Oil Refinery Supply Chain Modelling Using Pipe Transportation Simulator

Jakub Dyntar[1], Jan Škvor[2]

[1] **Department of Economics and Management, Institute of Chemical Technology Prague, 16628, Czech Republic,**

[2] **Department of Economics and Management, Institute of Chemical Technology Prague, 16628, Czech Republic,**

Abstract

This paper describes an application of Pipe Transportation Simulator (PTS) in oil refinery supply chain modelling. We develop the simulator in Witness simulation software environment using MS Excel for input data loading and outputs upgrading. PTS is particularly suitable for "what-if" analysis in the crude oil, fuels or gas supply chains where the products are transported among warehouses and refineries through the pipe lines. To discuss the basic functionality of proposed simulator we employ PTS to simulate a real oil refinery supply chain consisting of 16 warehouses and 3 refineries placed in the Czech Republic and Slovakia. The refineries and warehouses are connected together with 21 pipe lines. PTS is used to verify a plan of fuels movements among warehouses and refineries as well as a plan of repairs of certain pipe lines in the selected time period of the length of 30 days.

Keywords: *Discrete Event Simulation, Supply Chain Management, Oil Refinery Supply Chain, Agent-Based Modelling.*

1. Introduction

Nowadays the principles of Supply Chain Management (SCM) are frequently applied in the material and information flow control. As reported in [1] SCM is defined as a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores so that merchandise is produced and distributed at the right quantities, at the right locations, at the right time, in order to minimize system-wide costs while satisfying service level requirements. As reported in [2] SCM is the concept of material and information flow management leading to the opportunities in terms of cost and lead times reduction and improved quality. SCM encompasses the planning and management of all activities involved in sourcing, procurement, conversion, and logistics to ensure smooth and efficient operations [3].

Contemporary problems in process systems engineering often require a model of the process, product, or system for their solution [4]. In contrast to traditional process systems where artefacts with physical and chemical interactions are the key constituents, supply chains are best thought of as socio-technical systems where complex production technologies interact with distributed, intelligent, autonomous entities, each with their own dynamics, goals, desires and plans [5]. There is a significant challenge for many researchers in modelling such complex systems. Numerical modelling can be adopted to represent such complex socio-technical systems. One subset of these, optimisation models, is widely used, especially when the scope of the problem is limited to selected supply chain functions such as planning [6]. Basically, the supply chain dynamics can be modelled through two approaches. First approach is based on a set of balance equations similar in structure to those used to model chemical processes [7]. This approach is possible to apply in tasks dealing with inventory optimization or manufacturing batch scheduling. The socio-technical nature of supply chain problems, however, motivates an alternative modelling paradigm - agent-based models [5]. Agent-based models are now widely considered to be a promising way for decision support in supply chains [8], [9], [10].

The framework of these models is usually based on the discrete event simulation [11]. In general, a simulation can be defined as the process of designing a mathematical-logical model of a real system and experimenting with this model on a computer. Discrete event simulation concerns the modelling of a system as it evolves over time by a representation in which the state variables change instantaneously at separate points in time [12]. Simulation allows the user to monitor the dynamics of a system under various conditions and provides its users with an understanding of the system being modelled. The main reasons to use discrete event simulation for system analysis in supply chain management are the possibility to include dynamics and the simplicity of modelling [13]. In

Copyright (c) 2012 International Journal of Computer Science Issues. All Rights Reserved.

contrary to classical modelling approaches such as the mathematical programming, simulation has a capability of capturing uncertainty and complexity that is well suited for supply chain analysis [14]. This was proven for example in [15] where seven different modelling approaches for global logistics systems using mathematical programming were examined. Only one model in the review utilised stochastic lead times and only a few included other stochastic characteristics. Examples of the discrete event simulation applications in supply chain studies include [16], [17], [18].

