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Stochastic programming approach for the optimal tactical planning of the downstream oil supply chain

Camilo Lima, Susana Relvas*, Ana Barbosa-Póvoa

CEG – IST, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal

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A B S T R A C T

This paper develops a multistage stochastic programming to optimally solve the distribution problem of refined products. The stochastic model relies on a time series analysis, as well as on a scenario tree analysis, in order to effectively deal and represent uncertainty in oil price and demand. The ARIMA methodology is explored to study the time series of the random parameters aiming to provide their future outcomes, which are then used in the scenario-based approach. As the designed methodology leads to a large scale optimization problem, a scenario reduction approach is employed to compress the problem size and improve its computational performance. A real-world example motivates the case study, based on the downstream oil supply chain of mainland Portugal, which is used to validate the applicability of the stochastic model. The results explicitly indicate the performance of the designed approach in tackling large and complex problems, where uncertainty is present.

1. Introduction

The worldwide oil market is inserted into an unstable and uncertain environment, whose uncertainties represent potential risks for the entire network, arising from a wide variety of sources, such as economy, environmental rules or speculative activities. Generally, uncertainty effects can be translated into the oil supply chain (OSC) as fluctuations in production levels, volatility of prices and unforeseeable demands. In order to cope with such effects when planning supply chains, decision support tools that can cope with such uncertainty should be used so as to guarantee operation profitability.

Optimization approaches have been the most used methodologies when designing and planning oil supply chains (Lima et al., 2016), and these approaches have been proved to be adequate to deal with uncertain parameters (Zeballos et al., 2014). However, in the supply chain, few uncertainty factors have been taken into account when using such approaches and, thus, there is a need to further explore them and diversify the sources of uncertainty (Barbosa-Póvoa, 2014). Likewise, the application of diverse quantitative approaches needs to be investigated as alternative to enhance the treatment of uncertainty within the stochastic problems, not only to widen but also to detail the few treated sources of uncertainty (Lima et al., 2016). Nowadays, the main quantitative models applied to deal with uncertain factors within supply chain problems are methodologies such as the stochastic programming, robust programming and fuzzy programming (Carneiro et al., 2010).

This paper aims to contribute to this area by providing an effective approach to cope with the presence of uncertainty in the decision making process, through the application of different methodologies, namely, by the combination of the time series analysis, scenario-based approach and multistage stochastic programming. The time series analysis characterizes the uncertainty associated to the random parameters, and then assists in the generation of the scenarios for the scenario-based approach, which in turn provides the inputs to the stochastic programming. At each time point, such inputs work as the realizations of the random parameters, and then the decisions are made. Also, a scenario reduction approach is applied to aid solve the established stochastic problem. The stochastic solutions are properly evaluated by the value of the stochastic solution at time t (VSS_t).

In order to illustrate the effectiveness and adequacy of the proposed approach, the Portuguese OSC is investigated. This network comprises two refineries, three storage depots, 278 local markets and four transportation modes, where the crude oil is received at

* Corresponding author.
E-mail address: susana.relvas@tecnico.ulisboa.pt (S. Relvas).

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Table 1
Papers about uncertainty in the downstream oil supply chain, from 2000 on.

Author	Planning levels			Modeling approach	Uncertainties	Optimization purpose		
	Strategic	Tactical	Operational			Cost	Profit	Other
Dempster et al. (2000)	X	X	–	Stochastic programming	Product demand	X	–	–
Al-Othman et al. (2008)	–	X	X	Two-stage stochastic MILP	Market demands and prices	X	–	–
MirHassani (2008)	X	X	X	Stochastic MILP	Product demand	X	–	–
Ghatee and Hashemi (2009)	X	X	–	Fuzzy programming	Market demands and oil availability	X	–	–
Carneiro et al. (2010)	X	X	–	Two-stage stochastic MILP	Product demand, market prices and oil supply	–	X	–
Ribas et al. (2010)	X	X	–	Two-stage stochastic MILP, and the robust min-max regret and max-min models	Product demand, market prices and oil supply	–	X	–
MirHassani and Noori (2011)	X	X	X	Two-stage stochastic MILP	Product demand	X	–	–
Oliveira and Hamacher (2012a)	X	X	–	Two-stage stochastic MILP	Product demand	X	–	–
Oliveira and Hamacher (2012b)	X	X	–	Two-stage stochastic MILP	Product demand	X	–	–
Oliveira et al. (2013)	X	X	–	Two-stage stochastic MILP	Product demand	X	–	–
Oliveira et al. (2014)	X	X	–	Two-stage stochastic MILP	Product demand	X	–	–
Tong et al. (2011)	–	X	X	Two-stage stochastic MILP	Demand and yield	X	–	–
Leiras et al. (2013)	–	X	X	Two-stage stochastic LP	Product demand, market prices, oil supply and process capacity	–	X	–
Tong et al. (2014a)	X	X	–	Fuzzy programming	Product demand, conversion rates, biomass availability and operation costs	X	–	–
Tong et al. (2014b)	X	X	–	Two-stage stochastic MILP	Product demand, biomass & oil availability, oil price and technology evolution	X	–	–
Tong et al. (2014c)	X	X	–	Robust optimization	Product demand and biomass availability	X	–	–

