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ORIGINAL PAPER

TOWARDS EXPLORING BULLWHIP EFFECTS IN NATURAL GAS SUPPLY CHAIN

Davor Dujak[1], Dario Šebalj[1], Adam Koliński[2]

1) Josip Juraj Strossmayer University of Osijek, Osijek, **Croatia**, 2) Poznań School of Logistics, Poznań, **Poland**

ABSTRACT. **Background:** Bullwhip (or Forrester) effect is well studied phenomenon in many supply chains where small variations in customer demand have a tendency to become larger and larger when created by upstream members of the supply chain resulting in unneeded increasing in upstream inventory. However, there is substantial deficiency of scientific research on bullwhip effect in natural gas supply chain. Due to relatively smaller number of supply chain members and huge volumes flowing through the natural gas supply chain, benefits of decreasing or even eliminating negative consequences of bullwhip effect could be enormous. This paper aims to provide more insights in reasons for the occurrence, nature and consequences of bullwhip effect by measuring and analysing it in natural gas supply chain of Republic of Croatia.

Methods: After observation of orders and consumption from natural gas supplier, comparisons were made on monthly and yearly level. Well known and accepted metrics were used to calculate existence of bullwhip effect.

Results: Results didn't show existence of bullwhip effect on lowest level of natural gas supply chain what is in accordance with other researches. Best solution for mitigating potential or real bullwhip effect are information sharing while working on joint demand forecast in supply chain and use of newer forecasting method

Conclusion: Expected results should contribute to better understanding of bullwhip phenomenon in natural gas supply chain, but also provide possible avoiding strategies based on building trust in supply chain and on appropriate use of information and communication technologies.

Key words: natural gas, bullwhip effect, supply chain, information distortion.

INTRODUCTION

Natural gas is fossil fuel (not renewable resource) that can be find below the surface of the earth, and is made of many components – with methane being predominant. Although it is not as clean as renewable sources of energy, it is still most environmental friendly fossil fuel (it emits less quantities of harmful emissions in environment). Therefore it is considered as the best transitional fuel between fossil fuels and different renewable sources [Fernandez et al, 2018]. Due to ratio of price and efficiency, as well as availability (it can be found almost everywhere in the world) and environmental friendliness, natural gas has become one of most important energy sources. According to International Energy Agency [2018], natural gas supplies 22 % of the energy used worldwide, it is used for almost 25 % of electricity generation (in natural gas power plants) and it can be said that industry as a whole is main driver of growing demand for natural gas. Growing demand for natural gas in future will be determined by global economy growth as well with rising consumption that comes with rising living standards, and with a fact that natural gas is good bridge to prevailing or (hopefully) complete use of only renewable resources in the future.

Due to its growing usage today and in future, but also to relatively frequent price changes (same as for other fossil fuels), cost optimization becomes crucial issue in natural

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gas business. Price of natural gas generally consists of two parts: price of gas as commodity at the well (the "wellhead" price) and the "basis" price. The basis is so called location differential part of the price which consists of cost of transport via pipeline, suppliers and brokers profit margins, and risk/liquidity premium (depending on the state of the market, customers' credit and other factors). As it can be seen, major contribution to the price consists of supply chain or logistics costs, and managing this cost can substantially improve competitiveness of an organisation or whole natural gas supply chain. Jacoby [2012] talks about complexity of gas and oil supply chain management and points out two generic strategies most applicable to companies from this supply chain: rationalization and synchronization. Substantial savings in logistics costs (rationalization) could be achieved by reducing or even avoiding the Bullwhip effect (through synchronization). The bullwhip effect is the tendency of small variations in demand to become larger as their implications are transmitted upstream through the supply-chain. Usually it is resulting in unneeded increasing in upstream inventory levels that consequently results in other problems for supply chain members. Certain studies [Bray, Mendelson 2012; Shan et al. 2013] estimate that around two-thirds of companies are affected with bullwhip effect. Although bullwhip effect is well studied phenomenon in most of supply chains, there is still significant lack of researches regarding bullwhip effect in natural gas supply chain or in natural gas industry at all. Due to relatively smaller number of supply chain members and huge volumes flowing through the natural gas supply chain, benefits of decreasing or even eliminating negative consequences of bullwhip effect could be enormous. Additionally, it is not uncommon that companies on different echelons of natural gas supply chain have same owner and therefore avoiding negative bullwhip effects should be even easier – but it is still happening

The main goal of this paper is to present natural gas supply chain on model of Croatian natural gas supply chain system and to investigate possibilities of occurrence of bullwhip effect in it. To achieve the main goal, the authors have set two research questions.

