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# Event driven process simulation of pipeline networks

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A novel simulation method is introduced here for transporting liquids through a pipe network in the oil industry. The aim is to ensure the balance among product availability, sales, and transport in each production and distribution point, to display the actual schedule and its effects, and to identify inconsistencies. The product pipelines connect sites where tanks are available to store liquids temporarily. The tanks are uploaded and downloaded continuously according to a schedule. This schedule is to be validated, i.e., it must be ensured if a planned operation can be performed, e.g., at download there are enough liquid in the source tank and at upload there is enough free capacity in the target tank.

## 1. Introduction

Process simulation has a very important role in the industry. Even when all the components of a system are well known, i.e., it is clearly defined how a component will react to a specific input, we can only guess how the system as a whole will respond to a particular action. Usually, the system is just too large to completely understand its inner workings. This is usually the consequence of two attributes or their combinations. First, the system has a great number of components each with plenty of properties. In this case, there are too much data to keep all of it in mind. Second, the system is highly complex. The input of the system may affect several components, these components affect other components, etc. A single input may cause a ripple effect in the whole system. It is a real possibility that our initial input causes unwanted side-effects or in some cases exactly the opposite what was originally intended. If a system is both complex and has a great number of building blocks then it is extremely difficult to predict the reaction for some action.

A simulator calculates the system behavior, i.e., the future states of the system, for a given input based on the current state and the operations of its components. Moreover, by running different scenarios a simulator helps us to analyze the system, identify bottlenecks, and plan its future operation. It should be always kept in mind that the simulation is only a representation of the physical system, consequently, the accuracy of the results depend on the accuracy of representation.

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Performing process simulations are especially important for the oil industry. In the downstream division a large number of products are to be produced. The Supply Chain Management (SCM) departments in the oil companies are responsible for coordinating the transport and the storage of both the raw materials and the products.

MOL Plc is the major Hungarian oil company. A significant point of the MOL Group strategy is to improve and extend the practical adaptation of the Supply Chain Management philosophy continuously. The SCM department of MOL had not such a simulator program which would totally satisfy all of its needs, consequently, a novel process simulation method is designed and developed. This method is based on the extensive experience of the personal of SCM department and tested with real life data.

## 2. Problem definition

A simulator application is to be developed which is capable to: (i) keep track of the products and raw materials under the supervision of the SCM department, (ii) assist the design of the product pipeline schedule, (iii) ensure the feasibility of the monthly rolling plan, (iv) and simulate and visualize the transports in the product pipelines.

The proposed system can be also perceived as a decision support tool. Decision making in the oil industry is an outstandingly complex process. Decisions are made at different stages within the supply chain distribution and at different levels in the management hierarchy. The decisions also differ in business scope, time horizon, time resolution, data certainty, and process detail. Consequently, there are a high number of factor affecting the decisions. Still, a large number of oil and chemical companies are still held back by obsolete decision making processes; see (Lasschuit and Thijssen, 2004) and (Cheng and Duran, 2004). Decisions and communications across the supply chain are ineffective and delayed, because of off-line erratic spreadsheets, functional barriers between departments, and lack of transparency. This all leads to slow and inept day-to-day decisions that cost companies dearly in terms of financial performance. The legacy way of decision making which is based on spreadsheets, meetings, and phone calls all stand in the way of speed and effectiveness, consequently, a novel, efficient tool is needed to assist the decisions in product pipeline scheduling.

## 3. Literature review

Modeling, simulation, scheduling, and production planning are major research topics in the oil industry. In this section an outline is to be given about articles related to decision support, process simulation, and product pipeline scheduling.

An early flowsheeting simulation package has been proposed and implemented in (Vasek, 1983). The authors have recognized that simulation has a major role in design and proved that significant results can be achieved using the desktop computers of that time.

An overview about the production planning approaches in the process industry has been presented in (Crama, 2001). The differences and the similarities among different methods have been underlined. Moreover, the distinctive features of process industry have been presented as they relate to production planning issues. The difficulties encountered with the implementation of classical flow control techniques have been discussed and various approaches to overcome them have been referenced. A survey of specific flow control models and algorithmic techniques specifically for process industries have been also discussed.