The aim of this paper is to describe an application of Pipe Transportation Simulator (PTS) in oil refinery supply chain modelling. We develop the simulator in Witness simulation software environment using MS Excel for input data loading and outputs upgrading. PTS is particularly suitable for "what-if" analysis in the crude oil, fuels or gas supply chains where the products are transported among warehouses and refineries through the pipe lines. To discuss the basic functionality of proposed simulator we employ PTS to simulate a real oil refinery supply chain consisting of 16 warehouses and 3 refineries placed in the Czech Republic and Slovakia. The refineries and warehouses are connected together with 21 pipe lines exchanging motor oil (MO) and petrol (P 95). PTS is used to verify 5 different varieties of the plan of fuels movements among warehouses and refineries as well as the plan of repairs and the plan of dispatch in the selected time period of the length of 30 days.

The rest of this paper is structured as follows. First, in Section 2, we provide basic information about Witness discrete event simulation software. In Section 3 Pipe Transportation Simulator is introduced. In Section 4 the basic functionality of proposed simulator is discussed based on the real oil refinery supply chain model. Finally, the paper is summarised.

2. Witness simulation software

Nowadays there is a large availability of discrete event simulation software each with some strengths and weaknesses. In [19] it is possible to find the results of survey on the most widely used discrete event simulation software comparing 7 different software products according to 12 different criteria. Additional information about functionalities of different discrete event simulation software is reported for example in [20] or [21].

Witness is Lanner Group's simulation software package designed for both discrete event and continuous simulation of business processes. It can be linked with many common spreadsheet and database. The simulation optimization is realized with help of Witness Optimizer module which contains combinatory optimization algorithms such as Hill Climb or Simulated Annealing. The software provides its user with a scenario manager for the analysis of the simulation results. Witness VR incorporates stunning 3D displays to any Witness simulation model and is designed to be used where first class presentation of a key proposal is required.

3. Pipe Transportation Simulator (PTS)

As it is stated in preceding section our simulator is developed in Witness simulation software environment using MS Excel for input data loading and outputs upgrading. PTS is particularly suitable for "what-if" analysis in the crude oil, fuels or gas supply chains where the products are transported among warehouses and refineries through the pipe lines. The basic structure of proposed solution is displayed in Figure 1.

3.1 PTS

The core of the solution is represented by the Witness simulation model which consists of four types of agent such as:

- Production agent
- Transportation agent
- Storage agent
- Retailer agent

The production agent is designed to deliver products into the simulated supply chain. It is characteristic with available amount of products that is willing to provide to storage agents during a simulated period of time. Once the production agent provides some quantity of products in favour of a storage agent its available amount of products during the simulated period is irreversibly decreased. In the PTS environment the production agent represents for example a refinery that pushes fuels to the pipe lines, terminals where crude oil delivered in boats is pumped to the tanks and then to the pipe lines etc.

The transportation agent receives products from storage agents and provides products to other storage agents and to retailer agents. Despite it has a storage capacity its basic function is to transport the products. In every moment of the simulation run it is characteristic with available amount of products that is willing to provide to storage or retailer agents and with the maximal amount of products that can store. In the PTS environment the transportation agent represents usually a warehouse where products are

Copyright (c) 2012 International Journal of Computer Science Issues. All Rights Reserved.

stored until they are provided to retailers or pumped to the pipe lines for further processing or storing.

The storage agent receives products from another storage, transportation or production agent. It is a passive element characteristic with the constant volume derived from its length and diameter and with the direction of product flow. In the PTS environment the storage agent always represents a pipe line. This pipe line is full of products usually ordered in batches because of their different densities. Whenever another storage agent or a transportation or production agent provides a certain amount of a product to a storage agent, this storage agent has to release the same amount in favour of other storage agent or a transportation agent. In case of more than one transported product the type of released product is usually different from the one received.

