]	(Ribas et al. 2011)									✓	✓	✓
[50]	(Tong et al. 2011)									✓	✓	✓
[51]	(Gupta and Grossmann 2012)	✓	✓	✓	CPE			✓	✓			
[52]	(Oliveira et al. 2012)	✓	✓	✓	CPE		✓	✓			✓	✓
[53]	(Sahebi and Nickel 2013)	✓	✓	✓		✓	✓	✓	✓			✓
Total	#	8	21	32	15	2	6	23	19	29	24	27
	%	15.1	39.6	60.4	28.3	3.8	11.3	43.4	35.8	54.7	45.3	50.9

Mula et al. (2010) reviewed 44 mathematical models pertinent to supply chain production and transport planning, and found that "All but five of the reviewed works focus on the tactical decision level". It is expected to happen in our review over the literature related to the crude oil supply chain. The tactical level is an integral part of the reviewed papers. The works in this field are well established and rich. Amongst the tactical decisions, refinery production planning attract attracted a lot of interest, while the oilfield production planning has the least works.

At strategic level, a great deal of the reviewed articles deals with strategic. Amongst them, with only two exceptions (Alabi & Castro, 2009; Kuo & Chang, 2008a), the facility location, allocation, and/or relocation features are undertaken at the strategic level. These numerous papers are witness of this fact that facility location is a well-established research area within the COSC problems. Melo et al. (2009) also address this fact for the supply chain models . From the facility relocation group, the capacity expansion - with two exception of (Fernandes, Relvas, & Paula Barbosa-Póvoa, 2011; Kim, Yun, Park, Park, & Fan, 2008) - is studied in the all studies. Dealing with technology issues and outsourcing problems are scarce. Although outsourcing can reduce the costs, thus, improve the profits and gain the competitive advantages for a company. Another kind of these alliance contracts is joint venture agreements. Companies with diverse strengths and weaknesses cooperatively bid for Joint Ventures (JV) formation, in order to overcome complexity, uncertainty, and risk of international projects. These challenges are very apparent in the oil industry projects, especially in the upstream segment, where the costs, risk, shortage of drill rig, knowledge and technology issues obviously require a collaborative approach, i.e. JV, on the largest projects. This gap motivates us to deal with these challenges. For this aim, we formulate a mathematical programming model to optimize the joint venture formation problems, in Chapter 3.

Obviously, technology selection, upgrading and downgrading, as well as outsourcing need more attentions in future researches, which are accessible all by forming a joint venture agreement (See section 3.1). We will discuss that how a joint venture can help a company to reduce the costs, develop the competitive position, acquire and share new capabilities, technologies, skills, and knowledge through the partner companies, as will be discussed in Section 3.1.1.

2.5.3 Crude Oil Supply Chain Design and Planning

The oil industry supply chain consists of the same levels of decisions (strategic, tactical, and operational). The crude oil supply chain mathematical models optimize the design and planning of a number of subsystems of this network, e.g. crude oil transportation, oilfield development, refinery planning, and distribution (Shah et. al, 2010). The strategic and tactical decisions in relevant to the crude oil supply-chain design and planning are reviewed, in what follows. This literature is reviewed according to the following classes: oilfield development (oilfield infrastructure investments and planning), crude oil transportation, transformation planning, distribution planning, and multisite crude oil supply chain planning. As mentioned before, one of the key criteria of our selection process was integration and expansion of the model. As a result, a vast majority of the papers considered at least two kinds of the abovementioned classes. Table 2.4 represents a summary of the reviewed papers with respect to these classes.

2.5.3.1 Oil Field Development

Oil field development is a costly and complicated under taking for the oil companies. This kind of problems is specified by long-time planning horizon and a wide number of alternatives to wells, platforms, and oilfields, and their pipeline connection infrastructure (Iyer, Grossmann, Vasantharajan, & Cullick, 1998). A large group of the reviewed papers (18 papers of all), account for 35.3%, placed their attentions on this kind of problems (see Table 2.4).

Oil field development problems can be cast into three broad categories:

(i) *Investment planning*: A typical investment model would deal with a given number of alternatives. An alternative is a set of projects where at most one is allowed to start in any one of several years. The projects can be an oilfield development, capacity expansion, technology selection, technology upgrading, and/or technology downgrading. All of the investment models which reviewed here are focused on the oilfield and pipeline development. A mixed integer programming model for investment planning of these fields has been used, and the objective function of them is maximizing of the Net Present Value (NPV). The main involved decisions are when and which projects should be initiated. On the other hand, *project selection* and *project planning* are the two main types of the decisions involved in.

(ii) *Facility Location-Allocation:* Choosing the location of the production platforms, well platforms, crude oil wells and their allocation is a complicated optimization problem. One of the earliest works in the oilfield development is addressed by Devine and Lesso (1972). They solved a continuous two-dimensional location-allocation problem that made of wells, well platforms, and production platforms.

(iii) *Production Planning:* Oil field production planning is deal with to optimization of the performance of reservoirs. These models can be distinguished by the linearity and nonlinearity of reservoir performance equations.

As mentioned above, an oil field development model may be captured one of three above categories or a hybrid of them. One attempt to do this is of Aboudi et al. (1989). They presented the achievements of an operations research project involved planning of the crude oilfield development and transport systems. They highlighted the importance of developing transport systems for crude oil transportation from the oilfields to oil terminals and customers, as well as the significance of the selection of new producing fields. Haugland et al. (1988) extended the oil field design model of Aboudi et al. (1989) by considering, simultaneously, production planning for each well. Nygreen et al. (1998) implemented the model proposed by Haugland et al. (1988). They described an investment planning model that had been in professional use for 15 years by the Norwegian Petroleum Directorate in new oilfields and pipelines. All the cited researchers were participated in making a model not very different from the others. Iyer et al. (1998) formulated the investment planning, facility location-allocation, and production planning, simultaneously. The model takes oil rig constraints, surface pressure constraints, and the reservoir performance into account. In addition, piecewise linear approximations are applied to approximate the nonlinear reservoir performance equations. The computational burden of the model was heavy to solve for realistic multi- field sites. Carvalho and Pinto (2006a) reformulated the model developed by Tsarbopoulou (2000). The reformulated model contained a smaller number of binary variables. Moreover, they applied heuristic techniques (i.e. a bi-level decomposition and design cuts) and achieved a marked enhancement in solution time using the proposed algorithm. Furthermore, Carvalho and Pinto (2006b) contributed their work to study multiple reservoirs at the same time. Ulstein et al. (2007) provided a tactical model of Norwegian petroleum production problem. The net income of the problem is maximized. They dealt with system breakdowns, quality constraints, and demand variations through various cases. The model is able to find feasible approaches to satisfy the demand for varying network configurations. This ability is a main advantage of the model.

In all of the models mentioned in the previous paragraph, the nonlinear behavior of reservoir was not considered or approximated by linear constraint(s). Grossmann and co-workers (van den Heever & Grossmann, 2000; van den Heever, Grossmann, Vasantharajan, & Edwards, 2001), as opposed to their previous work (Iyer et al., 1998), explicitly formulated a nonlinear reservoir equation in the model. The consequent large-scale model is optimized by an iterative aggregation/disaggregation algorithm which was proposed by them (van den Heever & Grossmann, 2000). To achieve a better efficiency in solution time, then, they introduced a bi-level decomposition method (van den Heever et al., 2001). At the next step, Grossmann and co-workers developed their studies by dealing with complex economic objectives that were consisted of royalties, tariffs, and taxes for the multiple gas fields site (van den Heever, Grossmann, Vasantharajan, & Edwards, 2000).

In the papers cited above, certainty of the parameters is a major assumption. To deal with uncertain parameters, Jørnsten (1992) and Haugen (1996) applied stochastic programming to the model presented by Nygreen et al. (1998). Haugen (1996) considered uncertain demand and recoverable amounts crude oil, while Jonsbråten (1998) tackled the uncertainty of crude oil price. The expected net present value of the model is maximized to determine strategic and tactical decisions, in order to design and operate the oilfield projects. Aseeri et al. (2004) developed the model of Iyer et al. (1998) by studying uncertainty in the oil prices, and well productivity indexes. The budgeting constraints and financial risk management are also introduced in their model. Goel and Grossmann (2004) optimized the investment and operation issues of a multi-site oilfield under uncertainty in the size and quality of reserves by elaborating a general model. To reduce the complexity of the model, a relaxation approach is used, to identify upper bounds. To predict lower bounds, multistage stochastic programs for a fixed scenario tree are solved. Later a branch and bound algorithm suggested where lower bounds are generated by Lagrangean duality (Goel, Grossmann, El-Bakry, & Mulkay, 2006). This model considered the nonlinearity of reservoir as well as the uncertainty. For more extensions, Tarhan et al. (2009) more detail (e.g. the type, number, and construction of infrastructure) are added into the problem. Their model aimed at the planning of offshore oilfield development including internal uncertainty in the initial maximum oil flow rate, recoverable oil volume, and water breakthrough time of the reservoir. In their proposed model the resolution of these uncertainties are affected by previous decisions. The paramount importance of their work was that the resolution of uncertainty, rather than to be resolved immediately, was gradual over time.

Recently a fairly generic model elaborated by Gupta and Grossmann (2012). They presented a strategic/tactical model to develop offshore oilfields. The model involved decisions pertaining to production rates in each time, well drilling, period FPSO (floating production, storage and offloading) installation and expansions, and connections. Possibility of the existing crude oil wells, well platforms and production platforms is an important parameter to translate the realistic oilfield development problems into mathematical models, which is mentioned only in few papers. Sahebi & Nickel (2013) to have a rational model define some binary variables in their work, to study the available facilities as well as possible facilities, at the same time. They also considered the availability of the drilling rig, which is very critical in the oilfield development problems, as a constraint.

Table 2.4: Crude oil supply chain design and planning.

Ref.	Oilfield Develop.	Crude Oil Transport.	Transform. Plan.	Primary Transport.	Secondary Transport.	Multisite COSC Plan.
[1]	✓					
[2]	✓	pipeline				
[3]	✓	pipeline				
[4]				✓	✓	
[5]	✓	pipeline				
[6]	✓					
[7]	✓	pipeline				
[8]	✓	pipeline				
[9]		✓	✓	✓		✓
[10]		✓	✓	✓		✓
[11]	✓					
[12]	✓					
[13]		✓		✓		
[14]	✓					
[15]	✓					
[16]	✓	pipeline				
[17]			✓			
[18]		✓	✓	✓		✓
[19]			✓	✓		
[20]			✓		✓	
[21]	✓	pipeline				
[22]	✓	pipeline				
[23]	✓	pipeline				
[24]	✓	pipeline				
[25]		✓	✓	✓	✓	✓
[26]			✓	✓		
[27]			✓	✓		
[28]			✓			
[29]			✓			
[30]			✓	✓	✓	
[31]		✓	✓	✓	✓	✓
[32]		✓	✓	✓	✓	✓
[33]			✓	✓	✓	
[34]		✓	✓	✓		✓
[35]			✓			
[36]		✓	✓	✓	✓	✓
[37]		✓	✓	✓	✓	✓
[38]		✓	✓			
[39]	✓	pipeline				
[40]			✓	✓		
[41]		✓	✓	✓	✓	✓
[42]		✓		✓	✓	
[43]		✓	✓	✓	✓	✓
[44]			✓	✓		
[45]		✓	✓	✓	✓	✓
[46]			✓			
[47]			✓	✓	✓	
[48]				✓	✓	
[49]		✓	✓	✓	✓	✓
[50]		✓	✓	✓	✓	✓
[51]	✓	pipeline				
[52]		✓		✓		
[53]	✓	✓				
Total	19# / 35.8%	31# / 58.5%	29# / 54.7%	27# / 51%	17# / 32.1%	14# / 26.4%
	13#	15#		23#		

2.5.3.2 Crude Oil Transportation

Strategic crude oil logistics is of great importance within the crude oil supply chain. Crude oil logistics network initiates at wellheads and terminates at the final delivery point to the customers (i.e. refinery, international market). The shipping crude oil from the oilfield to the refinery, entitled 'crude oil transport', is the first element of crude oil logistics network. The crude oil usually is transported through pipeline and carried via marine transports (i.e. oil tanker, vessel, and barge).

As shown in Table 2.4 crude oil transportation is an intriguing issue in the crude oil industry. The crude oil transportation has been modeled in the 29 papers of all. Three subgroups of these works can be distinguished: crude oil transportation is coupled with oil field development, coupled with transformation planning, and none of them (focused only on the worldwide crude oil transportation).

From this group, 13 of the surveyed papers take into account oil field development and crude oil transportation. All of them, with one exception of (Sahebi & Nickel, 2013), only considered pipeline connections in their study. Merely three of these papers considered the possibility of capacity selection for pipeline network (Aboudi et al., 1989; Jørnsten, 1992; Nygreen et al., 1998). Sahebi and Nickel (2013) deal with the capacity selection of pipeline network, as well as, planning of the crude oil tankers. This model makes decision to buy or rent which kind of oil tankers, and when.

The second group is made up of 15 papers (see Table 2.4). They attempted to take into account crude oil transportation costs as well as transportation modes. Transportation mode selection was not captured in the three references (Al-Othman, Lababidi, Alatiqi, & Al-Shayji, 2008; Kuo & Chang, 2008 a, b). In addition, it is observable that all but one of the 15 papers take crude oil transportation and transformation into account and the distribution planning as well (Rocha, Grossmann, & Poggi de Aragão, 2009).

Escudero et al. (1999) formulated an LP model that concerned with the Supply, Transformation and Distribution (STD) of an oil company. The STD network consists of several logistics node i.e. origin tank storages, transforming sites, transshipment nodes, and destination depots. It also comprises suitable arcs to illustrate capacitated transportation means between nodes' pairs. They defined two main subsets of transportation means; discrete and continuous flow product transportation means. Another novelty of their model was accounting for transportation time among depots by using different transportation mean. Unlike the model of Escudero et al. (1999), Dempster et al. (2000) formulated a same problem which did not allow the supply of end-products or the spot sale of crude oil products, i.e. pure trading is eliminated. Neiro and Pinto (2004) developed an integrated model for the refinery supply chain. Although this model considered refinery planning and supply chain management for multiple sites, the refineries are connected only by a simple linear model of pipeline network with no account of other transportation means and distribution. Ghatee and Hashemi (2009) extended the model proposed of Neiro and Pinto (2004) by considering uncertainty in the pipelines capacity as a consequence of expert's viewpoint and granular information. To sort fuzzy granular information, they based their attempts on special ranks. More extension of the model by Neiro and Pinto (2004), was elaborated in the work of Guyonnet et al. (2009). They added the scheduling of the crude oil transportation as well as distribution of final products.

Various transportation methods in order to import the raw materials and intermediates (by tankers) were studied by Kuo and Chang (2008a, b). Transportation capacities were included in their model, but no transportation time. Ribas et al. (2010) considered different transportation modes as well as the opportunity of investment at the transport arcs to expand the transportation capacity. To the best of our knowledge, the most advanced model of crude oil transportation is the model of Rocha et al. (2009). They incorporated transportation modes, corresponding capacity, 3PL, class of ships, and (un/off) loading capacity into the model, although the transportation time was neglected.

Two references studied a pure crude oil transportation model (Chen, Lu, & Qi, 2010; Iakovou, 2001). Iakovou (2001) addressed the strategic maritime transportation of petroleum products and crude oil. The model supported a decision-maker who requires satisfying the given supply/demand of several ports by shipping crude oil and petroleum products to and from ports. The decision has made in such way to have the minimal level of transportation costs and expected risk costs (due to oil spills).

Chen et al. (2010) configured the transportation network of import crude oil. As a first step, they carried out a detailed investigation into the source nodes, stream, transportation arcs and oil terminal ports of import crude oil. A mathematical programming model, thereafter, is proposed to minimize logistics costs.

2.5.3.3 *Transformation Planning*

The oil transformation process is certainly one of the most complex chemical ones. This process consists of particular procedures coming with several possible designs and characteristics. Transformation mainly is done in the refinery and petrochemical. The main objective in a refinery (petrochemical) is to transform crude oil (refined products) into intermediate and final refined products of higher value. A specific series of procedure units, crude oil storage tanks, and final and intermediary products storage tanks are in operation within a refinery while pipelines interconnecting them to each other. Bengtsson and Nonås (2010) reviewed the recent literature on the refinery planning and scheduling. They treated three different categories of activities; crude oil unloading and blending, transformation, and product blending and recipe optimization. As mentioned before, we focus on the strategic and tactical models. As a result, the scheduling of crude oil blending, unloading, process scheduling, product blending and recipe optimization stand out of our review. The transformation planning generally identifies which raw material (i.e. crude oil and intermediate products) to procure and which products to produce. More specifically, the aim of the transformation planning is to make decisions on which run-mode to operate in each procedure unit, to meet the customers' demand, with a minimum level of inventory and production expense. In the transformation planning level the forecast of future demand and prices are of the essence.

As summarized in Table 2.4, 29 papers of reviewed references are motivated to tackle the transformation (production) planning problems. One of the first contributions to address the transformation planning in the context of a downstream oil supply chain was that of Escudero et al. (1999). They took account of uncertainty in spot selling price, spot supply cost, and product demand through a linear programming (LP) model. Dempster et al. (2000) formulated a stochastic programming to plan a consortium of oil companies. To supply, produce, and distribute the crude oil products, first, a deterministic LP model is developed by the authors. Like Escudero et al. (1999), the deterministic model then was used as a foundation to apply a stochastic approach including uncertain demand, and uncertain spot supply cost. Li et al. (2004) suggested an model to plan refineries with uncertainty in the demand and the raw material. The expected revenue is calculated from a proposed "loss function".

In literature, various extents of nonlinearity in the blending and processing operations are elaborated. Neiro and Pinto (2004) proposed a large-scale model in which several refineries are connected by considering nonlinearity for refinery units and product blending. According to yield vectors, Elkamel et al. (2008) formulated the nonlinear rigorous unit models. Kim et al. (Kim et al., 2008) coupled with the nonlinear property relations in the blending units. Al-Qahtani et al. (2008) considered uncertainty (i.e. product prices, raw material cost, process yield, and lower product market demand) as well as risk of variations in both projected benefits and forecasted demand. Hence the model dealt with nonlinearity coming from formulation of the risk components.

2.5.3.4 Distribution

The refineries are origins of refined products to transport along the logistics chain. Products are transported along the first stage of the chain by using 'primary transport'. Sear (1993) expressed that "this term is used to cover the bulk carriage of products to depots where 'break bulk' occurs before final transport to customers". Primary transportation means comprise pipeline, marine transportation, and railcar. The final leg of the chain entitled 'secondary transport'. The secondary transportation network starts at the distribution center crosses into retailers or customers (e.g. airports, gas stations, or other types of retailers). Secondary transport is typically road vehicle, but in some cases includes other modes such as railcar. In this work, we label the primary transportation, storage at depots and distribution centers, and secondary transportation as a 'distribution' problem.

The distribution works can also fall into two groups; pure distribution problems, and production-distribution problems. The former models deal with only distribution facilities (i.e. distribution center, depots, and oil storage) and transportation facilities (crude oil terminal, ports, transportation modes, etc.) with no accounting of the upstream and midstream entities (i.e. platforms, refineries, etc.). The later ones refer to those that tackle production planning (oil field production and/or midstream transformation) and distribution planning in a single model.

All but four of the references are fold into the second group (Chen et al., 2010; Iakovou, 2001; MirHassani & Noori, 2011; Sear, 1993). The works of Chen et al., (2010) and Iakovou (2001) are described previously. Sear (1993), probably, was the first who proposed the logistics of crude oil industry. He addressed an LP model to manage the downstream oil logistics. The work dealt with crude oil purchasing and transportation, transformation of crude oil and transportation, and depot operation. The work did not consider the cost of transformation at the refinery, only considered the refinery as a node in the network. Hence, the model dealt with a pure distribution, no accounting of production planning at the refinery. MirHassani and Noori (2011) involved the capacity expansion for a distribution network of crude oil products under an uncertain environment. They assumed the future demand as facing uncertain parameters. Oliveria et al. (2012) present an investment planning model to consider the capacity expansion for the transportation links and storage tanks, under demand uncertainty. Their general model deals neither with oilfield development problems, nor with the transformation planning ones.

Pondering over the production-distribution works, two subgroups come into sight; distribution planning coupled only with transformation planning, coupled with crude oil supply and transformation planning. In literature, the latter group is called multisite supply chain design which is studied in the following.

2.5.3.5 *Multisite Crude Oil Supply Chain Planning*

A typical crude oil supply chain is made up of a set of crude oil suppliers and a set of refineries with interconnections of final / intermediate product flows, and a set of depots and distribution centers. A multisite COSC model deals simultaneously with crude oil supply, transformation, and distribution. This kind of problems has received a lot of attention in the literature. Shah et al. (2010) review oil-refinery supply chain literature and conclude that the multisite supply and distribution problems are essential parts of a COSC design and planning. They introduce that studying the details of processes at multi various sites and interconnecting between the sites and the proper logistics are the main challenges on dealing with these problems.

One of the earliest attempts to take this kind of problem into account, was of Escudero et al. (1999). As described before, they developed an LP model that concerned with the Supply, Transformation and Distribution (STD) of an oil company. The result of their model determined the optimal material flows through the network. Dempster et al. (2000) formulated a same problem which a few differences. Neiro and Pinto (2004, 2005) developed an integrated model for a crude oil supply. In this work, the network system is made of a set of crude oil suppliers, a set of refineries, and a set of distribution centers. Intermediate and final product flows, through pipelines, interconnect refineries and crude oil suppliers. The other distribution through pipelines defined from refineries to intermediate depots, terminals or directly to distribution centers. Al-Othman et al. (2008) extended the model of Neiro and Pinto (2004, 2005). The novelties were integrating petrochemical into the network, considering penalties on lost demand and backlog in the objective function, and dealing with uncertainty features. Kuo and Chang (2008a, b) considered maritime transportation (importing of crude oil and intermediates), petrochemical (refinery) planning, and distribution of the products to domestic customers (via pipelines or by trucks). Alabi and Castro (2009) planed a refinery supply chain characterized with a complete horizontal integrated supply chain from crude oil supply to crude oil distribution. Indeed they integrated and adapted the three models were taken from the other works; crude oil-supply model, refining process model, and product distribution model. To reduce the computational burden of the overall problem, the Dantzig-Wolfe methods and block coordinate-descent decomposition were employed. Recently, Tong et al. (2011) addressed a multisite planning model. In their paper, the crude oil supply consisted of crude oil suppliers, a jetty tank area to unload crude oil, a crude oil tank before production, a refinery with its input and output interfaces, final product tanks, distribution centers, and customers. The total expense of crude oil procurement, transportation, and penalties for customer dissatisfaction and inventory violation formed the objective function, in this work. The production volume and run time length (i.e. ‘production profile’) considered being determined.

As before discussed, the crude oil supply chain consists of numerous functions such as exploration, oil production (i.e. primary recovery, enhanced recovery, and abandonment), crude oil transportation, oil transformation, and distribution of crude oil and refined products. As summarized in Table 2.4, all of the models take no account of exploration, enhanced recovery, and abandonment. And different activities commonly are tackled in separated models. The most comprehensive works are belonging to the multisite crude oil planning category, which does not consider the oil field development although. This matter, vertical and horizontal integration, is of paramount importance and should be stressed more, in the future works. Along this direction, we opt the joint venture as a well-established collaboration contract in the oil industry context to fill this gap (see Chapter 3). In addition, we also integrate the oilfield development problem with the crude oil transportation problem to have an integrated upstream crude oil supply chain model. This mathematical programming model will be elaborated in Chapter 4.

2.6 MODELING APPROACH

In general, modeling approach is identified by the type of the inputs, statements, and objectives. The objective of supply chain models is studied in the next section and called purpose. Beamon (1998) introduced a classification in terms of inputs. His four classes are: (1) deterministic analytical models, where all variables are specified and known, (2) stochastic analytical models, in which at least one of the variables is uncertain and unknown, (3) economic models, he reviewed two game theory problems, and (4) simulation models. This reviewed placed on the mathematical models which may be deterministic or stochastic analytical ones. As a result, works those implied economic models (no work) or simulation models (i.e. Karimi and co-workers (Julka et al., 2002a; Julka et al., 2002b; Koo et al., 2008; Pitty et al., 2008; Srinivasan et al., 2006), and Sinha et al. (2009)) were stood out.

Table 2.5: Modeling approach codes.

Modeling approach	Detail	Code
Linear programming	Linear programming	LP
	Mixed integer/Integer linear programming	MLP
Non linear programming	Non linear programming	NLP
	Mixed integer/Integer nonlinear programming	MNLP
Multi/Single	Single-Objective Function	SOF
Objective Function	Multi-Objective Function	MOF
Deterministic or	Deterministic Programming	DP
Uncertain variables	Stochastic Programming	SP
	Fuzzy Mathematical Programming	FMP

Mula et al. (2010) prescribed another classification. Their broad categories are: (Non) Linear Programming, Multi-objective (Non) Linear Programming, Fuzzy Mathematical Programming, Stochastic Programming, (Meta) Heuristics algorithms, and Hybrid models. Their work has several vague points, (1) heuristics and meta-heuristics should be considered as solution techniques rather than modeling approach, (2) the multi objective function can be employed by the fuzzy and stochastic programming, and (3) certainty and uncertainty of parameters were not shown (we study the uncertainty issues in Section 4.8). Considering all, we adapted their way and used the following criteria to classify the models:

(i) Linear programming vs. Non-Linear programming;

(ii) Continues variables vs. Integer and Mixed Integer variables;

(iii) Single vs. Multi Objective Function; and

(iv) Deterministic vs. Uncertain.

Table 2.5 provides a summary of the various types of modeling approach to classify the reviewed papers. The nature of objective functions is also studied in Section 2.7. Additionally, heuristics and Meta heuristics algorithms are addressed in the solution methods section.

Aslam and Ng (2010) presented a literature review of multi objective optimization for supply chain management. Their review showed that almost 70% of the publications used mathematical programming approaches, particularly mixed integer programming and mixed-integer nonlinear programming to model and optimize supply chains. This fact is also observed by Mula et al. (2010) and Melo et al.(Melo et al., 2009). They found that among the reviewed papers, the linear programming-based modeling approach is in the majority. In these papers, the authors opted mixed integer linear programming models in particular. Conversely, nonlinear programming is only used in two references among 44 papers of Mula et al. (2010). This matter is also evidenced by our review. Almost 77.4% of the references implied the linear programming. From this group, mixed integer programming model are on the top in terms of majority (see Table 2.6). It is clear that a mixed integer program is of the essence to model investment, facility location, facility relocation, and/or facility allocation problems. As a result, all but six of reviewed model dealt with mixed integer programming (Dempster et al., 2000; Escudero et al., 1999; Iakovou, 2001; Jian-ling, Jun-ling, & Yun-shu, 2010; Ribas, Leiras, & Hamacher, 2011; Sear, 1993). All LP models focused only on the tactical level to optimize the crude oil transportation, production profile of a refinery, and/or distribution problems. The nonlinearity is a key feature of the COSC problems that has to receive much attention. The nonlinearity in the COSC models arises from formulating of:

(i) Oil reservoir performance equation (i.e. (Goel et al., 2006; Gupta & Grossmann, 2012; Tarhan et al., 2009; van den Heever & Grossmann, 2000; van den Heever et al., 2000, 2001));
(ii) Refining operations and blending (i.e. (Elkamel et al., 2008; Kim et al., 2008; Neiro & Pinto, 2004, 2005));
(iii) The risk components (Al-Qahtani et al., 2008) and the Standard Loss Function (Li et al., 2004).

