Chapter 1
Introduction

Oil companies are global organizations whose decisions are related to the supply of petroleum, refining, and distribution in a highly complex environment. Typically, these companies operate with strongly diversified sources of petroleum supply, a long cast of products, and multiple markets, making vital the advanced planning of all activities along the supply chain. Such planning includes the selection of investments in infrastructure, definition of oil production (from oil fields and offshore platforms) and of petroleum products production (from oil refineries), as well as the distribution among the refineries and to the final consumers of oil products.

Major oil companies are characterized by integrated and vertical structures. This is justified by significant economies of scale, especially in the refining and transportation activities, and also because it is a business that involves many uncertainties, and consequently many risks. Moreover, the interdependence of operations in the oil industry requires that companies plan and optimize their investments on an enterprise-wide level (Grossmann, 2005). This requires one to consider large supply chains, including oil platforms, marine terminals, refineries, distribution terminals, and thousands of links between them. Given this context, careful evaluation of the investment options in the petroleum products supply chain gains particular importance and the use of a tool that represents its complexity becomes crucial.

For almost 50 years, companies in the oil and chemical industries have led the development and use of linear mixed-integer programming to support decision making at all levels of planning (Shapiro, 2004). Although the research literature on the strategic modeling of supply chains in this field is quite rich, only a fraction of the studies have explicitly included uncertainty in the formulation together with other decisions, such as investment planning. According to Sahinidis (2004), the incorporation of uncertainty into planning models using stochastic optimization remains a challenge due to the large computational requirements involved.

An overriding feature in the oil industry is precisely its wide range of uncertainties, which are typically related to the unpredictable levels of demand for refined products, fluctuations in prices in domestic and international markets and inaccuracies in the forecasted production of oil and gas. For this reason, some works have used techniques based on mathematical programming to support decision-making under uncertainty in the oil industry (e.g., stochastic optimization) (Escudero et al., 1999; Dempster et al., 2000; Al-Othman et al., 2008; Khor et al., 2008; Ribas et al., 2010). However, there is an inherent trade-off between how precise is the representation of the uncertainties and the computational tractability of these large-scale stochastic programming problems. On the one hand, one might need a large number of scenarios in order to accurately represent the uncertainties. On the other hand, it might turn out to be computationally infeasible to deal with a large number of scenarios by solving deterministic equivalents of stochastic programming problems.

1.1 Objectives

In this thesis, our primary objective is to develop a framework that is able to support the strategic investment planning for the petroleum supply chain, taking into consideration the effects of demand uncertainty. In order to accomplish this objective, we propose a set of tools for representing this problem and its particular features, especially regarding the characteristics that are inherent to the investment planning for the petroleum logistics infrastructure. Such a framework comprises a mathematical model to represent the problem, techniques to represent and include the consideration of the uncertainty into this model, and specialized numerical methods that allow the efficient solution of the problem for the test sets we considered.

As for secondary objectives, we list the following achievements. We consider the use of Sample Average Approximation as a technique for incorporating the demand uncertainty, showing how one can use this technique for generating and controlling scenarios that will represent the uncertainty. In addition to that, we develop alternative decomposition methodologies focused on exploiting the particular structure of the problem in order to solve it in a efficient manner. The first decomposition technique is based on the stochastic Benders decomposition, further improved by novel acceleration techniques. The second is a novel algorithm based on Lagrangean decomposition. Another objective is to show a successful application of the framework to a real case study. Throughout the thesis we show how one can use each of the proposed tools in order to represent the uncertainty and to efficiently solve the investment planning problem for the distribution of petroleum products in northern Brazil.

1.2 Thesis Organization

This thesis is organized in six chapters as follows:

- In chapter 2, we present the problem to be investigated in this study, giving details about the context involved and assumptions that are made. We approach the problem relying on two-stage stochastic programming. We present in this chapter the model formulation developed to represent the problem at hand.
- In chapter 3, we discuss the Sample Average Approximation (SAA) framework as means of obtaining approximated solution to the investment planning problem under demand uncertainty. We also show how this technique can be used as a scenario reduction tool, making it possible to deal with large scenario sets. We conclude this chapter with numerical results from a real case study for the supply chain investment planning of petroleum products in northern Brazil. The results suggests that the proposed technique provides an efficient framework to obtain solutions that are statistically guaranteed to be close to true optimal solutions.
- In chapter 4, we present a framework based on Benders decomposition and show how it can be applied to solve our problem. We also develop novel acceleration techniques for the Benders decomposition that improve even further the performance of the presented decomposition framework. We close this chapter providing numerical results that support the potential of the proposed approach when compared with other techniques recently developed for accelerating Benders decomposition.
- In chapter 5, we consider the case when some of the second-stage variables might be required to be integer. In this context, the Benders decomposition framework cannot be readily applied. To circumvent this drawback, we present an alternative decomposition framework based on Lagrangean decomposition. The novelty of this approach is related with the strategy used to update the Lagrange multipliers during the algorithm execution, as well as with the way we formulate the nonanticipativity conditions. We end the chapter presenting numerical results that suggest that the proposed approach outperforms the traditional subgradient algorithm for updating of Lagrange multipliers.
- In chapter 6, we close our thesis drawing conclusions, stating the contributions made, and giving future directions to further developments of this research.