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Simulating the Operational Scheduling of a Real-World Pipeline Network

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Abstract

This paper addresses the problem of developing a simulation model to aid the operational decision-making of scheduling activities in a real-world pipeline network. Basically, the simulation model should represent three different behaviors: production, transport and demand of oil derivatives. Batches are pumped from (or pass through) many different areas and flow through pipes which are the shared resources at the network. It is considered that different products can flow through the same pipe and each oil derivative has its proper tankfarm at refineries, terminals or harbor. The simulator makes use of an optimal scheduling sequence of batches that balance demand requirements to the production planning, considering inventory management issues and pipeline pumping procedures. The simulation model represents a real-world pipeline network designed to aid typical activities of an operator such as inventory management at different and batch performance analysis by visualization tank levels and pipe utilization rate.

Keywords: discrete event simulation, operational research, pipeline network.

1. Introduction

This paper addresses the development of a simulation model for the operational decision-making of scheduling activities in a real-world pipeline network. There are many works in the literature regarding scheduling of transfer tasks in oil industry [1]. Most of them present optimization models to achieve a better performance in terms of amount of products transferred in a time horizon, resource utilization, energy cost, minimum inventories and so on. Other ones are dedicated to provide an optimal scheduling for pipe transfers [2, 3]. In this case, operational constraints such as product interface, throughput and simultaneous operations should be considered.

Basically, transfer and storage tasks are characterized by many different procedures. These procedures can be modeled by formal models such as Petri nets [4] or Workflow [5]. But these approaches require a better understanding of the process involved and simplifications is frequently necessary. Although interest exists to develop formal models for these problems, either to verify procedures or to obtain optimal solutions, little attention is given to develop simulation models that allows checking the plant behavior under different conditions. Moreover, simulation models allow to include operational details not considered in other models. In this paper, the proposed simulation model is used with a short term scheduling optimization package that provides the scheduling to be simulated. This is accomplished by using a discrete event simulation model [6] implemented in EXTEND [7]. In this model, a scheduler generates events at times provided by the optimization package. Each event carries out information about different batches, which are characterized by attributes such as type, route (source, pipes and destination), volume and flow rate for each product to be transferred. These attributes allow to calculate the inventory level at different areas.

This paper is organized as follows. Section 2 presents some operational issues that should be considered for modeling a real-world pipeline network. Section 3 describes the proposed discrete event simulation model, giving particular attention to the pipe model, while Section 4 presents the simulation results for inventory level and pipe utilization. Finally, Section 5 concludes the paper.

2. Operational issues in a pipeline network

The scenario illustrated by Fig.1 involves 9 areas (including 3 refineries, 1 harbor which either receives or sends products, and 5 distribution centers). The scenario includes 15 pipes, each one with a particular volume (e.g. pipe A has more than 42000 m^3). Some pipes can have their flow direction reverted according to operational requirements. Each product presents a specific tankfarm according to the considered area. More than 10 oil derivatives can be transported. For instance, a typical operation involves pumping a batch from a source to a destination area passing by three intermediary areas. In this case, a product is pumped through four pipes. During the scheduling horizon, many batches are pumped from (or passing through) different areas. Due to pipes be shared resources, they can generate allocation conflicts, even for minor delays. Hence, the optimization package must provide scheduling details including pumping sequence in each area, volume of batches, while satisfying many operational constraints.

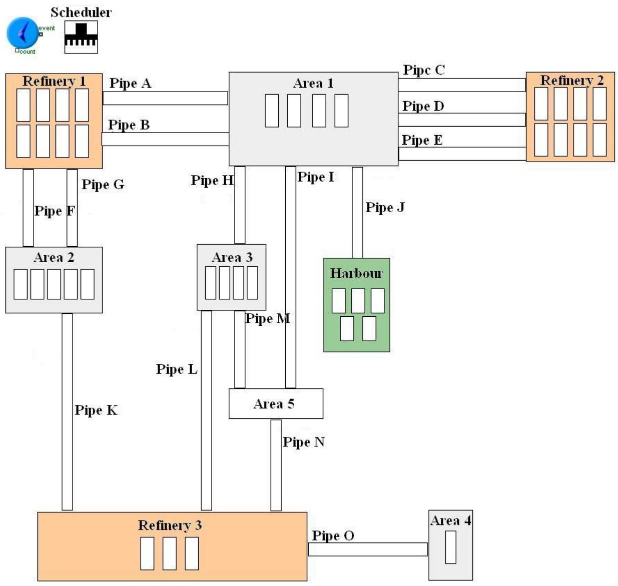

Figure 1 – Pipeline network

Pipes have an internal volume that is always full-filled. When a product is pumped from a source, previously stored products in the pipe are pushed out according to the product flow rate. Moreover, stored products should be routed to their original destination. At each area, products arriving from pipes can be stored in tanks or routed to other pipes. A set of tanks in each area can store different products. Inventory level can increase or decrease according to the volume and flow rate of each product pumping or due to local production and demand. Nowadays, the scheduling process is still defined by operator's skills.

3. Discrete event simulation model

A discrete event simulation is based on a schedule event list that contains events to be executed. An event corresponds to an instantaneous action or condition occurred. In the proposed discrete event model, each event corresponds to a pumping start. It carries out information about a batch characterized by attributes such as type, route (source, intermediate pipes and destination), volume and flow rate of each product to be pumped. After starting, pumping is accomplished at constant flow rate which determines a linear inventory change. In fact, the real flow rate depends on the fluid dynamics of each product and it can be quite variable. However, we have considered a constant flow rate determined only by the product to be pumped and route to be used. This could be done based on operator's experience.