World-wide crude transportation is the central logistics operation that links the upstream and downstream functions and plays a crucial role in the global supply chain management in the oil industry. Cheng and Duran (2004) have developed a decision support system to investigate and improve the combined inventory and transportation system in a representative world-wide crude supply problem. This system is based on the integration of discrete event simulation and stochastic optimal control of the inventory/transportation system. Its aim is to assist decision makers with the study, design, and control of the world-wide crude supply chain. Uncertainties arising from travel time and crude demand are formulated as a Markov decision process. The solution method for the optimization problem is based on dynamic programming.

Lewandowski (1994) presented an object oriented methodology for modeling a natural gas transmission network. Each element of the network, such as a gas pipeline segment or a node, is represented as an object, which are assembled into a network. This methodology has been implemented using a collection of C++ classes for structured modeling of dynamical systems. This collection of classes makes it possible to simulate hierarchical dynamical system using the state variables and submodels as components of a model.

Herrán-González et al. (2009) focused on the modeling and simulation of a gas distribution pipeline network with a special emphasis on gas ducts. Gas ducts are the most important components of such kind of systems since they define the major dynamic characteristics. Two simplified models have been presented which include the inclination term, neglected in most related papers. MATLAB and Simulink have been applied to solve three examples. The results are compared with the existing ones in the literature.

A decision support tool has been presented in (Lasschuit and Thijssen, 2004) for supply chain planning and scheduling in the oil and chemical industry. The system provides a coherent framework, including mechanisms which allow consistent economic and operational steering, taking into account real-time information on actual operations and market economics. The resulting mathematical programming model is a mixed-integer non-linear programming (MINLP) model: integer aspects arise because of fixed and investment costs, tiered pricing, and cargo costs. Non-linear relations are mainly caused by economic variables and non-linear unit operations.

A general framework for modeling petroleum supply chains has been introduced in (Neiro and Pinto, 2004). Different models have been proposed for tanks, pipelines, and refineries. The connected models has a complex topology based on which a MINLP problem is formulated. Rejowski and Pinto (2008) generalized the previous methodology from discrete to continuous timeframe.

## 4. System architecture

The proposed decision support and simulation tool is named as ProdSim which refers to *prod*uct pipeline and tank *sim*ulation. Figure 1 illustrates the inputs and outputs of ProdSim. The current state of the system is known, which are the content of tanks and the product pipelines. Tanks at a given site may be handled individually or in an aggregated way. The former means that the operator specifies exactly which tank is the target of a transport, while in the latter case, only the target site is given. The state information is updated regularly. If all the operations are carried out according to the schedule then the update only confirms the simulated values.

The physical layout and the properties of the simulated system are also known. Providing information about the products, tanks, sites, and pipeline structure is the modeling step, mapping a real life system into conceptual model. The application is flexible as the underlying model can be easily changed. The product pipeline network is highly complex, e.g., there are branching points at various locations, parallel product pipelines, the pipe diameter may change between two sites, and the direction of the flow can also be reversed.

Each tank is dedicated into a single product because different products requires different infrastructure, e.g., mixer, tap. The capacity of each tank has two components: the mobile and immobile part. The immobile part can not be downloaded in regular operation.

The demands for the different products are known in advance, this includes the type of the product, its amount, and the delivery time. Only few sites have processing capability, the other sites just distribute the products. The products are transported by barges, railway tank car, trucks, or product pipelines. The demands may change over time, which has to be taken into consideration.

An operator specifies the future operation of the plant by defining the blending order schedule and the product pipeline schedule. The blending order schedule is the production plan for the different products. The product pipeline schedule defines for each product the circumstances of its transport, the time, source, target, and path. The three main operations are the upload, download, and transport. Upload typically occurs at a supply site after the refinery produced the desired product, download usually appears at a demand site where the product is passed to the customer. The term transport from now on is used only for transport in a product pipeline. Different types of liquids are transported through a given pipe next to each other. Fortunately, the mixing of the liquids is not problem from scheduling point of view. Two liquids started from the same location may have different destination sites. The begin and end points of the liquids within each product pipeline are calculated. The system can indicate when a liquid reaches a branching point when the valves have to be set into a new position. The motion of the liquid in a product pipeline is driven by the recently pumped liquid at the source. It may happen that transportation of a liquid is needed just to drive a liquid already in the pipe.