Demand from final consumers to gas supplier is in substantial share unpredictable. Although, it depends on some known factors like weather and seasonality, still many suppliers struggle with accurate demand forecast. In theory, this should be fertile ground for the bullwhip effect and reason for forming first research question.

Q1: Does Bullwhip effect exists in the natural gas supply chain in Croatia?

From initial talks to natural gas supply chain member was concluded about lack of knowledge about bullwhip effect, as well as about activities to prevent it or decrease it. Second research question was formed in quest for appropriate bullwhip avoiding/decreasing activities in natural gas supply chain.

Q2: What can be done to decrease negative consequences of bullwhip effect in natural gas supply chain?

The paper is organised as follows. After introduction part, paper follows with literature review on bullwhip effect and its occurrence in natural gas supply chain. A next chapter describes natural gas supply chain of Republic of Croatia – its members, relationships, main flows and system functionality. Methodology and research results of measuring bullwhip effect in Croatian natural gas supply chain are presented next, while paper ends with discussion and conclusion remarks.

LITERATURE REVIEW

Bullwhip effect

Bullwhip effect is well known phenomena in supply chains defined as the amplification of order volatility along the supply chain [Wang, Disney 2016]. Its first written research is connected to book by Jay Wright Forrester Industrial Dynamic from 1961 [Forrester 2013] where he describes his empirical findings of increasing demand fluctuation seen by each new upstream supply chain member. Therefore, bullwhip effect is often also called Forrester effect. Although researches has be done novelty in this area arises slowly - one of most important was introduction of Beer game simulation game by Sterman in late 1980's [Sterman 1992] as an adequate behavioural decision model. Term bullwhip was first used by company Procter & Gamlbe (P&G) in 1990's who noticed order variance amplification phenomenon between the company and its suppliers [Wang, Disney 2016]. Furtherly, huge breakthrough happened in 1997 when Lee et al. [1997] suggested new causes, calculation, results and counter activities to avoid bullwhip effect. This paper is credited with considerable widespread of term bullwhip effect in academic sphere. Until today, bullwhip effects are noted in nearly all industries.

As Pilevari et al [2016] highlights, bullwhip generates fluctuation in three aspects in supply chain - information, physical and financial. They lead to revenue decrease (stock-out lost sale, low customer service/satisfaction, low quality, free return policies, forecast inaccuracy) and cost increase (high inventory carrying cost, high stock-out cost, high faster shipping cost, high setup and change-over cost, high labour cost - due to overtime, high material cost, high outsized facilities to handle peaks in demand, resulting in alternating under or over-utilisation).

Bullwhip effect main causes are: updating demand forecast, order batching / large lot size, price fluctuation (promotional sales), long lead times and / or to many intermediaries, and increased orders due to lack of information sharing [Lee et al 1997]. For other connected more detailed causes of bullwhip effects see Pilevari et al. [2016], but most important fact is that all causes have their roots in lack of coordination between supply chain members.

According to Domanski et al. [2009], one of critical factors in fighting the bullwhip effect is a proactive approach taken by managers. Therefore, organizations and supply chain should conduct some of activities for decreasing (or even avoiding) bullwhip effect like [Chopra, Meindl 2016; Balasubramanian et al. 2001]:

- reducing uncertainty (POS data and other information sharing, centralising demand information and forecasting),
- reducing lead time (through cross docking, faster suppliers, or decreasing information flow in lead time),
- reduce variability (reduce order batches and avoid price variability – e.g. every-day-low-price programs),
- forming alliance (e.g. Vendor Managed Inventory approach and eliminate gaming in shortage situation).

There is also different classification of bullwhip effects researches. Wang & Disney [2016] categorised all researches on bullwhip effect according to methodologies used into empirical, experimental, analytical and simulation-based approaches. Sari et al. [2004] categorized bullwhip effect researches according to main discipline in which they are conducted: system dynamics discipline, statistics and operations research discipline and control engineering discipline. While bullwhip effect research started from system dynamics discipline, authors point out additional contribution given by these two other disciplines.

