Application of Discrete Event Simulation in LPG Storage Operation and Optimization

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Abstract

In this paper, we present an application of discrete event simulation in Liquid Petroleum Gases (LPG) storage operation and optimization. The proposed solution consists of Witness simulation model supported by MS Excel for data loading and outputs upgrading. The solution upgraded into the form of LPG Storage Simulator (LPG SIM) adopts the principles of agent-based modeling and is suitable to support the decision making in LPG manufacturing, storing and distribution supply chain optimization. We apply our simulator to identify possible capacity constraints of LPG storage and expedition area owned by two operators (petrochemical company SYNTHOS Kralupy, a.s. and crude processing company ČESKÁ RAFINÉRSKÁ, a.s. (CRC) connected with planned intensification of LPG manufacturing. With help of LPG SIM we test 4 different varieties differing in the total amounts of products flowing from the CRC Fluid Catalytic Cracking unit to LPG storage and expedition area equipped with the rail way tank cars (RTC) loading and road tank-trucks (RT) loading terminal. For each simulated variety we specify the requirements on storage and expedition capacities ensuring the smooth product flows through the LPG storage area, gasoline blending requirements and the requirements on products expedition in RTC and RT.

Keywords: *Supply Chain Management, Agent-Based Modeling. Discrete Event Simulation, Logistics*

1. Introduction

Agent-based modeling (ABM) is now widely considered to be a promising way for a decision support in supply chains [1], [2]. A supply chain can be defined as a network of autonomous or semiautonomous business entities collectively responsible for procurement, manufacturing and distribution activities associated with one or more families of related products [3]. To model the supply chains dynamic two basic approaches can be adopted. First approach is based on a set of balance equations similar in structure to those used to model chemical processes [4]. This approach is possible to apply for example in tasks dealing with inventory optimization. The socio-technical nature of supply chain problems, however, motivates an alternative modeling paradigm - agent-based models [5]. These models are based on simulating the actions and interactions of autonomous agents with a view to assessing their effects on the system as a whole. ABM combines elements of game theory, complex systems, emergence, computational sociology, multi-agent systems and evolutionary programming. Agent descriptions provide an ability to specify both static and dynamic characteristics of various supply chain entities. Each agent is controlled by a subset of control elements usually derived from analytical models such as inventory policies or vehicle routing algorithms. A review of recent literature on agent-based models is given in [6]. ABM applications can be found to solve a variety of business problems. In [7], [8] and [9] ABM applications in manufacturing can be found. In [10] ABM application in vehicle routing is described. In [11] ABM is used to estimate the behavior of the players involved in supply chains. In [12], [13], [14] examples of ABM applications in other fields of study are provided.

The framework of agent-based models is usually built in a discrete event simulation software environment. Discrete event simulation (DES) concerns the modeling of a system as it evolves over time by a representation in which the state variables change instantaneously at separate points in time [15]. In contrary to the mathematical programming, it has a capability of capturing uncertainty and complexity that is well suited for supply chain analysis [16]. When used in supply chain modeling DES usually brings benefits such as [17]:

- the understanding the overall supply chain processes and characteristics,
- the ability to capture system dynamics using probability distributions,
- the minimization of risks linked with possible changes of simulated system.

The applications of DES in supply chain modeling can be found for example in [18], [19] and [20]. Nowadays there are many discrete event simulation tools available in the market. These tools enables user to carry out “what-if” experiments with the computer model of a real system in a relatively short time and to propose and verify the changes for its higher performance. Most of these tools have advanced graphics/animation features as well as the modules for combinatory optimization. The results of survey on the most widely used discrete event simulation software can be found in [21]. Additional information about functionalities of different discrete event simulation software is summarized for example in [22].

The aim of this paper is to present an application of discrete event simulation in Liquid Petroleum Gases (LPG) storage operation and optimization. We propose a solution consisting of Witness simulation model linked with MS Excel for data loading and outputs upgrading. Witness is Lanner Group’s simulation software package designed for the discrete event simulation of business processes. Our solution upgraded into the form of LPG Storage Simulator (LPG SIM) adopts the principles of agent-based modeling and is suitable to support the decision making in LPG manufacturing, storing and distribution supply chain optimization. We apply our simulator to identify possible capacity constraints of LPG storage and expedition area owned by SYNTHOS Kralupy, a.s. (Synthos) and crude processing company ČESKÁ RAFINÉRSKÁ, a.s. (CRC) connected with planned CRC LPG manufacturing intensification. With help of LPG SIM we test 4 different varieties differing in the total amounts of products flowing from the CRC Fluid Catalytic Cracking (FCC) unit to LPG storage and expedition area. For each simulated variety we specify the requirements on storage and expedition capacities ensuring the smooth product flows through the LPG storage area, gasoline blending requirements and the requirements on products expedition in the rail way tank cars (RTC) and road tank-trucks (RT).