Table 2.6 shows a growing trend to capture uncertain features in the analytical models. Almost 47.2% of the reviewed models took uncertainty into account. This fact showed that it is imperative to model the future problems on the stochastic analytical model. In the crude oil supply chain literature, two-stage stochastic programming models with recourse, to a large extent, are employed by researchers. The only multi objective function model is of (Iakovou, 2001), in which the objective functions are minimization of the transportation cost also the expected risk cost (due to oil spills).

2.7 PURPOSE

The purpose of a supply chain model can be qualitative or quantitative performance measures. Bearmon (1998) proposed that although some aspects of qualitative purposes may be quantified, there is no single direct numerical approach to measure them. He also presented supplier performance, effective risk management (ERM), flexibility, and customer satisfaction as qualitative ones. And quantitative performances are pertained to costs, customer service and inventories. In terms of costs, cost minimization (CM), revenues maximization, profit maximization (PM), and return on investment maximization are studied. In terms of customer services, the maximization of flows, the flexibility in volume or delivery, the minimization of backorders dates or the maximization of the service level are taken into account. In the literature, the maximization of safety inventories is also sometimes considered (see (Beamon, 1998; Mula et al., 2010) for a deeper discussion about each purpose).

Bearmon (1998) and Mula et al. (2010) reviewed the literature of supply chain mathematical models and observed that the cost minimization is the main purpose whereas the maximization of revenues or sales, to a lesser extent, is observed. Conversely, in the oil industry profit maximization (or net present value) is the main ones and cost minimization is captured to a lesser extent (see Table 2.6). The qualitative factors are studied to a lesser extent, however quantitative ones are the main purposes opted to consider.

As a result, the traditional designs of crude oil supply chain commonly are based on economic purposes. However, during the last two decades, as environmental regulations become stricter, environmental objectives are becoming of high importance (e.g. (Al-Sharrah, Elkamel, & Almanssoor, 2010; Guillén-Gosálbez & Grossmann, 2010; Pinto-Varela, Barbosa-Póvoa, & Novais, 2011)). Within the crude oil supply chain, economic and environmental performances must be taken into account simultaneously. The objectives of mathematical programming models for supply chain, recently, have extended even further to involve supply chain security, risk, and sustainability dimensions (Speier, Whipple, Closs, & Voss, 2011). These extensions are also very applicable and essential within oil industry context, hence, should be dealt with in future works.

Two of the proposed mathematical models in this thesis include more than one performance measure. In the joint venture model, we take a number of purposes into account (for more detail, see Chapter 3). Additionally, the environmentally conscious model also takes account of environmental performance and economic performance indicators through a single model (see Chapter 5).

2.8 SOLUTION TECHNIQUE

A vast variety of solution techniques have been employed to SCM models. Goetschalckx (2011) prescribed some of the more prevalent ones applied in the supply chain models, as following:

- ***Exact Mathematical Optimization.*** The exact optimization techniques sometimes are used. Since the supply chain programming models generally are integer, non-linear, stochastic, and large-scale problems, the computational burden of the exact optimization for realistic-size problem instances are dramatically significant.
- ***Hierarchical Decomposition.*** To reduce the computational complexity of the problem, a reduction approach should be defined. A suitable reduction approach for the supply chain problems is the hierarchical decomposition, which is applied to transform the original problem into separate different levels of decision making. Mathematical decomposition techniques divided into two broad classes: primal decomposition (e.g. *Benders decomposition*) or dual decomposition (e.g. *Lagrangean relaxation* and decomposition).
- ***Stochastic Simulation.*** In high fidelity models for example in operational supply chain models, simulation is most often used and is less applied to aggregate strategic models.
- ***Ad hoc Heuristics.*** A large number of heuristics or local search techniques are employed to solve mathematical programming model of supply chain problems. Some of most often used ad hoc Heuristics techniques are Neural Networks, Genetic, Ant Colony Algorithms, Particle Swarm Optimization, and Simulated Annealing.

Table 2.6: The modeling approaches and purposes of the reviewed papers.

Ref.	Linear		Non linear		Objective		Analytical Model			Purpose			
	LP	MLP	NLP	MNLP	SOF	MO	DP	SP	FM	CM	PM	ER	Other
[1]		✓			✓		✓				✓		
[2]		✓			✓		✓				✓		
[3]		✓			✓			✓			✓		
[4]	✓				✓		✓				✓		
[5]		✓			✓			✓			✓		
[6]		✓			✓		✓				✓		
[7]		✓			✓			✓			✓		
[8]		✓			✓		✓				✓		✓
[9]	✓				✓			✓		✓			✓
[10]	✓				✓			✓		✓			
[11]				✓	✓		✓				✓		
[12]				✓	✓		✓				✓		
[13]	✓					✓	✓			✓		✓	
[14]				✓	✓		✓				✓		
[15]		✓			✓			✓			✓	✓	
[16]		✓			✓			✓			✓		
[17]		✓		✓	✓			✓					✓
[18]				✓	✓		✓				✓		
[19]				✓	✓			✓			✓		
[20]		✓			✓		✓			✓			
[21]		✓			✓		✓				✓		
[22]		✓			✓		✓				✓		
[23]		✓		✓	✓			✓			✓		
[24]		✓			✓		✓				✓		
[25]		✓			✓			✓			✓		
[26]		✓			✓		✓			✓			
[27]				✓	✓			✓		✓			
[28]				✓	✓		✓				✓		
[29]		✓			✓			✓			✓		
[30]				✓	✓		✓				✓		
[31]		✓			✓		✓				✓		
[32]		✓			✓		✓				✓		
[33]		✓			✓			✓		✓			
[34]		✓			✓		✓					✓	
[35]		✓			✓		✓			✓			
[36]		✓			✓				✓	✓			
[37]		✓			✓		✓						
[38]		✓			✓		✓			✓			
[39]				✓	✓			✓			✓		
[40]		✓			✓			✓		✓			
[41]		✓			✓			✓			✓	✓	
[42]		✓			✓		✓			✓			
[43]	✓				✓		✓			✓			
[44]		✓			✓			✓		✓			
[45]		✓			✓			✓			✓	✓	
[46]					✓			✓			✓		
[47]		✓			✓		✓				✓		
[48]		✓			✓			✓		✓			
[49]	✓				✓			✓			✓		
[50]		✓			✓			✓		✓		✓	
[51]		✓		✓	✓		✓				✓		
[52]		✓			✓			✓		✓			
[53]		✓			✓		✓				✓		
Total #	6	37	0	12	52	1	28	24	1	17	33	6	3
Total %	11.3	69.8	0	22.6	98.1	1.9	52.8	45.3	1.9	32.1	62.3	11.3	5.7

- ***Constraint Programming.*** Constraint programming successfully is applied to operational supply chain models. Although this techniques has been used rarely for strategic models.

Melo et al. (2009) suggested a more general classification of solution methods, in supply chain management. Their work is more suitable to gain our goals. According their study, the solutions techniques can be fallen into four categories;

- ***General solver, exact solution:*** Mathematical programming software is used to approach either the optimal solution of mathematical model or until a solution within a pre-determined gap. This gap is specified reflecting of the "worst" quality accepted by the decision-maker (58.3% of reviewed papers).

- ***General solver, heuristic solution:*** represent the run of an off-the-shelf solver until a given time limit is reached (6.3% of reviewed papers).

- ***Specific algorithm, exact solution:*** refers to the special-purpose techniques such as decomposition methods, column generation, branch-and-cut, and branch-and-bound. Among these techniques, decomposition algorithms have been a popular solution technique (20.8% of reviewed papers).

- ***Specific algorithm, heuristic solution:*** special-purpose approaches based heuristics and metaheuristics (i.e. Lagrangian relaxation, and etc.) to solve realistically sized problem with complex severity (14.6% of reviewed papers).

2.9 SHARED INFORMATION

The significant benefit of information sharing has been reported, remarkably to moderate the bullwhip effect (Huang, Lau, & Mak, 2003). Information sharing, in a supply chain, introduced as the extent of shared information through the supply network. According to Huang et al. (2003) shared information may fall into six various broad groups: product, process, recourses, inventory, orders and planning. We modified their classification for the crude oil supply chain models. Tables 2.7- 2.9 summarize the different scheme of shared information acquired in the papers reviewed. It is worth pointing to the shared information related to transportation costs (crude oil and final products of refinery) and refining costs.

Table 2.7: The shared process information of the reviewed papers.

Ref.	Shared process information																	
	Exploratio		Drilling		Recovery		Separation		Oil Transportation			Refining		Transportaion			Replenish-ment cost
	time	Cost	time	cost	type	cost	time	cost	time	cost	Mode	inter-action	cost	time	cost	Mode	
[1]			✓	✓													
[2]			✓	✓	Pri	✓		✓		✓	✓						
[3]				✓	Pri	✓					✓						
[4]														✓	✓	✓	✓
[5]				✓	Pri	✓				✓							
[6]			✓	✓													
[7]				✓	Pri	✓		✓		✓							
[8]				✓	Pri	✓		✓		✓	✓						
[9]									✓	✓	✓		✓	✓	✓	✓	
[10]										✓	✓		✓		✓	✓	
[11]				✓	Pri	✓		✓									
[12]					Pri	✓		✓									
[13]										✓	✓				✓	✓	
[14]				✓	Pri	✓		✓									
[15]			✓	✓	Pri	✓		✓									
[16]				✓	Pri	✓		✓		✓							
[17]													✓				
[18]								✓		✓	✓	✓	✓		✓	✓	
[19]													✓		✓		
[20]												✓	✓	✓	✓	✓	✓
[21]				✓	Pri	✓				✓							
[22]				✓	Pri	✓				✓							
[23]				✓	Pri	✓		✓		✓							
[24]					Pri	✓				✓							
[25]								✓		✓			✓		✓		
[26]												✓	✓		✓		
[27]															✓		
[28]													✓				
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[30]													✓		✓	✓	
[31]										✓			✓		✓		
[32]										✓			✓		✓		
[33]													✓		✓	✓	
[34]										✓	✓		✓		✓		✓
[35]												✓	✓		✓		
[36]										✓	✓				✓	✓	
[37]										✓	✓		✓		✓	✓	
[38]										✓	✓						
[39]				✓	Pri	✓		✓		✓							
[40]												✓	✓		✓		
[41]										✓	✓	✓	✓		✓	✓	
[42]										✓	✓				✓	✓	
[43]										✓	✓		✓		✓	✓	
[44]												✓	✓		✓		
[45]										✓	✓	✓	✓		✓		
[46]												✓	✓				
[47]													✓		✓	✓	
[48]															✓	✓	
[49]										✓	✓	✓	✓		✓	✓	
[50]										✓	✓				✓	✓	
[51]				✓	Pri	✓		✓		✓							
[52]										✓	✓				✓	✓	
[53]			✓	✓	Pri	✓		✓		✓	✓						
Total #	0	0	5	17	17	17	0	14	1	30	19	10	25	3	29	18	3
%			9.4	32.1	32.1	32.1		26.4	1.9	56.6	35.8	18.9	47.2	5.7	54.7	34	5.7

Chima (2007) investigated the role of supply chain management in the oil and gas industry. He emphasized that crude oil production, exploration and acquisition functions are strongly intertwined, yet traditionally; they mostly are managed and studied as independent functions. This matter is observed at Table 2.7 in which no reviewed papers center on exploration at all. The next important issues can be drown form the study are that the processing time (i.e. drilling time, separation time, and transportation time) are pointed rarely.

In fact, it is becoming more challenging to discover new crude oil reservoirs and the existing crude oil reservoirs are going to deplete. Consequently, oil companies are being under pressure to consider an integrated crude oil supply chain by taking account of primary, secondary, and tertiary recovery. Table 2.7 shows that there exists no attempt to do this integration across the crude oil supply chain. All of the reviewed papers dealt only with the primary recovery mechanism, and some of them studied the possibility of injection wells but no secondary or tertiary mechanism. It is a significant gap in this context which should be bridged by further research.

Table 2.8 shows the significant importance of the crude oil price in the programming of the crude oil supply chain models. All reviewed papers, with only eight exceptions, regard this parameter as a product shared information. Shared parameters related to refinery products, emerges to a lesser extent. Meanwhile, only seven papers capture shared information related to petrochemical products. As regards shared information in terms of inventories, inventory level and cost stand out and, to a lesser extent, information about backorder cost and service level. The backorder issues should take into account much more, since the postponement decisions (i.e. the possibility of not filling customer demands on time) are strategic decisions and enhance the flexibility of supply chain model. The planning demand is shared by a vast majority of the reviewed paper, as opposed to shared information in terms of order features. Table 2.9 tells us that the production and transportation capacity are noticeable in terms of resource availability. At the other extent, drilling capacity information is shared by a few works. The availability of drilling rig is a challenging issue for all drilling companies although. As a result, more research is needed more research on the drilling rig availability and planning of it. This necessity motivate us to consider this constraint in the integrated upstream crude oil supply chain model (see Section 4.3.4)

Table 2.8: The shared product, inventory, order, and planning demand information of the reviewed papers.

Ref.	Product						Inventory				Order		Planning
	Crude oil		Refinery		Petrochemica		Inventory		Backorde	Sevice	Flexibilit	Limit	Demand
	price	type	price	type	price	type	level	cost	cost	level		Date	
[1]	✓	✓	✓										✓
[2]	✓												✓
[3]	✓	✓											✓
[4]			✓	✓			✓	✓					✓
[5]	✓												✓
[6]	✓												✓
[7]	✓												
[8]	✓												✓
[9]	✓	✓	✓	✓			✓	✓	✓				✓
[10]	✓	✓	✓	✓			✓	✓					✓
[11]	✓												✓
[12]	✓												✓
[13]		✓		✓									✓
[14]	✓												
[15]	✓												✓
[16]	✓												
[17]	✓		✓	✓			✓	✓		✓			✓
[18]	✓	✓	✓	✓			✓	✓					✓
[19]	✓	✓	✓	✓			✓	✓					✓
[20]				✓			✓	✓	✓				✓
[21]	✓												
[22]	✓												
[23]	✓												
[24]	✓	✓								✓			✓
[25]	✓	✓	✓	✓	✓	✓	✓	✓	✓				✓
[26]	✓	✓	✓	✓						✓			✓
[27]	✓	✓			✓	✓				✓			✓
[28]	✓	✓	✓	✓									✓
[29]	✓		✓	✓			✓	✓	✓	✓			✓
[30]	✓	✓	✓	✓				✓					✓
[31]	✓	✓	✓	✓	✓	✓	✓	✓	✓				✓
[32]	✓	✓	✓	✓	✓	✓	✓	✓					✓
[33]				✓			✓	✓	✓				✓
[34]	✓	✓	✓	✓			✓	✓					✓
[35]	✓	✓	✓	✓	✓	✓				✓			✓
[36]		✓		✓			✓						✓
[37]	✓	✓	✓	✓			✓	✓	✓	✓			✓
[38]		✓					✓	✓	✓				✓
[39]	✓												
[40]	✓	✓	✓	✓									✓
[41]	✓	✓	✓	✓									✓
[42]		✓											✓
[43]	✓	✓	✓	✓	✓	✓	✓	✓	✓				✓
[44]	✓	✓	✓	✓						✓			✓
[45]	✓	✓	✓	✓	✓	✓							✓
[46]	✓	✓	✓	✓			✓			✓			✓
[47]	✓		✓	✓			✓	✓	✓	✓			✓
[48]				✓			✓						✓
[49]	✓	✓	✓	✓			✓	✓					✓
[50]	✓	✓	✓	✓			✓	✓	✓	✓			✓
[51]	✓												
[52]				✓			✓	✓		✓			✓
[53]	✓									✓			✓
Total #	44	30	26	31	7	7	23	21	11	13	0	0	45
Total %	83	56.6	49.1	58.5	13.2	13.2	43.4	39.6	20.8	24.5	0	0	84.3

Table 2.9: The shared resources information of the reviewed papers.

Ref.	Shared resources information							
	Drilling capacity	Recovery capacity	Separatio capacity	Transport capacity	Refinery capacity	Petrochemic capacity	Invntory capacity	Replenishment / Loading rate capacity
[1]		✓	✓					
[2]		✓	✓	✓				
[3]		✓		✓				
[4]				✓	✓		✓	✓
[5]		✓						
[6]	✓	✓	✓					
[7]		✓	✓					
[8]		✓	✓	✓				
[9]			✓	✓	✓		✓	
[10]			✓	✓	✓		✓	
[11]		✓	✓					
[12]		✓	✓					
[13]			✓	✓				
[14]		✓	✓					
[15]	✓	✓	✓					
[16]		✓	✓	✓				
[17]							✓	✓
[18]				✓	✓		✓	✓
[19]					✓		✓	✓
[20]				✓	✓		✓	✓
[21]		✓						
[22]		✓						
[23]		✓	✓	✓				
[24]		✓	✓	✓				
[25]			✓		✓	✓	✓	
[26]				✓	✓			✓
[27]						✓		✓
[28]					✓			✓
[29]					✓		✓	
[30]				✓	✓		✓	
[31]				✓	✓	✓	✓	
[32]				✓	✓	✓	✓	
[33]				✓	✓		✓	
[34]				✓	✓		✓	✓
[35]				✓	✓	✓		✓
[36]				✓			✓	✓
[37]				✓	✓		✓	✓
[38]			✓	✓	✓		✓	✓
[39]	✓	✓	✓					
[40]				✓	✓			
[41]				✓	✓	✓	✓	✓
[42]				✓			✓	
[43]				✓	✓	✓	✓	
[44]				✓	✓			✓
[45]				✓	✓	✓	✓	✓
[46]					✓		✓	
[47]				✓	✓		✓	
[48]				✓	✓		✓	✓
[49]				✓	✓			
[50]				✓	✓		✓	✓
[51]	✓	✓	✓					
[52]				✓			✓	
[53]	✓	✓	✓	✓				
Total #	5	19	20	34	28	8	26	18
Total %	9.4	35.8	37.7	64.2	52.8	15.1	49.1	34

2.10 UNCERTAINTY FEATURES

Generally, in the supply chain context, mathematical programming models fall into two classes: descriptive models and prescriptive ones (Shapiro, 2004). Descriptive models are constructed to forecast and compute the future quantity of variables, for example to determine future amount of the customer demands, the costs of manufacturing and distribution, the costs of raw materials, and the price of products. Prescriptive models are formulated to optimize the problems or determine a set of best feasible decisions for the supply chain managers. Note that almost all optimizations are constructed from the forecasted parameters that have somewhat of uncertainty. For this reason, the models in which all the parameters assumed to be deterministic are not realistic. This is becoming more unrealistic when the model is making decision at the strategic level of supply chain problems, since the strategic levels are dealing with a relative long-time horizon of, 5 to 15 years. In addition, decision makers commonly would not have perfect information to specify all parameters with known and certain quantities. This fact triggers a high uncertainty related to these decisions (e.g. demand, price, product yield, lead time, etc.). A less uncertainty is expected for shorter planning horizons, i.e. tactical and operational supply chain models.

To provide the robustness and consistency of a model, the model should take account of uncertain parameters. As said before, Schmidt and Wilhelm (2000) overviewed the strategic and tactical model of global supply chain problems. They addressed that, over such a long planning horizon, a high level of uncertainty associated with exchange rates, political environments, and demand. To provide a sound appreciation of uncertainty features and find the gap in this area, we scan the uncertainty of models and the improvement opportunities. Table 2.10 summarizes the uncertainty features those are considered in the reviewed papers. With regard to it, 23 of the reviewed papers are tackled at least one uncertain parameter. Among these uncertain factors, demand, crude oil price, and product price are more demanded. The recoverable amounts of reservoir and product yield in a refinery are proposed to a lesser extent.

In summary, the mathematical programming of crude oil supply chain problems under uncertainty relatively is a new research direction, and modeling approaches and solution techniques are still heaving into sight. In this direction, the most popular of modeling approaches is stochastic programming in which two-stage techniques are commonly employed to optimize the models. As future research directions, accurate specification of uncertainty and efficient solution techniques of the large-scale problems explicitly arise in this context.

2.11 ENVIRONMENTAL IMPACTS

In the past few decades, the stricter environmental regulations led to an increasing will among oil companies to deal with the environmental impacts of their functions. In consequent, great attempts have been made to incorporate the environmental concerns along with the traditional economic indicators of today's business world. One of the main strides, along this direction, is the Environmentally Conscious Supply Chain Management (ECSCM) concept (see e.g. (Guillén-Gosálbez & Grossmann, 2010)). The ECSCM concept represents the control and management of the all immediate and eventual environmental impacts of associated functions, entities, and materials to transform raw materials (e.g. crude oil) into final products (e.g. petroleum derived products) (Beamon, 2005). The ECSCM is an emerging area, and have posed new challenges for the crude oil supply chain practitioners and the oil industry. Despite this growing significant importance of the environmental conscious supply chain management, environmental impacts of crude oil supply chains have been studied by a few works within a narrow scope (see Table 2.10). The importance of this bridging will become more highlight, when note that there exist a large number of potential origins to emit pollutants in oil industry. For example, the crude oil tankers and utilities consumptions are the main origins of emissions through the crude oil supply chain. The energy required for operating upstream facilities in the crude oil supply chain represents enormous energy consumption. Whereas, ships and oil tankers are of the highest polluting combustion origins per unit of fuel used. As a result, environmentally conscious design of crude oil supply chain, especially of upstream segment, should be taken more attentions.

Table 2.10: The uncertainty features, environmental aspects, and global factors of the reviewed papers.

Ref.	Uncertain Features						Environmental Aspects			Global Factors
	Recoverable amount	Crude oil price	Product yield	Product price	Demand	Others	Property contraints		CO_2	
							Weight	Volume		
[1]										
[2]										
[3]		✓			✓					
[4]										
[5]	✓	✓			✓					
[6]										
[7]		✓								
[8]										
[9]		✓		✓	✓		✓	✓		
[10]		✓		✓	✓					
[11]										
[12]										✓
[13]										
[14]										✓
[15]	✓	✓								
[16]	✓					✓				
[17]		✓		✓	✓					
[18]							✓	✓		
[19]		✓		✓	✓		✓			
[20]										
[21]										
[22]										
[23]	✓					✓				
[24]									✓	
[25]		✓		✓	✓					
[26]							✓			
[27]		✓	✓	✓	✓					
[28]							✓		✓	
[29]		✓	✓	✓	✓					
[30]										
[31]										
[32]										
[33]					✓					
[34]							✓	✓		
[35]							✓			
[36]					✓					
[37]							✓	✓		
[38]										
[39]	✓									
[40]		✓		✓	✓		✓			
[41]		✓		✓	✓		✓	✓		
[42]										
[43]										✓
[44]		✓		✓	✓		✓			
[45]		✓	✓	✓	✓					
[46]			✓							
[47]										
[48]					✓					
[49]		✓		✓	✓		✓	✓		
[50]			✓		✓					
[51]										
[52]					✓					
[53]										
Total #	5	16	5	12	19	2	12	6	2	3
%	9.4	30.2	9.4	22.6	35.8	3.8	22.6	11.3	3.8	5.7

Various methodologies are used in the literature to avoid environmental damage as part of the supply chain design objectives. In the supply chain context, modeling practitioners considered the environment as a constraint on operations and merely as a design objective. To the best of our knowledge, there exist a few papers in the crude oil supply chain literature that take environmental aspects into account as an objective function. According to Table 2.10, all of the 13 papers that concerned with environmental effects treated the environmental issues as a constraint only on the refinery operations. These quality (property) constraints were imposed specially on the blending operations of refinery. The quality is indicated by the chemical structure. Some quality indicators represent the content of single elements while others show weighted summations of a number of components (Ulstein, Nygreen, and Sagli 2007). Within the capabilities of specifying quality constraint, we are able to manage the amount of Greenhouse Gas emissions, wastes, and other pollutants. Therefore, it makes sense to interpret the quality constraints as environmental conscious constraints. The only oil supply chain model which is taken environmental impact into account directly belongs to Elkamel et al. (2008). In this work, a mixed-integer non-linear programming model is proposed to plan refinery production by achieving optimal profit. Meanwhile, by using different CO_2 mitigation options, they attempt to decrease CO_2 emissions to a given target.

In nutshell, the stricter environmental regulations attracted a growing will of oil companies to take environmental thinking into account. As previously reviewed, the topic of environmentally conscious design, within the crude oil SCM context, has been ignored with a few exceptions. Almost all of these papers use quality constraints and focuses only on the refinery planning, with no care of the environmental impact of the crude oil transportation and of the oil field development. This drawback should be resolved by applying the environmentally conscious design to the crude oil supply chains. As a consequence, we elaborated a mathematical programming model for an upstream crude oil supply chain, in which both economic performance and environmental performance indicators are taken into account through a single model.

2.12 GLOBAL FACTORS

Over the few last decades, rapidly expansion of world-wide marketplace led to a wide dispersion of supply chain functions, e.g. procurement, production, assembly, transportation, and distribution functions (Schmidt & Wilhelm, 2000). This fact is more apparent in the oil industry context, which should deliver its product to the whole wide world. Under this global logistics of the crude oil industry and with the emergence of the globalization in today's economy, dealing with global crude oil supply chain is of the essence. We should distinguish between them to provide a realistic model of a real crude oil supply chain problem. A domestic model considers a single economic zone (i.e. a unified governance country or unified groups of countries such as the continental United States and the European Union). Whilst the global supply chain models study multiple economic zones and, thus, take account of international factors.

Previously, we overview some papers which review the literature on the global supply chain, in Section 2.1.2. In summary, they mention that much of the research have ignored the global factors such as the international taxation issues, the nonlinear effects of international taxation, the explicit inclusion of suppliers, the inclusion of inventory costs as part of the decision problem, the allocation of transportation cost among subsidiaries, the transfer price, and transportation mode selection (see e.g. Vidal and Goetschalckx (1997), Schmidt and Wilhelm (2000), Goetschalckx et al. (2002), Meixell and Gargeya (2005)). This conclusions are also observed in the crude oil context (see Table 2.10).

Despite the essence of this fact and its surrounding challenges, in the literature of crude oil supply chain an explicit difference between a domestic and international supply chain has not been seen. The study of various global factors associated with the crude oil supply chain models is still lacking in literature. This lack possibly is a consequence of the computational complexities of the resulting nonlinear large-scale mathematical programming models. With three exceptions (Jian-ling et al., 2010; van den Heever et al., 2000, 2001), all of the reviewed papers took no account of international factors in their models (see Table 2.10). In conclusion, although difficult globalization features are resolved in the literature of supply chain models; a few simple models are formulated in the crude oil supply chain context. This research direction demands further attentions in future researches.

