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Event-driven Simulation of Liquid Transportation Through Pipeline Networks for Oil Companies

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An event-driven simulation system is presented here for the transportation of liquid through pipeline network. An oil company produces various products in refineries and transport them mainly through pipelines to depots where the products are sold. A schedule is required for the transportation. The schedule defines the type of product to be transported, its amount, the start and end time of the transport, and the path. A schedule is called feasible if it takes into consideration tank capacity, product availability, deadlines, etc. Naturally, it is essential to check the feasibility of a schedule. Manual feasibility checking can be carried out only for a short time period, 3-4 days, and only if the complexity of pipeline network is modest. If schedules are needed for longer time periods, as long as 30 days, then a simulation model for the movements in the pipelines is needed. The implemented simulation system is applied by an Eastern-European oil company. The reduced stock levels and the better schedule means more efficient operation, less energy consumption, and less impact on the environment.

1. Introduction

Performing process simulations is particularly important for the oil industry. There are plenty of products to be produced. Transport and storage of both the raw materials and the products is the Supply Chain Management (SCM) departments' responsibility. To help scheduling and decision making the simulator calculates the behaviour of the oil transport system step by step, consequently, as to analyse the system, identify bottlenecks, and plan future operations. The developed event-driven simulator is currently used by a major Hungarian oil company in order to operate more efficiently and as a result, in a more environmentally friendly way. The simulator was tested with real life data. Simulation, scheduling, modelling, and production planning are significant research areas in the oil industry. This section presents an outline about articles related to decision support, process simulation, and product pipeline scheduling.

The central logistics operation that links the upstream and downstream functions is the world-wide crude transportation. It plays an important role in the global supply chain management of the oil industry. Cheng and Duran (2004) have designed a decision support system to help investigate and improve the combined inventory and transportation system in a world-wide crude supply problem. This system utilizes integration of discrete event simulation and stochastic optimal control of the inventory/transportation system. The research intends to assist decision makers with the study, design, and control of the world-wide supply chain.

A general framework for modeling petroleum supply chains has been introduced by Neiro and Pinto (2004). Different tanks, pipelines, and refineries models have been considered. The complex topology of connected models results in a MINLP problem. This methodology has been generalized from discrete to continuous timeframe.

Tolchinsky et al. (2016) have created a three-temperature heat-transfer model based on the viscous-plasticity generalization of the Bingham flow model in a pipe or channel, which allows, in principle, to find the longitudinal distribution of temperatures. This model allows extension without changing its major provisions on a wide range of phenomena occurring in the flow of oil and oil products, e.g. the melting and hardening, the change of the threshold yield stress, slip at the boundaries of the flow region, the viscosity change from the content of the dispersed phase.

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Jobson et al. (2017) have developed surrogate models, which allow the results of multiple process simulation runs to be regressed as multiple input–multiple output models for the purposes of design and operational optimization. New techniques are enhancing current capabilities for operational optimization and design of crude oil distillation systems.
Tak et al. (2017) have introduced a cost-optimal inspection and replacement planning model which takes into consideration the corrosion rate in a pipeline. The planning model was an MINLP problem, including integer variables for the pipe wall thickness, an inspection number and continuous variables for the inspection times

2. Problem definition

In this paper, a novel process simulation method has been designed and developed to support the scheduling of the logistics system in the oil industry. The features of the simulator are the following.

- Helps the design of tank schedule, product pipeline schedule, blending order schedule, and product allocation. The product pipeline schedule defines the circumstances of the transportation of each product and it contains the transportation time, source, path, and target. Tank extraction is the download of its content and the tank upload refers to its refilling. The last production step in petrochemistry is blending. Final products are the mixtures of different additives to the semi-products. Blending order schedule is the timetable for blending operations. Allocation means the distribution among transportation types of products, which are available at a given site.
- Tracks the products and raw materials from blending to selling under departmental supervision, consequently, their locations are always known.
- Makes the monthly optimized plan feasible day by day. Monthly optimized plans contain all the processes (blending, uploads, downloads, pipeline transports, etc.) which happen during the actual month.
- Simulates and visualizes the transportation in the product pipelines in one single model.