The rest of this paper is structured as follows. First, in Section 2, we provide basic information about simulated LPG storage and expedition area. In Section 3 stored products and LPG manufacturing, storage and distribution supply chain are described. In Section 4 the description of LPG SIM is given. In Section 5 its basic functionality is discussed simulating 4 different varieties differing in the total amounts of products flowing from the CRC FCC unit to LPG storage and expedition area. Finally, the paper is summarized.

2. LPG storage and expedition area

LPG storage and expedition area (see Figure 1) is located in Kralupy nad Vltavou, the Czech Republic, and it is operated by 2 companies: petrochemical complex Synthos and crude processing company CRC. Synthos is a producer of Butadiene based on pyrolytic C_4 fraction supplied by pipeline and rail way. CRC produces LPG from installed refining technologies and Methyl Tertiary Butyl Ether (MTBE) based on Raffinate I from Butadiene production. Each company is operating 12 spherical storage tanks á 200-850 m^3 effective capacity.

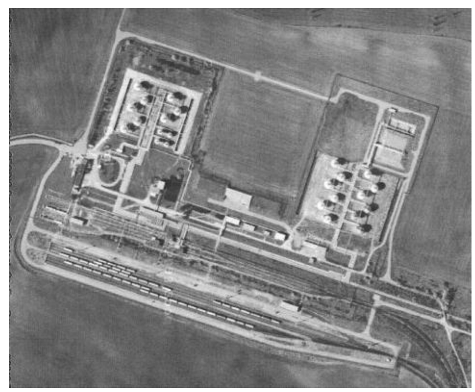

Fig. 1 LPG Storage and expedition area (Source: [23])

The area is fenced, operated locally by field operators and/or from central control room (located in production site about 3 km far away) and equipped by cooling/fire fighting emergency system capable to operate via remote control. Additionally to spherical tanks, CRC is also operating 5 horizontal pressure tanks for Propylene and other LPG á 1000 m3 (produced at FCC unit) which were built in 1998-2000 by CBI Lummus (see Figure 2).

Fig. 2 Completion of construction of propylene horizontal tanks in LPG storage area (Source: [24])

Nowadays both companies are operating independent loading and unloading railway system. Furthermore CRC is also operating a system for RT loading. The existing rail loading system has been separated by mentioned companies and 1 new facility has been built by Synthos (see Figure 3) due to identified capacity constraints derived from planned Butadiene manufacturing intensification (see [25]).

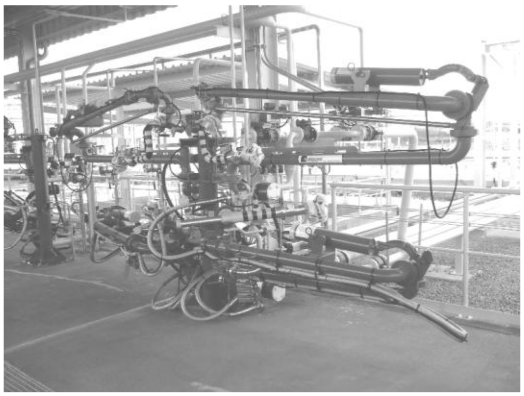

Fig. 3 New loading-unloading railway system built and operated by Synthos (Source: [26])

New loading-unloading railway system was built by company Intecha Praha in 2009 and is operated by Synthos since the end of 2009. The project of construction of new loading (1 position)/unloading (6 positions) facility was associated with construction of new rail pumping station and safety tank.

3. Stored commodities, simulated LPG manufacturing, storage and distribution supply chain

In LPG storage area the following raw materials, semi-products and final products are stored and manipulated:

- C_4 fraction which is produced at Steam Cracker located in Litvínov (70 km far from LPG storage area) and supplied by pipeline,
- Butadiene which is the final product of Synthos,
- Raffinate I which is C_4 based final product of Synthos and serves as a raw material for CRC MTBE production,
- Raffinate II which is C_4 based final product of CRC from production of MTBE,
- Propane which is C_3 based final product of CRC,
- Propylene which is C_3 based final product of CRC,
- FCC C_4 fraction which is C_4 based final product of CRC,
- Normal/Iso-Butane which is C_4 based final product of CRC,
- Propane-Butane which is C_3/C_4 mixture based final product of CRC.

The subject of interest in our study represents the part of supply chain displayed in Figure 4 and the final products of CRC such as Propane, Propylene, Normal/Iso-Butane, Propane-Butane, FCC C_4 and Raffinate II flowing from CRC FCC and MTBE production units to LPG storage area.