2.13 SUMMARY

In today's business world, oil companies cannot be productive and competitive, and, thus, will not survive without taking the supply chain management concepts into account. Consequently, the management of the Crude Oil Supply Chain is increasingly receiving substantial prominence. The vast number of papers and books and their increasing growth are the witness of this fact. To foster insight into issues intertwined with the COSC problems; this chapter is devoted to an extensive review of the mathematical programming models in this context. The classification approach for this review is based on a taxonomy framework. In this framework, ongoing and emerging issues surrounding the strategic and tactical decisions of COSC problems are investigated. As a main goal, the gaps of literature are analyzed to recommend possible research directions.

In this chapter, we start with the studying of the previous review papers in this context. Afterwards, in Section 2.2, the review methodology is discussed. In the following section, the taxonomy framework is adapted for this thesis. Thereby, we describe the criteria which are used to classify this review. We classified the papers reviewed sequentially, in Section 2.4 -2.12. In the following, we point out the main of discussed possible research directions.

As illustrated in Section 2.5.2, dealing with outsourcing problems is considered in few papers. These collaboration contracts can develop the competitive advantages of oil companies. Another kind of collaboration contracts which is well-established for oil companies is joint venture agreement. Companies with diverse strengths and weaknesses cooperatively bid for joint venture formation, in order to overcome complexity, uncertainty, and risk of oil projects. To deal with these challenges, we formulate a mathematical programming model to optimize the joint venture formation problems, in Chapter 3.

As can been easily observed from the various tables throughout the review, some research directions still remain to be addressed such as (i) full vertical integration of decisions (i.e. studying all strategic and tactical decisions in a single model, specifically enhanced recovery and abandonment problems), (ii) capturing full horizontal integration of the crude oil supply chain (i.e. studying the complex structures), (iii) dealing with nonlinear models, which is of the essence to formulate refineries' operations. Along this direction, in Chapter 4, we formulate an integrated model that deals with strategic and tactical decisions, simultaneously. On other side, the proposed model consider a full horizontal integration of the upstream crude oil supply chain by taking wells, well platforms, production platforms, transportation means (i.e. pipelines and oil tankers), oil terminals and customer into account. Since the focus of this model is put on the upstream segment, considering linear equations is almost rational. Additionally, joint venture is also an appropriate contract in the oil industry context to structure an integrated network of different companies to collaborate with each other.

According to Section 2.7, the objectives of mathematical programming models for supply chain, lately, have extended even wider to involve supply chain security, risk, and environmentally dimensions (Speier et al., 2011). These developments are also applicable, and even are essential to be studied within the oil industry context. In consequence, two proposed models in this thesis deal with these challenges, which are presented in Chapters 3 and 5.

Considering the environmental thinking is a growing will of oil companies due to the stricter environmental regulations. As illustrated in Section 2.11, only a few papers have used quality constraints as environmental impact constraints in their models. These studies concentrated on the refinery planning, with no care of the environmental impact of the crude oil transportation and of the oil field development. To resolve this drawback, we formulated a mathematical programming model for an upstream crude oil supply chain, in which both economic performance and environmental performance indicators are taken into account, simultaneously.

Beyond the contributions of this thesis, some research directions still need further research. Capturing uncertain features and global features of the COSC problems are the other emerging areas in this context. The significant importance of global factors in optimization of the COSC problems, are undoubtable. Hence, the resultant complexity of the global factors, uncertain parameters, environmental impacts, and non-linear equations encourage the development of efficient algorithms that can solve these complex large-scale models as translations of the realistic real-sizes problems. Additionally, developing efficient solution techniques of multi objective function problems, as a result of considering environmental impacts, is also necessary. Another direction for the future research is to study uncertainty with multi-stage stochastic models, rather than two-stage problems which most often has been taken into account as only programming model of studying stochastic problems.

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Chapter Three

Joint Venture Formation and Partner Selection in the Upstream Crude Oil Supply Chain Context

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The dynamic nature of international business opportunities is rapidly growing. This growth made it challenging to "go alone" into the international business opportunities. Due to this increasing complexity, risk, magnitude, and uncertainty involved in major international projects, companies are attracted to cooperatively bid for, and to perform international projects. For this goal, organizations with diverse strengths and weaknesses cooperate in these projects by forming Joint Venture (JV). Joint venture can be introduced as a contractual arrangement by which two or more partners (individual or business party) agree to collaborate in an economic activity, and share control, risks, and profits under pre-agreed specifications. Joint venture is a unique approach to form partnerships among companies and organizations, for a finite time, without having to merge. Beyond these advantages of the JVs, in business environments (e.g. global crude oil business) where the fast approach to up-to-dated knowledge, advanced technology, and new markets are more critical than ever before, joint ventures have formed as a popular collaboration (Kumaraswamy, Palaneeswaran, & Humphreys, 2000). JVs have also long been popular for large capital projects to attract the investments. Joint ventures are not only used in manufacturing international projects, but also in R & D projects, in construction projects, and also in the crude oil industry's projects.

Joint ventures are a key characteristic of the oil and gas industry, remarkably in the upstream segment on the largest projects, in which the technology, risk and cost concerns evidently corroborate a collaborative approach, not "going alone". Additionally, International Oil Companies (IOCs) and National Oil Companies (NOCs) collaborate with independents for entry to attractive reserves. For example, in 2010, public and national companies invested a total of US$17 billion in energy projects - the majority of them under joint ventures scheme (EYGM, 2011). More specifically in the drilling sector, shortages of rigs and personnel have attracted players to creatively design incentive contracts. Hence, JV is an attractive complex approach on upstream oil segment that should be taken into account. Making decision on the optimal arrangement of JVs is a challenging issue because of the large variety of JV contract types. All JVs contracts consist of interesting combinations of expertise, labor capital, assets, and resources. The appropriate joint venture optimizes these combinations to form a dynamic capital investment in the oil industry. To figure this out, this chapter is provided in order to form an optimal joint venture to undertake oilfield projects (e.g. oilfield development, recovery enhancement, etc.).

The chapter is organized as follows. In Section 3.1, we give an extensive overview on the background of the JV. Thereby, we describe the joint venture formation motives, which are: the transaction cost motives, the strategic behavior motives, and an organizational knowledge and learning motives. We discuss each of these motives in brief. Then, all five stages of the joint venture formation decisions process are explained. As a consequence, we found the leading role of partner selection stage, in the joint venture context. Due to this significant importance, this stage will be discussed in more detail in the following subsection.

To provide a concise imagine of this problem, Section 3.2 describes the problem explicitly. This section will answer these questions: What is the problem? Who are the partners in this joint venture model? What is the scope? Thereby, the given parameters, the assuming limitations, the supposed variable decisions, and the aims of this mathematical programming are illustrated. This problem is formulated in Section 3.3. In order to examine the computational effectiveness of the model, an example is described in Section 3.4, and solved by CPLEX. The summary of this chapter is accessible in Section 3.5.

3.1 PROBLEM BACKGROUND

There are many recent research works on joint ventures; they span several disciplines and topics. Wong and Ellis (2002) point out that JV research can be broadly categorized into three areas: (i) antecedents (e.g. JV formation motives, and partner selection); (ii) outcomes (studies relating to failure and performance measurement); and (iii) joint venture management issues (e.g. control and conflict). In this part, our focus is placed on the relevant literature on the antecedents. We review the background of the JV formation motives, the JV formation decision process, and the partner selection phase of a JV formation process, in sequence. The idea is to highlight the relevant decisive factors for a multi-criteria goal programming model.

3.1.1 JV Formation Motives

According to some researchers, the emerging of joint ventures is as a result of the benefits and value added of using this kind of collaborations. There are a number of prospective value drivers which in some studies are also called “motivations to joint venture”. Kogut (1988) proposes three motivations to form joint ventures: the **transaction cost motives**, the **strategic behavior motives** and an **organizational knowledge and learning motives**.

The transaction cost motives stem from the theory of transaction cost. Transaction cost theory supposes that firms attempts to minimize the sum of production and transaction costs. The transaction costs are those which are induced as a consequent of the firms' transactions with other companies. This theory argues how firms should choose to transact according to minimize the above criterion (Kogut, 1988). The transaction cost perspective of joint venture motivates companies to form joint ventures to drive down total cost of their transactions with other firms. For example, by syndicating of capital and resources, increasing trust, sharing risk, and reducing uncertainty, a joint venture can reduce the **agency costs**, create value and provide further opportunities to cooperate or integrate (Kogut, 1988; Pape & Schmidt-Tank, 2004). Companies can achieve **economies of scale** and, thus, costs reduction by cooperating in joint ventures. To appreciate cost synergies in this collaboration context, the creation of a critical mass for large capital projects (e.g. drilling costs, oilfield development projects, and R&D costs) and the usage of complementary technologies and knowledge are other possibilities. In some cases, a joint venture can be formed to reduce transaction costs by taking over economic or political **barriers to entry into a market** (e.g. access requirements or tariffs)(Zhang, 2007).

The strategic behavior motives of JVs are derived from the strategic behavior theory. This theory points out that the competitive positioning of a firm is obviously influenced by its strategic behavior (Kogut, 1988). Strategic behavior theory argues that a company should contemplate the influence of its decisions on its competitive positioning and the impact of resultant positioning on profitability of the company, before making decision on how to transact with other companies. In other words, a company will follow the strategy which is able to provide the maximum profit potentials through ameliorating the company's competitive position (Blenman & Xu, 2008). To develop the **competitive position** in a market and, as a consequence, increase the profit possibilities, companies can form a joint venture. Pape and Schmidt-Tank (2004) discuss how a joint venture can improve the strategic positioning of its partners. According to their conclusions, teaming up with other partners of a JV, a company realizes **economies of scale** and, thus, reaches **superior bargaining power** to sell or purchase at markets. The next strategic goal of joint venture formation may be to **secure access to new markets**, as a result of overcoming economic or political barriers to entry into new market. Then, the joint venture partners can open up new revenue sources. Another way to gain greater **competitive advantages** is owing to the first accessing to a new market through a joint venture. For this purpose, a company may make barriers to entry for competitors or can improve its position, especially in difficult markets. Finally, a joint venture can facilitate **further cooperation**, since the first fences, which are the most challenging ones, are mended among the partners and they are now cooperatively integrated. Using existing integrated infrastructure can lead to a more rapidly introduction of potential profits and innovations.

Organizational knowledge and learning perspective, based on the organizational theory, views JVs as an effective way thereby companies learn or seek to retain their capabilities. The tacit knowledge and organizational knowledge can efficiently be transferred through this collaborations, JVs (Zhang, 2007). As a result, a joint venture is preferred to other forms of cooperation, in order to **acquire** and **share** new **capabilities**, **technologies**, **skills**, and **knowledge** through the partner companies. This allows them to execute current opportunities and generate future profit opportunities at lower production and transaction costs.

In summary, joint ventures create value for all joint partners when their collaboration generates benefits for all collaborative companies, after outweighing the disadvantages and the total cost of their foundation. As discussed, joint ventures principally generate value through three mechanisms: a reduction of transaction cost, an improvement of the strategic positioning, and learning advantages of this collaboration. Several authors have provided many additional reasons for the establishment of JVs from different points of view.

3.1.2 JV Formation Decision Process

The process of establishing a joint venture has not been commonly agreed upon. There exist a vast varieties point of view in the literature, about the process of structuring joint venture (for review, see e.g. (Ashayeri, Tuzkaya, & Tuzkaya, 2012; Hajidimitriou & Georgiou, 2002; Islam, Ali, & Sandhu, 2011; Rumpunen, 2011; Ulas, 2005; Wu & Barnes, 2011; Zahra & Elhagrasey, 1994)). Following the JV and alliance structuring literature, a JV formation decision process would logically be distinguished in five stages, namely, (1) internal preparation or pre-partner selection decision process period, (2) partner identification, (3) partner selection (evaluation and choice), (4) negotiations, and (5) implementation, management and control of the JV (adapted from (Hajidimitriou & Georgiou, 2002; Rumpunen, 2011; Visser, 2007)).

The first step, as mentioned, is the internal preparation within the **venturer** party[1] should define and specify the potential projects to create a joint venture, sub-projects of each, and sequence of the sub-projects. A detailed description of required ventures (e.g. of resources, assets, capital, technology, expertise and labor) for each sub-project is also provided to make clear what is expected so that a prospective **investor** party [2] can offer tailor-made venture. This knowledge is also important to search and identify the best initial basket of prospective partners. At the end of this face a requirement document, Request for Information (RFI), is available.

At the first phase of the second step, the venture party determines the selection criteria. Since, the criteria for JV partner selection are largely case-specific (Rumpunen, 2011), the criteria selection is not discussed deeply here (interested readers are referred to (Al-Khalifa & Peterson, 1999; Hacklin, Marxt, & Fahrni, 2006; Hajidimitriou & Georgiou, 2002; Islam et al., 2011; Özgen, 2007; Rumpunen, 2011; Ulas, 2005; Visser, 2007; Wu & Barnes, 2011)). Some of main grounds to build the criteria on are JV formation motives. Nevertheless formalization of the criteria is surely an important step for modeling purpose. The results in earlier studies

[1] a partner of a joint venture that forms initially the joint venture, and controls over that JV (i.e. the National Oil Company (NOC), which is the owner of the oilfields and the holder of the projects).

[2] a partner of a joint venture that collaborates through the joint venture and does not have joint control over it (i.e. the other NOCs - except venturer company - and all International Oil Companies (IOC), which are considered as prospective partners to collaborate in the JV).

about the relationship between motives for the JV and importance of various selection criteria are mixed. Nielsen (2003) found strong support for the relationship between motives and the relative importance of selection criteria (all the seven regression equations had moderate to high R squares and significant F values). While Chen and Glaister (2006) found moderate support for their hypotheses concerning the relationship between relative importance of the selection criteria and the strategic motivation for JV formation. At next phase of the second step, the venturer searches and identifies prospective partners with regard to the existed selection criteria. Then, the venturer sends the RFI to the long-listed potential partners, screen the provided response of the potential partners, and shorten the list of potential partners to continue with. To shape the best basket of potential partners to evaluate and negotiate with, the venturer company should send out a more detailed requirements document, Request for Proposal (RFP), to the potential partners at the remaining short list. The RFP document should specify the requested services and ventures in more detail.

Afterwards the responses are evaluated using the selection criteria defined before, and the best choices will be picked up (this key decision making process will be discussed later). When a right basket of partners is picked out, the underscored potential partners are called for negotiations. At the end of the negotiation process, the parties sign the contracts. Subsequently, the parties will start to implement and manage the JV with respect to the contractually agreed sharing of ventures and control over the JV.

3.1.3 Partner Selection

Ever since early 70's, the partner selection has been considered a key decision in the literature on joint ventures. Partner selection is viewed as crucial for formation, operation and subsequent success or failure of the joint venture (Rumpunen, 2011). Conducted research has shown that 30 to even 70 percent of the JVs are failures, are unstable and/or do not meet the goals set for them (Hacklin et al., 2006; Rumpunen, 2011; Zahra & Elhagrasey, 1994; Zhang, 2007). A major factor in failure is poor selection of partners (Zahra & Elhagrasey, 1994). Therefore, the appropriate selection of the partner is of the essence in the JVs. However, although a number of JV partner selection studies declare the importance of the partner selection process. For example, Reusa and Ritchie (2004) found almost 30 studies with a linkage to partner selection in their review of International JV research in ten major journals with regard to studies on international business between the years 1988 and 2003 (For comparison among these 388 IJV studies in total, the most popular points of focus were entry strategies and partner learning, together covering close to 100 articles (Rumpunen, 2011)).

The common characteristic of the literature on the partner selection to joint venture, is that the researchers carry out an ex post analysis of motives, criteria, practices and/or outcomes of partner selection processes (Hajidimitriou & Georgiou, 2002). In other words, the mainstream in this area is the descriptive research. However, normative (quantitative) decision making has been neglected within these types of research frameworks. To the best of our knowledge, there is only one quantitative model for the partner selection process, which is of Hajidimitriou and Georgiou (2002), in the joint venture context. They propose a goal programming (GP) model to form joint venture and select its partners. The GP model has the ability to take account of multiple performance level of the corresponding attributes and, thus, attempts to achieve the goals with these levels. The drawback of their model is that the model select just one partner at a time. As at the partner selection stage, most of all information is qualitative, and the financial information (i.e. costs, price, and interest rate) are roughly presented, picking a single partner out is make no sense. A combination of potential partners may generate better solutions for the joint venture comparing with only one candidate being identified (Wu & Barnes, 2011).

As mentioned, a goal programming model is implied by Hajidimitriou and Georgiou (2002) to select a partner to cooperate in a joint venture. The goal programming is one of the main mathematical programming models have been in use for partner selection. Basnet and Leung (2005) proposed a supplier selection model under an inventory lot-sizing scenario over multi-period. They determine what products to order in what quantities with which suppliers in which periods. Ravindran et al. (2010) developed a partner selection problem by elaborating value-at-risk and miss-the-target risk models. They proposed a multi- criteria optimization problem, and used GP approach to solve the problem in two separate stages, named qualification and order quantities allocation stages. Vanteddu et al. (2011) introduced a goal programming model for focus dependent supplier selection problems. They took inventory costs and the supply chain "cycle time" reduction costs into account.

In nutshell, the partner selection is the heart of the joint venture formation decision process. The success of the JV depends on this process. As a result, the main goal of this study is the elaboration of a quantitative method for the partner selection process within a JV context. As discussed before, a right basket of selected partners can lead to better consequences for the joint venture comparing with only one player being selected. Hence, a mathematical model will imply to indicate the best basket of partners to collaborate in the current JVs. In addition, the developed model take multiple objectives into account, and more specifically is based on the goal programming approach, owning to the great significance of multiple criteria and factors in the joint venture formation problems.

3.2 PROBLEM STATEMENT

To figure out the problem explicitly, this section outlines the important issues of the problem concisely.

3.2.1 Joint Venture Formation

The formation process of a joint venture has been discussed before. The first and second step to establish a joint venture is the internal preparation and partner identification, in order. Within these steps, the venturer party should define and specify the potential projects, the sequence of the projects, a detailed description of the required ventures, and the selection criteria of partners to form an optimal arrangement of joint venture. Accomplishing the first and second steps, we can study the partner selection step of JV formation decision process.

Consider an oil company as a venturer party (VP) to form and control over the joint venture (i.e. the NOC which is the owner of the oilfields and the holder of the projects). The VP has access to several potential partners to establish the best JV. The venturer company plans to undertake a given $|K|$ potential projects over a given planning horizon comprising $|T|$ multiple periods $t \in T = \{1, 2, \dots, |T|\}$ of a given fixed length (day, week, etc.). Each project needs a predetermined amount of the v^{th} venture which can be supplied by the p^{th} potential partner or by the VP. The mission is to establish the optimal JV, through a mathematical model, founded on the Goal Programming approach.

The joint venture problem can now be stated as follows.

Given:

(1) the potential projects, their features such as expected duration to conclude, required investment and ventures in each period, and their dependency relations;
(2) a multi-period planning horizon;
(3) the selection criteria;
(4) the potential partners to collaborate in JV, their features e.g. their ability to supply budget and ventures in each periods; and
(5) the goals, their weights and the priority levels.

Determine:

(1) the specifications of contracts that the venturer should sign with the selected partners;
(2) the amount of ventures and budget that the venturer should order under each contract in each period;
(3) the start and finish times of the projects; and
(4) the total cost for JV forming

Assuming:

(1) the dependency relationships cannot be neglected;
(2) all project should be finished before the end of the planning horizon;
(3) the number of selected partners can be more than one; and

(4) the amount of investment and ventures, which are supplied by partners or venturer party, are roughly considered as continuous variables without any loss of generality.

Aiming to:

(1) Select the set of contracts with partners that meet the projects' demand (i.e. budget and ventures) in each period, and minimize unwanted deviations of the joint venture.

3.2.2 Goal Programming

Goal Programming (GP) is a multi-objective programming approach which is based on the concept of satisfying the objectives. GT does not attempt to study a well-defined utility function, which is almost unachievable to represent the decision maker's (DM) preferences into a reliable mathematical programming model (Tamiz, Jones, & Romero, 1998). On the contrary, in this situation the DM introduces a set of goals (or targets) and attempts to achieve them as closely as possible. Goal Programming models fall into two major classes. In the former class, weighted GP, the weights are assigned to the unwanted deviations, in accordance with their comparative importance to the DM. And, then, the unwanted deviations are minimized as an Archimedean sum. In the latter class, a number of **priority levels** are assigned into the deviational variables to minimize them in a lexicographic scheme. A lexicographic minimization represents a sequential process to minimize each priority level, whilst minimum values reached by all higher priority level minimizations have to be sustained. In consequence, this class is called lexicographic GP (Tamiz et al., 1998).

As pointed out before, Hajidimitriou and Georgiou (2002) proposed a GP approach to select right partners of a joint venture problem. As an advantage of goal programming techniques, this model is able to take account of multiple performance level, i.e. priority levels in goal programming context. In other words, they used a lexicographic GP to select the best partner to join. Their model selects only one partner which is not an optimal combination of partners' collaboration. In this chapter, we will introduce a lexicographic GP model, with more realistic constraints and goals, to select optimal basket of partners. One of the advantages of the lexicographic models is that the decision makers can investigate and analyze the influence of different orders of priority levels on the solutions. In the next section, we will formulate the above described problem.

3.3 FORMULATING THE MATHEMATICAL PROGRAMMING MODEL

In this section, we describe a linear deterministic model to form joint venture and select appropriate partners to collaborate with. This deterministic model can be a well-established basis for the further research. The notation that will be used throughout the model is provided in Tables 3.1-3.3.

3.3.1 Lexicographic Goal Programming

Speaking algebraically, consider that our goal programming has Q goals. We give the index $q = 1, \dots, Q$ to them. There are also n decision variables which are termed by the $\underline{x} = x_1, x_2, \dots, x_n$. Let's consider $f_q(\underline{x})$ as a function of the decision variables which show the actually achieved value of the q^{th} goal. The b_q represents a numeric target level, what is aspired to accomplish, for the q^{th} goal. Then, Eq. (3.1) states the basic formulation of the q^{th} goal:

$$f_q(\underline{x}) + n_q - p_q = b_q \qquad \forall q \qquad (3.1)$$

Table 3.1: Model notation, sets and indices.

Symbol	Sets
K	The set of projects; $k \in K = \{1, 2, \dots, \lvert K \rvert\}$
P	The set of potential partners; $p \in P = \{1, 2, \dots, \lvert P \rvert\}$
V	The set of ventures; $v \in V = \{1, 2, \dots, \lvert V \rvert\}$
T	The set of period times; $t \in T = \{1, 2, \dots, \lvert T \rvert\}$
FS	The set of projects which have Finish to Start dependency relation
FF	The set of projects which have Start to Finish dependency relation
SS	The set of projects which have Start to Start dependency relation
SF	The set of projects which have Start to Finish dependency relation

Table 3.2: Model notation, parameters.

Parameters	Description
d^k	the expected duration of the k^{th} project
$Inv_{\tau t}^{k}$	required volume of investment in period t for the k^{th} project, if it is started in period τ
$V_{\tau t}^{kv}$	required amount of the v^{th} venture in period t for the k^{th} project, if it is started in period τ
UI_{pt}	upper bound on total amount of budget which can be supported in period t by the p^{th} potential partner
UI_t	upper bound on total amount of budget which can be supported in period t by the venturer company
UV_{pt}^{v}	upper bound on total amount of the v^{th} venture which can be provided in period t by the p^{th} potential partner
UV_t^{v}	upper bound on total amount of the v^{th} venture which can be provided in period t by the venturer company
CV_{pt}^{kv}	cost of a unit of the v^{th} venture provided by the p^{th} potential partner, to supply the k^{th} project in period t
CV_t^{kv}	cost of a unit of the v^{th} venture provided by the venturer company, to supply the k^{th} project in period t
RT_{pt}^{k}	The interest rate of investment in the k^{th} project in period t. This amount should be paid to the p^{th} potential partner at the end of the project (T) by the venturer company
i	interest rate

Here, the parameters n_q and p_q are the negative deviational variable and the positive deviational variable of the q^{th} goal, respectively. In other words, these variables denote the differences between the target level and actually achieved level. Then, according to the nature of each goal, one of the deviational variables is usually considered as the unwanted deviational variables for that goal. The distinctive feature of lexicographic goal programming is the priority levels. We allow the model to L priority levels with corresponding index $l = 1, \ldots, L$. Now, a function of unwanted deviational variables, at each priority level, should be defined as $z_l = h_l\left(\underline{n}, \underline{p}\right)$. In fact, this function measures the 'lack' of achievement of the goals, and, hence, is termed an achievement function (Jones & Tamiz, 2010).

Table 3.3: Model notation, variables.

Variables	Description
s_t^k	1; if the k^{th} project is started at the beginning of period t
f_t^k	1; if the k^{th} project is finished until the end of in period t
inv_{pt}^k	the amount of investment in the k^{th} project in period t by the p^{th} potential partner
inv_t^k	the amount of investment in the k^{th} project in period t by the venturer company
v_{pt}^{kv}	the amount of the v^{th} venture provided by the p-th potential partner, to supply the k^{th} project in period t
v_t^{kv}	the amount of the v^{th} venture provided by the venturer company, to supply the k^{th} project in period t
$\underline{Inv_t^k}$	required investment for the k^{th} project in period t
$\underline{V_t^{kv}}$	required amount of the v^{th} venture for the k^{th} project in period t
CF_t	the cash flows from the venturer party's point of view
NCF	net present value of the cash flows
CoV	present value of the total cost of the ventures
$TCJV$	present value of the total cost of the joint venture formation

The previous considerations form the generic algebraic model of the lexicographic GP model:

$$Min\ Z = \{z_1, \dots, z_L\} \tag{3.2}$$

Subject to:

$$\begin{aligned} f_q(\underline{x}) + n_q - p_q &= b_q \qquad \forall p \\ \underline{x} &\in F \\ n_q, p_q &\geq 0 \qquad \forall q \end{aligned} \tag{3.3}$$

The parameter F denotes the feasible space for the decision variables, $\underline{x}$. In the subsection, we will explain the first priority level of the goal programming for the current joint venture model.

3.3.2 Cost oriented model-Goal level

As mentioned before, the main distinguishing feature of lexicographic GP is the priority levels of the goals. The criteria, goals and priority levels should be defined within the pre-partner selection and partner identification stages. The prioritization of the criteria between or within levels is specified by the venturer company according to the strategic objectives of the JV formation. We assume that the venturer party considers the cost of the joint venture formation as the most prominent criterion of this JV model. The total cost to form the joint venture, which should be paid by the venturer, is called $TCJV$. Then the cost goal is the following:

$$TCJV + n_{CJV} - p_{CJV} = b_{CJV} \tag{3.4}$$

The $TCJV$ is calculated from the subtraction of the total cash flows of investments (NCF), from the total cost of ventures (CoV), as stated in Eq. (3.5).

$$TCJV = CoV - NCF \tag{3.5}$$

The venturer should pay the CV_{pt}^{kv} to the p^{th} potential partner for each unit of the v^{th} to supply the required ventures of the k^{th} project in the period t (as stated in the first part of Eq. (3.6)). It is also possible that the venturer company supports the required ventures of the k^{th} project by its own ventures (as stated in the second part of Eq. (3.6)). Therefore, the net present cost of supplying the required ventures for the JV should be:

$$CoV = \sum_{t}\sum_{p}\sum_{k}\sum_{v} CV_{pt}^{kv}\, v_{pt}^{kv}(1+i)^{-t} + \sum_{t}\sum_{k}\sum_{v} CV_{t}^{kv}.\, v_{t}^{kv}(1+i)^{-t} \tag{3.6}$$

In Eq. (3.6), v_{pt}^{kv} and v_{t}^{kv} represent the amount of the v^{th} venture to supply the k^{th} project in the t^{th} period which is provided by the p^{th} potential partner and by the venturer itself, respectively. Note that the i shows the interest rate which is used to calculate the present value of the ventures' cost in Eq. (3.6).