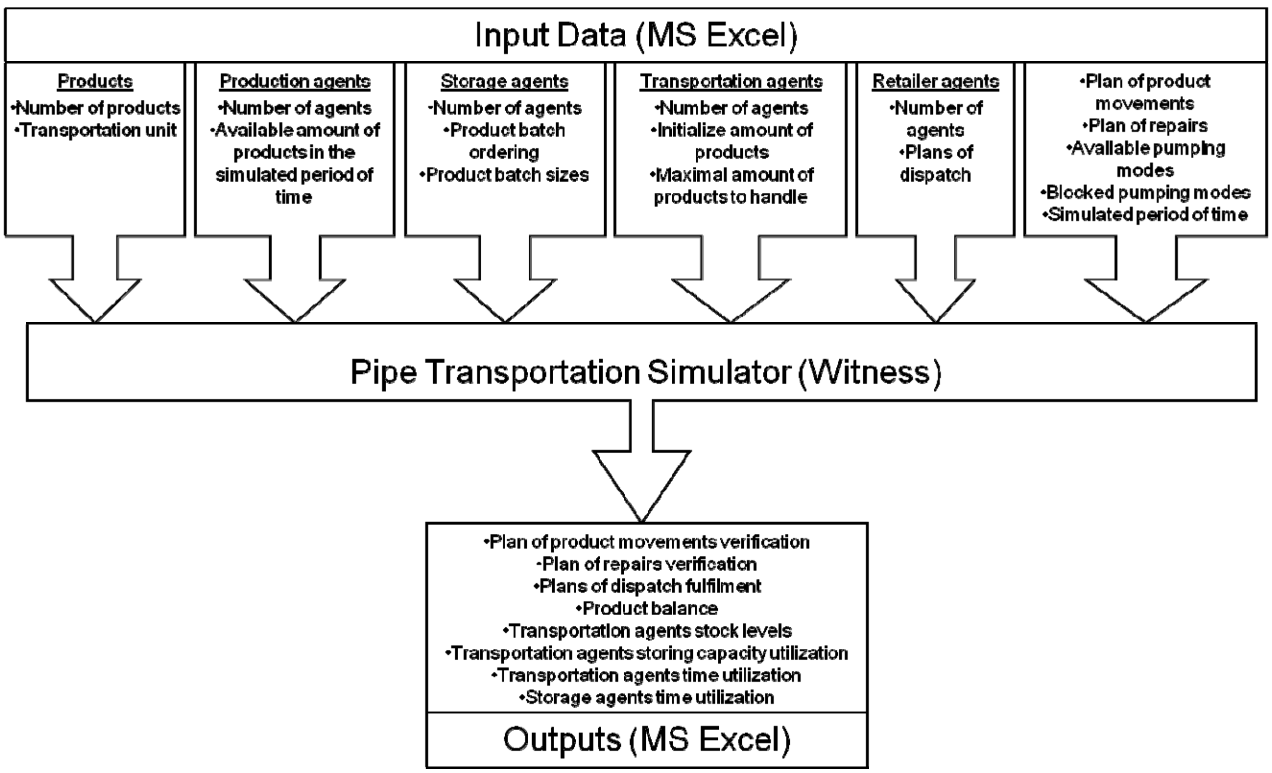

Fig. 1 Basic structure of proposed solution

The retailer agent is opposite to the production agent. It takes the products from transportation agents. It is characteristic with a plan of the dispatch where the requirements on a certain amount of a product are specified during the simulated period of time. In the PTS environment the retailer agent represents for example fuel stations demanding fuels from warehouses, refineries demanding crude oil for its processing etc.

The storage agents connect production agents with transportation agents, transportation agents one another and constitute the routes. In the other words a route consists of a starting place that can be transportation or production agent, certain number of storage agents and a final place which is always a transportation agent. The routes completed with pumping powers for all transported products constitute **pumping modes**. The pumping modes control the product movements among production and transportation agents trying to satisfy the requirements of retailer agents.