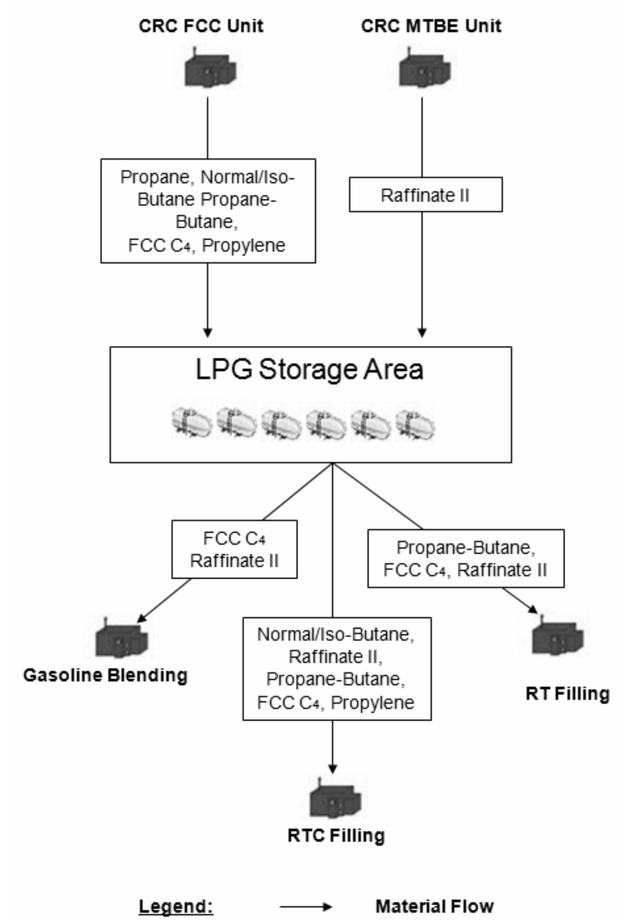

Fig. 4 Simulated part of LPG manufacturing, storage and distribution supply chain

Based on Propane-Butane mixing plan, Propane is subsequently pumped from storage tanks reserved for Propane storing to the tanks reserved for Propane-Butane storing where it is mixed with FCC C_4 in required seasonal ratio to obtain Propane-Butane. Similarly, certain amount of Raffinate II and FCC C_4 flows from storage tanks to gasoline blending unit to be added to gasoline for its octane number increase based on gasoline blending plan. The rest of CRC final products is loaded to RTC or RT in loading terminals and distributed to final customers according to their requirements. Before RTC or RT are filled with the products the storage tanks to be dispatched have to be circulated for a certain period of time while the analysis of accurate chemical composition is carried out to obtain the certification of quality. The RTC filling occur in the train terminal equipped with two loading platforms where two trains of the total length of 2·12 = 24 RTC can be shunted. The device for the RTC filling is able to fill two tanks simultaneously (one in each train) and then both trains are shifted. Because of strict safety regulations both platforms must be operated together. The RT are filled with products in terminal equipped with one filling position.

4. LPG Simulator

LPG Simulator is designed in Witness simulation software environment supported by MS Excel for input data loading and outputs upgrading. Its original appearance is displayed in Figure 5.