The first step for supply chain members is to be aware of bullwhip existence. This is a prerequisite for organisations and whole supply chains to managing it and reducing it, as well as its effects. According to Azhar [2011], bullwhip effect could be observed on:

- one company level in different industries – e.g. apparel [Mack 1953], food [Hammond, 1994; Lee et al 1997], electronics industry [Holt et al 1968; Terwiesch 2005];
- whole industry (or more companies from one industry] – e.g. automotive industry [Blanchard 1983], machine tool industry [Anderson et al 2000] or textile industry [Zymelman1965]; or
- multiple industries - Miron and Zeldes [1988] compared food, tobacco, apparel, chemicals, petroleum and rubber industry, Cachon et al. [2007] categorized companies into three levels of a supply chain: manufacturing, wholesale and retail industry level.

When it comes to measuring the bullwhip effects, there are different approaches [Parra-Pena et al. 2012; Fransoo, Wouters 2000; Fu et al. 2015; Chen, Lee,2012; Centeno, Perez

2008; Cannella et al. 2013], but most accepted metric is called bullwhip effect ratio (BEratio). According to Chen & Lee [2012], BEratio can be calculated in two ways:

- as ratio of variance of orders and variance of demand, or
- as ratio of variance of production and variance of demand.

In first case BEratio depicts distortion of information flow (by comparing variance of orders with variance of demand), while in second case BEratio represents distortion of material flow (by comparing variance of production and variance of demand). In all options there is consensus that bullwhip effect exists if BEratio value is larger than 1.

In different settings researchers choose different metrics, mostly according to available data about organisations and their supply chains, but Chen and Lee [2012] here highlight that BEratio is more suitable metric than absolute difference metric – especially when there is a need to compare bullwhip effect for different products.

Bullwhip effect in natural gas industry

Bullwhip effect research in natural gas industry are extremely rare, and if they are made they are analysed jointly with oil industry [Chima 2007; Miron, Zeldes 1988; Cachon et al. 2007; Azhar 2013]. Binlootah & Sundarakani [2012] elaborate using of VMI (Vendor Managed Inventory) as a tool for mitigating bullwhip effect in oil and gas industry. There are even less or no studies on lower downstream natural gas supply chain level, and this is area where this paper is trying to fill the gap. Zhang and Zhang [2013] detected a delay as main reason for bullwhip effect. Tomasgard et al. [2007] gave a review of optimization models for the natural gas value chain. Sherhart [2013] studied bullwhip in British Petroleum (uses Theory of Constraints to mitigate the bullwhip effect). There are only few studies of bullwhip effect on multiple levels of natural gas supply chain [Azhar 2013; Jacoby 2012]. Azhar [2013] have found bullwhip effect in most of studied companies but not totally consistent increase in demand variability upstream the supply chain. She also concluded that smaller companies had larger bullwhip effect, while larger integrated companies exhibited a lower bullwhip effect.

