Managing Distribution in Refined Products Pipelines Using Discrete-Event Simulation

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ABSTRACT

The management of oil-product pipelines represents a critical task in the daily operation of petroleum supply chains. Efficient computational tools are needed to schedule pipeline operations in a reliable and cost-effective manner. This work presents a novel discrete event simulation system for the detailed scheduling of a multiproduct pipeline consisting of a sequence of pipes that connects a single input station to several receiving terminals. The pipeline is modeled as a non-traditional multi-server queuing system involving a number of servers at every pipe end that perform their tasks in a synchronized manner. By using alternative priority rules, the model decides which server should dispatch the entity waiting for service to the associated depot. Also, the model deals with the timely fulfillment of terminal demands and the system response to unexpected events. In combination with optimization tools, the proposed simulation technique permits to easily manage real-world pipelines operations with low computational effort.

INTRODUCTION

Pipeline management plays a key role in the petroleum business. Refined products pipelines are regarded as the most reliable and cost-efficient way to transport large amounts of liquid fuels over long distances. In contrast to other transportation modes, pipelines can operate continuously with almost no interruptions despite bad weather conditions. Furthermore, they have an important edge on environmental and safety issues. Pipelines transport a variety of oil derivatives in successive batches and operate in two different ways: segregated or fungible mode. Segregated products are branded or blend stock materials destined for

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some specific client so that the same batch that is received for shipment in the origin is delivered to the client. Moreover, fungible batches consist of generic products fulfilling standard specifications. Shippers will receive a batch containing an equivalent product featuring the same specifications, but may not be the original lot they provide at the origin.

**Pipeline Scheduling**

The pipeline scheduling process is aimed at developing both the input and the delivery schedules. On one hand, the input schedule indicates the sequence of pump runs at every input terminal, as well as the injected product, batch size, starting time and pump rate for each run. Finding the optimal product sequence and lot sizes is a combinatorial problem that seeks to minimize interface costs due to product mixing while satisfying promised delivery dates. Since separation devices are rarely used, some sequences are definitely forbidden because of product contamination. On the other hand, the delivery schedule specifies the product batches partially/totally leaving the pipeline and the amounts diverted to the assigned destinations on every pumping run. In addition, it provides the times at which pumps should be turned on/off and valves at terminals are to be open/close for accomplishing the delivery plan. Its main goal is to meet depot demands while lowering the number of pipeline stoppages and pump switching to get savings on both energy costs for restarting flow in idle segments, and pump maintenance costs. Most of the computational burden in pipeline scheduling comes from these three difficult tasks: pump sequencing, batch sizing, and batch allocation to receiving terminals. By heuristically choosing them, the remaining operational decisions can be taken in a short CPU time. However, the final pipeline schedule is greatly influenced by those heuristic-based decisions previously taken (Boschetto et al., 2008).

Different approaches were proposed to study pipeline scheduling problems, including rigorous optimization models, knowledge-based techniques (Sasikumar et al., 1997), discrete-event simulation (Mori et al., 2007; García-Sánchez et al., 2008), and decomposition frameworks (Hane & Ratliff, 1995; Neves et al., 2007; Boschetto et al., 2008; Moura et al., 2008). Rigorous optimization methods generally consist of a single MILP (Mixed Integer Linear Programming) or MINLP (Mixed Integer Nonlinear Programming) mathematical formulation and are usually grouped into two classes: discrete and continuous, depending on the way volume and time domains are handled. Discrete formulations divide both the pipeline volume into a number of single-product packs, and the planning horizon into multiple time intervals (Magatão et al., 2004; Zylgier & Kelly, 2009; Rejowski & Pinto, 2003, 2008; Herrán et al., 2010). Most of them generally use uniform time and volume discretization. However, a later paper of Rejowski and Pinto (2008) assumes that each pipeline segment is composed by packs with equal or different pre-specified volumes to account for variations in the pipeline diameter, and the scheduling horizon comprises time intervals of adjustable duration to allow changes in the pump injection rate. On the other hand, available MILP-continuous optimization tools for pipeline scheduling, like the one proposed by Cafaro and Cerdá (2004, 2008), do not require any kind of decomposition or discretization scheme. They are able to find the optimal schedule for a single-origin pipeline with multiple output terminals by minimizing the sum of pumping, interface and inventory costs. Recently, the same authors developed an MILP-continuous formulation for scheduling pipeline networks with multiple input terminals (Cafaro & Cerdá, 2009). In any case, however, continuous approaches just provide the set of “aggregate” batch stripping operations to be done during every pumping run without specifying the detailed sequence of batch “cuts” to be performed by the pipeline operator. Generally, there are many ways to disaggregate such accumulated product discharges, i.e., several alternative cut sequences. Hence, the development of an efficient detailed output schedule through a continuous optimization approach is...
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