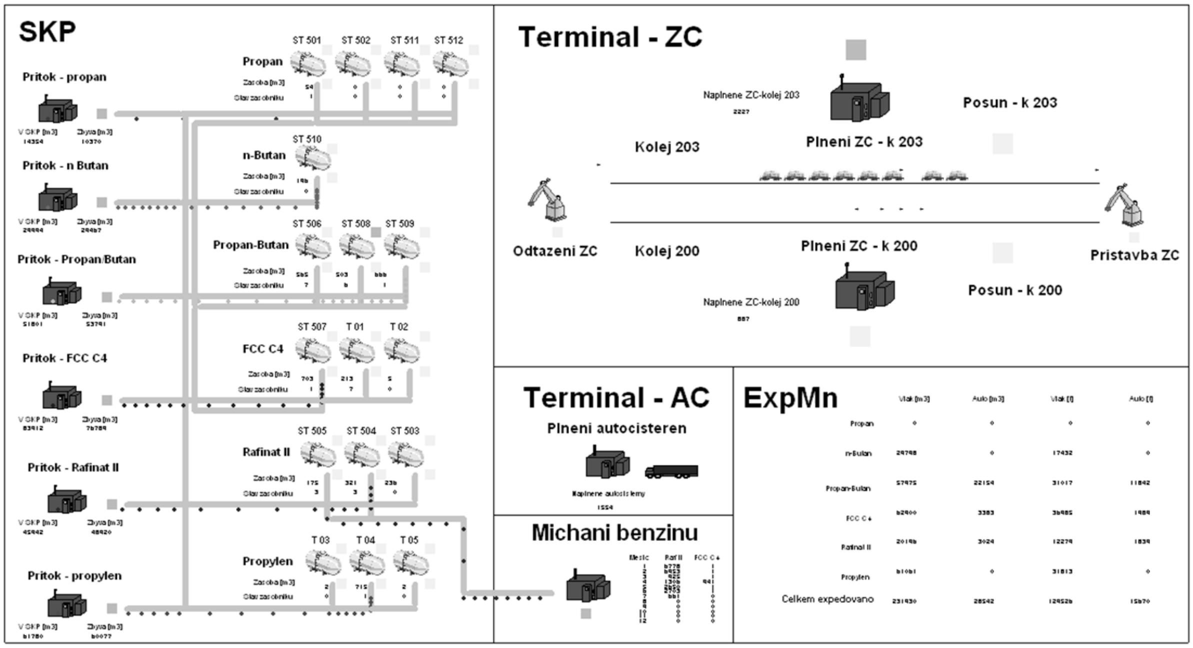

Fig. 5 Original appearance of LPG SIM

LPG SIM consists of four basic types of agents such as:

- Production agent,
- Storage agent,
- Transportation agent,
- Retailer agent.

The production agent is designed to deliver CRC final products such as Propane, Propylene, Normal/Iso-Butane, Propane-Butane, FCC C_4 and Raffinate II from CRC FCC and MTBE units to LPG storage area. For the material flow control Push principle is applied. To simulate the supply chain displayed in Figure 4, 6 production agents are involved. Each agent is characteristic with a plan of product flow describing the type of product, its total amount and the flow rate in simulated period.

The storage agent is a passive element and represents a storage tank in LPG storage area. It receives either CRC final products from production agents or Propane and FCC C_4 from a transportation agent in case of Propane-Butane mixing. To simulate the supply chain displayed in Figure 4, 17 storage agents are involved. Each storage agent is characteristic with a product to be stored in, the storage capacity, current stock level and the set of the control elements describing its ability to receive products from a transportation agent or to provide a transportation agent with products. Each storage agent is also controlled by the set of rules describing the process of certification. These rules are dealing mainly with the frequency of chemical analysis and the length of the product stiring within a storage tank subsequently enabling the storage agent to release a product in the favor of a retailer agent.

The transportation agent ensures the movements of Propane and FCC C_4 among the storage agents in case of Propane-Butane mixing (1 transportation agent) and the flow of Raffinate II and FCC C_4 from a storage agent to the gasoline blending unit (1 transportation agent). The agent works on the basis of Propane-Butane mixing plan where

Propane/FCC C_4 seasonal ratio for Propane-Butane mixing is specified and gasoline blending plan where the quantities of FCC C_4 and Raffinate II to be added to gasoline in simulated period are specified.

The retailer agent demands products from storage agents. In our simulator 2 retailer agents are involved. One represents RTC loading terminal and one represents the loading terminal for RT filling. Both retailer agents involved in simulator are characteristics with the loading performance and use Pull principle for the material flow control. It means that whenever a retailer agent has the free loading capacity and a storage agent is able to provide a retailer agent with products the retailer agent starts to release its storage capacity. The product exchange among storage and retailer agents is limited by several constraints, in most cases derived from strict safety regulations.

All input data including agent's characteristics (i.e. storage capacities, current stock levels etc.), plans of product flows from CRC FCC and MTBE units to LPG storage area, plan of supply Raffinate I to MTBE unit, plan of Propane-Butane mixing occurring in Propane-Butane storage tanks and plan of gasoline blending is downloaded to LPG SIM from MS Excel spreadsheets. Then the simulation starts to run and the outcomes are recorded.

Outcomes in the form of agent's utilization, balance of product flows through the LPG storage area, stock levels and the plan's fulfillment recorded during the simulation run is exported to MS Excel spreadsheets and rearranged to required graphical appearance (see for example Figure 6).