The simulation system can also be viewed as a decision support tool. Decision making in the oil industry is a particularly complex process. Decisions are made within supply chain distribution and at the management level. Decisions are also diverse regarding in business scope, time horizon, time resolution, data certainty, and process detail. Thus, there are a several factors which have an effect on the decisions. For instance, Hungary, a relatively small country has a complex pipeline structure, shown in Figure 1. It has two refineries, one petrochemical site, 19 sites, 235 tanks, and 30 product types.

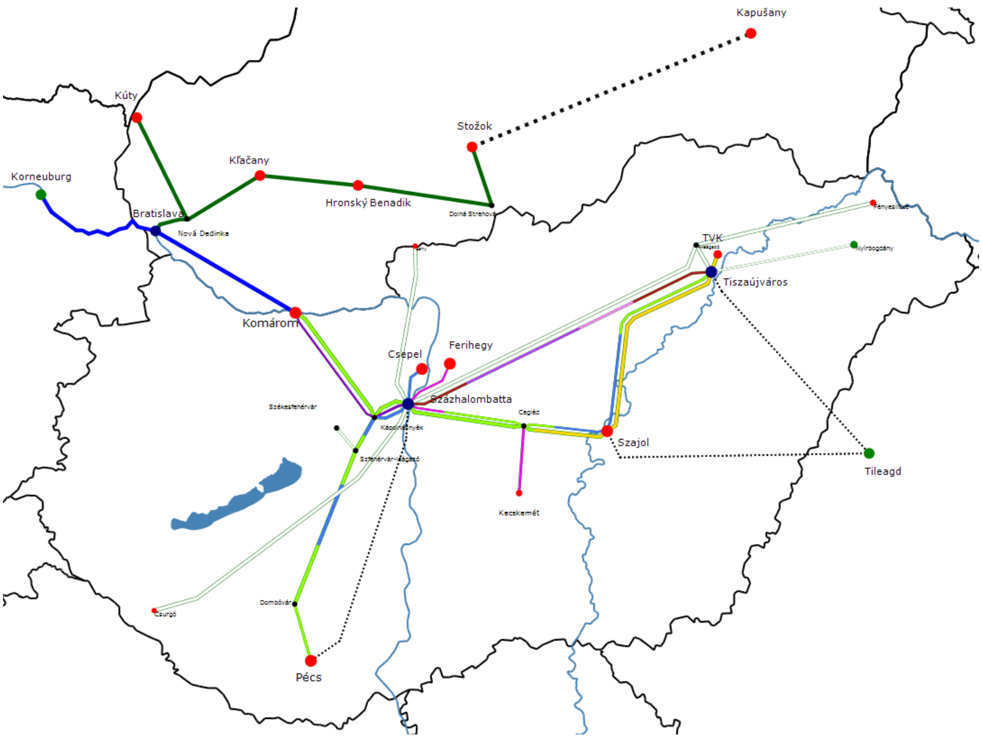

Figure 1: Pipeline structure of Hungary; lines denote pipes and dots denote refineries and depots

Lack of transparency, functional barriers between departments, ineffective scheduling make decisions and communication limited. These result in delayed or even improper day-to-day decisions, which lead to financial deficiencies. The traditional way of decision making which is based on spreadsheets, meetings, and phone calls all hinder the speed and effectiveness of the process, not mentioning the unnecessary waste of resources. This is why a novel, efficient tool is needed to facilitate the decisions of scheduling.
The problem is complex because a lot of factors have to be taken into account. These are the pipe-transport planning, refinery function, sales at every site, and determination of the sequence of products. One of the most important tasks is to collect all scheduling information. Decision has to be made about the time horizon (four days long pipe transport plan vs. one day long allocation plan). With the help of the simulator, the company can focus on the prediction of imbalances and reacting sooner, instead of error-handling.

3. Architecture of Event-driven Simulator (EDS)

This simulator introduced here is a novel Event-Driven Simulator (EDS). Figure 2 illustrates operation of the simulator. The system operates using the data of the physical system. First, information on the products, tanks, sites, and pipeline structure must be given. It is followed by the modelling step, mapping a real life system into a conceptual model. The product pipeline network is complex, e.g., there are parallel product pipelines, the pipe diameter is not standard, there are branching points at various locations, and the direction of the flow may also be reversed.