To calculate the cash flow of the investments in the JV, from the venturer party's point of view, we should distinguish between the investments by the potential partners and by the venturer. The received investments from the potential partners is considers as cash inflows. While, the cash outflows come from the investments of the venturer party. The cash flow of the investments in the t^{th} period, described as the "difference amount" between the sums of cash inflows and cash outflows.

$$CF_t = \sum_{k}\left(\sum_{p} inv_{pt}^{k} - inv_{t}^{k}\right) \qquad \forall t \tag{3.7}$$

In the Eq. (3.7), the inv_{pt}^{k} and inv_{t}^{k} show the invested amount in the k^{th} project, in the t^{th} period, by the p^{th} potential partner and by the venturer party, in order.

The net present value of the cash flows is the sums of discounted cash flows in all periods. Eq. (3.7) describes the cash flows of all period times, except the T^{th} period in which we have other cash outflows, as well. These cash outflow are the paybacks of the partners' investments. We assume that the p^{th} potential partner agreed to invest in the k^{th} project in the t^{th} period, to get its money back in period T, with the (RT_{pt}^{k}) as a rate of return. Therefore, the net present value of cash flow, is the sum of all these term which are discounted back to the present values, as stated in Eq. (3.8).

$$NCF = \sum_{t} CF_t/(1+i)^t - \sum_{t}\sum_{p}\sum_{k}\left(RT_{pt}^{k} inv_{pt}^{k}\right)/(1+i)^T \qquad \forall t \qquad (3.8)$$

3.3.3 Cost Oriented Model - Constraints

3.3.3.1 Projects relationships Constraints

As explained in the problem statement section, the venturer defines the sequence of the projects. In a project network, these sequences are called "dependency relations". There are four kinds of dependencies with respect to the sequence of the elements, which should be defined. To the best of our knowledge, there is no mathematical model to describe these relations as constraints to form the feasible space of a project network. We introduce the mathematical format of these dependency relations to shape a more realistic model. Before studying them, it is worth taking a look at the some logical relations, as stated in the next subsection.

Logical Relationship

Herein, the parameters s_t^k and f_t^k defined as binary variables. The s_t^k is one if the k^{th} project is started at the beginning of period t. While the f_t^k must be one if the k^{th} project is finished at the end of period t. Logically, a project of the JV must start once, in Eq. (3.9), and can finish only once, as in Eq. (3.10).

$$\sum_{t=1}^{T} s_t^k \geq 1 \tag{3.9}$$

$$\sum_{t=1}^{T} f_t^k \leq 1 \tag{3.10}$$

If the k^{th} project is started in the t^{th} period, then it must be finished after its expected duration time (d^k), at the end of period $t + d^k - 1$.

$$s_t^k \leq f_{t+d^k-1}^k \qquad \forall t, k \tag{3.11}$$

Dependency Relations

There are four kinds of "dependency relations" which are defined with respect to the sequence of the projects.

Finish to Start (FS) constraints:

If $(i, j) \in FS$, then j^{th} project can't start before the i^{th} project is finished. In other words, if the j^{th} project starts in the t^{th} period, then the i^{th} project has to be finished until the end of period $t - 1$.

$$\text{If} \quad s_t^j = 1 \Rightarrow \sum_{\tau=1}^{t-1} f_\tau^i = 1 \qquad \forall t, \quad \text{or} \qquad \text{If} \quad \sum_{\tau=1}^{t-1} f_\tau^i = 0 \Rightarrow s_t^j = 0 \qquad \forall t,$$

The above relationship is formulated in Eq. (3.12) as a constraint to shape the feasible space of the problem.

$$\sum_{\tau=1}^{t-1} f_\tau^i - s_t^j \geq 0 \qquad \forall t, (i, j) \in FS \tag{3.12}$$

Finish to Finish (FF) constraints:

If $(i, j) \in FF$, then j^{th} project can't finish before the i^{th} project is finished. That means if the j^{th} project is expected to finish in the t^{th} period, then the i^{th} project must be finished until the end of period t.

$$\text{If} \quad f_t^j = 1 \Rightarrow \sum_{\tau=1}^{t} f_\tau^i = 1 \qquad \forall t \quad \text{or} \qquad \text{If} \quad \sum_{\tau=1}^{t} f_\tau^i = 0 \Rightarrow f_t^j = 0 \qquad \forall t,$$

The above algebraic equations can be formulated as Eq. (3.13).

$$\sum_{\tau=1}^{t} f_\tau^i - f_t^j \geq 0 \qquad \forall t, (i,j) \in FF \qquad (3.13)$$

***Start to Start (SS) constraints*:**

If $(i,j) \in SS$, then j^{th} project can't start before the i^{th} project is started. In other words, if the j^{th} project is started in the t^{th} period, then the i^{th} project must already be started. Note that, we assume that this order of projects can start simultaneously, as well.

$$\text{If} \quad s_t^j = 1 \Rightarrow \sum_{\tau=1}^{t} s_\tau^i = 1 \quad \forall t \quad \text{or} \quad \text{If} \quad \sum_{\tau=1}^{t} s_\tau^i = 0 \Rightarrow s_t^j = 0 \quad \forall t,$$

The aforementioned relation is described in the following constraint:

$$\sum_{\tau=1}^{t} s_\tau^i - s_t^j \geq 0 \qquad \forall t, (i,j) \in SS \qquad (3.14)$$

Start to Finish (SF) constraints:

If $(i,j) \in SF$, then j^{th} project can't finish before the i^{th} project is started. Logically speaking, if the j^{th} project finishes at the end of the period t, then the i^{th} project must be started before, or immediately at the beginning of the next period, $t + 1$.

$$\text{If} \quad f_t^j = 1 \Rightarrow \sum_{\tau=1}^{t+1} s_\tau^i = 1 \quad \forall t \quad \text{or} \quad \text{If} \quad \sum_{\tau=1}^{t+1} s_\tau^i = 0 \Rightarrow f_t^j = 0 \quad \forall t,$$

The above relation is described in the following constraint:

$$\sum_{\tau=1}^{t} s_\tau^i - f_t^j \geq 0 \qquad \forall t, (i,j) \in SF \qquad (3.15)$$

3.3.3.2 Resource Constraints

Logical resource constraints

It is obvious that the required investment and ventures for a project vary in each period according to the start time of the project. Therefore, to calculate the total assigned investment ($\underline{Inv_t^k}$) and the assigned ventures ($\underline{v_t^{kv}}$) to the k^{th} project in period t, it is necessary to know when the k^{th} project is started. The parameters $Inv_{\tau t}^k$ and $V_{\tau t}^{kv}$, in Eqs. (3.16-3.17), show the required investment and the required v^{th} venture, respectively, for the k^{th} project in period t, if the the k^{th} project is started in the period τ.

$$\sum_{\tau} Inv_{\tau t}^k \,.\, s_\tau^k = \underline{Inv_t^k} \qquad \forall t, k \qquad (3.16)$$

$$\sum_{\tau} V_{\tau t}^{kv} \,.\, s_\tau^k = \underline{v_t^{kv}} \qquad \forall t, k, v \qquad (3.17)$$

Resource constraints of the k^{th} project

Eqs. (3.18-3.19) guarantee that the partners and the venturer will supply the required investment and ventures to the k^{th} project in each period.

$$\sum_{p} inv_{pt}^k + inv_t^k \geq \underline{Inv_t^k} \qquad \forall t, k \qquad (3.18)$$

$$\sum_{p} v_{pt}^{kv} + v_t^{kv} \geq \underline{v_t^{kv}} \qquad \forall t, k, v \qquad (3.19)$$

Resource constraints of the p^{th} potential partner

Each potential partner has some predefined upper bounds to budget and supply the ventures. Eq. (3.20-3.21) impose these upper bounds on the p^{th} potential partner in the period t.

$$\sum_{k} inv_{pt}^k \leq UI_{pt} \qquad \forall t, p \qquad (3.20)$$

$$\sum_{k} v_{pt}^{kv} \leq UV_{pt}^v \qquad \forall t, p, v \qquad (3.21)$$

Resource constraints of the venturer company

The venturer has also some upper bounds to invest and supply the ventures, as stated in Eq. (3.22-3.23).

$$\sum_{k} inv_t^k \leq UI_t \qquad \forall t \qquad (3.22)$$

$$\sum_{k} v_t^{kv} \leq UV_t^v \qquad \forall t, v \qquad (3.23)$$

3.4 MODEL APPLICATION

3.4.1 Example description

The case study chosen to illustrate the application and computational effectiveness addresses a Joint Venture formation in the Persian Gulf. The venturer party, which is a national oil company and the owner of the oilfields, aimed to drill an offshore recovery well in its own proved oilfield. The venturer deals with the internal preparation step, first. Then, the venturer company determines the selection criteria, according to the highlighted motives. Finally, our proposed model is applied to from the best Join Venture.

Within the internal preparation step activities, sequence and dependency relations, and a detailed description of required resources (e.g. of capital investment, technology, expertise and labor) for each activity are specified. For the sake of simplicity, the detail tasks and activities are ignored. For example, Rolstad (1991) listed 23 activities to manage just the start-up phase of a project development in the Norwegian offshore industry. By this way, we should describe more than 100 activities for the current JV problem which is impossible herein.

As shown in Table 3.4, the JV project consists of the five main activities which are associated with one oil well drilling program. Through the start-up phase the detail personnel requests, job description, organization plan, scope of work, material requisition schedule, report format, and detail planning procedure will be planned. Then, the drill expert team will design all characteristics of the well drilling procedure (e.g. well location, the actual hole size, drill muds, drill direction, drill program, vertical seismic profiling, well testing, etc.), and select drill rig. Rig selection will be based on the characteristics of the oil well's site, physical environment, water depth, drilling depth, the mobility required, and weather and ice conditions, as well as other safety and environmental criteria. After the oil well design phase, the drill operation will be started by means of a mobile offshore drill unit. The offshore drill units will be supplied through logistics support means including two supply vessels and one offshore helicopter. Supply vessels are operating from a shore base facility with the capability of storing and delivering drilling supplies, and other bulk commodities including provisions. Offshore helicopter will be required to transport personnel, and light supplies and equipment. Finally, the drilled well will be completed to get ready to recover crude oil. The anticipated required resource and expected duration of each aforementioned activity are summarized in Table 3.4. The dependency relations of the activities are, also, illustrated in Table 3.5. To gain a better image of these relations, Figure 3.1 is presented. As this figure shows, the third activity, A3, has very interesting relationship. This activity can start after starting the A2 and A4. Then the A2 and A4 have Start-to-Start relations with the A3. At the other side, A3 has to be started before finishing of A2, i.e. Start-to-Finish relation. And its last relation is as a result of the dependence of A5 on A3, and, thus, the resulting Finish-to-Start relation between them.

Moreover, the venturer has identified eight potential partners that sound to be appropriate to collaborate. Tables 3.6 and 3.7 provided the available resource at each potential partner for each activity and corresponding costs of them, respectively.

Table 3.4: Description of the project activities and corresponding required resources.

Activity		Expected Duration	Required Resource	Unit	Required Amount
A1.	Start-up & Planning	3 months	A1.1. Expert Team	man-hour	4800
			A1.2. Labour	man-hour	15000
			A1.3. Budget	$1000	344
A2.	Well Design	3 months	A2.1. Expert Team	man-hour	5200
			A2.2. Labour	man-hour	16000
			A2.3. Budget	$1000	368
A3.	Drilling Operations	4 months	A3.1. Drilling Rig	#	1
			A3.2. Expert Team	man-hour	9600
			A3.3. Labour	man-hour	58400
			A3.4. Budget	$1000	5180
A4.	Logistic Support	7 months	A4.1. Helicopter	#	1
			A4.2. Marine Vessel	#	2
			A4.3. Budget	$1000	1240
A5.	Well Completion	2 months	A5.1. Expert Team	man-hour	8400
			A5.2. Labour	man-hour	33000
			A5.3. Budget	$1000	719

After determination of the selection criteria, Table 3.8 represents the selection criteria, priority levels and goals (aspiration level). Note that the venturer party considers the cost of the joint venture formation as the most prominent criterion. Hence, the priority level of the cost objective function is labeled PL0. While, based on their importance to accomplish the venturer's strategic objectives, the rest criteria are ranked into four priority levels, labeled PL1, PL2, PL3, and PL4. The criteria of these original priority levels, which are equally weighted, are named the priority groups. For example, the criteria number 1, 3, 10, and 14 are called priority group 1 (PG1).

Table 3.5: The dependency relations amongst the activities.

Finish to Start	Start to Finish	Start to Start	Finish to Finish
A1 , A2	A3 , A2	A2 , A3	A5 , A4
A3 , A5		A4 , A3	

Table 3.6: Available amount of the resources at the venturer and potential partners to support each activity.

Required Resource	Available at Venturer	Available at Partner No. 1	2	3	4	5	6	7	8
A1.1. Expert Team	2392	3391	2337	2947	1777	2654	2548	3149	1844
A1.2. Labour	7360	10435	7190	9066	5468	8166	7841	9689	5674
A1.3. Budget	169.28	240.01	165.37	208.53	125.76	187.83	180.35	222.86	130.49
A2.1. Expert Team	4416	6261	4314	5440	3281	4900	4705	5814	3404
A2.2. Labour	26864	38088	26243	33092	19957	29808	28621	35366	20708
A2.3. Budget	2382.80	3378.35	2327.71	2935.24	1770.15	2643.90	2538.66	3136.95	1836.81
A3.1. Drilling Rig	0	1	0	1	0	1	0	1	0
A3.2. Expert Team	4416	6261	4314	5440	3281	4900	4705	5814	3404
A3.3. Labour	26864	38088	26243	33092	19957	29808	28621	35366	20708
A3.4. Budget	2382.80	3378.35	2327.71	2935.24	1770.15	2643.90	2538.66	3136.95	1836.81
A4.1. Helicopter	0	1	1	1	0	1	0	1	0
A4.2. Marine Vessel	1	2	2	1	0	1	1	1	1
A4.3. Budget	570.40	808.72	557.21	702.64	423.74	632.90	607.71	750.93	439.70
A5.1. Expert Team	3864	5478	3775	4760	2871	4287	4117	5087	2979
A5.2. Labour	15180	21522	14829	18699	11277	16843	16173	19984	11702
A5.3. Budget	330.74	468.93	323.09	407.42	245.70	366.98	352.37	435.42	254.96

After indication of selection criteria, the venturer evaluates each eight potential partners concerning the abovementioned qualitative selection criteria. The qualitative results are converted into quantitative scores with respect to a seven-point discrete scale. Table 3.9 provides the used scores of each partner for each selection criteria in this application.

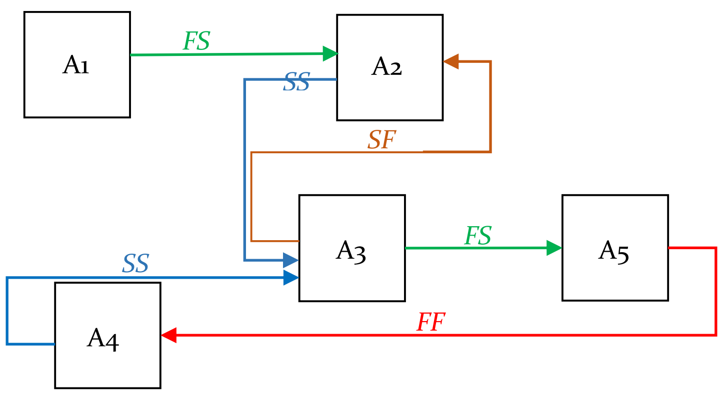

Figure 3.1: A schematic description of the dependency relations.

Table 3.7: The cost/rent amount of the resources which are supplied by the venturer and the potential partners

Required Resource	Cost at Venturer	Resource Cost at Partner No.							
		1	2	3	4	5	6	7	8
A1.1. Expert Team	52	79	72	70	58	77	62	54	72
A1.2. Labour	14	22	20	19	18	21	17	15	20
A2.1. Expert Team	57	86	78	76	61	84	68	59	79
A2.2. Labour	19	29	26	26	18	28	23	20	27
A3.1. Drilling Rig [a]	-	4392	-	3891	-	4299	-	2995	-
A3.2. Expert Team	63	95	86	84	73	93	75	65	87
A3.3. Labour	28	43	39	38	30	42	34	29	39
A4.1. Helicopter [a]	-	269	245	239	-	264	-	184	-
A4.2. Marine Vessel [a]	224	338	308	300	-	331	269	231	309
A5.1. Expert Team	63	95	86	84	58	93	75	65	87
A5.2. Labour	28	43	39	38	22	42	34	29	39

[a]- $1000

3.4.2 Numerical Results

As mentioned before, the cost function is prioritized as the first priority level. For the cost goal, the positive deviation variable, p_{CJV}, represents the undesired deviation, as stated in Eq. (4). The rest objective functions $z_1,\ z_2,\ z_3,$ and z_4 are linear expressions of negative deviation variables which came from the four priority groups, as shown in Table 3.8. The linearity of these expressions is owing to the equality of importance of criteria within each group. Accordingly, the objective function i is the summation of the negative deviation variables of the priority group i. In other words, the objective functions are $z_1 = n_2 + n_4 + n_8 + n_9$, $z_2 = n_1 + n_3 + n_{10} + n_{14}$, $z_3 = n_5 + n_6 + n_7$, and $z_4 = n_{11} + n_{12} + n_{13}$.The goal level of the each objective functions is the sum of the goal levels for each element. In consequence, the target of the each level are $b_{z1} = b_2 + b_4 + b_8 + b_9 = 28$, $b_{z2} = b_1 + b_3 + b_{10} + b_{14} = 28$, $b_{z3} = b_5 + b_6 + b_7 = 21$, and $b_{z4} = b_{11} + b_{12} + b_{13} = 21$.

Table 3.8: The partner selection criteria, priority levels, and goals.

Motive	No	Criterion	Priority	Goal	Group
Transaction Cost	0.	Cost Function	PL0	2.1e+6	
	1.	Firm Size	PL2	7	PG2
	2.	Financials	PL1	7	PG1
	3.	Credit Status	PL2	7	PG2
	4.	Technological Capabilities	PL1	7	PG1
Strategic Behaviour	5.	Compatible Management Style	PL3	7	PG3
	6.	Compatible Organization Cultures	PL3	7	PG3
	7.	Compatible Strategic Objectives	PL3	7	PG3
	8.	Our Trust in the Partner	PL1	7	PG1
	9.	Reputation	PL1	7	PG1
	10.	Prior JV Performance	PL2	7	PG2
Organizational Knowledge & Learning	11.	Knowledge Level	PL4	7	PG4
	12.	Transferring Technologies	PL4	7	PG4
	13.	Share Skills and Knowledge	PL4	7	PG4
	14.	Cooperate in R&D	PL2	7	PG2

Twelve yearly planning periods are assumed. The implementation in IMB ILOG CPLEX Optimization Studio using CPLEX 12.5 leads to a MILP model with 6280 constraints, 3241 continuous variables, 188 binary variables, and 19138 nonzero coefficients. It takes a few seconds to accomplish a solution with a 0% integrality gap on an Intel Core Duo 2.9 GHz computer. In the first solution, we employed the priority levels of Table 3.8. Total cost of the Joint Venture formation is the top priority goal. While, the other priority groups of criteria PG1, PG2, PG3, and PG4 are ranked second, third, fourth and fifth, respectively. By this way, the solution 1 recommends the partner 1, 4, and 6 to form the joint venture. The generated deviations of all goals from this solution are represented in Table 3.10. It is worth mentioning that the model determines the exact feature of the Joint Venture formation, as well. In other words, the model indicates which partners cooperate, how many of resources are supplied by each of the selected partners and the venturer, how much of capital investment should be supported by whom, which activity should be started and finished in each period time. The resulting plan of activities is depicted in Figure 3.2. The comparison of this figure with Table 3.4 and Figure 3.1 is recommended for interesting readers.

Table 3.9: The selection criteria scores at each potential partner.

Criterion No.		Potential Partner 1	2	3	4	5	6	7	8
1.	Firm Size	6	7	4	3	5	3	3	4
2.	Financials	6	4	4	5	6	6	5	5
3.	Credit Status	6	4	6	6	3	5	7	6
4.	Technological Capabilities	7	6	6	4	7	5	6	5
5.	Compatible Management Style	4	6	6	3	5	6	5	6
6.	Compatible Organization Cul-	3	7	6	5	5	4	4	4
7.	Compatible Strategic Objectives	5	4	5	7	6	6	4	4
8.	Our Trust in the Partner	6	6	5	7	6	5	6	5
9.	Reputation	4	6	5	4	6	6	4	7
10.	Prior JV Performance	4	6	6	3	5	4	4	6
11.	Knowledge Level	6	6	6	5	5	6	4	5
12.	Transferring Technologies	6	5	5	5	5	5	5	4
13.	Share Skills and Knowledge	5	4	4	6	3	4	5	4
14.	Cooperate in R&D	6	4	5	5	6	5	7	5

To show the flexibility and efficiency of the model, three more different priority level rankings of priority groups are implemented, and the results are summarized in Table 3.10. From Table 3.10 it is evident that the model provides the flexibility for the decision maker to carry out a vast variety of scenarios analysis just by adjusting the priority levels. As can be noted different scenarios generated different solutions, while in all solution partner 1 is always present and partner 6 in three out of 4 scenarios. Such analysis can further help to decide about a robust solution given the possible priority changes.

Table 3.10: The numerical results of the model.

Priority Group of criteria	Priority Level	Deviation	Selected Partner	Priority Level	Deviation	Selected Partner
Solution 1			1, 4, 6.	**Solution 2**		1, 3, 6.
Total Cost	**PL1**	1.24E+04		**PL1**	1.24E+04	
PG1	**PL2**	15		**PL3**	20	
PG2	**PL3**	22		**PL4**	20	
PG3	**PL4**	22		**PL2**	21	
PG4	**PL5**	19		**PL5**	17	
Solution 3			1, 4.	**Solution 4**		1, 6.
Total Cost	**PL2**	2.83E+06		**PL2**	9.17E+05	
PG1	**PL1**	8		**PL3**	12	
PG2	**PL3**	15		**PL1**	13	
PG3	**PL4**	14		**PL4**	17	
PG4	**PL5**	12		**PL5**	11	

3.5 SUMMARY

In this chapter, joint venture formation and partner selection problems which are important issues in the oil industry were investigated. We overviewed the background of the joint venture (i.e. the motivations for JVs, and partner selection), in Section 3.1. The following section explained the main features of the problem to provide a precise "problem statement" section. In Section 3.3, the goal programming model was formulated to select right partners followed by explaining the decision variables, the parameters, the objectives and, of course, the mathematical equations of the predefined goals. Section 3.4 illustrated the model application, experimenting hypothetical but realistic data of a NOC. In the following, we discuss key results of this chapter and suggest some avenues which require further research.

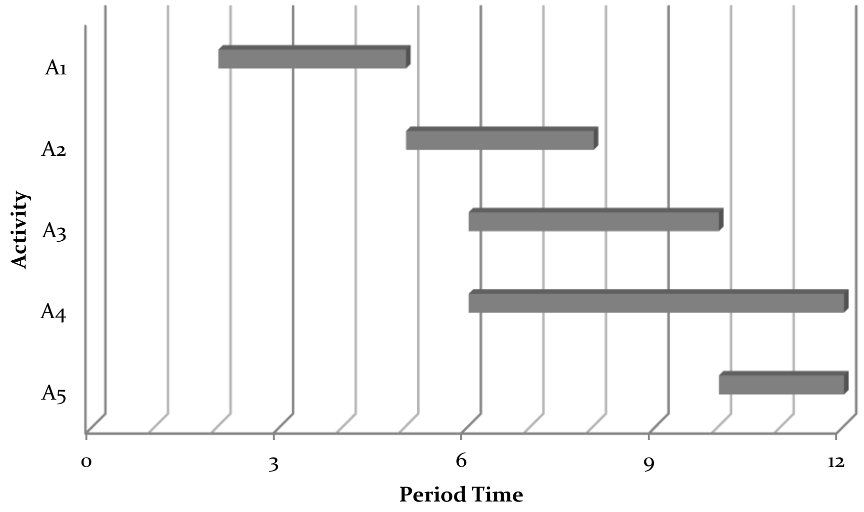

Figure 3.2: A figure to illustrate the resulting plan for activities by Solution 1.

A unique elaboration of our model is that the joint venture's partners are not investigated in isolation, but the resulting joint venture project is also evaluated as a whole system. Dealing with the complicated dependency relations of the project activities, decision makers are demanded to schedule all in a single model. Additionally, a multi criteria approach is implemented using the goal programming approach. The approach considers different goals and priority levels coming from strategic aims and views of the venturer party. By doing so, instead of having one unique solution for the decision maker, a set of solutions is produced, by altering the priority level rankings. As a future research avenue, a larger number of activities can be considered by introducing an efficient solution algorithm. Moreover, an integrated Multi Criteria Decision Making approach (e.g. ANP, AHP, etc.) can be applied to indicate the criteria and criteria priority levels of goals. Another future research direction may be taking account of more detailed financial aspects of international joint venture formation, like international factors, currency exchanging and tax.

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Chapter Four

Integrated Upstream Crude Oil Supply Chain Model

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The oil industry supply chain involves all decision levels (strategic, tactical, and operational), just like other supply chains. The crude oil supply chain mathematical models consist of the design and planning of several functions of this network, e.g. crude oil transportation, oilfield development, refinery planning, and distribution. In Chapter 2, we carried out a comprehensive literature review on the mathematical programming models of the COSC. We observed from the various tables throughout the review, some research directions still remain to be dealt with such as (i) full vertical integration of decisions (i.e. studying all strategic and tactical decisions in a single model), (ii) capturing full horizontal integration of the crude oil supply chain (i.e. capturing a comprehensive range of entities to configure the complex structures), (iii) dealing with nonlinear models, which is required in refineries' operations. As a consequence, in this chapter, we elaborate a linear deterministic mathematical model, which (i) integrates the strategic and tactical decisions by dealing with oilfield development and crude oil transportation problems simultaneously, and (ii) configures a convergent-like structure network consisting of a comprehensive range of upstream entities (e.g. crude oil wells, well platforms, production platforms, pipelines, oil tankers, and customers). There are some more contributions which will be explained in the following.