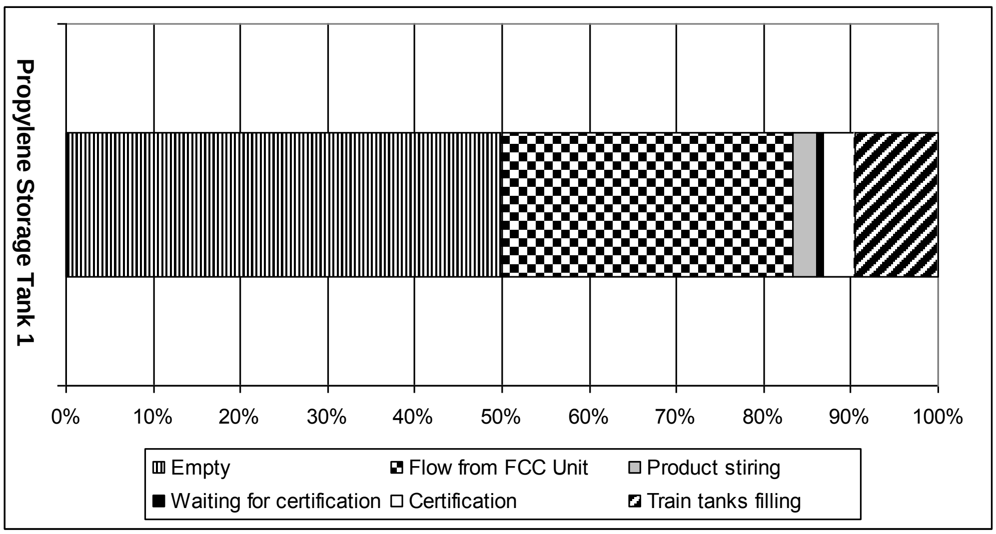

Fig. 6 Utilization of a storage agent during simulated period (Propylene storage tank)

Finally the outcomes are analyzed to discover possible constraints negatively influencing the performance of simulated system.

5. LPG SIM performance assessment

To discuss basic functionality of LPG SIM and to assess its performance we simulate 4 different varieties differing in the total amounts of products flowing from the CRC FCC unit to LPG storage and expedition area in simulated period of the length of one year. These varieties are described in Table 1.

Tab. 1 Simulated varieties

Variety/Product	Propane	Normal/Iso-Butane	Propane-Butane	FCC C_4	Raffinate II	Propylene	Total
Variety 1	-	-	-	-	-	-	-
Variety 2	+ 79%	+ 0%	+ 0%	+ 93%	+ 0%	+ 14%	+ 34%
Variety 3	+ 92%	+ 0%	+ 0%	+ 100%	+ 0%	+ 21%	+ 38%
Variety 4	+ 219%	+ 0%	+ 0%	+ 153%	+ 0%	+ 123%	+ 79%

Variety 1 describes the real product flow from CRC FCC and MTBE units during the year 2008 and serves as a reference to Varieties 2, 3 and 4 capturing the planned FCC unit manufacturing intensification. In all simulated varieties the flow rate of products changes at the same way as it is displayed in Figure 7.

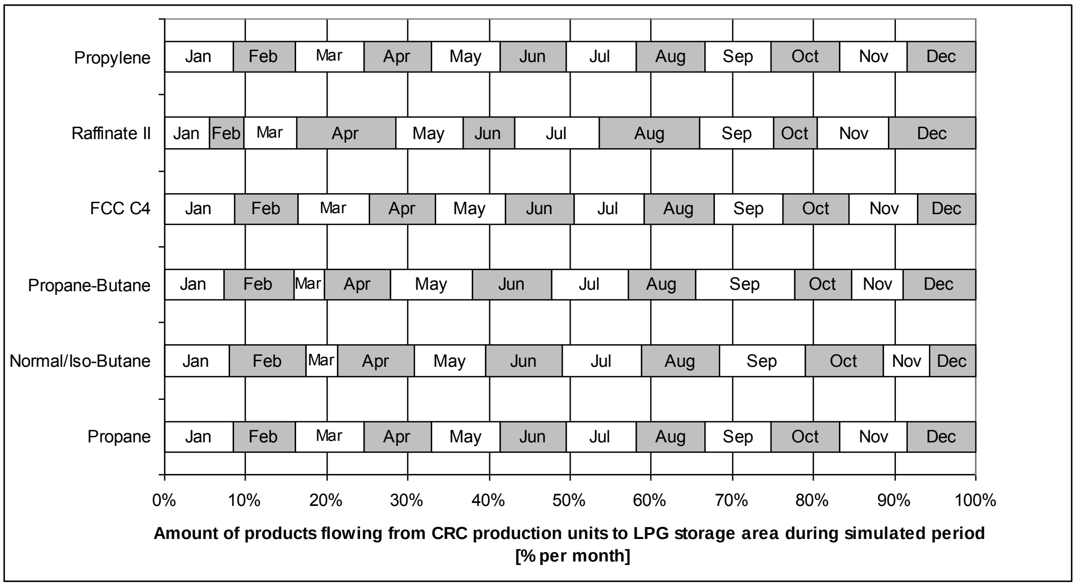

Fig. 7 Monthly percentages of total amount of products flowing from CRC FCC and MTBE production units to LPG storage area

When reaching the LPG storage area the flow of products is split up for each simulated variety as stated in Table 2.

Tab. 2 Material flow split up in LPG storage area

Material Flow Split Up/Product	Propane	Normal/Iso-Butane	Propane-Butane	FCC C_4	Raffinate II	Propylene
Propane-Butane Mixing	100%	0%	0%	According to the amount of Propane	0%	0%
Expedition in RTC	0%	100%	63%		43%	100%
Expedition in RT	0%	0%	37%		14%	0%
Gasoline Blending	0%	0%	0%	7%	43%	0%

The monthly percentages of total amount of Raffinate II and FCC C_4 flowing from LPG storage area to gasoline blending during simulated period is displayed in Figure 8 and represent the plan of gasoline blending.