The output of ProdSim is the validated product pipeline schedule, blending order schedule, and the future states of the system as it evolves in the simulated time period. The operator plans the schedules and justifies them with ProdSim that has been designed exactly to this task. The future states of the system can be given either in the form of printed reports or in a visualization module, where the changing content of the tanks and the product pipelines can be displayed.

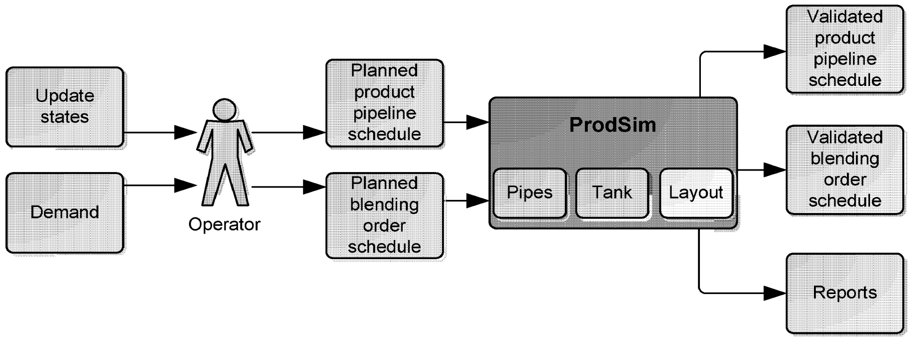


*Figure 1. The inputs and outputs of ProdSim*

Figure 2 displays the functional parts of ProdSim: the administration module, the simulation engine, the visualization module, and the underlying database. The first three module is used directly in the simulation process, the forth one is used indirectly. The administration module is a client program which is connected to the database server. The client can be installed onto any PC. The simulation engine operates on a dedicated server. It may require some time as it involves a great number of SQL queries and heavy computation. The results are also shown in the client program. The changing content of each product pipeline can be displayed, as well as the levels of tanks can be compared, or the potential inconsistencies can be highlighted. Berning et al. (2004) proposed a similar module for monitoring production schedules graphically.

Performing a simulation has three main steps: (i) providing the input to ProdSim, the planned product pipeline schedule, blending order schedule, and the updates of the current system state, (ii) running the simulation, (iii) visualization and analysis of the results. In case of an inconsistency, the whole process has to be repeated.

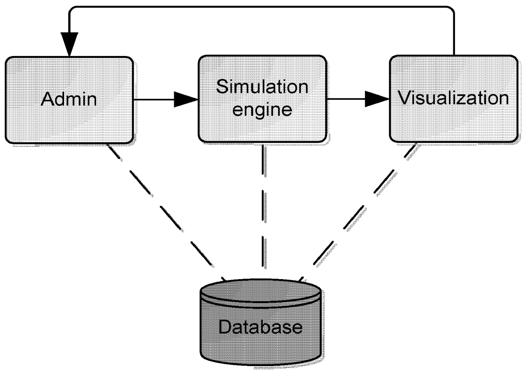


*Figure 2. The functional structure of ProdSim*

## 5. Summary and future work

A simulator and decision support tool, termed ProdSim, has been presented which aims to validate the planned product pipeline schedule and the blending order schedule. ProdSim is capable to calculate the future states of the system, i.e., the contents of the tanks and the product pipeline. The results can be presented in legacy reports and charts or in a visualization module which can display the changing content of the pipes and the tanks.

In the future, ProdSim is to be further improved. Specifically, a much tighter integration is envisioned between ProdSim and the other systems of MOL. This would greatly reduce the burden of the operators and ease the use of ProdSim.

It is also our intentions to fully automate the design of the product pipeline plan and the blending order schedule. It can be done by formulating and optimizing a mathematical programming model. In this scenario the task of the operator is to carefully set the parameters of the model and to supervise the system.

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