This chapter starts with an overview of the background of the oilfield development and crude oil transportation, in order to point out the contributions of the proposed model in this chapter. Afterwards, in Section 4.2, we describe the dimensions of the problem. In this section, a short overview of variables, parameters, assumptions and objectives is presented. In the following section, the mathematical model of the proposed problem is formulated. We present the constraints and explain the rationality behind each. Section 4.4 illustrates the instance generation procedure and the proposed sensitivity analysis. This section ends with discussions of the results. In the 'summary' section, we overview this chapter and discuss the conclusions briefly. Thereby, possible future directions are also recommended.

4.1 BACKGROUND

The strategic and tactical decisions related to the crude oil supply chain design and planning are reviewed, in the Subsection 2.5.3. The following classes of problems are addressed in upstream context: oilfield development (oilfield infrastructure investments and planning) and crude oil transportation. A vast number of potential locations for wells, well platforms, and production platforms (i.e. facility location problem), inteccontions of them with pipelines (allocation problems), and delivering the crude oil to customers (crude oil transportations) specify these problems. Oilfield development projects are costly, complex, risky, long-time planning problems. As a result, optimizing this segment of the crude oil industry is a challenging problem for the practitioners and managers. For this purpose, an integrated model of Upstream Crude Oil Supply Chain (UCOSC) is elaborated in this chapter. To better understanding of contributions, we summarize the papers related to the oil-field development and crude oil transportation problems in Table 4.1. We introduce a number of decision groups which are used to classify the literature in order to show our novelties. The following terms are employed to investigate papers reviewed.

- *Drilling planning (DP)* represents selecting the locations of wells from a predetermined set of potential points, and planning in which period, which wells should be drilled.
- *Platform Installation Planning (PIP)* determines which locations of a predetermined set of potential points are appropriate to install production platforms and well platforms. This term also plan that when platforms will be installed.
- *Production Planning (PP)* makes decision on the recovery volume of crude oil from wells, and on the volume of crude oil flows at each production platform.
- Due to the availability of the drilling rigs a limited number of wells will be able to be drilled in each period. Imposing this limitation is called *drilling rig constraint (DRC).*
- *Pipeline Capacity Selection (PCS)* is also an interesting challenge in this context.
- As shown in Table 4.1 all but three of the reviewed works took no account of the *existing wells (EW) and pipelines (EP)* (Aboudi et al., 1989; Haugen, 1996; Ulstein, Nygreen, & Sagli, 2007). In other words, most of the references assumed a green oil field and model the problem to find the best locations, allocations, plans etc. We study the existing wells and platforms as well as the potential ones (see Eqs. (4.43-4.46)). Sharing pipelines is an interesting possibility which is undertaken by considering the existing pipelines.

Table 4.1: Comparison of the integrated UCOSC model with the previous works.

References: Author(s) (year)	DP	PIP	PP	DRC	PCS	EW	EP	SL
Haugland et al. (1988)	✓	✓	✓					✓
Aboudi et al. (1989)			✓			✓	✓	
Jørnsten (1992)			✓					
Haugen (1996)			✓			✓	✓	
Iyer et al. (1998)	✓	✓	✓	✓				
Jonsbråten (1998)	✓	✓	✓					✓
Nygreen et al. (1998)			✓		✓			
van den Heever & Grossmann (2000)	✓	✓	✓					
van den Heever et al. (2000)	✓	✓	✓					
van den Heever et al. (2001)	✓	✓	✓		✓			
Aseeri et al. (2004)	✓	✓	✓	✓				
Goel and Grossmann (2004)	✓	✓	✓					
Carvalho & Pinto (2006a)	✓	✓	✓					
Carvalho & Pinto (2006b)	✓	✓	✓					
Goel et al. (2006)	✓	✓	✓					✓
Ulstein et al. (2007)			✓			✓	✓	
Tarhan et al. (2009)	✓	✓	✓					✓
Gupta & Grossmann (2012)	✓	✓	✓	✓				
The Current Work	✓	✓	✓	✓	✓	✓	✓	✓

- A minimum *service level for each customer (SL)* is also considered in order to ameliorate production flexibility and reliability. The reviewed works, with only four exceptions (Goel et al., 2006; Haugland et al., 1988; Jonsbråten, 1998; Tarhan et al., 2009), did not take demand planning (or flexibility) into consideration. The current model is allowed to find the best customer satisfaction level for each customer in each period (Eq. (4.26)).

At the other side, the crude oil transportation is of great importance within the crude oil supply chain. The crude oil supply chains initiate from the crude oil reservoirs and terminate at the delivery points (e.g., refinery, international markets and customers, spot market, etc.). The shipping crude oil from the oilfield to the refinery, entitled 'crude oil transport', is the first element of crude oil logistics network. The crude oil usually is transported through pipeline and carried via marine transports (i.e. oil tanker, vessel, and barge).

Crude oil transportation is an intriguing issue in the petroleum industry. The worldwide crude oil transportation problems were formulated individually with lack of concentration on oil field developments issues (Chen, Lu, & Qi, 2010; Iakovou & Douligeris, 1996; Sear, 1993). Iakovou (2001) addressed the maritime transportation of crude oil. The model supported a decision-maker who requires the crude oil and petroleum products transportation to and from several ports, in order to satisfy each port. Chen et al. (2010) optimized the configuration of the China import crude oil transportation network. 12 of the summarized works (Table 4.1) take into account oil field development and crude oil transportation. All of them only considered pipeline connections in their study. Merely two of these works considered the possibility of capacity selection for pipeline networks (Nygreen et al., 1998; van den Heever et al., 2001).

To have a seamless flow of crude oil from oil fields to supply local customers and/or international markets the current work emerges. As a result, one of the main novelties is that the current study tackles the crude oil transportation as well as oil field development in a single model.

4.2 PROBLEM STATEMENT

The problem that we deal with in this chapter is an integrated model of offshore oilfield development and crude oil transportation problems. We assume that there exist some proved oilfields containing a number of reservoirs. Each of them consists of several potential wells (W). A drilled and completed well it must be connected to a well platform (WP), to recover oil from it. The recovered oil is a mixture of water and crude oil. The recovered oil at WPs is pumped to production platforms (PP) through the pipes. The liquid is processed at PPs to separate out water. Thereafter, the crude oil will be pumped to the customers (C) via pipelines (PL) or will be carried by oil tankers (TK).

Table 4.2: Model notation , sets and indices

Symbol	Description
w	potential well, $w \in W = \{1, 2, \dots, \lvert W \rvert\}$
wp	potential well platform, $wp \in WP = \{1, 2, \dots, \lvert WP \rvert\}$
pp	potential production platform, $pp \in PP = \{1, 2, \dots, \lvert PP \rvert\}$
f	facility, $f \in F = \{w \cup wp \cup pp\}$
c	customer, $c \in C = \{1, 2, \dots, \lvert C \rvert\}$
tk	oil tanker types, $tk \in TK = \{1, 2, \dots, \lvert TK \rvert\}$
pl	pipeline types, $pl \in PL = \{1, 2, \dots, \lvert PL \rvert\}$
t	period, $t \in T = \{1, 2, \dots, \lvert T \rvert\}$

The problem makes investment, transportation, and operation decisions over a given planning horizon. Decisions for the project investment are selecting in which periods and at which potential points should Ws be drilled, and at what locations and in which periods WPs should and PPs be installed. In other words, investment embraces facility location-allocation as well as project planning decisions. Transportation decisions are capacity selection for the pipeline connections that are to be installed as well as the number of oil tankers and the amount of oil that should be delivered to the customers. Operation decisions concern the amount of oil extraction and production during each time period. The purpose is to optimize the complex economic tradeoffs that arise from the investment, transportation and operation decisions. The economic performance indictor in this model is the maximizing of the net present value of the project.

4.3 MATHEMATICAL FORMULATION

In this section, we first introduce the objective function and then present the constraints. The notation that will be used throughout the model is provided in Table 4.2-4.5.

Table 4.3: Model notation, parameters.

Symbol	Description
j_t^w	productivity index of the w^{th} well in the t^{th} period
pd_t^w	maximum pressure drop from the w^{th} well bore to well head in the t^{th} period
OWR_t^w	maximum oil-to-water flow ratio of the w^{th} well in the t^{th} period
U_t^{wp}	maximum extraction capacity of the wp^{th} well platform in the t^{th} period
U_t^{pp}	maximum production capacity of the pp^{th} production platform in the t^{th} period
U_t^{pl}	maximum capacity of the pl^{th} type of pipeline in the t^{th} period
UN_t^W	maximum number of wells which can be drilled during the t^{th} period
D_t^c	demand volume of the c^{th} customer in the t^{th} period
SL_t^c	service level of the c^{th} customer in the t^{th} period
I_t	discounting factor at the t^{th} period
Prc_t^c	sale price of oil for c^{th} customer in the t^{th} period per unit volume
BC_t^f	drilling or building cost of the f^{th} facility in the t^{th} period
BC_t^{pl}	installation cost of the pl^{th} type of pipeline per distance unit in the t^{th} period
FRC_t^{tk}	fixed rent cost per tk^{th} tanker in the t^{th} period
c_t^{tk}	transportation cost per distance unit per unit of crude oil volume carried by the tk^{th}
FOC_t^f	fixed operation cost of facility f in the t^{th} period
ExC_t^{wp}	extraction cost per unit of fluid extracted by the wp^{th} well platform in the t^{th} period
PrC_t^{pp}	production cost per unit of crude oil produced by the pp^{th} production platform in the t^{th} period t
$Lng^{(.\,,\,.)}$	length of the pipeline $(.\,,.) = \{(wp,pp)\,,(pp,c)\}$
$Dist^{pp,c}$	length of the maritime route between the pp^{th} production and cth customer
Cp^{tk}	capacity of the tk^{th} tanker

4.3.1 Objective Function

The objective function of this mathematical model is to maximize the net present value of the oilfield development projects and crude oil transportation. The net present value should be calculated using the profit and a discounting factor for each time period,

$$Max\ NPV = \sum_{t \in T} I_t\ PF_t \tag{4.1}$$

The money left over after covering costs represents profit. Therefore total revenue minus total costs determines it,

$$PF_t = Rev_t - TCost_t \qquad \forall t \tag{4.2}$$

Revenue is the received amount of money for selling products or services. It can be calculated by multiplying the total amount of oil sold to each customer (satisfied demand) and the sale price of oil in each time period,

$$Rev_t = \sum_c Prc_t^c \ \overline{D}_t^c \qquad \forall t \tag{4.3}$$

The total cost in each time period is the sum of capital, transportation, and operation costs,

$$TCost_t = CC_t^{Total} + TrC_t^{Total} + OpC_t^{Total} \qquad \forall t \tag{4.4}$$

Capital costs for every time period t come from drilling wells (CC_t^W), building well platforms (CC_t^{WP}), building production platforms (CC_t^{PP}), and building pipelines (CC_t^{PL}) in that period,

$$CC_t^{Total} = CC_t^W + CC_t^{WP} + CC_t^{PP} + CC_t^{PL} \qquad \forall t \tag{4.5}$$

Capital costs of wells, well platforms, and production platforms are calculated by the following equations,

$$CC_t^W = \sum_w (BC_t^w \ b_t^w) \qquad \forall t \tag{4.6}$$

$$CC_t^{WP} = \sum_{wp} (BC_t^{wp} \ b_t^{wp}) \qquad \forall t \tag{4.7}$$

$$CC_t^{PP} = \sum_p (BC_t^{pp} \ b_t^{pp}) \qquad \forall t \tag{4.8}$$

Table 4.4: Model notation, binary and integer variables.

Symbol	Description
b_t^f	1 if the f^{th} facility is drilled or built in the t^{th} period
$b_t^{(w,wp)}$	1 if the interconnection between the w^{th} well and the wp^{th} well platform is installed in period t
$b_t^{pl,(wp,pp)}$	1 if the pl^{th} type of pipelines is installed in the t^{th} period between wp and pp
$b_t^{pl,(pp,c)}$	1 if the pl^{th} type of pipelines is installed in the t^{th} period between pp and c
$open_t^f$	1 if the f^{th} facility is open in the t^{th} period
$open_t^{(w,wp)}$	1 if the interconnection between the w^{th} well and the wp^{th} well platform is open in the t^{th} period
$open_t^{pl,(wp,pp)}$	1 if the plth type of s is open in the t^{th} period between the wp^{th} well platform and the pp^{th} production platform
$open_t^{pl,(pp,c)}$	1 if the pl^{th} type of pipelines is open in the t^{th} period between pp and c
N_t^{tk}	number of the tk^{th} oil tanker in the t^{th} period

The capital costs of pipelines is calculated by taking the pipe cost per mile and multiplying it by the distance of facilities,

$$CC_t^{PL} = \sum_{wp}\sum_{pp}\sum_{pl} Lng^{wp,pp}\ BC_t^{pl}\ b_t^{pl,(wp,pp)} + \sum_{pp}\sum_{c}\sum_{pl} Lng^{pp,c}\ BC_t^{pl}\ b_t^{pl,(pp,c)} \qquad \forall t \qquad (4.9)$$

The building costs per mile of pipeline (BC_t^{pl}) vary according to the type of the installed pipe (pl) (as mentioned above).

The rent of oil tankers brings the transportation costs. The oil tankers vary in capacity and cost.

$$TrC_t^{Total} = \sum_{pp}\sum_{c}\sum_{tk}(N_t^{tk}\ FRC_t^{tk} + Dist^{pp,c} c_t^{tk}\ oil_t^{tk,(pp,c)}) \qquad \forall t \qquad (4.10)$$

Table 4.5: Model notation, continues variables.

Symbol	Description
$oil_t^{w,wp}$	extracted oil volume from the w^{th} well by the wp^{th} well platform in the t^{th} period
$water_t^{w,wp}$	extracted water volume from the w^{th} well by the wp^{th} well platform in the t^{th} period
$oil_t^{wp,pp}$	transported oil volume from the wp^{th} well platform to the pp^{th} production platform through the pipeline in the t^{th} period
$water_t^{wp,pp}$	transported water volume from the wp^{th} well platform to the pp^{th} production platform through the pipeline in the t^{th} period
fld_t^{wp}	total extracted fluids at the wp^{th} well platform in the t^{th} period
$oil_t^{pp,c}$	total transported crude oil volume from the pp^{th} production platform to the c^{th} customer in the t^{th} period
$oilpl_t^{pp,c}$	transported crude oil volume from the pp^{th} production platform to the c^{th} customer through the pipeline in the t^{th} period
$oiltk_t^{pp,c}$	transported crude oil volume from the pp^{th} production platform to the cth customer by oil tanker in the t^{th} period
$oil_t^{tk,(pp,c)}$	carried crude oil volume from the pp^{th} production platform to the c^{th} customer by the tk^{th} type of oil tankers in the t^{th} period
$\overline{D}_t^c$	satisfied demand of oil volume of c^{th} customer in the t^{th} period
NPV	net present value of the project
PF_t	total profit in the t^{th} period
Rev_t	total revenue in the t^{th} period
$TCost_t$	total cost in the t^{th} period
CC_t^{Total}	total capital cost in the t^{th} period
CC_t^f	capital cost of the f^{th} facility in the t^{th} period
CC_t^{PL}	capital cost of the pipeline network in the t^{th} period
TrC_t^{Total}	total transportation cost in the t^{th} period
OpC_t^{Total}	total operation cost in the t^{th} period
$ExtrC_t^{WP}$	extraction cost at the wp^{th} well platform in the t^{th} period
$ProC_t^{PP}$	production cost at the pp^{th} production platform in the t^{th} period

The operating expenditure is the sum of extraction costs at well platforms and production costs at production platforms,

$$OpC_t^{Total} = ExtrC_t^{WP} + ProC_t^{PP} \qquad \forall t \qquad (4.11)$$

The extraction costs include fixed operation costs and a linear function of the amount of the extracted fluid over all the well platforms,

$$ExtrC_t^{WP} = \sum_{wp} (FOC_t^{wp} open_t^{wp} + ExC_t^{wp} \, fld_t^{wp}) \qquad \forall t \qquad (4.12)$$

The production costs include fixed operation costs and a linear function of the amount of the oil produced at production platforms,

$$ProC_t^{PP} = \sum_{pp} (FOC_t^{pp} \, open_t^{pp} + PrC_t^{pp} \sum_{c} oil_t^{pp,c}) \qquad \forall t \qquad (4.13)$$

4.3.2 Constraints

4.3.2.1 Input and output balance constraints in the nodes:

The following constraints set up a balance between input and output oil and water flow of each well platform, each production platform, and each customer at the end of each planning horizon.

$$\sum_{w} oil_t^{w,wp} = \sum_{pp} oil_t^{wp,pp} \qquad \forall\, wp, t \qquad (4.14)$$

$$\sum_{w} water_t^{w,wp} = \sum_{pp} water_t^{wp,pp} \qquad \forall\, wp, t \qquad (4.15)$$

$$fld_t^{wp} = \sum_{w} oil_t^{w,wp} + \sum_{w} water_t^{w,wp} \qquad \forall\, wp, t \qquad (4.16)$$

$$\sum_{wp} oil_t^{wp,pp} = \sum_{c} oil_t^{pp,c} \qquad \forall\, pp, t \qquad (4.17)$$

$$\bar{D}_t^c = \sum_{pp} oil_t^{pp,c} \qquad \forall\, c, t \qquad (4.18)$$

The total transported crude oil from the pp^{th} platform to the c^{th} customer during time period t can be calculated by summing the total pumped crude oil and the total carried crude oil by ship/marine transport during time period t

$$oil_t^{pp,c} = oilpl_t^{pp,c} + oiltk_t^{pp,c} \qquad \forall\, pp, c, t \qquad (4.19)$$

The total amount of carried (pumped) crude oil during time period t is calculated by summing the carrying over all types of oil tankers (pipelines)

$$oiltk_t^{pp,c} = \sum_{tk} oil_t^{tk,(pp,c)} \qquad \forall\, pp, c, t \qquad (4.20)$$

$$oilpl_t^{pp,c} = \sum_{pl} oil_t^{pl,(pp,c)} \qquad \forall\, pp, c, t \qquad (4.21)$$

4.3.2.2 Capacity Constrains:

The oil flow rate from well w to wp can be calculated using the oil-to-water ratio and the water flow rate of that well in time period t. The upper bound of oil recovered from an open well is limited by the productivity index of the well and the allowable pressure drop,

$$\sum_{wp} oil_t^{w,wp} \leq (1 + OWR_t^w)\,|t| \sum_{wp} water_t^{w,wp} \qquad \forall\, w, t \qquad (4.22)$$

$$\sum_{wp} oil_t^{w,wp} \leq \ j_t^w\, pd_t^w\, |t| open_t^w \qquad \forall\, w, t \qquad (4.23)$$

Oil and water can be extracted from a well and pumped to a well platform during time period t if there is an available well platform in that time period and if the sum of fluids is less than the upper bound of the well platform. Extracted oil and water should be pumped to a platform, and the total volume must be less than the capacity of that production platform

$$fld_t^{wp} \leq \ U_t^{wp} open_t^{wp} \qquad \forall\, wp, t \qquad (4.24)$$

$$\sum_{wp} (oil_t^{wp,pp} + water_t^{wp,pp}) \leq \ U_t^{pp}\, open_t^{pp} \qquad \forall\, pp, t \qquad (4.25)$$

The customers' demand can be satisfied completely or at least the customer's service level should be guaranteed.

$$SL_t^c . D_t^c \leq \overline{D}_t^c \leq D_t^c \qquad \forall\, c, t \qquad (4.26)$$

To consider the genuine drill rig limitations, the inequality (4.27) states that the number of the drilled wells should be less than a specific number in each period. The total transported crude oil by tk^{th} type of oil tankers is less than the number of tk^{th} type tanker times its capacity

$$\sum b_t^w \leq UN_t^W \qquad \forall\, t \qquad (4.27)$$

$$\sum \sum oil_t^{tk,(pp,c)} \leq Cp^{tk} N_t^{tk} \qquad \forall\, tk, t \qquad (4.28)$$

4.3.2.3 Interconnection and pipe connection constraints:

Wells, well platforms, and production platforms should be connected by pipelines. The extracted oil should be pumped from the available well platforms to the available production platforms. After that crude oil can be pumped through pipelines or be transported by oil tankers to customers.

The interconnection between the w^{th} well and the wp^{th} well platform is available if the w^{th} well and the wp^{th} well platform are both available in the t^{th} period. Note that only one type of pipe is taken into account for the interconnection of Ws and WPs.

$$open_t^{(w,wp)} \leq open_t^w . open_t^{wp} \qquad \forall\, w, wp, t \qquad (4.29)$$

Similarly, the pipeline between a well platform and a production platform can be ready if both the well platform and the production platforms are available in the t^{th} period. The pipeline between platform pp and customer c will be ready if pp is ready for production

$$open_t^{pl,(wp,pp)} \leq open_t^{wp} . open_t^{pp} \qquad \forall\, pl, wp, pp, t \qquad (4.30)$$

$$open_t^{pl,(pp,c)} \leq \ open_t^{pp} \qquad \forall\, pl, pp, c, t \qquad (4.31)$$

Notice that the equations (4.29) and (4.30) are quadratic and should be linearized before implemented a general MILP solver (i.e. CPLEX). The following equations remove the non-linear terms in the model.

$$open_t^{(w,wp)} \leq open_t^{w} \qquad \forall\, w, wp, t \qquad (4.32)$$

$$open_t^{(w,wp)} \leq open_t^{wp} \qquad \forall\, w, wp, t \qquad (4.33)$$

$$open_t^{pl,(wp,pp)} \leq open_t^{wp} \qquad \forall\, pl, wp, pp, t \qquad (4.34)$$

$$open_t^{pl,(wp,pp)} \leq open_t^{pp} \qquad \forall\, pl, wp, pp, t \qquad (4.35)$$

Obviously, oil and water can be pumped through pipelines if interconnections and pipelines are ready during time period t. The following constraints mean that the fluids can be transported by a connection, if the connection and both nodes of the connection are available. Inequalities (4.37) and (4.38) impose the capacity constraints of pipe types (pl) on the flows. For example, Inequality (4.37) states that the stream of liquid is acceptable between wp and pp if there exists a pipeline (of type pl) to link them. The amount of this flow should also be less than the total capacity of pipe pl during the period t.

$$oil_t^{w,wp} + water_t^{w,wp} \leq U_t^{wp} . open_t^{(w,wp)} \qquad \forall\; w, wp, t \qquad (4.36)$$

$$oil_t^{wp,pp} + water_t^{wp,pp} \leq \sum_{pl} U_t^{pl} . open_t^{pl,(wp,pp)} \qquad \forall\; wp, pp, t \qquad (4.37)$$

$$oilpl_t^{pp,c} \leq \sum_{pl} U_t^{pl} . open_t^{pl,(pp,c)} \qquad \forall\, pp, c, t \qquad (4.38)$$

4.3.2.4 Building and opening constraints:

Facilities can be created only once (Eq. 4.39). A well can be interconnected, at most, to one well platform only once (Eq. 4.40). A WP can be connected to at most one PP, only one time via one type of pipeline (pl), as shown by Eq. 4.41. But a PP can supply more than one customer via only one pipeline per customer which has to be installed only once before (Eq. 4.42).

$$\sum_{t} b_t^{f} \leq 1 \qquad \forall\, f \qquad (4.39)$$

$$\sum_{t}\sum_{wp} b_t^{(w,wp)} \leq 1 \qquad \forall\, w \qquad (4.40)$$

$$\sum_{pl}\sum_{pp}\sum_{t} b_t^{pl,(wp,pp)} \leq 1 \qquad \forall\, wp \qquad (4.41)$$

$$\sum_{pl}\sum_{t} b_t^{pl,(pp,c)} \leq 1 \qquad \forall\, pp, c \qquad (4.42)$$

The number of facilities, pipelines, and interconnections available to operate during time period t can be determined by summing up the available facilities during the period $t-1$ and those that were built during period $t-1$,

$$open_t^f = open_{t-1}^f + b_{t-1}^f \qquad \forall\, f, t \qquad (4.43)$$

$$open_t^{(w,wp)} = open_{t-1}^{(w,wp)} + b_{t-1}^{(w,wp)} \qquad \forall\, w, wp, t \qquad (4.44)$$

$$open_t^{pl,(wp,pp)} = open_{t-1}^{pl,(wp,pp)} + b_{t-1}^{pl,(wp,pp)} \qquad \forall\, pl, wp, pp, t \qquad (4.45)$$

$$open_t^{pl,(pp,c)} = open_{t-1}^{pl,(pp,c)} + b_{t-1}^{pl,(pp,c)} \qquad \forall\, pl, pp, c, t \qquad (4.46)$$

Eqs. (4.43-4.46) provide the capability to manage the availability and possibility of facilities and connections and by setting $open_t^f$ or $open_t^{pl,(\,.\,,\,.\,)}$ one or zero. For example, if facility f is available, we set the $open_{t=0}^f = 1$. In addition, for example, if the connection of W th well to WP th platform is impossible, we will set $open_{t-T}^{(w,wp)} = 0$.

Since this problem is defined in a fixed network, the model size depends on the size of the index and parameter sets. Therefore, the number of constraints is calculated as follows:

$$\begin{aligned} &|T|(3|W| + 5|WP| + 3|PP| + 2|C| + |TK| + 4|W||WP| + |WP||PP| \\ &\quad + 3|PP||C| + 3|WP||PP||PL| + 2|PP||C||PL| + 1) \\ &\quad +2|W| + 2|WP| + |PP| + |PP||C| \end{aligned} \qquad (4.47)$$

The number of variables is determined as follows:

$$|T|(2|W| + 3|WP| + 2|PP| + |C| + |TK| + 4|W||WP| + 2|WP||PP| + 3|PP||C| + |PP||C||TK| + 2|PP||C||PL| + 2|WP||PP||PL|) \tag{4.48}$$

The number of parameters is calculated as follows:

$$|T|(4|W| + 4|WP| + 4|PP| + 3|C| + 2|TK| + 2|PL| + 1) + |WP||PP| + 2|PP||C| + |TK| \tag{4.49}$$

4.4 COMPUTATIONAL EXPERIMENTS

4.4.1 Instance Generation

For the purposes of computational studies, instances have been generated with different key parameters. Specific data have been modified according to a real-world (RW) example, provided by the Iranian National Oil Company in the Persian Gulf.

- Problem dimension: Instances have been generated with different dimensions. The key parameters for defining the dimensions are the number of potential wells, periods in the time horizon, and customers. Therefore, the instances are summarized by (# potential wells, # periods, # customers), e.g. a (5, 8, 5) problem is an instance in which the number of potential wells, periods, and customers is five, eight, and five, respectively.

- Time horizon: One of the most critical parameters in planning problems is the length of the planning horizon. As calculated in Eqs. (42) and (43), the model size directly depends on the length of indices and parameters. As a result, it is clear that by extending the time horizon the difficulty grows rapidly. In the next section, a sensitivity analysis is presented to find the impact of changing the time horizon on the results of the instances (see Section 4.2.1).

- Potential Wells: The number of potential wells for each offshore field within each period can be different. In Section 4.2.2 a sensitivity analysis on an instance with (*, 5, 5) dimension is performed.

- Drilling and installing cost: The costs to drill wells, set up platforms, and install pipelines have been generated and then adapted from the RW instance. All costs were compounded by discounting rate over time.