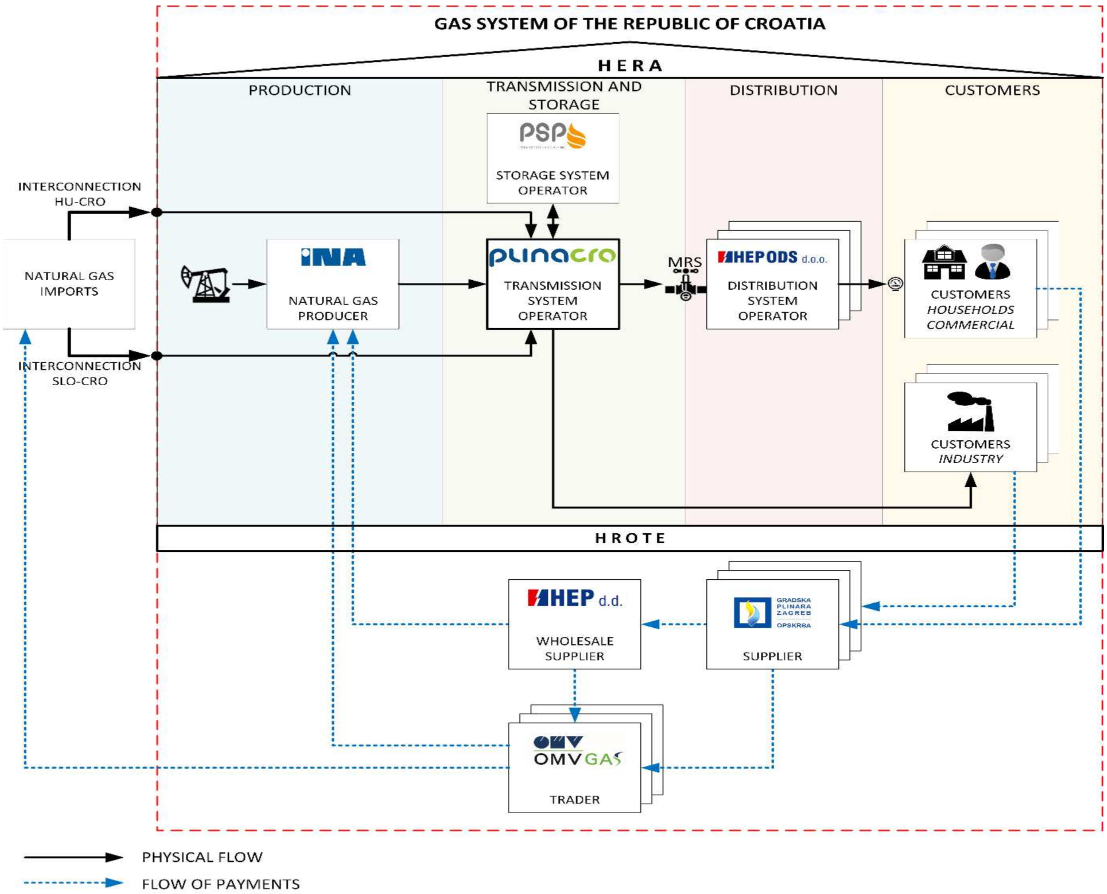
Recent studies in the oil and gas equipment industry have shown existence of bullwhip effect in upper parts of oil and gas supply chain [Jacoby 2012]. As a result of this study, Jacoby [2012] points out on for types of economic inefficiency: paying higher prices, having excess inventory during "the boom", making excessive capacity investments near the peak with low or negative return on investment on it, and loosing orders because of inability to fulfil them (inadequate capacity and long lead time in time of increased orders – "peak").

- Companies that are closer to final customer (more downstream) have lower level (or no) bullwhip effect ratio
- Smaller companies tend to have higher bullwhip effect ratio then bigger ones

According to Jacoby [2012], one of the reasons why oil and gas industry are so concentrated, is a fact that companies in oil and gas supply chain use vertical integration, scale and market dominance to protect themselves from bullwhip effect negative consequences.

NATURAL GAS SUPPLY CHAIN IN CROATIA

According to Strelec [2014], members of natural gas supply chain or gas market participants in Croatia can be divided into four basic groups: natural gas producer, system operators (transmission system operator, storage system operator, distribution system operator, gas market operator, LNG terminal operator), suppliers and traders, and customers. Supply chain of natural gas in Croatia with its members and physical and payment flows is shown at Figure 1. Some of them form logistical part of natural gas supply chain (gas physically flows through them), and some of them just participate in market or trade channels - they buy and sell natural gas without any physical contact with it. Examples of such supply chain members are certain suppliers or wholesalers who are intermediaries, but are not involved in any physical flow of natural gas.