The possibility to carry out a product movement is limited by several constraints. Omitting the individual characteristics of agents such as their storage or production capacities that determine the amounts of products available for other agents the substantial constraint is represented by impossibility to use some pumping modes simultaneously. If a product movement is going on between two transportation agents or between one production and one transportation agent, other product movements cannot take place at the same time in case of necessity to use a storage agent which is already in use. In

Copyright (c) 2012 International Journal of Computer Science Issues. All Rights Reserved.

PTS this is ensured so that for each pumping mode a set of blocked pumping modes is defined indicating the pumping modes that cannot be used at the same time.

3.2 Input data loading and simulation run

Basically input data can be divided into 4 groups:

- Number of transported and stored products
- Agent's characteristics including the plans of dispatch for retailer agents
- Set of available pumping modes and their blocked counterparts
- Plans of product movements and repairs

The data is loaded to PTS from MS Excel spreadsheet. Agent's characteristics except the plans of dispatch serve to create the basic structure of simulated system consisting of pre-defined Witness elements and to set the initial states of storage and transportation agents. Then the simulation starts to run and the product movements contained in the plan as well as the dispatch specified in the plans of retailer agents take place. The exchange of products occurring among agents change the batch ordering of products within storage agents, decrease the available amount of products of production agents and change the current available amount of products of transportation agents. Simultaneously the retailer agents decrease the current available amount of products of transportation agents according to their requirements contained in the plan of dispatch.

The product movements are characteristics with a time of start, type of transported product, its quantity and the pumping mode that specifies the pumping power and the route. A planed product movement doesn't start if the pumping mode specified to control this movement is blocked, if there is no available amount of product to be provided by the starting place of the route or if the final place of the route is not able to accept incoming product. Once the planed product movement begins all pumping modes forbidden to be used at the same time are blocked. The product movement is interrupted every time there is no available amount of product to be provided by the starting place of the route or if the final place of the route is not able to accept incoming product. In that case the product movement continues right after these circumstances pass. When a product movement is finished, blocked pumping modes are unblocked and available for other planed product movements.

A requirement of a retailer agent on a certain amount of product which is contained in the plan of dispatch is characteristics with a time of start, the type of product to be dispatched, its quantity and the transportation agent to satisfy it. The partial satisfaction of a requirement is not permitted.

The plan of repairs contains two types of product movement's constraints. First, a repair of a storage agent means the unavailability to use all pumping modes containing this agent during the specified period of time. This kind of repair is characteristics with the time of start, time of finish and a storage agent involved in the repair. A repair is started if the simulation time is greater or equal to the time of start and if the storage agent is not currently in use. Second, a repair of a transportation agent means the limitation of the maximal amount of products that can store during the specified period of time. This kind of repair is characteristics with the time of start, time of finish, the maximal amount of product to be stored and a transportation agent involved in the repair. A repair is started if the simulation time is greater or equal to the time of start and if the current available amount of products of transportation agent involved in the repair is smaller than maximal given amount. Once a repair is started it cannot be interrupted.

3.3 Outputs of simulation

The product movements, repairs and dispatches realized during the simulation run are recorded and used to calculate the statistics of plans fulfilment at the end of the simulation. These statistics as well as the storage agent's utilization, stock levels of the transportation agents, balance for all transported products and more outputs are then exported to MS Excel spreadsheet and rearranged to required graphical appearance.

In Figure 2 the appearance of storage capacity utilization for a transportation agent is displayed, in Figure 3 the time utilization for a storage agent is displayed in the form of Gantt chart.

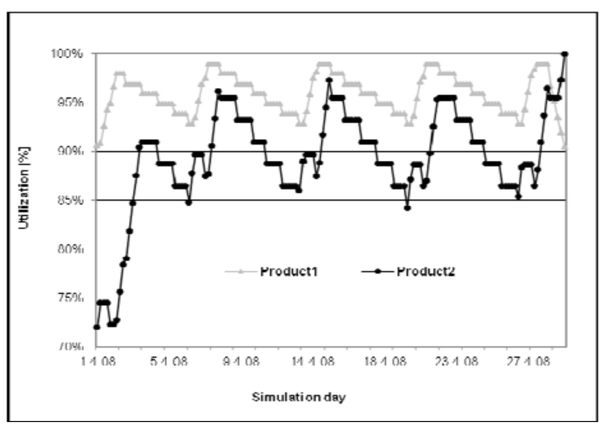

Fig. 2 Storage capacity utilization for a transportation agent

Copyright (c) 2012 International Journal of Computer Science Issues. All Rights Reserved.