refineries, transformed into refined products, and then dispatched either directly to local markets or indirectly through storage depots and later to local markets. Diverse transportation modes are considered.

The paper is structured as follows: Section 2 provides a literature review, whose focus is on how the uncertainty has been managed and addressed within downstream OSC. Section 3 defines the assumptions and characteristics of the problem in order to represent a real downstream OSC. Section 4 presents the methodological contributions, besides introducing the framework for managing the uncertainty related to the random parameters. Section 5 exhibits and explains the model formulation. Section 6 presents a real case study in order to exhibit the model performance. Section 7 displays and discusses the main results. Finally, Section 8 highlights the major findings and conclusions, besides identifying some study directions.

2. Literature review

In this work, the oil supply chain is understood as a network divided into three segments: the upstream, encompassing the exploration and production of crude oil; the midstream, comprising the refining operations; and the downstream, referring to the product distribution. The associated decision making process can be arranged into the strategic, tactical and operational planning levels, whose decisions are characterized by frequency, duration and effect. Typically, the strategic planning copes with the network structure in an annual scale, while the tactical one deals with resource allocations in a monthly scale, and the operational one handles the scheduling activity within a weekly scale (Lima et al., 2016).

In the oil market, mainly at strategic and tactical scales, uncertainties arise from a wide range of sources, leading to substantial risks for the entire system, besides making it more vulnerable to stoppages and high costs. Uncertainties are transmitted through the oil supply chain from oil production (upstream), passing through oil refining (midstream), until the product distribution (downstream), where they exert influence on the market prices and demands (Al-Othman et al., 2008). At the oil derivative market level, the demand volatility of these products is also uncertain, which propagates upstream. These phenomena imply that the planning of activities throughout the oil supply chain is always affected by such uncertainties (Oliveira et al., 2014), and thus uncertainty is an important subject to be taken into account when managing the oil supply chain. The application of mathematical programming techniques to help solving such issues is a relatively new research area, in which the development of modeling detailed approaches and efficient solution techniques are still required (Sahebi et al., 2014).

As summarized in Table 1, specifically to the downstream OSC management under uncertainty at strategic and tactical levels, just thirteen works were found in the specialized literature from 2000 to 2015, where the majority treats uncertainty through stochastic programming approaches (i.e., Dempster et al., 2000; MirHassani, 2008; Carneiro et al., 2010; MirHassani and Noori, 2011; Oliveira and Hamacher, 2012a,b; Oliveira et al., 2013, 2014; Tong et al., 2014b), and the minority by fuzzy mathematical programming (i.e., Ghatee and Hashemi, 2009; Tong et al., 2014a) and by the robust optimization approach (i.e., Tong et al., 2014c). Moreover, only Ribas et al. (2010) analyzes uncertainty by three different approaches: a two-stage stochastic mixed-integer linear programming (MILP) model; a robust min-max regret model; and a max-min model.

On the one hand, the major uncertain parameter investigated is the market demand, which is considered by all the aforementioned works, besides being addressed as the only source of uncertainty by seven of them (i.e., Dempster et al., 2000; MirHassani, 2008; MirHassani and Noori, 2011; Oliveira and Hamacher, 2012a,b; Oliveira et al., 2013, 2014). On the other hand, uncertainty on oil market prices has been less investigated, where only three of all articles treat such subject (i.e., Ribas et al., 2010; Carneiro et al., 2010; Tong et al., 2014b). Other