MAPPING OF NATURAL GAS SUPPLY CHAIN IN CROATIA AIMED AT CREATING A SIMULATION MODEL FOR SYSTEM IMBALANCE REMOVAL

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Abstract

With the growing importance of natural gas as the third most important fuel and fastest growing component of world primary energy consumption, its supply chains are becoming more complex in seeking ways for simultaneous optimization and further expansion. To gain clearer insight into situations and relations between members of the natural gas supply chain; to explore possibilities for optimization of its processes; to avoid multiplication of activities; and to prevent the occurrence of failures or catastrophes in the system, practitioners and scientist use supply chain mapping techniques. The paper aims to present existing types of supply chain maps, their benefits, limitations and methods for natural gas supply chain mapping through the case study method of mapping a Croatian natural gas supply chain. Mapping a natural gas supply chain serves the second objective of the paper, which is to develop a conceptual simulation model of physical and trading processes of natural gas in Croatia. Due to the mismatch of ordering (nominations) and withdrawal of gas made by balance groups, imbalances in the transportation system occur, which needs "balancing energy". Consequently, balance groups that have a mismatch over the permitted limits are penalized. Exploring the reserves of transportation and distribution systems, the model aims to minimize or eliminate the inefficiencies resulting from the mismatch between the order (nomination) and the withdrawal of gas from the transportation system made by the balance groups under regulated market conditions. The initial version of the model was developed using Arena Simulation Software.

Keywords: *supply chain mapping, natural gas, simulation modelling*

1. INTRODUCTION

Natural gas is one of the cleanest and environmentally friendly fossil fuels and energy sources. From its extraction to its consumption natural gas usually doesn't need to go through any transformation process [1]. World's most relevant study [2] predicts 45 percent increase in global worldwide natural gas demand (the biggest rise of all energy resources) in period from 2015 to 2040. Natural gas features have contributed to the growth of its use around the world, therefore its cost effective, on-time, safe and widely spread transport and distribution are in main focus of natural gas supply chain members. Logistics and supply chain management plays crucial role in provision of natural gas – according to [3] transmission and distribution of natural gas to final consumers' accounts for more than 30 percent of natural gas price. The importance of supply chain mapping in natural gas supply chains arises from need to gain clearer insight into situation and relations among members of natural gas supply chain at different levels, to explore possibilities for optimization of its processes, to avoid multiplication of activities and to prevent the occurrence of failures or even catastrophe in the system.

Republic of Croatia has high share of natural gas in overall primary energy production (27,1 %), as well as in overall primary energy consumption (21,9 %) [4]. Croatia produce around 50 % of its needs for natural gas and has one of smallest natural gas energy dependency in European Union (34,4 %) [5]. Its international part of natural gas supply chain is equally important as its domestic part since the Croatian natural gas supply chain is part of overall European natural gas supply chain, according to which the rules and directives are given by European Parliament and European Commission (Directive 2009/73/EC; EU Directive 2014/312/ EC).

The aim of this paper is twofold: *a)* to present existing types of supply chain maps, their benefits and ways of use for natural gas supply chain mapping through case study of mapping Croatian natural gas supply chain; *b)* based on the current supply chain analysis to identify the sources of the inefficiency of the process under regulated market conditions and to offer a conceptual simulation model that can serve to eliminate or minimize the inefficiencies resulting from the mismatch of the estimated demand and withdrawal of gas by the balance groups.

2. NATURAL GAS SUPPLY CHAIN MAPPING

Mapping is service, pervasive and supportive activity that is widely usable in all areas of supply chain management and by all members of the supply chain. Gardner and Cooper [6] define supply chain map as a *representation of the linkages and members of supply chain along with some information about the overall nature of the entire map*. Miyake et al [7] highlights how supply chain map result from the collection of different kinds of data and result in a holistic view that "no one person has ever caught in its entirety". Even most simple supply chain map, collaboratively developed, will lead to clearer understanding of each member's position and processes in supply chain, in turn can result in avoiding of work duplication in supply chain, higher motivation, better coordination, forecasting and replenishment efficacy, and increased chances for other supply chain process improvement [8]. To mitigate complexity, to clarify position and processes, and to ensure maximum possible optimization of natural gas supply chain, practitioners and scientist use mapping method in creating a "picture" of natural gas supply chain.