The simulation model described above was implemented using a simulation tool named EXTEND. This software package provides many capabilities for modeling structures commonly found in discrete event simulations. For instance, it provides functional blocks for queuing, routing, processing, batching, resources as well as statistical blocks. The proposed discrete event model is able to simulate pumping operations according to the scheduling established. Moreover, it is able to capture various operational constraints such as simultaneous pumping constraints.

Basically, the simulation model has three kinds of blocks: scheduler, tank and pipe block. The scheduler generates events at particular times (provided by the optimization package) and it sets event attributes (type, volume, route, and flow rate of each product) according to information stored on a database.

The attribute *type* represent one of ten possible oil derivatives that flows in the network at fixed rate given by *flow rate* attribute. The attribute *volume* is the amount of product in a batch. The attribute *route* contains a well-defined path from a source to a demand area considering all necessary pipes.

Each area contains an agregate storage (set of tanks) for each product. In this case, the level of an agregate tank are subject to three simultaneous behaviors: production, demand and transport. Production and demand fills and drains tanks, respectively, while transport may increase or decrease the tank level according to its role (source or destination). All level changes are linear, since production, demand and transport are assumed to have a constant flow rate. The initial condition for tanks is their level and storage capacity.

3.1. Pipe model

Particular attention is given to the pipe model, since it can store many different products. Basically, each pipe is modeled as a FIFO (First In-First Out) queue that stores and releases events (products pushed into the pipe) according to new products arrival. When a new product arrives, previous products stored in the pipe are pushed out according to the new product volume and flow rate. Moreover, old products in the pipe should be routed to their original destination. The internal pipe queue keeps track of order and quantity for each product entering into the pipe. Hence, the pipe model is quite complex due to a fragmentation caused by transport of different products. At the beginning of simulation, this fragmentation is defined by filling the pipe's internal queue with proper events representing the pipe status at time zero.

4. Simulation results

The simulation results were obtained for a scenario of 81 batches transferring about 8 products in a time horizon of 20 days. For example, inventory levels for product AK (aviation kerosene) at Refinery 2 (production) and Area 3 (demand) are shown in Fig. 2 and Fig. 3, respectively.

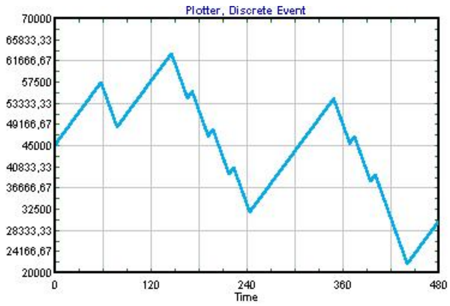

Figure 2 – Refinery 2 inventory

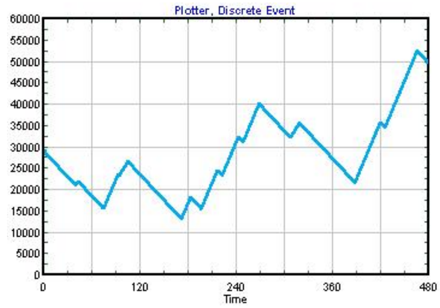

Figure 3 – Area 3 inventory

These figures represent transfers of AK from Refinery 2 to Area 3 using pipes D, I and M (see Fig. 1). The first transfer occurs approximately at time 60, as can be seen by the first inventory decreasing in Fig. 2. Nevertheless, this product only arrives at Area 3 about time 70, as can be seen by the first inventory increasing in Fig. 3. This is the necessary time to full-fill the whole pipe volume along to the route. As expected, the inventory variation is according to the scheduling provided [8], but note that small variations are due to minor product volume stored into the pipe. This volume is moved by consequence of other transfers. In other words, starting a transfer is an operation that can have a well-defined time, but its completion is only determined by other transfer or transfers that push the remaining product stored into the pipes. Thus, the simulation behavior is very close to a real one. The utilization pipe rates obtained are also provided, as shown in Fig. 4.

------ PIPES UTILIZATION ------

PIPE A	0,4198	PIPE F	0,2614	PIPE K	0,878
PIPE B	0	PIPE G	0,7412	PIPE L	0,2685
PIPE C	0,4312	PIPE H	0,6283	PIPE M	0,5942
PIPE D	0,3471	PIPE I	0,5549	PIPE N	0,0286
PIPE E	0,1208	PIPE J	0,3535	PIPE O	0,3256

Figure 4 – Utilization pipe rates (x 100%)

Note that pipe K has about 88% of utilization. It means that this pipe is used 88% of the time horizon indicating a possible bottleneck in the network or a strong demand for products along to this route. By using a computer Pentium 4 / 2.4GHz with 1GB RAM, about 3 minutes was necessary for simulation.

5. Conclusions

This paper addresses the development of a simulation model for the operational decision-making of scheduling activities in a real-world pipeline network. By using a discrete event simulation, actions such as pumping start could be separated from flow rate dynamics, which allows to separate scheduling actions from inventory management. Simulating the pipeline network operation allows to detect conflicts in pipeline allocation as well as tank security levels. At the same time, products inventory can be tracked and the impact of operational delays can be measured. Finally, the discrete event simulation reports many statistical measures as pipeline utilization rate and throughput. This could be used to identify bottlenecks, poor pipe utilization or even to identify and classify new scheduling approaches.

Acknowledgements

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