Omega 41 (2013) 955–968

Contents lists available at SciVerse ScienceDirect

Omega

journal homepage: www.elsevier.com/locate/omega

Integrated scheduling and inventory management of an oil products distribution system

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ARTICLE INFO

Article history:
Received 23 February 2012
Accepted 4 January 2013
Processed by B. Lev
Available online 15 January 2013

Keywords:
Supply chain management
Pipeline scheduling
Mixed-integer linear programming

ABSTRACT

The oil supply chain is facing new challenges due to emerging issues such as new alternative energy sources, oil sources scarcity, and price variability with high impact on demand and production and profit margins reduction. Additionally, the existence of large, complex and world wide spread businesses implies a complex system to be managed where distribution can be seen as one of the key areas that needs to be efficiently and effectively managed. Different types of distribution modes characterize the oil supply chain where the pipeline mode is one of the most complex to operate when having multiproduct characteristics. This paper addresses the planning of a generic oil derivatives transportation system characterized by a multiproduct pipeline that connects a single refinery to a storage tank farm. Two alternative mixed integer linear programming models (MILP) that aim to attain a set of planning objectives such as fulfilling costumers' demands (which is mandatory) while minimizing the medium flow rate are developed. Additionally, final inventory levels are avoided to be excessively low. A real world scenario of a Portuguese company is used to validate and compare the two alternative MILP models developed in this paper.

1. Introduction

The supply chain in the petroleum industry comprises many intermediate steps starting from the exploration phase at the wellhead, going through trading and transportation, refining and finally the distribution and delivery of the final products at the retail level. The major operational activities in such supply chain include planning, scheduling, real-time optimization and inventory control [12,30]. Decisions at these levels cause a large impact on the supply chain performance, which is mandatory in the global market faced today by companies. As stated by Grossmann [11], for process industry companies to remain competitive and economically viable, it is required an optimized supply chain where costs and inventories are reduced and where the operation is efficient while continuously looking for product quality improvement. Liu and Papageorgiou [15] state that, nowadays, not only cost should be used as a performance metric but responsiveness and customer service level as well. These are critical issues for the petroleum industry, which as being a global business faces tight competition, strict environmental regulations and lower margins [30].

Supply chain problems and inventory management problems have been studied extensively in recent years [10,21,18,9]. Focusing on the oil supply chain, planning and scheduling problems have been addressed by some authors in the past few years. These problems are characterized by a high complexity, given the multisite, multi-region/country, multi-product, multipurpose facilities and multi-client dimensions of this system. Nevertheless, several authors are starting to study this industry through integrated approaches so as to achieve an enterprise-wide optimization, such as in the proposed paper where pipeline scheduling is integrated with downstream inventory management. One of the areas requiring attention is the downstream distribution system that includes not only the management of the production facilities but also the optimization of the transportation, logistics and finished product distribution resources, which originate a wide set of decisions for managers. Examples can be found in the literature, such as the distribution planning of bulk lubricants in BP Turkey [31], shift scheduling of distribution tank trucks [14] or the trip packing problem applied to petrol stations replenishment proposed by Boctor et al. [1]. Among these activities we may find the scheduling of pipeline systems, which consists on a complex problem and has been studied over the last years mainly using exact methods.

Rejowski and Pinto [24] studied a system that comprises an oil refinery, one multiproduct pipeline connected to several depots that supply the local consumer markets with several oil products.

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0305-0483/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.omega.2013.01.001

The pipeline is conceptually divided into segments that connect two consecutive depots and therefore when pumping the products, each segment will include a single product at each time interval. The authors developed a large-scale MILP model, which was solved for a relaxation gap below 6%. With the goal of generalizing and improving the efficiency of the MILP formulation, Rejowski and Pinto [23] proposed a new model for the same problem, adding special and non-intuitive practical constraints. More recently, Rejowski and Pinto [22] proposed a novel MINLP formulation based on a continuous time representation for the same scheduling problem treated in their former works. They compared both discrete and continuous time representation formulations in terms of solution quality and computational performance. The continuous formulation presents better results for the same time horizon.

For the problem of Rejowski and Pinto [24], an alternative continuous time MILP model was proposed by Cafaro and Cerdá [6]. For comparison reasons, they considered the same time horizon and found optimal solutions in few seconds. Later on, Cafaro and Cerdá [4] present an MILP continuous-time framework for the dynamic scheduling of pipelines over a multiperiod moving horizon applied to the same problem. Solutions are found considering monthly time horizons weekly updated with CPU time varying from 16 to 330 CPU seconds.