There are two main groups of supply chain maps [9]: relationship-based maps and activity-based maps.

Relationship-based maps are also called strategic supply chain maps [6], and they are used primarily to identify all supply chain members (or at least some that are key members), their position in supply chain and relations to each other, and ways how resources are flowing between them. These kinds of maps give more strategic and general overview of place and role of each member in the supply chain, and usually avoid highlighting of particular activities.

Activity-based maps are focused on a certain part or whole supply chain process describing some physical, information or value flow in it (flow can take place within or between companies). The main goal is to increase understanding of processes usually by increased process visibility. Lambert et al. [9] points some more popular activity-based supply chain maps: time-based process maps, pipeline inventory maps and extended value stream maps.

Recent study by Dujak [8] has generated that in 68 % of selected and analysed papers authors decided to use natural gas supply chain maps for giving clearer and understandable situation, relations or process flow in natural gas supply chain. The most often used type of supply chain maps for mapping natural gas supply chain are relationship based maps (in 83 % of papers), based on strategically approach to primarily supply chain members and flows. The reason behind is a fact that relationship based maps are suitable for presenting more static environment what is most often case in natural gas supply chain papers. Time based supply chain maps that usually appear in form of process maps are used in only 33 % of analysed papers. According to the main topic and accents of paper's research, supply chain maps equally represent the whole natural gas supply chain as well as only parts of natural gas supply chain. Geographically representative maps are rare in papers dealing with natural gas supply chain. Furtherly, natural gas supply chain maps mostly don't use focal approach (are not drawn from the perspective of a supply chain member that is in focus) and don't use cycle view (as there are almost no return flows in natural gas supply chain). This is the reason why other models (like simulations and system dynamics) are also used to present the dynamics of the system or its part.

3. CROATIAN NATURAL GAS SUPPLY CHAIN

3.1. Integrated map of Croatian natural gas supply chain

Natural gas supply chain in the Republic of Croatia is a complex system that is built and operates on the given technological bases and in strictly defined rules and legal conditions. It can be seen as a multilayer dynamic structure in which physical flows and infrastructure, supply and final consumption as well as balancing are divided for rational utilization of all resources and capacities as well as fulfilling demand of all categories of consumers. Integrated map of Croatian natural gas supply chain is given in Figure 1.