Source: Šebalj, D., Mesarić, J. & Dujak, D., 2018

Fig. 1. Natural gas supply chain of Croatia

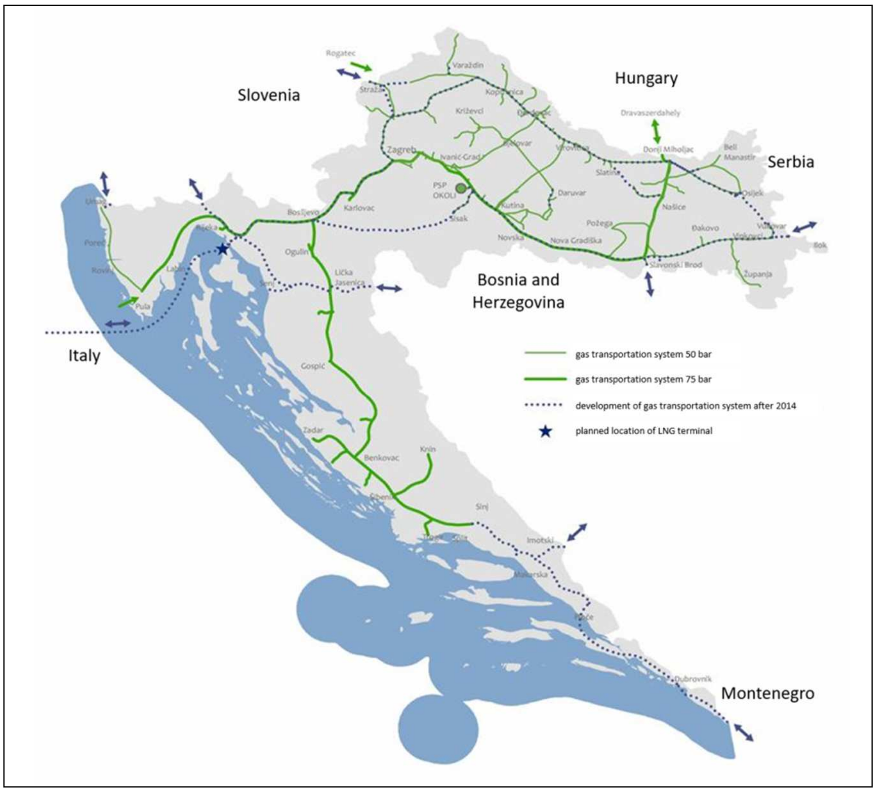
Croatian natural gas supply chain starts with gas production in Croatia or with gas import from some of most important European gas markets like Russia and Italy. Today, Republic of Croatia imports around 60% of natural gas needed, while only 40% is produced in Croatia. Domestic production is steadily declining and is performed by only one, partly state owned company, who has a license for gas production – INA d.d.

The natural gas transmission or transportation is a regulated energy activity performed as a public service and is also performed by the state-owned company Plinacro d.o.o., owner and operator of the transmission system [Energy in Croatia, 2016]. Figure 2 presents natural gas transmission system of the Republic of Croatia.

The transmission system currently covers about 95% of the territory of the Republic of Croatia. The total length of the pipeline in the transmission system is 2,693 km, of which 952 km are 75 bar working pressure pipelines and 1,741 km are 50 bar working pressure pipelines, while total transported volumes are around 3 billion m3 [Plinacro, 2018]. There are two connections with international gas transportation systems (Rogatec on Slovenian border and Drávászerdahely at Hungarian border). The main activity of transmission system is transportation and storage of natural gas throughout the country.

Storage system operator is an energy subject that performs energy activity of gas storage. Croatia currently has only one natural gas storage facility (PSP Okoli) managed by the company Podzemno skladište plina d.o.o. (storage system operator), which is owned by

Plinacro d.o.o.. Since the gas production is constant throughout the year and the gas consumption varies in summer and winter period, the technological processes in the underground gas storage take place in two cycles – injection cycle (April to October) and withdrawal cycle (October to April).



Source: Plinacro Ltd.

Fig. 2. The natural gas transmission system of the Republic of Croatia

There are 35 distribution system operators in Croatia which distribute gas (physically transport gas through a pipeline network) to each consumer's home or business facility. 13 companies operate exclusively in the energy activity of gas distribution, while 23 companies are organized as vertically integrated legal entities that, along with gas distribution, act as gas suppliers on gas market as well. Some of them are state-owned while majority are private companies. The length of the distribution network in Croatia is 19,153 km [HERA 2018].

According to the Gas market law [Official Gazette, No. 18/18], gas market operator is the energy subject that organizes gas market and is responsible for the management of the trading platform. For the Croatian gas market operator is designated Croatian Energy Market Operator d.o.o. [HROTE].

LNG terminal operator is responsible for operation, maintenance and development of the LNG terminal. The license for this activity has the company LNG Hrvatska d.o.o., which was issued in 2017 for a period of 3 years. The LNG terminal construction project is currently underway.