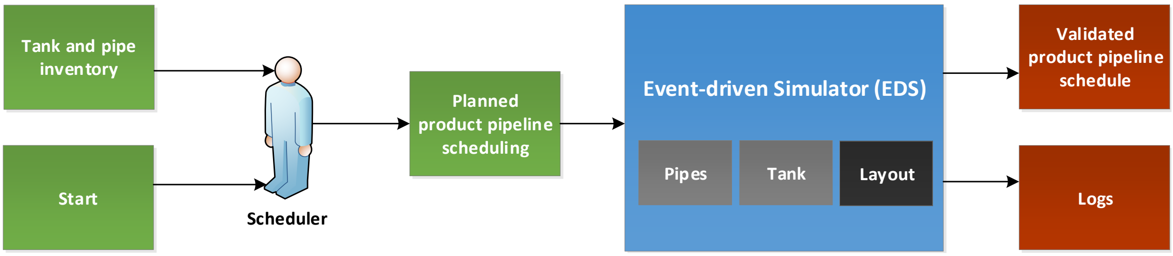

Figure 2: Operation of Event-driven Simulator

Tank and pipe capacity information need to be available for the operator. Each tank is dedicated to a single product, but this can be changed under particular circumstances. Each tank has two parts: mobile and immobile part. The immobile component cannot be downloaded in regular operation, which has to be taken into consideration at the operation.
Sales data is acquired by the operator as well. Product demands are identified in advance, these contain data types, e.g. the type and amount of the product and delivery time. Blending is only available at the refinery sites, other sites only store or distribute products. Products are transported in different ways, e.g. by barges, railway tank cars, trucks, or product pipelines. Demands can change, which has to be taken into account.
An operator plans operations by defining the allocation of products among means of transportation and the product pipeline schedule. Product pipeline schedule can be described by the three main operations: upload, download, and transport. Upload usually occurs on a supply site after a refinery has produced the required product; download can occur on both demand and supply sites where the products are delivered to the customer. The simulator considered transportation by pipelines originally but now it can handle barge and train transport as well. Different types of material are pumped through a pipe following one another. The effect of mixing adjacent materials is neglected from the scheduling point of view. The mixed material is transported back to the refinery on road. Two materials starting from the same site may have different destinations. Start and end-points of the liquids within each product pipeline are determined. The system shows when a liquid reaches a branching point when the valves have to be set into a different position. The flow of the liquid in a product pipeline is driven by the liquid pumped at the source at the same time. It may happen that transportation of a liquid is necessary only to drive a liquid which is already in the pipe.
The input of the EDS is the planned product pipeline schedule and its output is the validated schedule. If the schedule is not feasible, the operator makes adjustment in the planed schedule and reruns the simulation. Furthermore, operation logs, reports are created, which can assist future planning and predictions.

4. Operation of Event-driven Simulator (EDS)

The Event-driven Simulator simulates the aforementioned process. In this case, process simulation is preferred to optimization, as the objective function is very difficult to define. As some complex constraints are hard to

formalize, the overall decision depends on the operator; thus, this simulator is an effective tool to support the planning process.
Simulation demonstrates the future behaviour of a given system based on planned operations (e.g., pipeline transportation, tank upload, and download, etc.) in a given time interval. It calculates the new states of the system minute-by-minute. For each minute, exactly one calculation is carried out for each component of the system (e.g., material level of pipes and tanks, etc.) so that their new states can be found out. The system states are saved once for each hour to make the data processing faster during the visualization. This does not weaken accuracy from the visualization point of view. The accurate level of a tank is investigated and saved for important times, e.g., the end time of a download. As a consequence, the saved states give an adequate basis for graphical visualization of the calculated data. EDS, like other simulators, is not able to replicate real conditions perfectly, but it can flexibly handle the difference between the logical and the real system. These differences may stem from inaccurate calculations, model incorrectness, unplanned activities, etc. If any of the previously mentioned difference would occur, EDS enables manual data correction to eliminate errors.