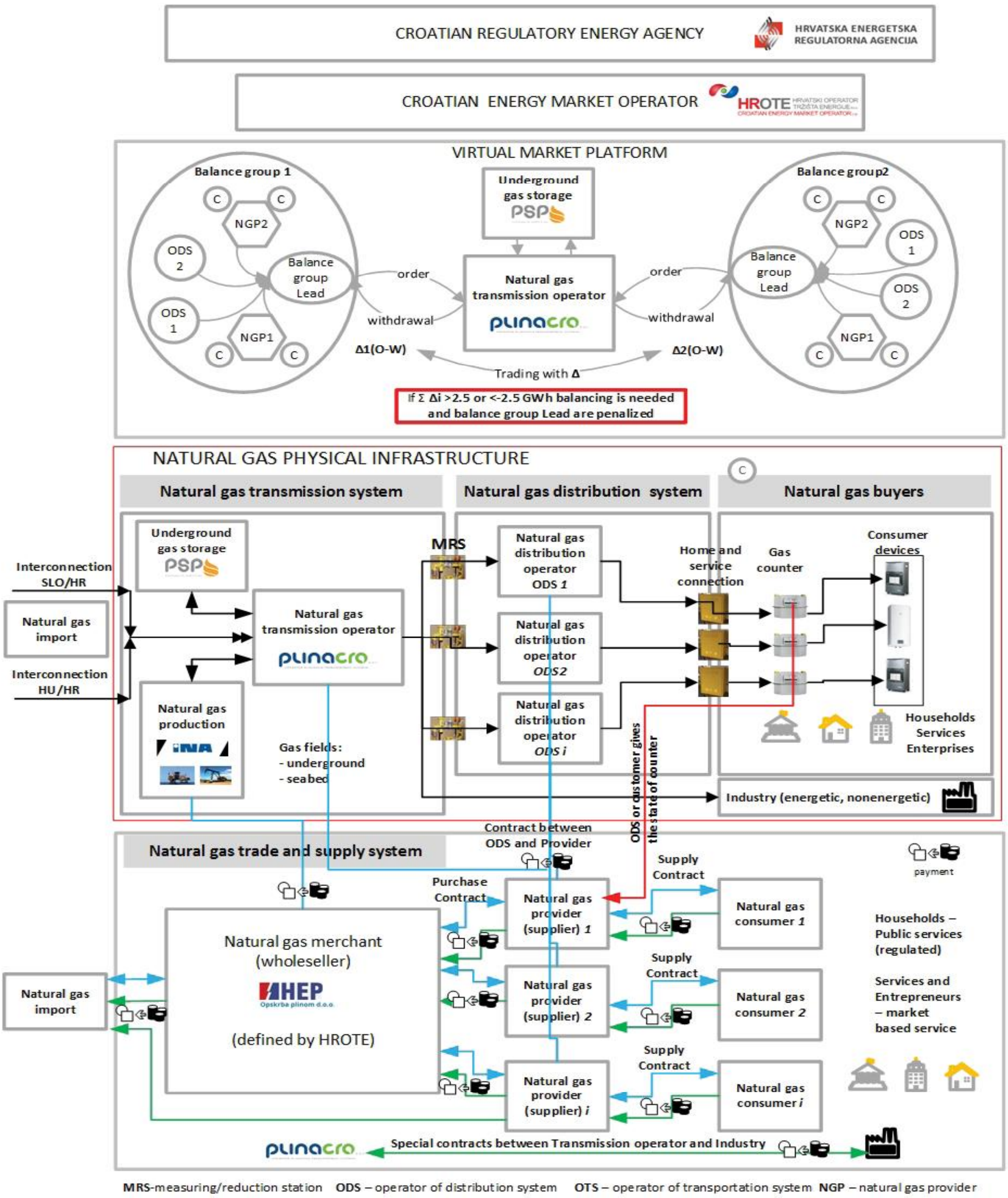

Figure 1 – Integrated map of Croatian natural gas supply chain (adapted and extended from http://www.gpz-opskrba.hr/korisne-informacije/shema-plinskog-sustava-i-trzista-plina-u-rh-55/55)

Physical infrastructure and material flows

Production

"Natural gas is produced from 16 on-shore and 10 off-shore gas fields meeting 70.7 percent of total domestic demand. However, when gas produced in the Adriatic that actually belongs to Croatia is included in calculation, domestic gas amounts to 56.1 percent of Croatian total gas demand. More than half of total gas production has been gained from the Adriatic Sea" [10; 133]. Overall production was 1.780,5 mil m^3, import was 1.060,1 mil. m^3, export was 367,4 mil m^3 and stock change was 56 mil m^3.

Gas Transmission

"Natural gas transmission is a regulated energy activity performed as a public service and represents the primary activity of the company PLINACRO Ltd, which is the owner and the operator of the gas transmission system. In 2015, 26.371 million kWh of natural gas were transported, of which 22 542 million kWh from the entry points to the exit measuring-reduction stations, and 3 829 million kWh to the underground gas storage Okoli. At the system level, maximum gas transmission achieved in 2015 was 113 million kWh/day.

PLINACRO manages a total of 2 694 km of pipelines of which 2 410 km was engaged in gas transmission in 2015. Gas is delivered from the transmission system through 164 connections at 157 exit measuring-reduction stations. 38 connections are in function of gas delivery points for industrial consumers on the transmission system, whereas 126 connections are used for gas delivery to gas distribution systems" [10; 134].

Storage

"The underground gas storage Okoli is operated by the company Podzemno skladište plina, Ltd. which is owned by the transmission system operator PLINACRO Ltd. and that generated its revenue through the provision of natural gas storage at regulated conditions defined by the Croatian Energy Regulatory Agency. Technical conditions, operation, management, development and maintenance of the storage system, connection with other parts of gas system, the rights and duties of operators and users of the gas storage system, contracting procedure as well as connecting with other parts of the gas system are regulated by the Rules of the gas storage system usage (UPR-175 - 1/2014 published on 29th December 2014), which is brought after a public hearing with the consent of the Croatian Energy Regulatory Agency. Maximum withdrawal capacity is 240 000 m^3/h, and maximum injection capacity is 160 000 m^3/h. During 2015 a total of 236 million m^3 of gas was injected into gas storage while about 290.8 million m^3 of gas were withdrawn during the withdrawal cycle" [10; 137].