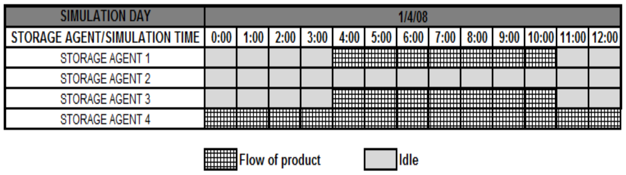

Fig. 3 Storage agent time utilization - Gantt chart

The outputs serve to control products movements among agents, to assess their utilization and to verify the plan of repairs as well as the plans of dispatch of retailer agents.

4. Oil refinery supply chain modelling using PTS

To determine the basic functionality of proposed simulator we employ PTS to simulate a real oil refinery supply chain. The simulated system consists of two refineries owned by Česká rafinérská Co. (ČeR) that are placed in the Czech Republic in Litvínov and Kralupy nad Vltavou and one refinery owned by Slovnaft Co. (Slovnaft) placed near Bratislava in Slovakia. These refineries pump MO and P 95 to the pipe net owned by Čepro Co. where the products are stored until they are distributed to final customers. Pipe net owned by Čepro Co. consists of sixteen warehouses and twenty one pieces of pipe that connect refineries and warehouses together. The placement of warehouses, refineries and the pipe net is displayed in Figure 4. Each warehouse is equipped with the rail terminal for the train tanks filling and with the terminal designed for fuels dispatch in the car tanks. The fuels are transported from these terminals to final customers such as petrol stations by 3 PLs.

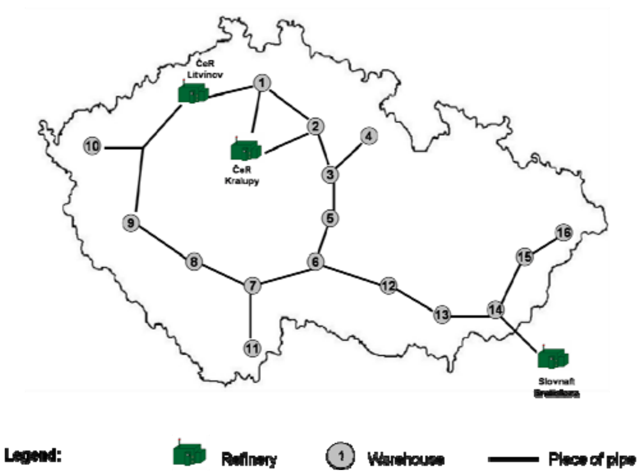

Fig. 4 Simulated oil refinery supply chain

Basic structure of simulated system is described in Table 1.

Table 1: Oil refinery supply chain - basic structure in PTS

Type of agent	No. of agents	Description
Production	3	refineries
Transportation	16	warehouses
Storage	21	pipe lines
Retailer	1	demanding products in all warehouses
2 products - MO, P 95		
90 pumping modes		
Transportation unit = 1 ton		
Length of simulation = 30 days		

All agents are initialized with help of input data loaded from MS Excel spreadsheet and furthermore all storage agents are filled with motor oil before the simulation starts to run. Then we simulate 5 varieties differing in product quantity delivered by production agents, product quantity demanded by retailer agent and number of planed product movements (see Table 2). These varieties in the form of the plans of product movements, plans of repairs and plans of dispatch are designed in cooperation with Čepro planners who are responsible for product movements planning in the real operation.