4.1 Components of the simulation

The database contains every piece of information, which describes the physical system (e.g., structure of the pipeline network, parameters of sites and tanks, etc.). That is why altering the simulation framework itself is not needed if the underlying physical system has been modified or extended; only the model has to be modified. For instance, if a new tank is implemented at a site the system model can be modified accordingly. In the course of the simulation the following four objects of the real system are involved: pipes, pipe branching points (pipe connections), tanks, and sites. The database contains their input data such as the activities during the simulation.
A tank object contains several important parameters. It has an immobile level which cannot be downloaded, and a mobile level which equals the capacity that can be utilized. Tanks can be handled individually as an aggregate tank depending on the parameters of the given site. Different products are assigned to different tanks; which can occasionally be changed under given conditions. A tank can be uploaded and downloaded simultaneously. Every tap is connected to a pump, which determines upload and download speed. Other parameters can be linked to tanks, e.g., owner of the given tank and the site where it can be found, etc. Tank level can be changed by upload and download. For instance, in Figure 3 depicts two parallel downloads (1st download: 6 h – 13 h, 2nd download: 11 h – 20 h).

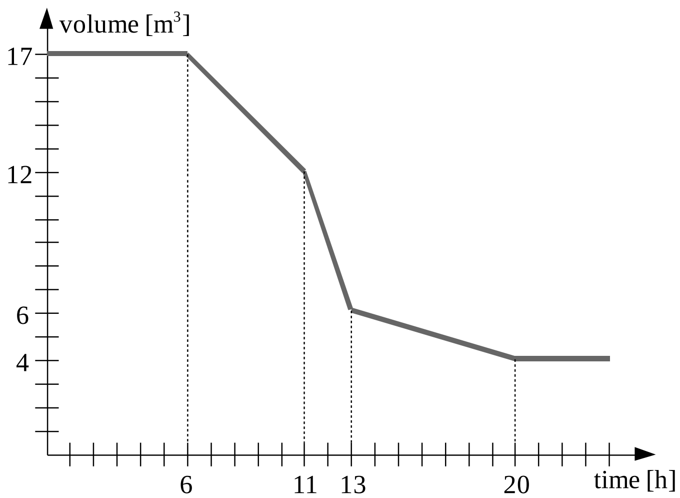

Figure 3: Tank download

The significant parameters of a pipe object are the following: starting point and end-point, diameter, length of pipe, and volume. The most important parameter of a site is a logical value which indicates if the tanks are to be considered individually or in an aggregated way. During the simulation, materials are transported through the pipeline network from one tank to another at another site. Figure 4 shows the operation of a product pipeline.

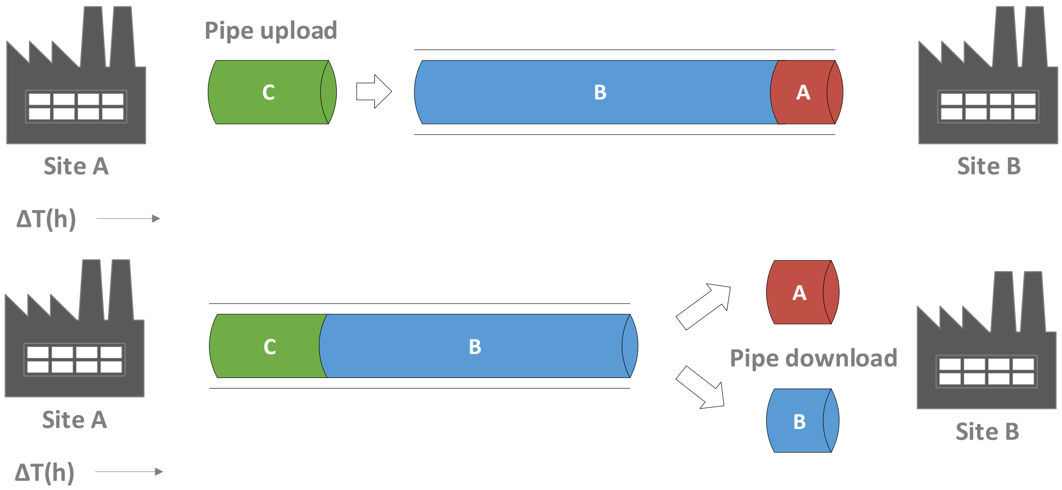

Figure 4: Operation of a product pipeline

The simulation consists of elementary time steps, in which the volume of the material, pumped from site A, unloads the same volume of material to site B. The pumping triggers the event "pipe upload", which generates further events. On Figure 4 it is the event of "pipe download". In case the pipe ends in an intersection, the material starts a "pipe upload" event. The simulation is terminated when the element list empties and no new events are generated. The complexity of the simulated system arises from the connections and dependencies of different objects. For instance, in the pipeline network, pipe items are connected with different diameters, which results in various transport speeds for the same product.