- Distances and transportation: All distances have been calculated approximately by detecting the place of facilities on the map. The costs to rent oil tanker have been generated for different kinds of oil tankers according to the original RW instance.

- All other parameters are generated so that the RW data can approve them. That means, the differences between them can be negligible.

4.4.2 Sensitivity Analysis

Mathematical practitioners from different disciplines and regulatory agencies worldwide agree on the significance of a precise Sensitivity Analysis (SA). of model-based inference. Sensitivity analysis is broadly defined as "the study of how the uncertainty in the output of a model (numerical or otherwise) can be apportioned to different sources of uncertainty in the model input" (Saltelli, Tarantola, Campolongo, & Ratto, 2004). On the other hand, SA is a technique to investigate how different values of an input variable will impact on outputs of the model. The most popular sensitivity analysis practice seen in the literature is that of one-factor-at-a-time (OAT). This consists of analyzing the effect of changing one factor at a time while keeping all others fixed (Saltelli & Annoni, 2010). OAT is carried out on this mathematical model for two key parameters, time horizon and potential wells.

To find an exact solution for the instances, the mathematical model is coded by CPLEX 12.2. Instances' data are generated and exported to EXCEL. The experiments are based on all instances or on a certain subset. Working with EXCEL becomes more effective while running a sensitivity analysis. For this purpose, the EXCEL environment is one of the best ones for changing parameters easily. In addition, it can interface with CPLEX without difficulty. In the remainder of this section, a sensitivity analysis has been performed with respect to time horizon and potential wells, in that order.

4.4.2.1 The length of the planning horizon

As mentioned in the previous section, the length of the planning horizon has a significant impact on the severity of the problem. For this reason, an RW instance with (8, *, 5) dimension is considered to perform the SA on it. The dimension states that the instance has eight potential wells and five customers with a variable number of time horizons. The impact of various planning horizons is investigated by performing SA.

In order to perform sensitivity analysis, the length of the planning horizon varies from 4 up to 24 years. According to Section 4.1, data is generated and adapted in each instance. Then each instance is solved by CPLEX 12.2. For more robustness of the solution times the program is executed at least three times for each instance. The average of the solution times is considered for each instance to analysis. The results of the SA with respect to time horizon are summarized in Table 4.6.

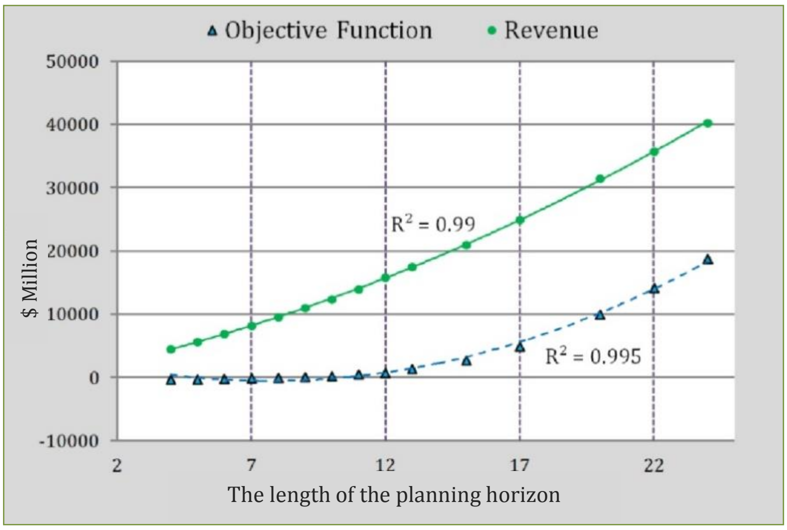

Figure 4.1: Objective function and revenue over the length of the planning horizon.

Table 4.6: The results of sensitivity analysis with respect to the length of the planning horizon.

Period	Solution time	Objective Function	Revenue	Capital cost	Oil tanker cost	Installed Pipeline
4	17,1	-321,15	4480,1	216,49	4572,8	-
5	25,9	-292,00	5702,1	216,49	5761,5	-
6	58,1	-239,67	6941,2	216,49	6946,4	-
7	50,9	-150,63	8208,9	322,08	8016,2	Local
8	58,2	-51,79	9592,6	323,26	9258,5	-
9	314,1	86,436	10968	357,64	10477	-
10	408,6	261,35	12425	370,84	11707	-
11	268,9	13925	8208,9	371,09	13031	-
12	202,2	745,74	15858	3827,5	11237	Local +Asia 1
13	219,7	1335,30	17464	3828,8	12249	-
15	238,2	2694,20	20938	8222,8	11705	Local , Asia 1+Asia 2
17	654,8	4930,10	24914	10189,0	9729,4	Local , Asia 1, Asia 2 +Africa
20	195,3	9948,38	31454	21321,3	158,74	Local , Asia 1, Asia 2, Africa + Europe
22	214,8	14169,50	35755	21321,3	0	All pipelines
24	267,0	18718,00	40318	21326,6	0	All pipelines

The table shows the financial results and solution times for all variants of the length of planning horizons. Planning for longer horizons, the objective function as well as the revenue increases. The capital costs increase although. Interestingly, this issue is observed by running an SA on different RW instances. Note that the revenue depends on the total amount of sales and also on the oil price. Both of these factors increase resulting in increases revenue. Figure 4.1 presents the revenue and the objective function over the length of the planning horizon. Note that the trade line is quadratic whereas R^2 is approximately 1 both, for the revenue as well as for the objective function. Therefore, the quadratic trade lines are approximated highly accurately. Thus, the length of the planning horizon has a significant direct impact on the values of the objective function and the revenue.

Table 4.6 shows us another important relationship among the capital costs, oil tanker costs, and pipeline costs as well as the time horizon. It can be observed that there is an inverse relationship between capital costs and oil tanker costs versus the length of the planning horizon (see Figure 4.2). Note that the transportation costs include oil tanker costs and pipeline network extension costs. The costs for oil tankers decrease with an increase in pipeline network extension costs and vice versa. As a result, these costs are related inversely with each other. Hence, the capital costs will be increased by adding a new pipeline, while oil tanker costs will be decreased. Figure 4.2 clarifies this fact. For instance, when the problem is planning for 11 years, the optimal planning is to install only a pipeline between production platform and local customer. By adding one year to the planning horizon, the results indicate that it is time to expand the pipeline network and install a pipeline for customer Asia 1 (Table 4.6). At this point, the capital cost shoots up, because of installing a new pipeline, whereas the oil tanker cost falls down. In the same way, at all peak points there is a new pipeline installation. According to Table 4.6, when the project is planned to deal with the customers for longer than 20 years, it is the opportune time to expand the pipeline network by connecting all customers to PP. In summary, the longer the time horizon, the higher the awkwardness to transport by oil tankers, and the more convenient the time to invest in pipelines.

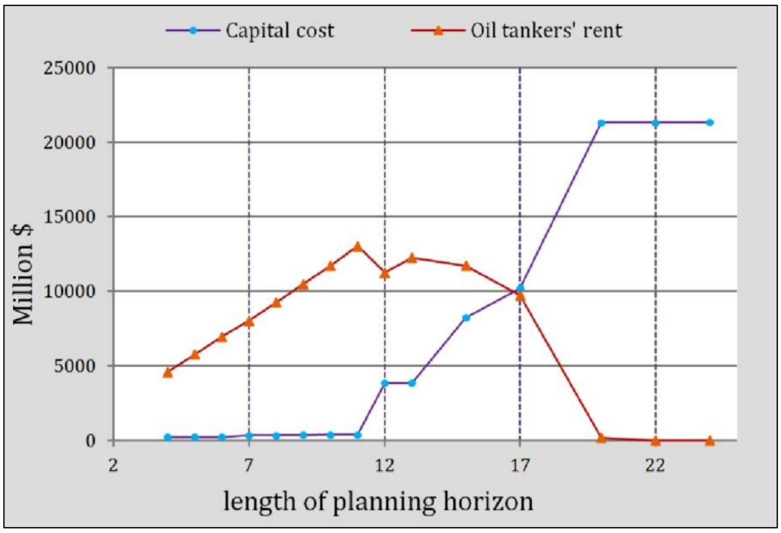

Figure 4.2: Capital costs and oil tanker costs over the length of the planning horizon.

We now explore the impacts of different planning horizons on financial outputs. We first investigate the difficulty of solving the problem for variant lengths of the time horizon. The solution time is illustrated in Figure 4.3. At first glance, this figure seems to be erratic. Nonetheless, it shows us several notable consequences. In this chart, two downward trends from 10 to 12 and from 17 to 20 are going against a long-term upward trend. In another words, as expected, the difficulty of the problem generally increases by extending the time horizon of planning. The exception at some points can be explained by comparing Figures 4.3 and 4.2. Interestingly, it can be found that while a new pipeline is installed, the difficulty of the problem is followed by a sharp drop-off. If a pipeline is available, transporting crude oil through it is more economical than carrying it by oil tankers. Thus, when a pipeline between a production platform and a customer is installed, the necessity of studying the corresponding set of oil tanker variables is resolved. Having less number of variables, the severity of the problem declines significantly and results in a decrease in the solution time.

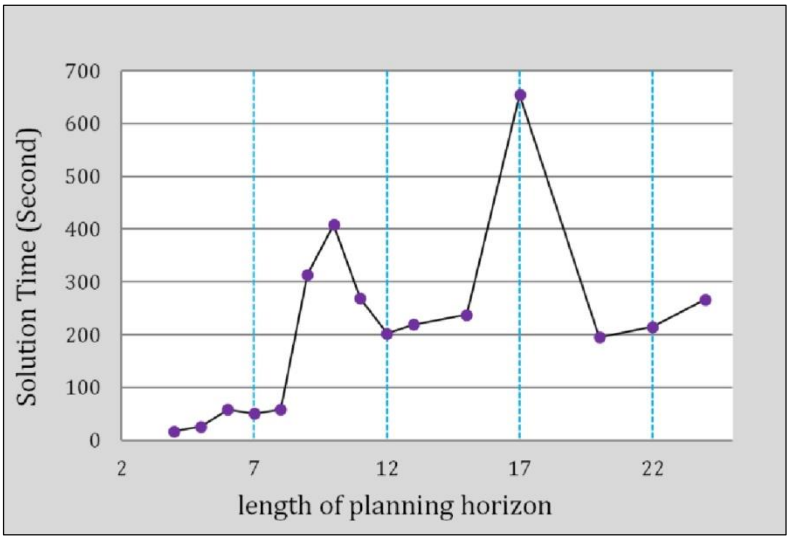

Figure 4.3: Solution time over the length of the planning horizon.

4.4.3 Potential Wells

This model has six major components; wells, well platforms, production platforms, customers, oil tankers, and pipelines. Among these, the set of potential wells can include a larger number. In addition, oil wells are the first link of the supply network. Hence, a feasible solution can be found if at least one well is drilled. In that case, all the other variables can get positive values once at least one potential well starts operating. Therefore, the number of potential wells has a significant impact on the results and complexity of the problem.

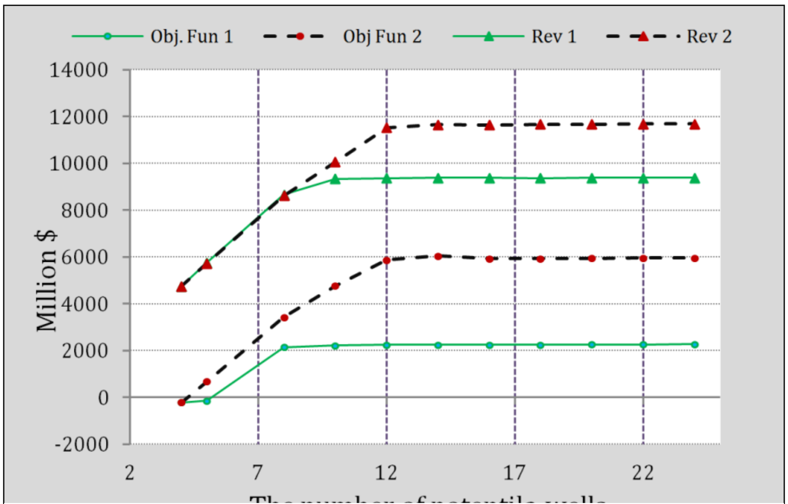

Figure 4.4: Sensitivity analysis with respect to the number of potential wells.

To perform a sensitivity analysis with respect to the number of potential wells, two original instances were generated. All parameters were adapted from the RW instances. The relationship between the optimal solutions of the problem and the number of potential wells is presented in Figure 4.4.

It can be observed in the figure that both (set) instances follow a similar trend and behavior. Note the impact of the number of the potential wells on the objective functions and revenues. Figure 4.4 reveals a severe increase in revenue with respect to the number of potential wells up to a certain point after which the revenue becomes almost unaffected by the number of potential wells. This point depends on the original instance. Each RW instance has a certain optimal number of wells which can be determined by solving the RW instance. This number shows the optimal number for drilling wells. In other words, if the problem is solved with a big number of potential wells, this certain number equals to the total number of drilled wells. After this point (hereafter it is called 'certain point'), there is virtually no change over the number of potential wells. In this situation, adding a new potential well will not have a significant effect on the difficulty and financial outputs. Nevertheless, at this point, the objective function in actual fact increases very slightly. This arises as a new potential well might have a better productivity and less drilling cost than the previously drilled ones. So drilling this well might cause less capital costs for drilling and better income of selling more oil.

Up to the certain point, the trade lines of the objective functions and revenues are quadratic in the number of the potential wells. All instances are solved fairly well with reasonable solution times. Experiments show that the solution times increase exponentially by adding a new potential well before reaching the certain point. As expected, after the certain point, there is a mild increase in the severity of the problem.

4.5 SUMMARY

In this chapter, we studied the UCOSC. Section 4.1 overviewed the background of the strategic and tactical decisions which are involved in this context. As described in this section, integrating the oilfield development and crude oil transportation is an interesting possible research direction which has been ignored until now. The other contributions of the proposed model were also summarized in a table in this section. In Section 4.2 the assumed problem was explained. Afterwards we presented a mixed integer model for the design and planning of offshore oilfields, in Section 4.3. Our model extends the classical facility location-allocation problems by several features. Beside some well-known aspects of multi-period, multi-commodity, multi-capacity levels and multi-location levels, we additionally considered aspects like production planning and project (well drilling and platforms installation) planning. Further, the model supports the selection of the transportation system and the planning of pipeline networks installations. The transportation alternatives and facility location-allocation, to the best of our knowledge, have not yet been addressed in the offshore oil literature simultaneously. In other words, some papers have only considered facility location and the others considered the transportation. It is clear that a key factor that has a significant impact on facility location decisions is transportation alternatives. There are two main kinds of transportation alternatives for crude oil in offshore field; oil tankers and pipelines. Both of these systems are considered in the current model.

Instances have been generated on the basis of a large variety of different properties, in Section 4.4. Carrying out the experiment on these examples showed how the different problem features effect the difficulty to solve the problem. The reasonable solution times proved the capability of general purpose solvers like CPLEX to solve the model up to a realistic size. The one-factor-at-a-time sensitivity analysis has been carried out by varying the length of the planning horizon and the number of potential wells. The sensitivity analysis showed that the complexity, the objective value and the revenue increase with a growing time horizon. Additionally, the SA encouraged more investment in the pipeline network in the case of longer planning horizons. Finally, we have seen that the objective function values improve quadratically with respect to the number of potential wells (up to the certain number of such wells).

Even though most of the instances can be solved in reasonable time, some of very large scale problems remain unsolved. To solve these cases, more sophisticated approaches are required such as mathematical decomposition, heuristic or Meta heuristic methods. An interesting extension for future models is the possibility of uncertainty of parameters like demand, price, and costs as well as nonlinearity of some constraints. In addition, the sensitivity analysis should be carried out further to understand the effects of uncertainty of model parameters on model outputs. Besides, capital investments in pipeline infrastructure, pumping costs are also important aspects that should be taken into account in future studies.

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Chapter Five

Environmentally Conscious Design of the Upstream Crude Oil Supply Chain

Outline

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The significant impact of oil in our daily live is indubitable. This industry also plays a vital role in the modern global economy, owning to the fact that it is the number one source of energy in the world. For instance, in 2010, about 41.2% of the world's total primary energy demand and 92.6% of transportation fuels are supplied through this industry. Moreover, the oil consumption has an increasing trend which will continue in the near future. Since oil reserves are limited, the importance of oil companies for the global economy becomes more significant. Hence, these companies are amongst the most profitable ones, all over the world.

During the last two decades, more stringent environmental regulations and lower-margin profits have caused a tighter competition in oil industry. In the oil industry, just like in every industry, companies endeavor to gain competitive advantage. Achieving competitive advantage strengthens and positions an oil company better within the industry; guaranteeing a long-term success. Competitive advantage theory suggests that businesses should pursue policies that produce high-quality goods at the lowest cost in the industry. Oil companies can gain a competitive advantage through creation of an effective “green” supply chain. Thus a vital instrument for oil industry to achieve competitive advantages is supply chain management. Christopher (2011) proposes that a company with efficient supply chain can improve and retain their competitive advantages over the rival companies. As a result, SCM can provide the best design of crude oil network to satisfy the demands preferably on the most value added and cost effective level. In this light, we consider supply chain management concepts as a fundamental framework to design the crude oil network by formulating a basic model in this chapter.

Additionally, there is an increasing will that organizations should capture the environmental impacts in their functions. To take environmental thinking into account, in this chapter, we analyze the environmental impact of the upstream crude oil supply chain via the Eco-indicator 99 which is founded on the Life Cycle Assessment (LCA) principles. We start with studying the background of this problem, in Section 5.1. Then, Section 5.2 describes the main features of the problem, followed by formulating the mathematical programming model in Section 5.3. In order to show the application of this model and to figure out the computational burden of this problem, Section 5.4 is provided. Finally, in Section 5.5 we give an overview on this chapter.

5.1 PROBLEM BACKGROUND

SCM commonly denotes the management of a complex and dynamic network of integrated companies or organizations that are involved in satisfying the final customer. It is obvious that the management and making decision about of this integrated network requires extensive efforts (Mirzapour Al-E-Hashem, Malekly, & Aryanezhad, 2011; Papageorgiou, 2009). Decisions made in the supply chain, mainly, vary according to the range of collaborated activities within the logistics network (spatial or horizontal integration), and vary according to the time scales of integrated of decisions (vertical or temporal integration: strategic, tactical and operational). Traditionally, decisions in a SC are fallen into three hierarchical levels. The key distinction between these decisions lies in their planning horizon. The strategic decisions cope with a rather long-time horizon of, perhaps in the oil industry, 5 to 20 years. The tactical level may deal with the time horizon of 6-24 months. Operational decisions covers only up to one week.

The crude oil industry supply chain consists of the same levels of decisions (strategic, tactical, and operational). In this context, oil supply chain models optimize a number of subsystems of this network, e.g. oilfield development, refinery planning, crude oil transportation, and distribution (Shah, Li, & Ierapetritou, 2010). One of the main problems that create a center of attention in this context is the oil field development. The problem embodies substantial required investment, long planning horizon, and a vast number of potential locations for crude oil wells, well platforms, production platforms, and their pipeline interconnections (Shah et al., 2010). As a result, oilfield development addresses a complicated, critical and costly undertaking in the crude oil SC. The other reason behind the picking up this kind of problem is the significant importance of strategic and tactical levels which is also evidenced by Goetschalckx et al. (2011). They reviewed the literature relevant to global logistics (supply chain). The results demonstrated that long-range survival, in today's global business world, will be very hard to accomplish without efficiently optimized strategic and tactical global supply chain plans. Strategic and tactical supply chain models can lead to savings in the 5-10% range, thus, can substantially improve the profits of the crude oil supply chain. Consequently, the current thesis which is concentrated only on the strategic and tactical levels is a motivated study to do. In addition, about one third of the published oil supply works are focused on oil field development. This high percentage proves the necessity of this study. Some recent works are of (Aseeri, Gorman, & Bagajewicz, 2004; Carvalho & Pinto, 2006; Gupta & Grossmann, 2012; Hayashi, Ligero, & Schiozer, 2010; van den Heever, Grossmann, Vasantharajan, & Edwards, 2000, 2001; Tarhan, Grossmann, & Goel, 2009).

As previously mentioned, the stricter environmental regulations led to an increasing interesting among oil companies to address the environmental impacts of their functions. In literature, the topic of environmentally conscious design, in the SCM context, has been studied employing several terms. The two popular topics that intertwined the SCM concepts and environmental impacts of supply chain activities are sustainable supply chain management (SSCM) and green supply chain management (GSCM) (Ashby, Leat, & Hudson-Smith, 2012). Recently, a number of literature reviews, which have been carried out on these two areas, those are(Abbasi & Nilsson, 2010; Ashby et al., 2012; Carter & Easton, 2011; Carter & Rogers, 2008; Gimenez & Tachizawa, 2012; Sarkis, Zhu, & Lai, 2011; Seuring, Sarkis, Müller, & Rao, 2008; Srivastava, 2007). An underlined issue in the previous reviews is the plethora of definitions for the SSCM and GSCM, both. Overall, in almost all of the definitions of GSCM, environmental thinking integrated into SCM problems as the central point of concern, while a broader perspective, including the social issues as well, adapted to define SSCM (Ahi & Searcy, 2013).

The scientific society has not yet agreed among themselves to use a universal metric to measure environmental impacts. This fact has motivated academics to study a plethora of environmental indicators. Among them, those are founded on Life Cycle Assessment framework are nowadays becoming the prevalent approach (Pozo, Ruíz-Femenia, Caballero, Guillén-Gosálbez, & Jiménez, 2012). The LCA is an environmental analysis of all the life cycle phases of the process, product, or activity, including extraction of raw materials; production, transportation and distribution; recycling, final disposal. Since, the outputs of a Life Cycle Assessment is too complicated to interpret, some methods are designed to translate them into metrics. One of the main schools of methods is the Eco-indicator 99 (Eco99) in which the environmental impact of the problem is measured (see Section 5.3.2). The standard Eco-indicator value is a suitable way to compare relative differences among distinct solutions of a problem, to help the management makes best decision.

Various methodologies, from mathematical point of view, are used in the literature of crude oil supply chain to avoid environmental damage as part of the SCM.

In this context, modeling practitioners considered the environmental impact as a constraint on operations and merely as a management objective. There are several publications on oil supply chain that include quality (properties) constraints (e.g. (Alabi & Castro, 2009; Al-Qahtani & Elkamel, 2008; Carneiro, Ribas, & Hamacher, 2010; Escudero, Quintana, & Salmerón, 1999; Leiras, Elkamel, & Hamacher, 2010; Neiro & Pinto, 2005; Neiro & Pinto, 2004; Ulstein, Nygreen, & Sagli, 2007)). The quality is indicated by the chemical structure. Some quality indicators represent the content of single elements while others show weighted summations of a number of components (Ulstein et. al, 2007). Within the capabilities of specifying quality constraint, we are able to manage the amount of Greenhouse Gas emissions, wastes, and other pollutants. Therefore, it makes sense to interpret the quality constraints as environmental conscious constraints. The only oil supply chain model which is taken environmental impact into account directly belongs to Elkamel et al. (2008). In this work, a mixed-integer nonlinear programming model is proposed to plan refinery production by achieving optimal profit. Meanwhile, by using different CO_2 mitigation options, they attempt to decrease CO_2 emissions to a given target. To the best of our knowledge, there exists a few works that take environmental impacts of crude oil supply chain operations into account as objective functions. Additionally, transportation and utilities consumptions are the main origins of emissions through the supply chains. The energy required for operating upstream facilities in crude oil supply chain accounts for massive energy consumption. Whereas, the shipping (i.e. crude oil tankers and supply vessels) is one of the world's highest polluting combustion origins per unit of fuel used (Kutz, Elkamel, & Abdul-Wahab, 2010).

In nutshell, the stricter environmental regulations triggers off a growing interest among oil companies to take environmental thinking into account. As previously reviewed, the topic of environmentally conscious design, within the crude oil SCM context, has been ignored with a few exceptions. Almost all of these papers use quality constraints and focuses only on the refinery planning, with no care of the environmental impact of the crude oil transportation and of the oil field development. This chapter intends to bridge the gap between the upstream crude oil supply chain design and environmentally conscious design.

5.2 PROBLEM STATEMENT

As described before, this thesis aims to study the network design within upstream segment of crude oil supply chain (UCOSC), and this chapter is provided to consider economic and environmental performances, simultaneously. The current network is assumed to embrace some proved fields, which consist of several wells. The wells would be opted from pre-defined points of potential locations, to be drilled. To complete the wells and to extract oil from it, one or more extracting technology should be established from a predefined set of potential technologies. After extracting the hydrocarbons, since the recovered oil is a mixture of water and crude oil, it should be cleaned to improve economic and environmental performances (Sahebi & Nickel, 2013). Therefore, the extracted hydrocarbons are pumped, through the installed pipes, to the established production platforms. These production platforms also will be picked out from a dozens of potential locations in which, it is possible to install one or more producing technologies. At the production platforms, storing technologies are also will be selected from a predefined set. Storage tanks are necessary to store process condensate, water or brine, liquefied natural gas (LNG), crude oil, as well as other materials used or produced throughout the crude oil processes. Crude oil is transported from the production platforms to customers (i.e. markets and refineries) commonly by oil tankers and pipelines, and rarely via rail cars, tank trucks, and barges. In this study, we will consider maritime transportations and pipeline network as transportation means.

The assumed problem is a typical network design, which is involving the facility location (i.e. locations of extracting and producing sites form a pre-selected set of potential locations), the facility allocation (i.e. assigning the wells to the production platforms, and the platforms to the customers), the technology selections with respect to the capacity, cost, and environmental impacts (i.e. choice of associated technological processes to extraction, production, and storage; and selection of pipes and oil tankers), the establishment planning (i.e. when the selected technology and/or connections will be established), as well as the flows of materials within the supply chain will be determined. Level of production and storage are constrained.

From an economical point of view, fixed investment costs to establish entities (i.e. drilling cost, capital cost of technologies, and the pipelines), operational costs, inventory costs, and transportation costs will be taken into account, simultaneously, with net earnings. To calculate net earnings, tax rate and salvage value are also taken into account.

In environmental assessment methodology, the LCA methodology is considered as a basis, and using the Eco-indicator 99 to calculate the life cycle inventory and introduce the damages in resource Depletion *(RD),* human health *(HH),* and ecosystem quality *(EQ).*

5.3 MATHEMATICAL FORMULATION

The supply network design model illustrated hereinabove should optimize two conflicting objectives. The economic performance is considered to be the Net Present Value, whilst the environmental performance is assessed by the Eco99 (Goedkoop & Spriensma, 2000). In this section, we first introduce the objective function and then present the constraints. The notation that will be used throughout this chapter is provided in Tables 5.1-5.5.

Table 5.1: Sets and indices.