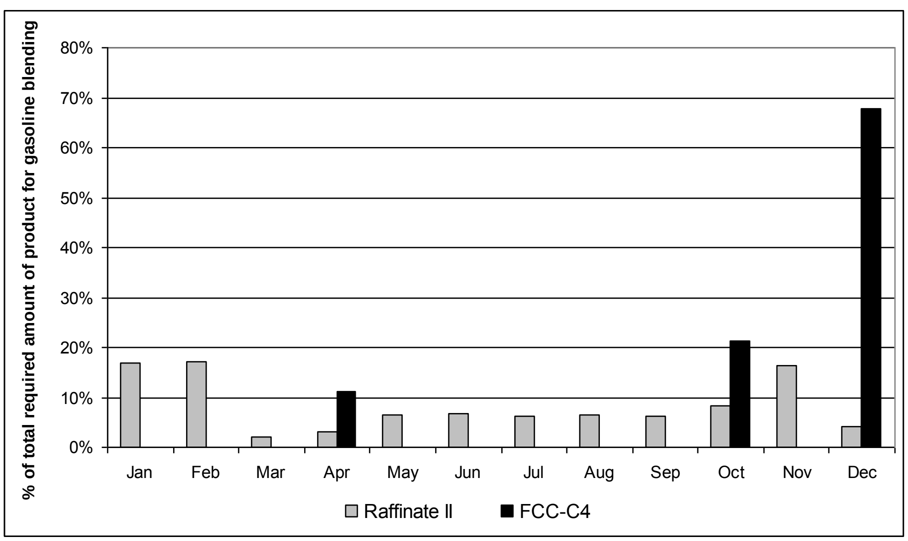

Fig. 8 Monthly percentages of total amount of Raffinate II and FCC C_4 flowing from LPG storage area to gasoline blending in 2008

The plan of Propane-Butane mixing occurring in Propane-Butane storage tanks represents the requirement to mix all Propane flowing from CRC FCC unit to storage area with appropriate amount of FCC C_4 according to the seasonal ratio.

For each variety the aim of the simulation is to find the structure of the simulated supply chain to fulfill the planned flow of products from CRC FCC and MTBE units to LPG storage area, to fulfill the planned flow of products from LPG storage area through the loading terminals and to fulfill the plans of Propane-Butane mixing and gasoline blending. That is why we propose and simulate up to 5 different cases for each variety until the fulfillment of the plans is reached. The description of all cases can be found in Table 3.

Tab. 3 Description of simulated cases

Case	RTC loading terminal is shared with Synthos	Certification of storage tank is realized before its releasing for expedition	Capacity of loading terminal for RT is doubled	The situation in RTC loading terminal is changed so that each loading platform is operated independently
a)	YES	YES	NO	NO
b)	NO	YES	NO	NO
c)	NO	NO	NO	NO
d)	NO	NO	YES	NO
e)	NO	NO	YES	YES

Case a) describes the structure of the supply chain which corresponds to the state in 2008 and requires no investments. Case b) describes the structure of the supply chain which corresponds to the state at the end of 2009 when Synthos started to operate the new rail loading and unloading facility. Similarly to previous case, Case b) requires no investments. The rest of proposed cases is focused on storage, RTC loading and RT loading capacity increase and requires investments.

The outputs coming from LPG SIM are displayed in Figures 9, 10, 11, 12 and serve to support the decisions about possible changes in LPG storage and expedition area.