Table 2: Simulated varieties

Variety	Increase of total products quantity delivered by production agents [%]	Increase of total products quantity demanded by retailer agent [%]	No. of planned product movements	No. of planned dispatch requirements	No. of planned repairs
1	-	-	54	690	4
2	5	5	61	690	4
3	10	10	69	690	4
4	15	15	76	690	4
5	20	20	82	690	4

The results for all simulated varieties are summarized in Table 3. For all varieties there is one planed repair starting out of time. With rising quantities of products delivered to the system by production agents the average utilization of storage agents rises but not fast enough to satisfy the requirements of the retailer agent. The reason is the bottleneck represented by the pipe line connecting warehouse 2 and warehouse 3 (see Figure 4) which is proven by the statistics of this pipe line utilization for all simulated varieties (see Table 4). In consequence the average storage capacity utilization of transportation agents declines as well as the ability to satisfy the requirements of retailer agent on time.

Copyright (c) 2012 International Journal of Computer Science Issues. All Rights Reserved.

Table 3: Outcomes of simulation

Variety	Product movements start [on time/planed]	Product dispatch start [on time/planed]	Repair start [on time/planed]	Avg. storage agents time utilization [%]	Avg. transportation agents storage capacity utilization [%]
1	53/54	690/690	3/4	31.7	80.4
2	60/61	690/690	3/4	32.9	80.3
3	68/69	690/690	3/4	34.5	80.3
4	71/76	678/690	3/4	38.8	79.6
5	71/82	655/690	3/4	39.0	78.7

Table 4: Utilization of the pipe line connecting warehouse 2 with warehouse 3

Variety	1	2	3	4	5
Pipe line utilization [%]	84.6	90.3	95.4	99.9	99.9

Based on the requirements of Čepro Co. we upgrade oil refinery supply chain model realized in PTS into the form of simple software application which is operate in Witness Model Viewer interconnected with Čepro information system. The appearance of the application which is used for the verification of the plans prepared by Čepro planners is displayed in Figure 5.