Distribution

There were 35 companies for natural gas distribution in the Republic of Croatia in 2015. Total gas distribution network in Croatia is 17 627 km long. During the 2015 1.081.786 mil m3 gas was distributed [10; 138].

Consumption

Overall consumption of natural gas in 2015 was 2.519,2 mil m^3 of which Energy sector own use was 129,0 mil m^3, energy transformation (thermo power plant, public cogeneration plants, heating plants, industrial heating plants, refineries, gas works and NGL plants) 881,6 mil m^3, Non energy use 495,6 mil m^3 and Final energy consumption 981,3 mil m^3 (Industry 211,1, Transport 4,0, households 540,0, services 204,8 and agriculture 24,1 mil m^3) [10; 140].

Supply

"The license for gas supply activities in Croatia in 2015 obtained 56 energy companies, out of which 46 were actively engaged in gas supply activities. Based on the gas Market Law ("Official Gazette" no. 28/2013 and 14/2014) Croatian Energy Regulatory Agency has issued General terms of gas supply ("Official Gazette" No. 158/2013). In early 2014, HEP (Croatian Electric Power Industry) was determined as the supplier in the wholesale gas market by the Decision on determining the supplier in the wholesale gas market ("Official Gazette" No. 29/2014). HEP is obligated to sell gas to suppliers in the public service for the needs of household customers under regulated conditions and provide a reliable and secure supply, including gas import to Croatia. [10; 142].

3.2. Development of simulation model

Starting from the integrated natural gas supply chain map and respecting the rules and legal frameworks of natural gas system, a conceptual solution of simulation model was proposed with the aim of exploring the possibility of eliminating system inefficiencies, i.e. exploring the possibility of adapting the system to balance disorders arising from the mismatch between gas nomination and withdrawal from the transmission system. The key problem with the nominations is to find the most reliable assessment models for the daily and even hourly consumption. The withdrawal of gas from the transmission system of particular balance group should be aligned with the order (nomination) placed to the transmission system. However, as errors in nominations (orders) always occur, the withdrawal of gas from the transmission system (and storage) is not consistent with the nominations, which causes imbalances in the transmission system. Due to the balancing transmission system with so called "balancing energy", balance group is being penalized. Although the balance groups have the ability to trade the surpluses and shortfalls on the trading platform, our goal is to explore what adaptive possibilities are available to the distribution systems for adaptation and to take part of the imbalance in accordance with their capacities and technological capabilities. Initial model is developed by using Arena Simulation Software. Graphical representation of model is given in Figure 2.