Symbol	Description
W	potential wells, $w \in W = \{1, 2, \dots, \lvert W \rvert\}$
PP	potential production platforms, $pp \in PP = \{1, 2, \dots, \lvert PP \rvert\}$
G	potential extracting technologies at ws, $g \in G = \{1, 2, \dots, \lvert G \rvert\}$
$\bar{G}$	potential producing technologies at pps, $\bar{g} \in \bar{G} = \{1, 2, \dots, \lvert \bar{G} \rvert\}$
$\bar{\bar{G}}$	potential storing technologies at pps, $\bar{\bar{g}} \in \bar{\bar{G}} = \{1, 2, \dots, \lvert \bar{\bar{G}} \rvert\}$
C	customers, $c \in C = \{1, 2, \dots, \lvert C \rvert\}$
TK	oil tankers types of 3LPs to collaborate, $tk \in TK = \{1, 2, \dots, \lvert TK \rvert\}$
PL	pipeline types, $pl \in PL = \{1, 2, \dots, \lvert PL \rvert\}$
T	period, $t \in T = \{1, 2, \dots, \lvert T \rvert\}$

5.3.1 UCOSC-Economic Model

Eqs. (5.1)-(5.9) allow to determine the NPV. The net present value is the summation of total cash flows (TCF_t), attained in each period t, and discounted with interest rate i:

$$f_1(x, y) = NPV = \sum_t TCF_t / (1 + i)^{t-1} \quad (5.1)$$

The total cash flow, in the t^{th} period, is calculated from subtracting the fraction of the total depreciable capital ($FTDC_t$) from the net earnings, as stated in Eq. (2a).

$$TCF_t = NE_t - FTDC_t \qquad t = 1, \dots, T - 1 \quad (5.2a)$$

A fraction (sv) of the total capital investments ($TFCI$) can be sold and salvaged, at the end of the time horizon. In the last period, to calculate the total cash flow, taking this amount into account is of the essence. This fraction, which denotes the salvage value of the supply chain, can vary according to the type of technologies, and facilities.

$$TCF_t = NE_t - FTDC_t + svTFCI \qquad t = T \quad (5.2b)$$

Table 5.2: Economic parameters.

Symbol	Description
$\overline{C_t^{w}}$	extraction capacity of the w^{th} well in t
$\overline{C_t^{\mathrm{g}}}$	upper bound on extraction capacity of the g^{th} technology in the t^{th} period
$\underline{C_t^{\mathrm{g}}}$	lower bound on extraction capacity of the g^{th} technology in the t^{th} period
$\overline{C_t^{\bar{\mathrm{g}}}}$	upper bound on production capacity of the $\bar{\mathrm{g}}^{\text{th}}$ technology in the t^{th} period
$\underline{C_t^{\bar{\mathrm{g}}}}$	lower bound on production capacity of the $\bar{\mathrm{g}}^{\text{th}}$ technology in the t^{th} period
$\overline{C_t^{\bar{\bar{\mathrm{g}}}}}$	upper bound on storage capacity of the $\bar{\bar{\mathrm{g}}}^{\text{th}}$ technology in the t^{th} period
ξ^{pp}	balance coefficient for lower bound of storage capacity associated with pp
$\overline{C_t^{w,pp}}$	upper bound on flows between w and pp in the t^{th} period
$\overline{C_t^{pl}}$	upper bound on transportation capacity of pipeline pl in the t^{th} period
$\overline{C_t^{tk}}$	upper bound on transportation capacity of oil tanker tk in the t^{th} period
$\overline{D_t^{c}}$	maximum demand of crude oil at market c in the t^{th} period
$\underline{D_t^{c}}$	minimum demand of crude oil to be satisfied at market c in the t^{th} period
$\overline{TFCI}$	maximum fixed capital investment in the t^{th} period
owr_t^{w}	maximum oil-to-water flow rate of the w^{th} well in the t^{th} period
i	Interest rate
sv	salvage value
ϑ	tax rate
ρ_t^{c}	price of crude oil sold at market c in the t^{th} period
φ_t^{w}	operating cost to drill the wth well in the t^{th} period
$\upsilon_t^{\mathrm{g},w}$	operating cost of the g^{th} extracting technology available at well w a per unit of fluid in the t^{th} period
$\upsilon_t^{\bar{\mathrm{g}},pp}$	operating cost of the $\bar{\mathrm{g}}^{\text{th}}$ producing technology available at platform pp a per unit of fluid in the t^{th} period
$\pi_t^{\bar{\bar{\mathrm{g}}},s}$	maintenance cost of the $\bar{\bar{\mathrm{g}}}^{\text{th}}$ storing technology available at platform pp a per unit of capacity in the t^{th} period
γ_t^{tk}	transportation cost per distance unit of oil tanker tk in the t^{th} period
γ_t^{pl}	transportation cost, to send per unit of crude oil through pipe pl in the t^{th} period
$\delta^{pp,c}$	distance between platform pp and market c
$\beta_t^{\mathrm{g},w}$	fixed investment term associated with the g^{th} technology at well w in the t^{th} period
$\beta_t^{\bar{\mathrm{g}},pp}$	fixed investment term associated with the $\bar{\mathrm{g}}^{\text{th}}$ technology at pp in the t^{th} period
$\beta_t^{\bar{\bar{\mathrm{g}}},pp}$	fixed investment term associated with the $\bar{\bar{\mathrm{g}}}^{\text{th}}$ technology at pp in the t^{th} period
$\beta_t^{w,pp}$	fixed investment term to establish a transport link between w and pp in the t^{th} period
$\beta_{pl.t}^{pp,c}$	fixed investment term to establish a pipeline pl between pp at c in the t^{th} period

Table 5.3: Environmental parameters.

Symbol	Description
μ_{EN}^{g}	energy consumed to extract per unit of oil with the gth technology
$\mu_{EN}^{\bar{g}}$	energy consumed to produce per unit of oil with the $\bar{g}^{th}$ technology
μ_{EN}^{tk}	energy consumed to transport per unit of crude oil per unit of distance by tk
μ_{EN}^{pl}	energy consumed to transport per unit of crude oil per unit of distance by pl
ξ_{p}^{EN}	quantity of pollutant p emitted to generate an unit of energy consumed
ϵ_{p}^{g}	quantity of pollutant p emitted to extract an unit of fluids by the gth technology
$\epsilon_{p}^{\bar{g}}$	quantity of pollutant p emitted to produce an unit of fluids the $\bar{g}^{th}$ technology
$\epsilon_{p}^{\bar{\bar{g}}}$	quantity of pollutant p emitted to store by the $\bar{g}^{th}$ technology
ϵ_{p}^{PL}	emissions of pollutant p per unit of crude oil transported one unit of distance through pipeline
ϵ_{p}^{pl}	emissions of pollutant p to transport one unit of crude oil per unit of distance through the pl^{th} pipeline
ϵ_{p}^{tk}	emissions of pollutant p to transport per unit of crude oil one unit of distance by tk
$\theta_{p,d}$	damage factor of pollutant p contributing to damage category d
ω_{d}	weighted value of the damages d

Eq. (5.3) states the net earning in period t which comes from the difference between the sales revenues ($SRev_t$) and the total variable cost. In this case, sales of crude oil determine revenues (Eq. (5.4)), whereas the total variable cost embraces: 1) drilling cost of selected potential wells, 2) cost associated with extraction technologies (g) operating at wells, 3) the operating costs associated with producing technologies ($\bar{g}$) at production platforms, 4) the maintenance cost of storing technology ($\bar{\bar{g}}$) available at platform, and 5) the cost of transporting materials or crude oil between the production platforms and customers/markets by oil tanker and/or pipeline, as appeared in Eq. (5.5).

$$NE_t = (1-\vartheta)\,(SRev_t - TVC_t) + \vartheta Dep_t \qquad \forall t \qquad (5.3)$$

$$SRev_t = \sum_{c}\sum_{pp} \rho_t^c QL_t^c \qquad \forall t \qquad (5.4)$$

$$TVC_t = \sum_{w} \varphi_t^{w} X_t^{w} + \sum_{w} \sum_{\text{g}} \upsilon_t^{\text{g},w} Q_t^{\text{g},w} + \sum_{pp} \sum_{\bar{\text{g}}} \upsilon_t^{\bar{\text{g}},pp} Q_t^{\bar{\text{g}},pp} + \sum_{pp} \sum_{\bar{\bar{\text{g}}}} \overline{C_t^{\bar{\bar{\text{g}}}}} \pi_t^{\bar{\bar{\text{g}}},pp} Y_t^{\bar{\bar{\text{g}}},pp} + \sum_{tk} \sum_{pp} \sum_{c} \gamma_t^{tk} \delta^{pp,c} NX_{tk,t}^{pp,cc} + \sum_{pp} \sum_{c} \sum_{pl} \gamma_t^{pl} \delta^{pp,c} QL_{pl,t}^{pp,c} \quad \forall t \quad (5.5)$$

In Eq. (5.3), ϑ represents the tax rate (Eq. (5.6) states the depreciation of the capital invested, Dep_t), whereas ρ_t^c , in Eq. (5.4), is the prices of crude oil at market c in period t. Furthermore, φ_t^w denotes the operating cost to drill the potential well w in period t, and the parameters $\upsilon_t^{\text{g},w}$ and $\upsilon_t^{\bar{\text{g}},w}$represent the operating cost of extracting technology g available at w, the operating cost of producing technology $\bar{\text{g}}$ at pp for a per unit of fluids in period t, respectively. Moreover, $\pi_t^{\bar{\bar{\text{g}}},pp}$denotes the maintenance cost of storing technology $\bar{\bar{\text{g}}}$ at pp for per unit of capacity in period t. To calculate the transportation cost in period t, the distance between platforms and markets is given by $\delta^{pp,c}$, whereas $\gamma_t^{tk}$and γ_t^{pl} are the transportation cost of an oil tanker tk per distance unit, and the transportation cost of pipe pl to send per unit of crude oil per distance unit in period t, in order.

$$Dep_t = \frac{(1 - sv)TFCI}{T} \quad \forall t \quad (5.6)$$

The straight-line method is assumed to calculate the depreciation of the capital invested (Dep_t), as shown in Eq. (5.6).

Eq. (5.7a) calculates the total fixed capital investment, and an upper bound is imposed on the fixed capital investment in each period by Eq. (5.7b).

$$TFCI = \sum_{t} FCI_t \quad (5.7a)$$

$$FCI_t \leq \overline{TFCI} \quad \forall t \quad (5.7b)$$

Table 5.4: Continuous variables.

Symbol	Description
$Q_t^{g,w}$	amount of extracted fluid associated with technology g at well w in the t^{th} period
Q_t^{w}	extracted fluid from the w^{th} in the t^{th} period
$Q_t^{w,pp}$	flows sent from well w to production platform pp in the t^{th} period
$Q_t^{\bar{g},pp}$	input flows to process by technology $\bar{g}$ at production platform pp in the t^{th} period
Q_t^{pp}	input flows at the pp^{th} production platform in the t^{th} period
QL_t^{pp}	output crude oil flows from the pp^{th} production platform in the t^{th} period
$QL_t^{pp,c}$	crude oil flows from the pp^{th} production platform to the customer c in the t^{th} period
$QL_{tk,t}^{pp,c}$	amount of crude oil carried from production platform pp to customer c by tk in t
$QL_{pl,t}^{pp,c}$	amount of crude oil transported from production platform pp to customer c through pipeline pl in the t^{th} period
QL_t^{c}	input crude flows at the cth customer in the t^{th} period
NPV	net present value
TCF_t	total amount of cash flow in the t^{th} period
NE_t	net earnings in the t^{th} period
$FTDC_t$	fraction of the total depreciable capital that must be paid in the t^{th} period
FCI_t	fixed capital investment in the t^{th} period
$TFCI$	total amount of fixed capital investment
$SRev_t$	sale revenue in the t^{th} period
TVC_t	total variable cost in the t^{th} period
Dep_t	amount of depreciation term in the t^{th} period
UE_p	quantity of pollutant p emitted associated with utilities consumptions
DE_p	quantity of pollutant p emitted associated with direct processes
LCI_p	life cycle inventory associated with pollutant p emitted
Dam_d	total impact in damage category d
$Eco99$	value of total Eco-indicator 99

Here, the parameter, FCI_t, represents the fixed cost investment in the t^{th} period, which is computed from the technology establishments and the transportation pipeline installations, as stated in Eq. (5.8).

$$FCI_t = \sum_{w}\sum_{g}\beta_t^{g,w}X_t^{g,w} + \sum_{pp}\sum_{\bar{g}}\beta_t^{\bar{g},pp}X_t^{\bar{g},pp} + \sum_{pp}\sum_{\bar{\bar{g}}}\beta_t^{\bar{\bar{g}},pp}X_t^{\bar{\bar{g}},pp} + \sum_{w}\sum_{pp}\beta_t^{w,pp}X_t^{w,pp} \quad \forall t \qquad (5.8)$$

Table 5.5: Binary and integer variables.

Symbol	Description
$X_t^{i,j}$	1 if the ith technology is establishing at j in the t^{th} period ; $(i,j) \in TN = \{(\text{g}, w), (\bar{\text{g}}, pp), (\bar{\bar{\text{g}}}, pp)\}$
$Y_t^{i,j}$	1 if the ith technology is established at j until period t; $(i,j) \in TN$
X_t^w	1 if the wth well is drilling in the t^{th} period
Y_t^w	1 if the wth well is drilled until period t
$X_t^{w,pp}$	1 if a link between w and pp is installing in the t^{th} period
$Y_t^{w,pp}$	1 if a link between w and pp is installed until period t
$X_{pl,t}^{pp,c}$	1 if pipeline pl between pp and c is installing in the t^{th} period
$Y_{pl,t}^{pp,c}$	1 if pipeline pl between pp and c is installed until period t
$NX_{tk,t}^{pp,c}$	number of the tk^{th} oil tankers are assigned to linkage of pp to c in the t^{th} period

In this equation, the parameters $\beta_t^{\text{g},w}$, $\beta_t^{\bar{\text{g}},pp}$, and $\beta_t^{\bar{\bar{\text{g}}},pp}$ are the fixed investment terms corresponding to extracting technologies at wells, producing technologies and storing technologies at platforms, respectively. Whereas, $\beta_t^{w,pp}$ and $\beta_{pl,t}^{pp,c}$ denote the fixed investment factors related to the installation of pipeline between wells and platforms, and platforms customers, in order.

Finally, a uniform distribution (equally distributed amount over the time) is assumed to pay the total fixed capital investment back, as shown in Eq. (5.9):

$$FTDC_t = \frac{TFCI}{T} \qquad \forall t \qquad (5.9)$$

5.3.2 UCOSC-Life Cycle Assessment Model

A Life Cycle Assessment model should assess the whole life cycle of the crude oil, from reservoir extraction, “cradle”, to use phase and disposal phase, “grave”. However, in this particular case, the environmental assessment is focused on the upstream crude oil supply chain. According to the LCA taxonomy, we consider a “cradle-to-gate” assessment that includes all the functions of crude oil supply chain from the recovery of crude oil to the delivery of cleaned crude oil to customers/markets. However, this thesis is not focused on the midstream and the downstream functions, i.e. transformation, distribution, secondary processing, product-use and disposal.

As discussed before, in this chapter we consider the Eco-indicator 99 approach to measure the environmental performances. The Eco-indicator 99 consist of three steps: **1)** accumulating the inventory of all environmental burdens (all relevant pollutants) from all the procedure that configure the life cycle of upstream crude oil supply chain which is called Life Cycle Inventory, **2)** indicating the damages via the Eco99 indicator datasheets, and **3)** closeting with the sum weighting of the damages.

In this section, a specific formulation for the upstream segment of oil industry is presented. We represent a "pollutant" index p as all the substances released. The main emission sources associated with the UCOSC can be fold into two broad groups; utility consumptions, and direct emissions.

5.3.2.1 Utility Consumptions

As mentioned previously, a main trigger for pollutants within the crude oil supply chains are the maritime crude oil transportation and utilities consumptions. The common transportation modes in the UCOSC are oil tankers and pipeline network. Emissions (e.g. nitrogen oxides) from maritime transportation seriously threaten the environment. Crude oil tankers are the world's highest the root cause of the emissions per unit of fuel consumed (Kutz et al., 2010). Additionally, the energy required for operating pump stations of crude oil pipelines accounts for massive energy consumption (either electrical or fossil fuels) (Abbasi & Garousi, 2010). In addition, the utilities consumptions at the wells and at the production platforms are also considerable.

We assumed that these sources of the emissions in the UCOSC are triggered by: (1) diesel consumption for maritime oil transportation, that is related to the distance between platforms and markets, to the quantity of crude oil, and to the oil tanker type used; (2) fossil fuels/electricity consumption in pump stations of pipeline network, that is according to the distance between two nodes, to the amount of transportation, and to the pipeline type used; and (3) the fossil fuels/electricity consumed in the extracting and producing processes. As a result, the total quantity of emitted pollutants within the UCOSC can be defined as Eq. (5.10).

$$UE_p = \xi_p^{EN} \left(\sum_w \sum_g \sum_t \mu_{EN}^{g} Q_t^{g,w} + \sum_{pp} \sum_{\bar{g}} \sum_t \mu_{EN}^{\bar{g}} Q_t^{\bar{g},pp} + \sum_{pp} \sum_c \sum_{tk} \sum_t \mu_{EN}^{tk} \delta^{pp,c} QL_{tk,t}^{pp,c} + \sum_{pp} \sum_c \sum_{pl} \sum_t \mu_{EN}^{pl} \delta^{pp,c} QL_{pl,t}^{p,c} \right) \quad \forall p \quad (5.10)$$

Here, the parameters μ_{EN}^{g} /$\mu_{EN}^{\bar{g}}$ are the energy used per unit of oil extracted/produced by technology g/ḡ. While $\mu_{EN}^{tk}$and μ_{EN}^{pl} are the energy consumed to transport per unit of crude oil by oil taker tk and pipeline pl per unit of distance, respectively. The ξ_p^{EN} is the emitted quantity of pollutant p to generate a unit of energy EN consumed.

5.3.3 Direct Emission of Processes

Emissions associated with the UCOSC are not restricted to the consumption of energy in utilities. The other source of emissions is the direct emission, which include

- ***Fugitive*.** Equipment leak is called fugitive emissions which are due to the leaks from sealed surfaces of oil equipment. The main fugitive sources are specific equipment components for instance connectors, flanges and valves. The oilfield extraction and producing activities associated with some specific equipment that trigger for fugitive emissions. This particular equipment includes pump stations, wellheads, pipelines, separators, and heater treaters.

- ***Wastewater*.** If the generated wastewater opens to the atmosphere, the VOC, HAP, CH, and HS are potentially released into the environment. The units used to transfer, store, and treat wastewater (e.g. oil/water separators, brine tanks, storage tanks, pits, and sumps) should be isolated. Some of these units in the upstream are.

- ***Storage Tank***. Storage tanks can be a possible root cause of VOC, HAP, CH emissions stations.

- ***Transportation***. The pollutants emit within crude oil transportation due to loading losses, pigging emissions, and fugitive pipeline leakage.

- ***Processes***. Generally, three potential emission sources are related to any process, emissions from fuel combustion, equipment leaks, and exhausted/vented gases from them.

Avoiding double consideration of the life cycle inventory; the current emission inventory should only compute the direct emissions of the main processes under study. Hence, the total pollutants quantity emitted directly within the upstream can be determined by Eq. (5.11).

$$\begin{aligned} DE_p = &\sum_{w}\sum_{g}\sum_{t}\epsilon_p^{g}Q_t^{g,w} + \sum_{pp}\sum_{\bar{g}}\sum_{t}\epsilon_p^{\bar{g}}Q_t^{\bar{g},pp} \\ &+ \sum_{pp}\sum_{\bar{\bar{g}}}\sum_{t}\epsilon_p^{\bar{\bar{g}}}\overline{C_t^{\bar{\bar{g}}}}Y_t^{\bar{\bar{g}},pp} + \sum_{w}\sum_{pp}\sum_{t}\epsilon_p^{PL}\delta^{w,pp}Q_t^{w,pp} \\ &+ \sum_{pp}\sum_{c}\sum_{pl}\sum_{t}\epsilon_p^{pl}\delta^{pp,c}QL_{pl,t}^{pp,c} \\ &+ \sum_{pp}\sum_{c}\sum_{tk}\sum_{t}\epsilon_p^{tk}\delta^{pp,c}QL_{tk,t}^{pp,c} \end{aligned} \qquad \forall p \qquad (5.11)$$

In this equation, the parameters ϵ_p^{g}, $\epsilon_p^{\bar{g}}$, and $\epsilon_p^{\bar{\bar{g}}}$ quantity of pollutant p emitted to extract per unit of fluids by technology g, to produce a unit of fluids by technology $\bar{g}$, to store by technology $\bar{\bar{g}}$, in order. Finally, the ϵ_p^{PL}, ϵ_p^{pl}, and ϵ_p^{tk} are the direct emissions of pollutant p to transport per unit of material one unit of distance by pipeline between w and pp, by pl between pp and c, and by tk between pp and c, respectively.

5.3.3.1 Pollutant inventory

The pollutants inventory, which is the total quantity of pollutants released, obtains from the summation of Eqs. (5.10) and (5.11).

$$LCI_p = UE_p + DE_p \qquad \forall p \qquad (5.12)$$

5.3.4 Environmental Impact

The environmental impact of the current problem is measured by the three categories of damage, as mentioned before. Following the Eco-indicator 99 approach, to calculate these damages, the pollutant inventory will be normalized by the given impact factors. In the following equation, $\theta_{p,d}$ shows the impact of per unit of emitted pollutant p on the damage category d.

$$Dam_d = \sum_p \theta_{p,d} LCI_p \qquad \forall d \qquad (5.13)$$

Finally, the weighted-sum method is applied to calculate the total environmental impact, the Eco-indicator 99 value, of these damages. In Eq. (5.14), the ω_d represents the normalized weight of damages d.

$$\boldsymbol{f_2(x,y) = Eco99 = \sum_d \omega_d Dam_d} \qquad (5.14)$$

5.3.5 UCOSC- Network Design Model

To formulate UCOSC-network, we inspired and modified the constraints of the mathematical model proposed in Chapter 4 (Sahebi & Nickel, 2013). In our model, the technology constraints are also taken into account.

5.3.5.1 Mass balance constraints:

Flows mass balance has to be satisfied in all nodes, in every instant t. The mass balances associated with this network are expressed via constraints (5.15) - (5.19).

$$Q_t^w = \sum_g Q_t^{g,w} = \sum_{pp} Q_t^{w,pp} \qquad \forall t, w \qquad (5.15)$$

$$\sum_w Q_t^{w,pp} = Q_t^{pp} = \sum_{\bar{g}} Q_t^{\bar{g},pp} \qquad \forall t, pp \qquad (5.16)$$

Eqs. (5.15) and (5.16) shows the mass balance at wells and platforms, so that the total extracted flows by all associated extracting technologies equal the total outflows from the current well to platforms, and the inflows to a production platform is the summation of all inflows to associated producing technologies. In the same way, the mass balance for outflows of production platforms are appeared in Eqs. (5.17)-(5.18). At the end of network, in customer nodes, the mass balance must be satisfied, as stated in Eq. (5.19).

$$QL_t^{pp} = \sum_c QL_t^{pp,c} \qquad \forall t, pp \qquad (5.17)$$

$$QL_t^{pp,c} = \sum_{tk} QL_{tk,t}^{pp,c} + \sum_{pl} QL_{pl,t}^{pp,c} \qquad \forall t, pp, c \qquad (5.18)$$

$$\sum_{pp} QL_t^{pp,c} = QL_t^c \qquad \forall t, c \qquad (5.19)$$

5.3.5.2 *Capacity Constrains:*

***Wells*:** The oil flow from well w to platform pp is calculated, in period t, using the oil-to-water ratio and the flow from that well w to production platform pp, as shown in Eq. (5.20). In addition, Eq. (5.21) imposes an upper bound on extracted flows from wells.

$$\sum_w owr^w Q_t^{w,pp} \geq QL_t^{pp} \qquad \forall t, pp \qquad (5.20)$$

$$Q_t^w \leq \overline{C_t^w} Y_t^w \qquad \forall t, w \qquad (5.21)$$

Technologies: Furthermore, the amount of fluids being processed by a technological procedure (i.e. g, $\bar{g}$, and $\bar{\bar{g}}$) in associated sites, must be within the given upper and lower capacity bounds of available technologies, Eqs. (5.22)-(5.23). Note that the storage capacity at a production platform must be more than a fraction (ξ^{pp}) of total produced crude oil at that production platform, Eq. (5.24).

$$\underline{C_t^{g}}\, Y_t^{g,w} \leq Q_t^{g,w} \leq \overline{C_t^{g}}\, Y_t^{g,w} \qquad \forall t, w, g \qquad (5.22)$$

$$\underline{C_t^{\bar{g}}}\, Y_t^{\bar{g},pp} \leq Q_t^{\bar{g},pp} \leq \overline{C_t^{\bar{g}}}\, Y_t^{\bar{g},pp} \qquad \forall t, pp, \bar{g} \qquad (5.23)$$

$$\xi^{pp}.QL_t^{pp} \leq \sum_{\bar{\bar{g}}} \overline{C_t^{\bar{\bar{g}}}}\, Y_t^{\bar{\bar{g}},pp} \qquad \forall t, pp \qquad (5.24)$$

Transportation links: The amount of fluids sent from wells to production platforms, and from production platforms to customers must lie under the upper bounds of the corresponding provided transportation link, as shown in Eqs. (5.25)-(5.27).

$$Q_t^{w,pp} \leq \overline{C^{w,pp}} Y_t^{w,pp} \qquad \forall t, w, pp \qquad (5.25)$$

$$QL_{pl,t}^{pp,c} \leq \overline{C_t^{pl}} Y_{pl,t}^{pp,c} \qquad \forall t, pp, c, tk \qquad (5.26)$$

$$QL_{tk,t}^{pp,c} \leq \overline{C_t^{tk}} NX_{tk,t}^{pp,c} \qquad \forall t, pp, c, tk \qquad (5.27)$$

Customers: floating of the crude oil demands within some given upper and lower bounds are allowed. This flexibility makes it possible to optimize the environmentally conscious design of crude oil supply chain by studying the trade-off between the added value of satisfying demand and the total cost of the design over the planning horizon.

$$\underline{D_t^c} \leq QL_t^c \leq \overline{D_t^c} \qquad \forall t, c \qquad (5.28)$$

5.3.5.3 *Building and opening constraints:*

In this model, X_t^i represents binary variable which is 1 if the i^{th} facility (i.e. well, techonologies, and transportation links) will be establishing in period t. Whereas, Y_t^i will be 1 if the i^{th} facility will be established/open in the t^{th} period. Eq. (5.29) shows the logical relationship between them. Eqs. (5.30) and (5.31) state that each facility can be installed only one time, and a well can connect at most to one production platform, respectively.

$$\boldsymbol{Y_t}^* = \boldsymbol{Y_{t-1}}^* + \boldsymbol{X_{t-1}}^* \qquad \forall \boldsymbol{t} \qquad (5.29)$$

$$\sum_t X_t^* \leq 1 \qquad \forall t \qquad (5.30)$$

$$\sum_{pp} \sum_t X_t^{w,pp} \leq 1 \qquad \forall w \qquad (5.31)$$

5.4 RESULTS AND DISCUSSIONS

5.4.1 Solution to the Multi-Objective Problem

A large number of approaches have been presented to optimize the multi-objective programming models. Among them, the goal-programming technique, the ε constraint technique, the weighted-sum are more popular among them. These techniques convert the multi-objective functions of the initial model into a set of single-objective function models. Since, dealing with single objective functions model is markedly easy, these techniques are vastly used in this context (Guillén-Gosálbez, Caballero, & Jimenez, 2008). Being able to generate and suggest a specified set of different solutions, to compare the objectives between them, to take the decision-makers' considerations into account, specifically, the weighted-sum technique is applied in this model. The weighted-sum technique multiplies the vector of objective function by a given vector of weights. Note that it makes sense only if all the objectives are measured exactly by the same unit. For this purpose, we normalize the objective functions, as follow.