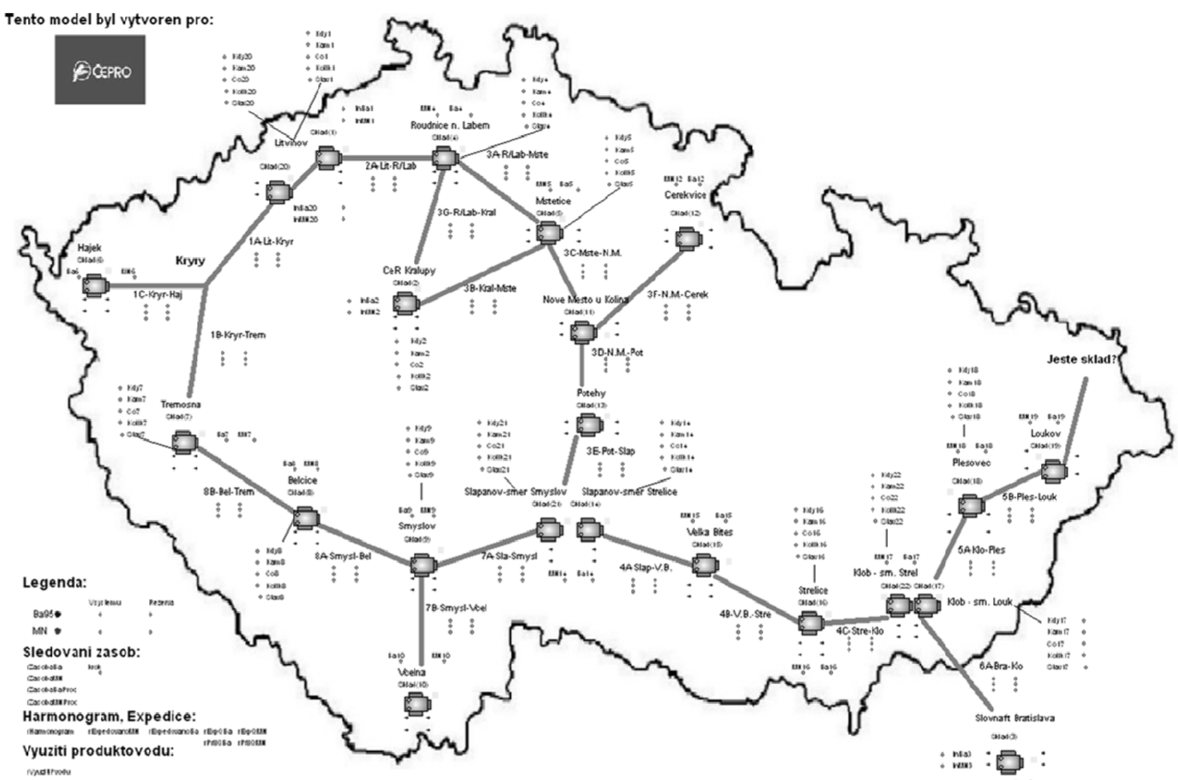

Fig. 5 Appearance of oil refinery supply chain model upgraded into the form of software application operated in Witness Model Viewer (original appearance provided to Čepro Co.)

5. Conclusions

In this paper we present the application of PTS in oil refinery supply chain modelling. We develop the simulator in Witness simulation software environment using MS Excel for input data loading and outputs upgrading and describe its basic functionality simulating the real system consisting of 16 warehouses and 3 refineries placed in the Czech Republic and Slovakia. Based on the requirements of Čepro Co. we upgrade oil refinery supply chain model realized in PTS into the form of simple software application which is operate in Witness Model Viewer interconnected with Čepro information system. Once in month this application is used to verify the plan of products movements as well as the plan of repairs. Its results support the cooperation among refineries, storage and transportation system operator and retailers in the fuels distribution. Furthermore it offers the possibility to support the decisions about pipe net transportation capacity or warehouse storage capacity enlargement in addition to changing requirements of retailers.

Nowadays we develop a programming procedure called Hungry Algorithm (HA) to add in the oil refinery supply chain simulation. HA is the combination of pull and push principle used to control the material flows and the simulated annealing algorithm for combinatory optimization. Our aim is to design HA to schedule fuel movements among warehouses and refineries in a way leading to the maximization of storage and transportation capacities utilization while respecting the requirements of retailers on fluent fuels deliveries.

We also prepare the simulation of European crude oil storage and transportation system containing Druzhba, Adria, TAL, IKL, OMW and AWP pipe lines and the warehouses and refineries placed in west and central Europe.

References

[1] D. Simchi-Levi, P. Kaminsky, E. Simchi-Levi, Designing and Managing the Supply Chain: Concepts, Strategies, and Case Studies. Irwin/McGraw-Hill, Boston, 2000.

[2] F. Persson and J. Olhager, Performance simulation of supply chain designs. International Journal of Production Economics, Vol. 77, No. 3, 2002, pp. 231-245.

[3] S. S. Pitty, W. Li, A. Adhitya, R. Srinivasan, I. A. Karimi, Decision support for integrated refinery supply chains Part 1. Dynamic simulation. Computers and Chemical Engineering, Vol. 32, No. 11, 2008, pp. 2767–2786.

[4] I. T. Cameron and G D. Ingram, A survey of industrial process modelling across the product and process lifecycle. Computers and Chemical Engineering, Vol. 32, No. 3, 2008, pp. 420–438.

[5] K. H. Van Dam, A. Adhitya, R. Srinivasan, Z. Lukszo, Critical evaluation of paradigms for modelling integrated supply chains. Computers and Chemical Engineering, Vol. 33, No. 10, 2009, pp. 1711–1726.

[6] S. Nilay, Process industry supply chains: Advances and challenges. Computers and Chemical Engineering, Vol. 29, No. 6, 2005, pp. 1225–1236.