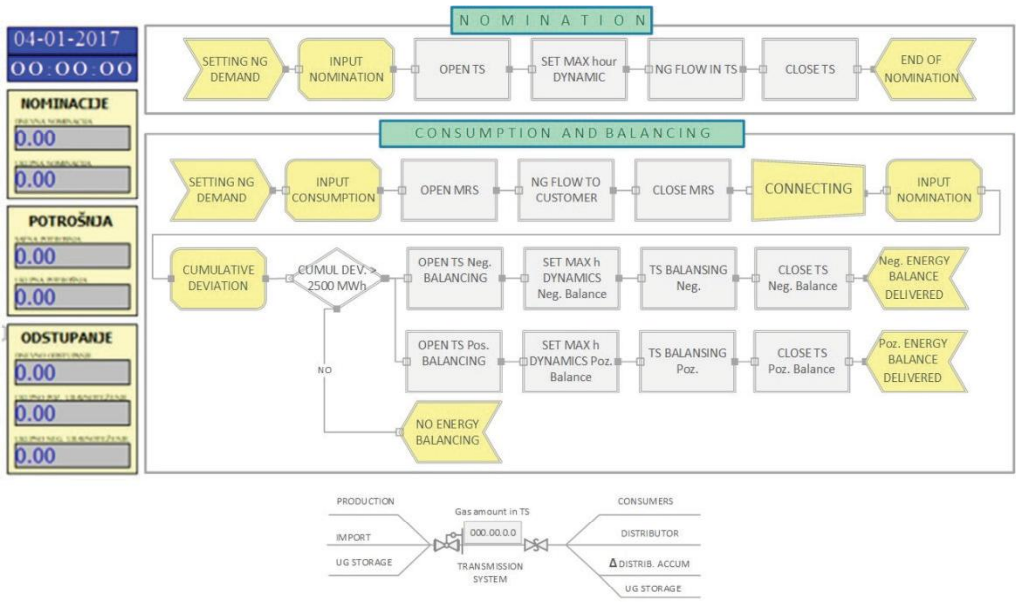

Figure 2 – Graphical representation of simulation model

Key variables of model are consumption per hour and daily nominated amounts of gas. The model works as follows: In the NOMINATION part starting point is setting gas demand for gas day. Based on actual data, the Input Analyser determines the equation that simulates the nomination. It comes to the "Open TS" module, which opens the gas in the TS. With the "Set nominal dynamics of the nomination" module, the total nomination is divided by 24, giving equal hourly nomination. The "Gas flow in TS" module is released into the transport system and the gas inlet valve closes after 24 hours.

In the part CONSUMPTION AND BALANCING – The "Setting NG demand" module simulates the distribution system consumption. This part of the process starts by creating gas consumption for each hour. The MRS valve opens and the gas is ejected from the transmission system to the distribution. The MRS valve is then closed. The "Connecting" module is waiting to be collected for all 24 hours. The module "Cumulative daily deviation" calculates the difference between daily nomination and daily consumption. When this cumulative deviation exceeds +/- 2,500,000 kWh then balancing the transportation system is done (withdrawing from or injecting to gas storage). If the deviation is > 2,500,000 kWh, negative balancing is made (because the nomination is higher than the consumption), and the gas withdrawal from the TS is made. If the deviation is less than -2,500,000 kWh, it is positive balancing, so the gas is injected to the TS.

Model was initially tested on the data publicly available on the Transportation system web site. We have the data of one month consumption on daily and hourly basis and nomination made of all balance groups on daily basis. Hourly consumption during the each gas day (according to input analyser) was distributed in accordance with Erlang distribution. Nomination (e.g. planned consumption) was equally distributed on every hour. Differences between consumption and nomination were calculated and cumulate on daily basis. We made 30 iteration for 24 hours. Cumulative monthly consumption error was 10.32% and cumulative monthly nomination error was 0.34%. Our initial model is made on assumption that 1 MRS exists as well as one balance group. Our future model will be enhanced including additional variables like gas pressure and temperature for altering distribution system capacity and also combination of more balance group associated to the distribution system. Data will be collected from 2 year historical data of the variables available on one of the biggest Croatian distribution system and all balance groups associated to the distribution system.

4. CONCLUSION

For a full understanding of the natural gas supply chain, it is useful to use different types of maps that reveal the participants, their roles, activities, processes, material, information and value flows as well as possible inefficiencies and risks that might occur in the supply chain. However, the maps generally have a static character and for the dynamics of the entire supply chain it is necessary to build additional models that will reveal the behaviour of the system and its dynamics relevant to the specific aspects of the system's observation. The integrative model of the natural gas supply chain with the consideration of rules, legal and technological frameworks in which the supply chain operates, is the basis for the development of a dynamic simulation model that seeks to solve some inefficiencies in the system. Since the parts of the gas market are regulated, as the key measures to ensure business process efficiency available to supply chain participants joined in balance group are well defined forecasting and demand planning as well as technological solutions for adaptation allowing consistency of supply and natural gas consumption. Modern prediction models of natural gas consumption, based on neural networks and machine learning methods, have shown promising results for solving the first problem [11] as well as a combination of different model (mathematical, multiple linear regression, dynamic model adaptation) [12]. Proposed simulation model will try to resolve the problem of adaptation of distribution system to compensate potential disturbances and thus avoid penalizing due mismatch of order and withdrawal. Model is in its testing phase and should be developed further on the real data from the two balance groups.

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