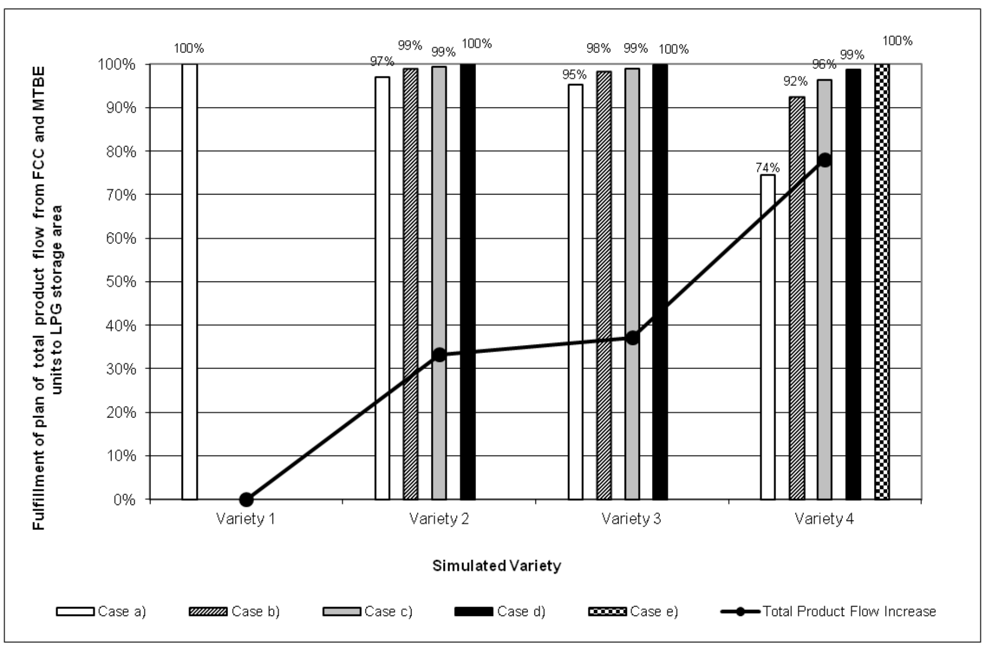

Fig. 9 Fulfillment of the planned flow of products from CRC FCC and MTBE units to LPG storage area

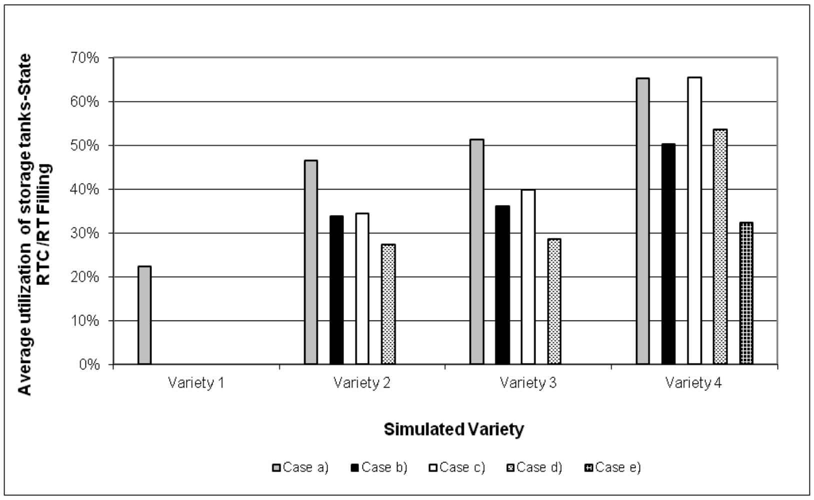

Fig. 10 Average utilization of Propane-Butane storage tanks (state: RTC/RT Filling)

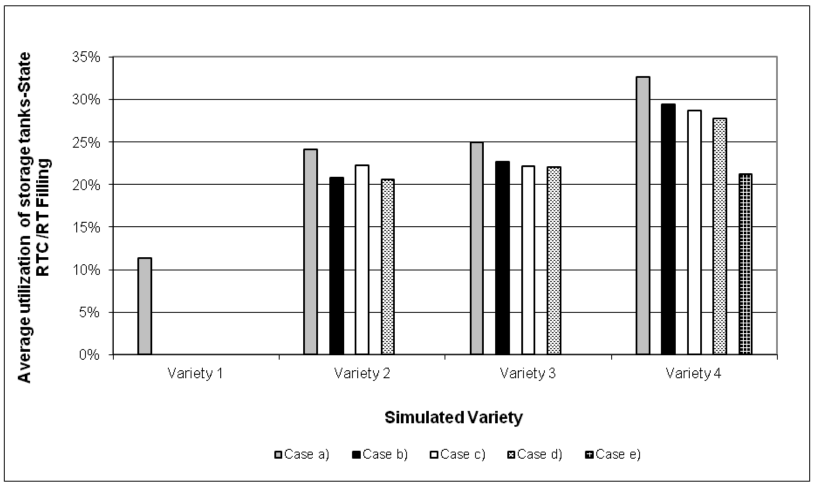

Fig. 11 Average utilization of FCC C_4 storage tanks (state: RTC/RT Filling)

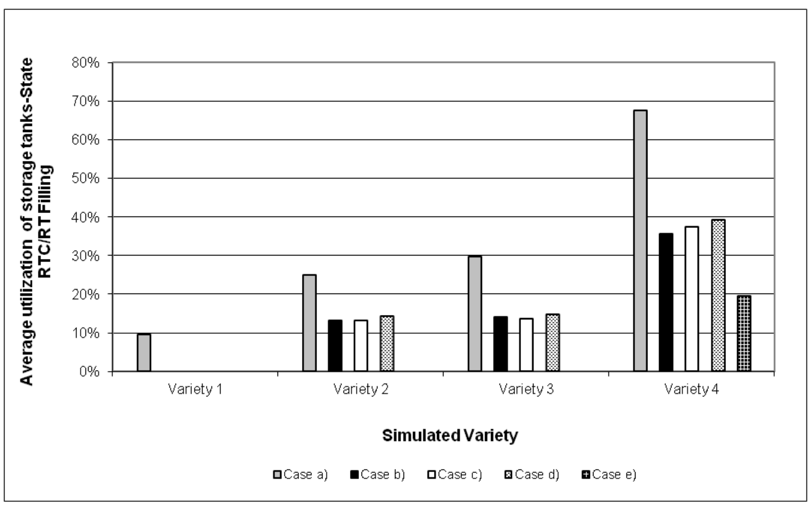

Fig. 12 Average utilization of Propylene storage tanks (state: RTC/RT Filling)