[7] C.C. Pantelides, Speedup-recent advances in process simulation. Computers and Chemical Engineering, Vol. 12, No. 7, 1988, pp. 745–755.

[8] N. Julka, R. Srinivasan, I. Karimi, Agent-based supply chain management. 1. Framework. Computers and Chemical Engineering, Vol. 26, No. 12, 2002, pp. 1755–1769.

[9] N. Julka, I. Karimi, R. Srinivasan, Agent-based supply chain management. 2. A refinery application. Computers and Chemical Engineering, Vol. 26, No. 12., 2002, pp. 1771–1781.

[10] F. D. Mele, G. Guillen, A Espuna, L. Puigjaner, An agent-based approach for supply chain retrofitting under uncertainty. Computers and Chemical Engineering, Vol. 31, No. 5-6, 2005, pp. 722–735.

[11] J. M. Swaminathan, S. F. Smith, N. M. Sadeh, Modeling Supply Chain Dynamics: A Multiagent Approach, Decision Sciences, Vol. 29, No. 3, 1998, pp. 607-632.

[12] A. M. Law, Simulation Modeling and Analysis. 4th ed., McGraw-Hill, New York, 2007.

[13] F. Persson and M. Araldi, The development of a dynamic supply chain analysis tool-Integration of SCOR and discrete event simulation. International Journal of Production Economics, Vol. 121, No. 2, 2009, pp. 574–583.

[14] S. Jain, R.W. Workman, L.M. Collins, E.C Ervin, Development of a high-level supply chain simulation model. In Proceedings of the 2001 Winter Simulation Conference, pp. 1129–1137.

[15] M. Goetschalckx, C. J. Vidal, K. Dogan, Modelling and design of global logistics systems: A review of integrated strategic and tactical models and design algorithms. European Journal of Operational Research, Vol. 143, No. 1, 2002, pp. 1–18.

[16] J. Wei and L. Krajewski, A model for comparing supply chain schedule integration approaches. International Journal of Production Research, Vol. 38, No. 9, 2000, pp. 2099–2123.

[17] A. I. Sivakumar, Multi-objective dynamic scheduling using discrete event simulation. International Journal of Computer Integrated Manufacturing, Vol. 14, No. 2, 2001, pp. 154–167.

[18] Ch. Zhang and Ch. Zhang, Design and simulation of demand information sharing in a supply chain. Simulation Modelling Practice and Theory, Vol. 15, No. 1, 2007, pp. 32–46.

[19] A. Cimino, F. Longo, G. Mirabelli, A General Simulation Framework for Supply Chain Modeling: State of the Art and Case Study. International Journal of Computer Science Issues, Vol. 7, No. 3, 2010, pp. 1–9.

[20] J. J. Swain, Discrete Event Simulation Software: New Frontiers in Simulation. OR/MS Today, Vol. 34, No. 5, 2007, pp. 32–43.

Copyright (c) 2012 International Journal of Computer Science Issues. All Rights Reserved.

[21] M. C. Fu, Optimization for Simulation: Theory vs. Practice, INFORMS Journal on Computing, Vol. 14, No. 3, 2002, pp. 192-215.

Jakub Dyntar received his Ph.D. in Chemical and Process Engineering, Economics and Management from Institute of Chemical Technology Prague (ICT) in June 2009. He is currently Assistant Professor at the Department of Economics and Management of ICT and the head of its logistics consulting team. In his work he focuses on the applications of discrete event simulation in supply chain modelling and on the forecasting and stock management of products with intermittent demand.

Jan Škvor took his degree in Economics and Management, in June 2010 from Institute of Chemical Technology Prague. He is currently Ph.D. student at the Department of Economics and Management of Institute of Chemical Technology Prague and the member of its logistics consulting team. In his work he focuses on the applications of discrete event simulation in supply chain modelling and on the effective design of supply systems using evolutionary algorithms.

Copyright (c) 2012 International Journal of Computer Science Issues. All Rights Reserved.