4.2 The simulation process

The simulation process has two main phases: preparatory phase and the main phase of simulation. At the preparatory phase system components and their states are loaded from a history. History logs result from a previous simulation which can also be modified manually if discrepancy has been identified. The operator can opt from a number of histories which are logged in the database.
In the main phase of the simulation (see Figure 5) the whole time interval is simulated by elementary (1 min) time steps. In each time-step, the current state of each system object is established and stored in the database at given time intervals (default is 1 h).

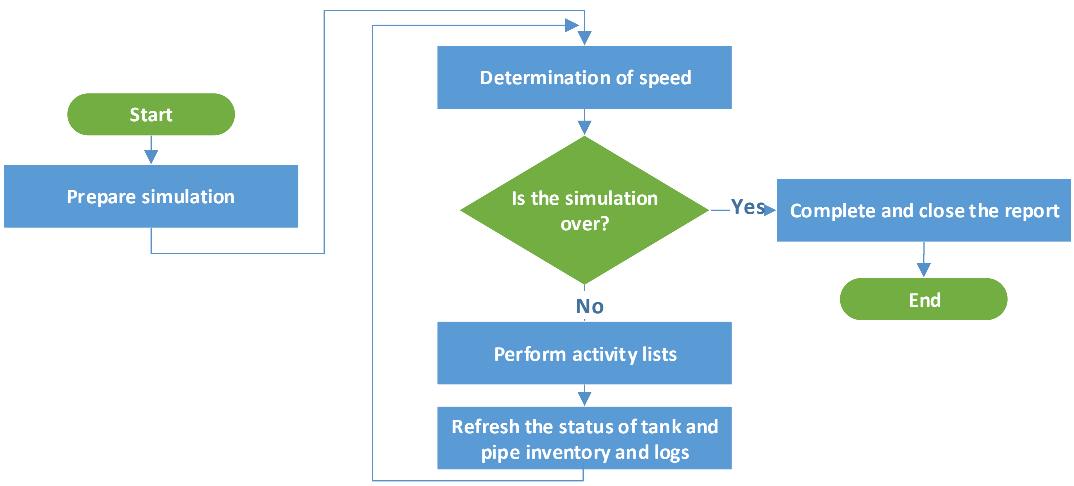

Figure 5: Flow chart of the simulation

The simulator is controlled by an iterative function for the repetitive execution of the elementary steps. It goes through the time interval of the plan in time steps starting with the one, which has the highest priority. The execution of an elementary event generates further events, which the simulator executes recursively until it

finishes the list of events. If the execution of all events succeeded, the simulator considers the elementary step to be successful and refreshes the status of tank and pipe inventory and logs.
In the simulator, there are two modes considering the level of details; the first is a simplified simulation which focuses on the pipe transports but neglects the tank level constraints. In this mode the simulation is performed very quickly (less than 1s) even in case of hundreds of pipe transports are present at the same time. The second mode is detailed which provides complete simulation, analyzing the whole system (about 30s). Consequently, the simulator can be used to experiment with multiple different plans.

5. Conclusions

A simulator and decision support tool has been introduced. It aims to validate the planned product pipeline schedule and make it efficient. Without using the simulator, it was feasible to schedule only 3-4 days in advance. Because of the short time horizon, it repeatedly happened that it was impossible to transport a bath through pipeline in time. In these cases, railway or road transport had to be used, which have more significant detrimental environmental impact than pipeline transport. The simulator makes it viable to plan for a longer time horizon (30 days) which helps to avoid the aforementioned situation. EDS is capable to determine the future states of the system, for instance, the contents of the tanks and the product pipeline. The results can be presented in history logs which can display the changing content of the pipes and the tanks and help the decision making processes. In the future, EDS is intended to be improved with further functions. It is our intention to streamline the simulator to depict real-life conditions with higher accuracy.

Acknowledgments

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