The outcomes of simulation prove that in case of no investments to storage, RTC and RT loading capacities it is not possible to reach the fulfillment of planned LPG manufacturing intensification described in Varieties 2, 3 and 4 [see Figure 9; Varieties 2, 3, 4; Cases a) and b)]. The reason is insufficient RTC and RT loading performance causing too slow storage capacity releasing [see Figures 10, 11, 12; Varieties 2, 3, 4; Cases a) and b)], inability to fulfill the plan of Propane-Butane mixing occurring in Propane-Butane storage tanks and subsequent interruption of product flows from FCC production unit.

For Variety 2 and Variety 3 the fulfillment of planned LPG manufacturing intensification is achieved if Case d) is realized [see Figure 9; Varieties 2, 3; Case d)] because of substantial acceleration of storage capacity releasing [see Figures 10, 11, 12; Varieties 2, 3; Case d)]. To realize proposed arrangements in Case d) the investment to the installation of continuous chemical composition analyzer in each storage tank has to be spent as well as the investment to the RT loading capacity increase.

For Variety 4 the fulfillment of planned LPG manufacturing intensification is achieved if Case e) is realized [see Figure 9; Variety 4; Case e)] because of even higher acceleration of storage capacity releasing [see Figures 10, 11, 12; Variety 4; Case e)] than in Case d). In addition to the investments described to realize proposed arrangements in Case d) the investment to RTC loading performance has to be spent to realize proposed arrangements in Case e). This additional investment should cover the reconstruction of RTC loading terminal in a way that each platform is operated independently or that new platform for RTC filling is constructed.

6. Conclusions

In this paper, we present an application of discrete event simulation in LPG storage operation and optimization. Based on the principles of ABM we propose the LPG Simulator and discuss its basic functionality simulating 4 different varieties differing in the total amounts of products flowing from the CRC FCC unit to LPG storage and expedition area. For each simulated variety we specify the requirements on storage and expedition capacities ensuring the smooth product flows through the LPG storage area, gasoline blending requirements and the requirements on products expedition in RTC and RT.

The modeling and simulation applied for real business case justified respective investment decisions of involved parties (Synthos and CRC) and provided CRC with realistic scheme for operation of LPG storage in line with production requirements, safety requirements, market requirements and all constrains applicable for RTC and RT loading and unloading activities. Nowadays, LPG SIM is provided to CRC in the form of simple software application to support the decisions about other possible LPG manufacturing, storing and expedition supply chain changes. Furthermore we plan to apply LPG SIM in the operative planning of RTC loading requiring sophisticated programming procedure that takes into account the requirements of customers on CRC final products deliveries together with the number of available RTC owned by rail way transportation companies. This application linked with CRC information system for continuous data exchange is going to be operated in Witness Viewer environment designed to run Witness models without possibility to change their structure.

The framework of LPG SIM based on ABM determines the simulator to be applied in other tasks dealing with the supply chain modeling and optimization. We see another possible application of our simulator for example in nitrogen fertilizers manufacturing, storing and distribution where the structure of the supply chain is similar to the one described in this paper.

Abbreviations

ABM - Agent-based modeling

CRC - Czech Refining Company (ČESKÁ RAFINÉRSKÁ, a.s.) owned by UNIPETROL, a.s., Shell Overseas Investment BV and ENI International BV

DES - Discrete event simulation

FCC - Fluid Catalytic Cracking: refining technology converting (usually) vacuum distillates into lighter products. Among others, significant amount of Liquid Petroleum Gases is created

LPG - Liquid Petroleum Gases: usually mixture of C3 hydrocarbons (propane, propylene) and C4 hydrocarbons (butanes, butanes)

LPG SIM - LPG Simulator consisting of Witness simulation model and MS Excel spreadsheet for input data loading and outputs upgrading

RTC - Rail way tank cars

RT - Road tank-trucks

Synthos - SYNTHOS Kralupy, a.s. - the Czech petrochemical company owned by SYNTHOS

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Ivan Gros is currently the Professor at the Department of Economics and Management of ICT Prague. In his work he focuses on supply chain management and operational research. He is the founder of the Czech Logistic Association and the guarantee of many international scientific conferences.