To normalize the objective functions, we optimize a single objective model considering the other objectives as constraints limited by some permissible bounds. Therefore, the following single MILP programming model is optimized to determine the best solution of the NPV objective:

$$\begin{aligned} & f_1(x_1^*, y_1^*) = \max\{f_1(x,y)\} \\ & \quad \text{S.T.} \\ & \qquad f_2(x,y) \leq \vartheta \\ & \qquad g(x,y) = 0 \\ & \qquad h(x,y) \leq 0 \\ & \quad x \in \mathcal{R}^n, y \in \{0,1\}^m \end{aligned} \qquad \text{(Prob1)}$$

The resulting (x_1^*, y_1^*) determints the best value of the economic objective and the worst value of environmental conscious objective function. Therefore, we call the $f_1(x_1^*, y_1^*) = \overline{NPV}$, and $f_2(x_1^*, y_1^*) = \overline{Eco99}$. Thus if problem (Prob1) is optimized to all possible values of ϑ and the resultant (x_1^*, y_1^*) are unique, the entire

Pareto solution set of the original multiobjective model is obtained. The other extreme sets of the objectives can be calculated by optimizing the following problem:

$$
\begin{aligned}
& f_2(x_2^*, y_2^*) = \min\{f_2(x,y)\} \\
& \text{S.T.} \\
& \quad f_1(x,y) \geq \acute{\vartheta} \\
& \quad g(x,y) = 0 \\
& \quad h(x,y) \leq 0 \\
& \quad x \in \mathcal{R}^n, y \in \{0,1\}^m
\end{aligned}
\qquad \text{(Prob2)}
$$

Then, $f_2(x_2^*, y_2^*) = \underline{Eco99}$ and $f_1(x_2^*, y_2^*) = \underline{NPV}$. The normalized values of these objective functions are:

$$\widetilde{f_1}(x,y) = \left(f_1(x,y) - \underline{NPV}\right)/(\overline{NPV} - \underline{NPV})$$

$$\widetilde{f_2}(x,y) = \left(\overline{Eco99} - f_2(x,y)\right)/(\overline{Eco99} - \underline{Eco99})$$

Assume that a panel of expert decided to consider the w_1 , and w_2 as the weights of the net present value and of the Eco-indicator value, respectively, to calculate the weighted-sum of the objective functions. Consequently, the weighted-sum of normalized objectives is the problem (Prob3).

$$
\begin{aligned}
& \text{Max } f_3(x,y) = w_1\widetilde{f_1}(x,y) + w_2\widetilde{f_2}(x,y) \\
& \text{S.T.} \\
& \quad h(x,y) = 0 \\
& \quad (x,y) \leq 0 \\
& \quad x \in \mathcal{R}^n, y \in \{0,1\}^m
\end{aligned}
\qquad \text{(Prob3)}
$$

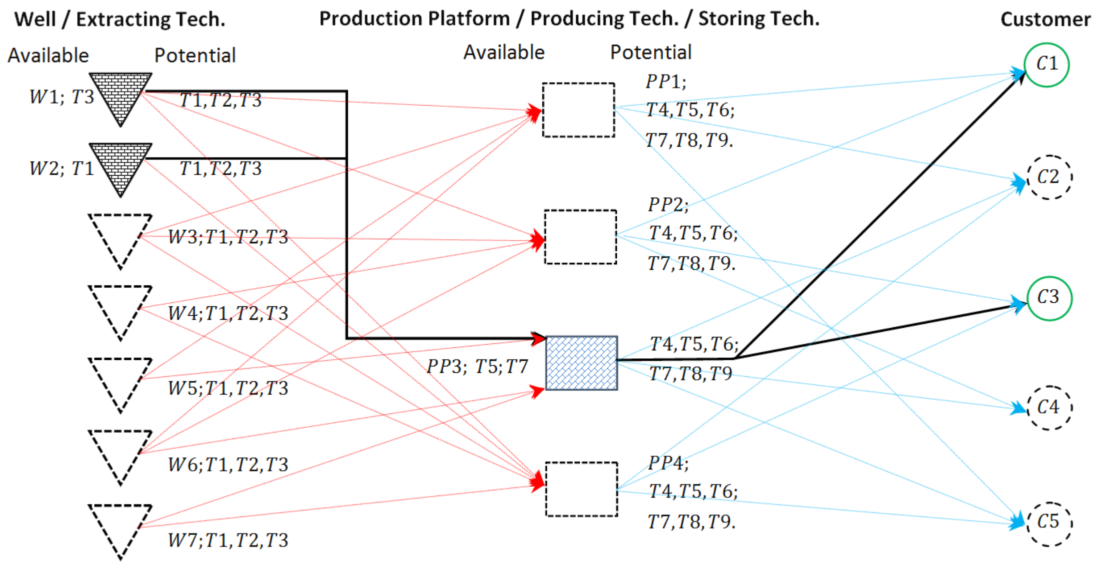

Figure 5.1: The available/potential Upstream Oil Supply Chain.

Solid line shapes and arrows show the available facilities and links, respectively.
Dash line shapes and arrows show the potential facilities and links, respectively.

5.4.2 Case Study

The case study chosen to illustrate the application and computational effectiveness addresses an existing UCOSC established in Persian Gulf. We compare different available technologies for extraction, production, and storage processes in terms of environmental and economic performance. The studied SC comprises crude oil extraction wells (W), production platforms (PP), storage tanks, transportation means and customer places (C). Two wells (i.e. $W1$ and $W2$ which are associated with extracted technologies $T3$ and $T1$, respectively); one production platform (i.e. $PP3$ associated with production technology $T5$ and storage technology $T7$); and two pipeline from $PP3$ are already established to supply the customers $C1$ and $C3$. The demand is expected to increase, since the previous markets are growing and the oil company proposes to supply several new customers (i.e. $C2$, $C4$, and $C5$). Hence, the problem deals with determining if capacity expansion of the existing facilities is better or opening some new other. Figure 5.1 is depicted the simplified potential super-structure of the case study.

Table 5.6: The data associated with oil wells

Oil Well	Capacity (MBs /Y)[a]	Oil-to-Water Rate	Drill Cost $1 X 10^6
W1	4.731	0.805	0 (drilled)
W2	4.715	0.924	0 (drilled)
W3	4.457	0.805	12.38
W4	4.907	0.839	13.63
W5	4.627	0.836	12.85
W6	4.908	0.895	13.64
W7	4.904	0.897	13.6
Period Rate [b]	-3%	-2%	+3%

a- Million Barrels per Year
b- increase/decrease rate in each period

.

To specifically introduce the problem, it is essential to explain all input data. Description of all data is impossible, although. Therefore, the most important data associated with the problem is given in Tables 5.6-5.11. Table 5.11 displays the main environmental data, whilst the remaining facility, technology, and cost data are explained in Tables 5.6–5.10. Additionally, the salvage value, the tax rate, and the interest rate are assumed to be 25%, 14%, and 8%, respectively.

Fourteen yearly planning periods are assumed. The implementation in IBM ILOG CPLEX Optimization Studio 12.5 leads to a MILP model with 6168 constraints, 3095 continuous variables, 840 integer variables, and 3920 binary variables. It takes about 10 minutes to accomplish a solution with a 0% integrality gap on an Intel Core i7-3520M, CPU Duo 2.9GHz, computer. Since an optimal solution is achieved in around 10 minutes, we do not explain running time solution in detail.

Table 5.7: Matrix of distances (Km) between the oil wells and the production platforms.

	PP1	*PP2*	*PP3*	*PP4*
W1	85.4	97.6	89.9	68.6
W2	74.1	66.8	83.0	99.5
W3	67.7	64.5	75.7	40.3
W4	71.6	53.0	103.4	71.6
W5	109.0	99.5	82.3	77.1
W6	63.1	60.5	78.6	56.2
W7	112.8	44.7	109.3	49.0

Table 5.8: The data associated with the potential technologies.

Technology		Capacity (MBs /Y)		Capital Cost
		Upper Bound	Lower Bound	\$1 X 10^5
Potential Extracting Technologies	*T1*	5.713	2.285	2.573
	T2	4.405	1.762	5.190
	T3	1.183	0.473	14.543
Potential Producing Technologies	*T4*	10.261	4.104	7.478
	T5	7.608	3.043	12.785
	T6	3.675	1.470	25.812
Potential Storing Technologies	*T7*	1.526	0.611	1.528
	T8	1.297	0.519	2.490
	T9	0.826	0.331	5.215
Period Rate		-2%	-2%	+3%

In order to assess comparable alternatives, the first problem (i.e. Prob1) is determining a UCOSC to maximize NPV, which is configured to supply the customers' demand. From the solution, the best NPV value ($\overline{NPV}$) is found. In fact, the technologies those have better economic performance are picked out, instead of those are more environmental friendly. As a consequence, it is produced the worst standard Eco99 value, which calculates the $\overline{Eco99}$. In Tables 7 and 8, the solution #1 represents the results of the Prob1.

The second problem is to find the best environmental conscious design of the current potential network. For this, the Prob2, which includes a single environmental objective function, is optimized. This provided the other extreme point of each objectives, those are the $\underline{Eco99}$ and the $\underline{NPV}$. Table 7 summarizes the objective values corresponding to the Prob1 and Prob2, which are labeled Solution No. 1 and Solution No. 14, in order.

.Table 5.9: Matrix of distances (Km) between the production platforms and the customers

	C1	*C2*	*C3*	*C4*	*C5*
PP1	118.6	907.5	315.7	942.7	1393.6
PP2	149.9	814.0	363.2	1147.1	1397.5
PP3	132.9	913.8	330.7	998.2	1299.9
PP4	123.8	797.6	403.0	885.4	1245.4

Table 5.10: The data associated with the customers.

Customers	Demand (MBs /Y)		Crude Oil Price
	Upper Bound	Lower Bound	$1
C1	8.091	3.236	101.00
C2	7.645	3.058	101.42
C3	8.259	3.303	100.73
C4	8.580	3.432	101.25
C5	8.255	3.302	100.98
Period Rate	+3%	+1%	+5%

Following the solution procedure, the normalized problem (Prob3) is solved. The weights interval is [0, 1]. The model is implemented by given eight different pairs of the objective functions' weights. The first applied pairs of weights and their coupled Solution No. are:

w_1	1	0.875	0.750	0.625	0.5	0.375	0.250	0.125	0
w_2	0	0.125	0.250	0.375	0.5	0.625	0.750	0.875	1
Solution No.	#1	#3	#4	#5	#6	#7	#8	#12	#14

Table 5.11: The environmental data associated with the potential technologies

Technology		Direct Emissions			Electricity [a]
		P1	*P2*	*P3*	(KWh)
Potential Extracting Technologies	*T1*	1.898	1.680	1.885	0.84
	T2	1.451	1.350	1.402	0.73
	T3	0.108	0.077	0.088	0.25
Potential Producing Technologies	*T4*	1.847	2.593	2.298	0.95
	T5	1.508	1.572	1.892	0.86
	T6	0.153	0.171	0.123	0.40
Potential Storing Technologies	*T7*	0.778	1.020	0.945	0.66
	T8	0.674	0.727	0.806	0.46
	T9	0.062	0.054	0.054	0.124

[a]- Electricity consumption to process per barrels of oil by each technology

Table 5.12: The solution results of the case study with different weights of the objective functions.

Solution No.	$f_3(x,y)$	w_1	$f_1(x,y)$ ($1 X 10 ^{7})	w_2	$f_2(x,y)$ (1 x 10^{10})		
					EQ	RD	HH
1	1.000	1.00	40.857	0.00	16.758	25.868	22.476
2	0.924	0.900	40.772	0.100	16.048	24.806	21.557
3	0.945	0.875	40.477	0.125	12.665	19.540	16.946
4	0.931	0.750	40.002	0.250	12.321	19.009	16.488
5	0.912	0.625	39.808	0.375	12.231	18.872	16.368
6	0.898	0.500	39.373	0.500	12.114	18.691	16.212
7	0.891	0.375	38.471	0.625	11.964	18.462	16.013
8	0.900	0.250	35.384	0.750	11.666	18.003	15.616
9	0.903	0.225	33.896	0.775	11.582	17.873	15.503
10	0.916	0.175	30.495	0.825	11.424	17.630	15.293
11	0.924	0.150	28.466	0.850	11.353	17.521	15.197
12	0.934	0.125	27.509	0.875	11.326	17.481	15.162
13	0.999	0.0001	22.778	0.9999	11.256	17.375	15.071
14	1.000	0.00	10.177	1	11.254	17.370	15.066

As shown in Table 5.12, the standard values of Eco99 declined slightly through the solution #1 to # 14, with a pronounced drop in solution #3. To make an explicit analysis of the environmental performance, a new pair of weights which is the (0.90, 0.10) and the resultant solution **#2**, is taken into account. There is still a dramatic improvement for the environmental impacts from the solution **#2** to #3. It is as a consequent of the switching to more environmental friendly technologies, in the solution #3. Herein, the technologies $T3$ and $T6$ are also installed, and the technologies $T2$ and $T5$ are preferred than $T1$ and $T4$, respectively (See Table 5.13).

The same strategy was applied to the net present value objective function. The NPV falls steadily from the solution #1 to #14, with two exceptions in the solution #12 and #14. To moderate these marked downturns, four other solutions are added in Table 7 including the solutions ***#9-11*** and the solution ***#13***.

Table 5.13: The comparison of the environmental and economic performances

Tech-nology	Economic Data			Environmental Data		Selected Technologies via Solution			
	Capacity	Capital Cost	Opera-tion Cost	Required Energy	Direct Emission	No. 1	No. 3	No. 9	No. 14
T1	high	high	high	high	high	*W1-W7*	*W2; W3*		
T2	medium	medium	medium	medium	medium		*W1-W7*	*W1-W7*	*W1-W7*
T3	low	low	low	low	low		*W1; W4-W7*	*W1-W7*	*W1-W7*
T4	high	high	high	high	high	*PP1-PP4*	*PP4*	*PP4*	
T5	medium	medium	medium	medium	medium	*PP3; PP4*	*PP1-PP4*	*PP1; PP3; PP4*	*PP1; PP3; PP4*
T6	low	low	low	low	low		*PP3; PP4*	*PP1; PP3; PP4*	*PP1; PP3; PP4*
T7	high	high	high	high	high	*PP1-PP4*	*PP1-PP4*		
T8	medium	medium	medium	medium	medium				
T9	low	low	low	low	low			*PP1; PP3; PP4*	*PP1; PP3; PP4*

In order to explicitly understand the conflict between environmental and economic performance of the technologies, and their effects on the network design, Table 5.13 is provided. This table compares the economic and environmental data associated with different technologies. Additionally, the selected technologies in the four chosen solutions are illustrated.

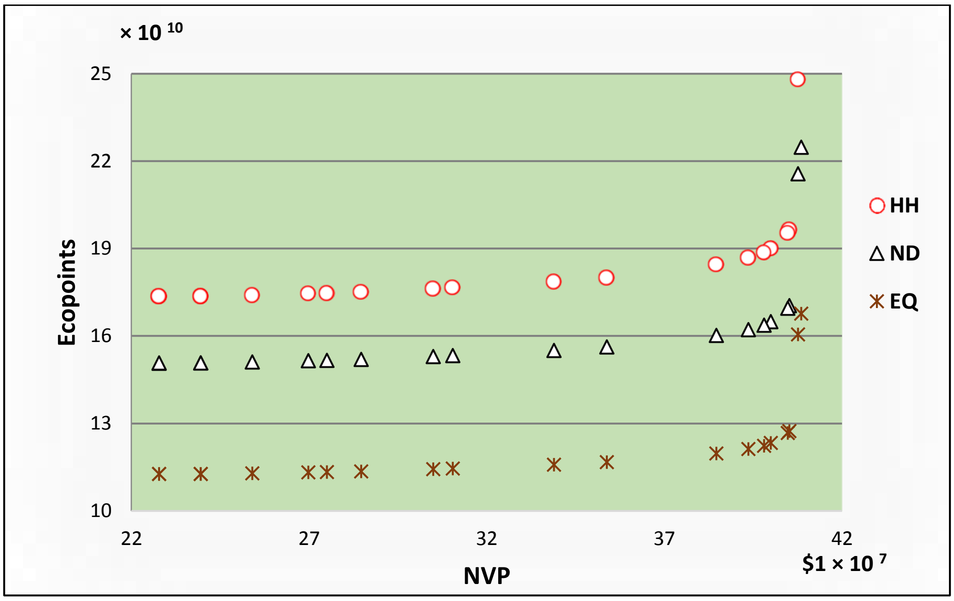

Figure 5.2: Projections of the solutions obtained from the multi-objective optimization of the case study.

To display the tradeoff between the environmental impact and the NPV, the Figure 5.2 is shaped form the data in Table 5.13. As seen, it is apparent that the three environmental metrics (RD, HH, and EQ) are conflicting with the economic objective (NPV). Given the traditional trade-off between environmental and economic criteria in many applications, this conflict was expected. It is due to that the technology alternatives that have higher capacity and lower capital costs are expected to produce worse environmental impacts. It is evident that Eco-indicator 99 and cost have a tendency to run contrary contradictory.

5.5 SUMMARY

In this Chapter, a short overview of 'sustainable' and 'green' supply chain is provided in Section 5.1. In this section, we also review the mathematical models which take environmental impacts into account in the crude oil supply chain. The problem is described in Section 5.2.

Afterwards a mathematical model for profitable and environmental conscious design of Upstream Oil Supply Chain (UCOSC) has been formulated in Section 5.3. The model presented a multi-period MILP that accounts for the multi-objective of optimization of the economic and environmental performance. The model considered the long-term strategic decisions such as facility location (i.e. locations of wells and production platforms); facility allocation (i.e. assigning the wells to the production platforms, and the platforms to the customers); technology selections with respect to the capacity, cost, and environmental impacts; and planning of establishments. The materials flows within the network are dealt with, as well. Extraction, production, and storage capacities are bounded within given limits. To analyze the environmental impact of the oil supply chain, the Life Cycle Assessment (LCA) methodology is considered as a basis of the environmental assessment methodology. The Eco-indicator 99 approach is used to calculate the life cycle inventory and introduce the damages in ecosystem quality (EQ), resource Depletion (RD), and human health (HH).

In section 5.4, a UCOSC case study is presented where two installed wells, five potential wells, one installed production platform, and three potential production platforms, and five customers are available. The normalized objective function is solved with several pairs of objectives' weights. The capabilities of our model and strategy have been illustrated by the solutions of this case study. These results have figured that pronounced environmental improvements can be accomplished through the technology selection. The proposed model and the results of the case study provided valuable insights in the design problem of an oil supply chain. This model also endeavors to direct the decision maker to the adoption of more-environmentally conscious design alternatives.

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Conclusions and Future Research

This thesis can be divided into two parts. The first part consists of Chapters 1 and 2. Thereby, the focus was put on giving an introduction into the crude oil industry and fostering insight into the mathematical programming model within crude oil supply chain context. The first aim of this part was to provide an introductory knowledge of the crude oil industry for the reader so that he can follow the proposed discussions. For this purpose, Chapter 1 was presented, which gave an overview of the oil industry, pointed out the critical role of crude oil, distinguished between onshore and offshore facilities, explained the entities of this industry, and discussed all functions through the tripe of crude oil from the exploration activities to the distribution functions. The second aim of this part was to investigate the literature to figure out gaps as possible directions of future research. To achieve this aim, Chapter 2 carried out a comprehensive literature review on the mathematical programming models, which were optimizing strategic and tactical decisions of the COSC problems. Chapter 2 started with an overview of previous literature review papers, and followed by adapting a taxonomy framework as classification scheme. Afterwards the selected papers were discussed according to the classification criteria. Finally, some more interesting gaps were picked to deal with these challenges in this thesis.

The second part of this thesis was devoted to study the proposed gaps and attempt to manage them. In this part, three concrete models were elaborated to form joint venture for upstream crude oil projects, to configure an integrated upstream crude oil supply chain, and to study environmentally conscious design of this supply network. This three contributed mathematical models were discussed in Chapter 4, Chapter 5, and Chapter 6 respectively. In each chapter, we tried to clarify the background of each problem, and thus highlight the contributions of each proposed mathematical model. We assumed that all equations are linear, and all parameters were considered deterministic. These mathematical models are basics to found the future research, such as adding global factors or taking account of uncertainty. In academic life, filling the gaps by gradually elaborating concrete models is the vital breathing space. In the followings, we go through these chapters in brief.

The magnitude of business dynamics has increased rapidly due to increased complexity, uncertainty, and risk of international projects. The growth of business dynamics made it increasingly tough to “go alone” into the international projects. As a consequence, companies with diverse strengths and weaknesses cooperatively bid for Joint Ventures formation. Forming a JV is an appropriate approach for companies to cooperate and share the risks and profits, for a finite time, without having to merge. JVs are a well-established aspect of the crude oil industry, specifically in the upstream segment, where the cost, risk, shortage of drill rig, knowledge and technology issues obviously demand a collaborative approach, i.e. JV, on the largest projects. As a result, JV is an attractive option at the upstream oil segment that should be taken into consideration. Making decisions on the optimal form of JVs is still a challenging problem, because the JVs contracts propose interesting arrangements of expertise, labour, resources, capital, and assets. In addition, the success of the JV is intertwined with the accuracy of the partner selection phase. Therefore, in Chapter 3, we formulated a multi-criteria goal programming model to select the best partners and to form an optimal joint venture for undertaking an oilfield project. The lexicographic goal programming technique was employed to minimize undesirable deviations from diverse goals such as resource needs (technological and expertise), budgetary requirements, time, etc.

As discussed, the crude oil industry plays a vital role in the modern global economy, due to the fact that it is the largest origin of energy in the world. Design and planning (i.e. strategic and tactical decisions) of the upstream crude oil supply chain have become crucial concerns of the crude oil practitioners and managers. At the other side, crude oil transportation is the key role to success in the global crude oil supply chain environment. Lack of this integration and comprehensiveness of the upstream crude oil models were observed in the literature (see Chapter 2). In Chapter 4, we developed a model to design the oilfield development and to plan crude oil transportation problems. A mixed integer model was proposed to extend the classical facility location-allocation problems by several features. Additionally, the proposed model in Chapter 4 supported the selection of the transportation system and the planning of the pipeline networks installations. This chapter ended with two one-factor-at-a-time sensitivity analyses, which have been done with respect to the length of the planning horizon and the number of potential wells.

The rapid growth in environmental legislation has resulted in an increasing companies' will to address environmental thinking through their Supply Chain (SC). In this context, great strides have been made to incorporate the environmental concerns, such as "green" and "sustainable" SC, along with the traditional economic indicators.

The crude oil tankers and the consumptions of the utilities are the main origins of emissions through the crude oil supply chain. The energy required for operating upstream facilities in the crude oil supply chain represents enormous energy consumption. Whereas, ships and oil tankers are of the highest polluting combustion origins per unit of fuel used. As a result, environmentally conscious design of upstream crude oil supply chain has created intriguing new challenges. In Chapter 5, we introduced an environmentally conscious mathematical model to design the upstream oil supply chain (i.e. oil field development, and crude oil transportation). The model configures the supply network, selects the technologies, establishes the pipeline network, and plans the oil tankers with optimizing the economic objective value (i.e. the net present value) and the environmental metric value (i.e. the standard Eco-indicator 99 value). To assess the environmental impacts, there is no agreement on a universal environmental metric. Hence, a plethora of indicators is developed to measure environmental impacts. The environmental indicators (e.g.

Eco-indicator 99) those founded on Life Cycle Assessment framework and are nowadays becoming the popular environmental assessment methodologies.

In this part of the thesis, we would like to propose a comprehensive overview of the most significant contributions throughout this thesis. The major contributions are:

1. Giving an introduction into the crude oil supply chain, including:
   1.1. An introduction to the crude oil industry.
   1.2. An introduction to the functions and entities of the crude oil supply chain.
2. Carrying out a systematic literature review, comprising:
   2.1. Adapting an appropriate taxonomy framework to use it as a classification scheme.
   2.2. Investigating the mathematical programming models in the crude oil supply chain context, comprehensively.
   2.3. Identifying the gaps of the literature and the possible research directions.
   2.4. Pointing out three interesting research direction to deal with them in this thesis.
3. Formulating the joint venture formation to execute the upstream crude oil projects, including:
   3.1. Giving an introduction into the joint venture formation motives.
   3.2. Giving an introduction into the joint venture decision process.
   3.3. Giving an introduction into the partner selection in the joint venture context.
   3.4. Taking multi criteria into account to make decisions by employing Goal Programming technique.
   3.5. Providing the possibility of selecting more than one partner to form a joint venture agreement.
4. Integrating a comprehensive upstream crude oil supply chain, consisting of:
   4.1. Taking account of the oilfield development problem and the crude oil transportation problem in a single model.
   4.2. Dealing with a comprehensive complex supply chain that consists of crude oil wells, platforms, and transportation means.
   4.3. Imposing a drilling rig constraint.
   4.4. Formulating the existing facilities, instead of studying a green oilfield.

5. Introducing an environmentally conscious mathematical programming model to design the upstream crude oil supply chain and select the associated technologies, including:
    5.1. Providing an introduction into the life cycle assessment concepts.
    5.2. Studying the crude oil literature from an environmental point of view.
    5.3. Formulating the environmental conscious model to configure the optimal network.

In a nutshell, we carefully reviewed the literature, identified possible research areas, and developed three basic mathematical models to fill gaps gradually. In addition, the required concepts (e.g. joint venture formation, joint venture motives, partner selection, life cycle assessment, and goal programming technique) were discussed.

Beyond the contributions of this thesis, some research directions still need further work. As all proposed models are deterministic, taking uncertain features and nonlinear equations into account is the other emerging area in this context. Then, the resulting mathematical model will be a large scale problem. To reduce the computational burden of these models, using the concept of a reduction is appropriate. In this context, the most popular techniques are decomposition techniques, such as benders decomposition, and Lagrangean relaxation and decomposition.

According to the literature review, which is presented in Chapter 2, the significant importance of global factors in optimization of the COSC problems is indisputable. Hence, the resultant complexity of the global factors, uncertain parameters, environmental impacts, and nonlinear equations emphasize the development of efficient algorithms that can solve these complex large-scale models as translations of the realistic real-sizes problems. Additionally, developing efficient solution techniques is also necessary to optimize multi objective function problems, particularly by considering environmental impacts. Another direction for the future research is to study uncertainty with multi-stage stochastic models, rather than two-stage problems which most often have been taken into account as the only programming model of studying stochastic problems.

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