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Operational scheduling of refined product pipeline with dual purpose depots

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A R T I C L E I N F O

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A B S T R A C T

Pipelines are one of the most economic and safe ways to transport oil derivatives to depots near the local markets. This is so, especially when there is a need for carrying a huge amount of petroleum products to long distance points. A pipeline may connect several refineries and depots where the connected points are able to inject products or receive them, or both (dual purpose depots). The main point of pipeline scheduling is to identify an optimal sequence of batches that satisfy demand with minimum costs. This paper presents an MILP continuous formulation for pipeline scheduling. The proposed model results in the reduction of problem size with respect to available models, and increases the accuracy. Computational results and data are reported.

1. Introduction

The refined petroleum product transportation is one of the main challenges in the oil industry. Transportation of crude oil from production areas or ports to refineries and refined petroleum products from refinery to depots near the local markets are main nodes in this chain. Decision tools based on operations research have been used for refinery operations over the years, but these tools have not been much attend to the refined petroleum product transportation until the past two decades and transportation operators had to rely on their own experiences.

A barrel of crude oil can be transformed into different refined products such as gasoline, kerosene, jet fuel, diesel and home heating oil. The products can be transported by road, railroad, vessels and pipelines. Among which, pipelines being an inexpensive carrier and able to carry a very large volume of products over long distances, are the most important method for transporting refined products. Moreover, pipelines are not affected by traffic and weather conditions. In the U.S. around two thirds of refined petroleum products are transported by pipelines [1].

In many cases, a variety of refined products are carried in the same pipeline without any separator devices, so during transportation an amount of products that are consecutive come into contact with each other and result in interface contamination. Contamination problems can almost be resolved by proper batch sequencing. An interface contamination may vary from a few barrels to perhaps 200 barrels, while a batch of products in the pipeline might be in huge numbers of barrels, MirHassani and Fani [2].

The most important purpose of multi product pipeline scheduling is delivering products to different demand points in the right time with minimum operational costs. This is a very complex task with many restrictive conditions. From the structural point of view, pipelines may be classified into three classes: unidirectional straight pipelines connecting several refineries

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and depots each, tree structure pipelines that branch in a few points and full network pipelines where the products may arrive at their destination from different routes, MirHassani and Fani [2].

This paper focuses on the first class of pipelines where a unidirectional straight pipeline connects several refineries and depots together while some of the depots are dual purpose i.e. they can inject products to the pipeline as well as receive products from it.

One of the main features of pipelines is that they must always be full of products. Hence, the only way to withdraw products by depots is to inject the same volume of products to the pipeline at the same time. For more details about how pipelines work and their importance in the oil industry, refer to [3].

1.1. Previous works

Different types of models have been proposed to study pipeline scheduling problems, such as knowledge based heuristic techniques (Sasikumar et al. [4]), simulation models (García et al. [5], Mori et al. [6]) and MILP or MINLP models. MILP or MINLP models are usually classified into two groups: discrete and continuous models. In discrete models not only is the horizon of scheduling segmented into the time intervals of equal or unequal sizes but also the pipeline volume is divided into a number of segments (Rejowski and Pinto [7,8], Magatão et al. [9], MirHassani and Ghorbanalizadeh [10]). Rejowski and Pinto [11] presented a continuous time MINLP formulation for multi product pipelines, which especially focused on booster configuration with a number of distinct pumping stages. However, the pipeline volume is still divided into many packs. Nevertheless, this model achieved better results as compared to previous works of these authors [7,8].

A continuous formulation in both time and batch volumes was first proposed by Cafaro and Cerda[1] for scheduling unidirectional pipelines with single origin and several depots along it. They extended their model to long time scheduling of pipelines with multiple delivery due dates for demands [12]. MirHassani and Fani [2] extended the Cafaro and Cerda model[1] to tree structure pipelines. Relvas et al. [13] introduced a continuous model based on [1] for a multiproduct pipeline which connects one refinery to one depot. They have focused on inventory management at the depot especially settling a period effect. Cafaro and Cerda [14] studied a similar problem with [13]; they introduced smaller MILP formulation providing better schedules in very less computational time. Relvas et al. [15] extended their previous work [13] in order to consider variable flow rates and pipeline stoppages. In addition, they developed approaches for updating scheduling when unpredictable events take place. As already mentioned, all continuous approaches deal with a refinery in origin and some depots along the pipeline which can only withdraw products from the pipeline.

Cafaro and Cerda [16] introduced an MILP continuous model for scheduling unidirectional pipelines which connect several refineries to several depots, so that some of the depots were dual purpose. In this model refineries or depots cannot inject into the pipeline simultaneously. They extended their model in [17] to account for simultaneous injections. They showed that the new model is better in terms of problem size and running time. In both papers [16,17], it is necessary to guess the number and location of empty batches among old batches in the pipeline. But it is not clear how the number and location of empty batches among old batches can be guessed.

Since some part of our work is close to [16,17] by Cafaro and Cerda, their main differences are worth mentioning:

- The distance between two successive injection points along the pipeline are defined as a segment and batch sequencing, for each segment is done in parallel and separately. Therefore, formulation of this model is different from previous MILP models [16,17].
- The type of product which is injected from a middle segment must be the same as the product that is located in the entrance of the segment. This requirement has been relaxed and it is possible that the type of these two products be different.
- It is not necessary to rely on guessing empty batches from among old batches. Also the proposed model can compute interface cost with higher accuracy because in the previous model when an empty batch lies between two real batches, it does not compute interface between two real batches.

This paper is organized as follows: Section 2 describes the studied problem. Section 3 illustrates the model in details including parameters, variables and relevant mathematical representation. In section 4 computational results are reported and the models main differences are explained. Finally section 5 gives some conclusions and sums up the paper.

2. Problem description

Consider a scheduling problem where several refineries must distribute P refined products (after now products) among D depots connected by a pipeline. Some of the depots through the pipeline are dual purpose, i.e. they can inject products to the pipeline and receive products from it. A typical multi-product pipeline is depicted in Fig. 1 which consists of a pipeline connecting two refineries to three depots in which depot 2 is dual purpose.

Refineries and depot D2 can simultaneously inject products in the pipeline under the following conditions: Assume D2 injects product P into the pipeline. If product P = P1 is injected at D2 then some amount of product P1 that lies before D2