The same research group relied on the problem of efficiently proposing a detailed solution for single sourced pipelines with multiple destinations, where it is essential to control at each batch injection on the origin the volumes and cuts to perform at each destination, while respecting all operational constraints. In order to overcome the problem complexity, Cafaro et al. [7] used a two stage approach, where the aggregate planning is done through a MILP model and then heuristics and simulation are combined to further detail the schedule. The MILP model is the stage that consumes larger CPU effort, which is emphasized when the problem complexity increases. The larger instance covers a period of 4 weeks.

Magatão et al. [17] proposed a decomposition strategy to address the short-term scheduling of activities in a specific pipeline system since it consists of a bidirectional pipeline. It connects a harbor to an inland refinery. The optimization structure is based on a MILP main model, one auxiliary MILP model, a time computation procedure, and a database, which gathers the input data and the information provided by the optimization blocks. Various instances were run and optimal solutions are found considering time horizons up to 120 h. Recently, Magatão et al. [16] solved the same problem with improved efficiency using a combined approach based on the usage of CLP (constraint logic programming) and MILP.

Relvas et al. [29] studied a system that comprises a pipeline pumping oil derivatives to a single distribution center. In this work, a continuous MILP approach is used to model the problem of oil derivatives pipeline transportation scheduling and supply management at the distribution center. Three scenarios were analyzed considering fixed, mixed, and free sequences of products. For the fixed and mixed cases, feasible solutions are found for a monthly time horizon. For the free sequence case, feasible solutions are found considering temporal decomposition (15+15 days time horizons). Therefore some difficulty has been faced when solving such problems. In order to overcome this problem a heuristic-based procedure was presented in Relvas et al. [28] where the sequence of products to pump was predefined. The heuristic was used prior to the model implementation and provides a set of information on the most desirable sequences of products to be pumped to the pipeline given the scenario starting conditions and requirements. Also, Relvas et al. [26] developed a novel rescheduling methodology, taking into account the variability of real plant changes with the definition of revisions of schedules in an effective way. Problems covering 1 month of time horizon, including initial plans and their revisions, with more than one perturbation, have been successfully solved. Cafaro and Cerdá [5] rely on the MILP formulation of Relvas et al. [29] to propose specific improvements and are able to find feasible solutions (using as stopping criteria of 2% of relative gap) considering a monthly time horizon (weekly updated using a rolling horizon).

Other works have been proposed in recent years that aim to study in detail either different approaches or different problem features, such as the usage of the Resource Task Network proposed by Castro [8], multiproduct pipeline trees studied by MirHassani and Ghorbanalizadeh [19] and MirHassani and Jahromi [20], pipeline networks using discrete-time MILP approaches for short term scheduling by Herrán et al. [13] and multiproduct pipeline networks for medium term scheduling using decomposition approaches by Boschetto et al. [2].

The works referred above emphasize the multiple complexity dimensions that multiproduct pipeline systems involve as well as different approaches used in order to solve the scheduling problem of such systems. The major problem dimensions can be thus related with the system topology (single pipeline, tree pipeline, mesh pipeline network, single or multiple origins and destinations) scheduling horizon (which in this problem is relatively large due to the operational lag created by the pipeline transportation duration), system limitations (mainly related with product quality and pumping flow rates) and coordination with origin and destination operations (mainly to maintain feasible inventory levels and production profiles). In this sense, a different number of approaches is being studied by different authors so as to conclude on the best representation approaches to use in such problems.

Analyzing the works here presented, it is easy to understand that to schedule a pipeline over a medium-term horizon (e.g., considering a one month time horizon), is common to use decomposition approaches or even to develop hierarchical methods, being commonly combined with mixed integer linear programming representations leading to complex algorithms.

The purpose of the present work is to overcome some of these difficulties by presenting a single model that provides a medium term horizon solution, considering the sequencing of products, batch volume sizing and inventory management at the distribution center. The system in study comprises a single source, single destination problem. Another feature of the proposed approach is the elimination of the iterative procedure to determine the optimal number of batches to pump in each scenario. The potential high number of variables added to eliminate this procedure is surpassed by a preprocessing step that reduces the binary variable index domain. Two models are proposed in this paper, which have a difference on the modeling of the sizing decision of batch volume. The fixed batch size model (FBS) uses a set of prefixed volumes of batches that vary with product, where a decision has to be taken to select which one to pump. On the other hand, the variable batch size model (VBS) provides for each product a valid interval for batch volume, being any intermediate value allowed. Such models appear as very efficient when compared to existent models as it will be seen later on the results section.

The remaining of the paper is organized as follows: Section 2 presents the generic problem under study, specifying data and desired results. Section 3 presents the concepts and hypotheses made prior to model formulation so as to obtain model solutions. Namely the notation used in the model formulation, the proposed model assumptions, the algorithm that enables the elimination of the iterative procedure to determine the required number of