Gas supply represents a purchase or an order of the certain amount of gas that will be later transported through distribution system. Therefore, gas suppliers are in direct contact with final consumers and are exposed to original demand (or retail-level demand). All other upstream supply chain member deal with derived demands. The fact that other upstream supply chain members usually don't have direct data about original demand is one of root reasons for developing phenomenon like bullwhip effect.

Natural gas trade covers the purchase and sale of gas, excluding gas sales to the final customer [Gas market law, Official Gazette, No. 18/18]. The gas trading license currently holds 8 companies.

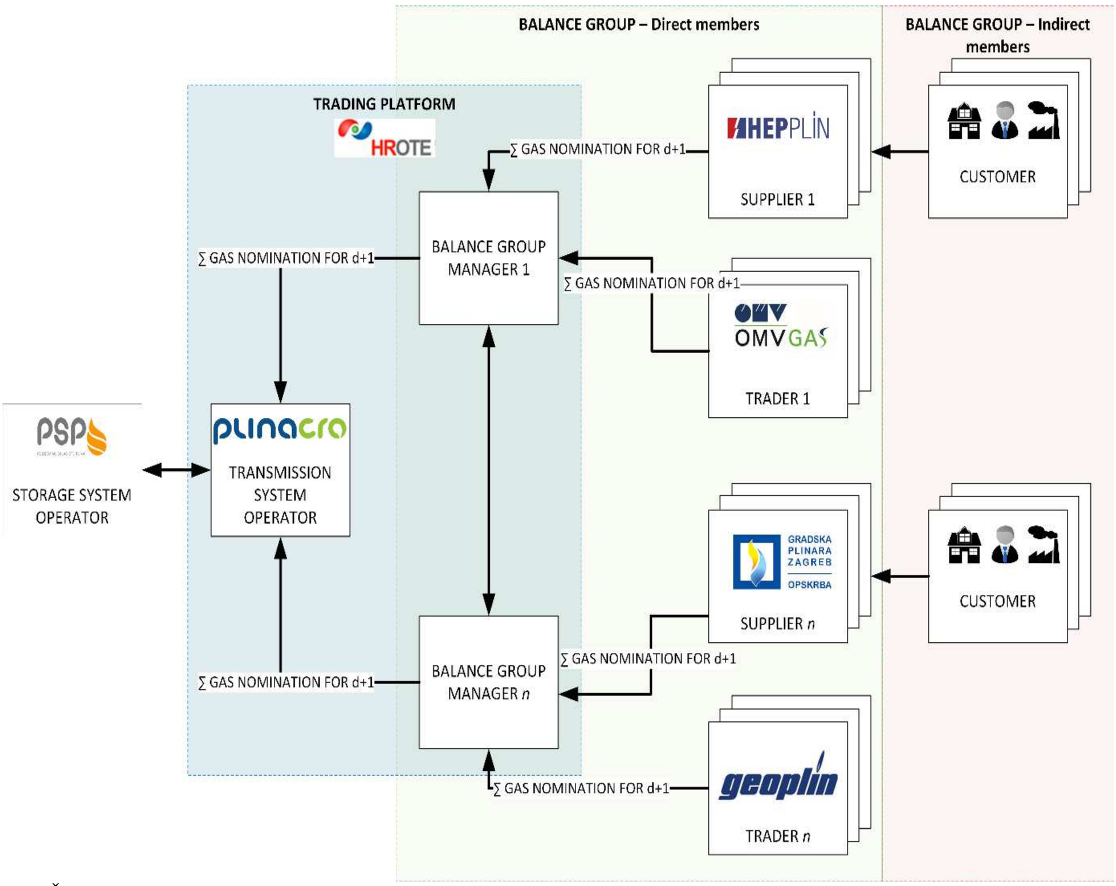
Within the scope of gas supply, customers are divided into two groups:

- households – the supply of households can be performed as a market service (by free choice of gas suppliers and negotiating terms and prices) or as a public service (under the prescribed general conditions and at a regulated price),
- commercial customers – for the supply of commercial customers the market principles are applied, that is, free contracting of mutual relations. This type of customers can be divided into those that are directly connected to the transmission system (large industrial consumers) and those connected to the distribution system.

The specificity of natural gas supply chain (both in Croatia and in most of other countries in the world) is that final consumer demand (original demand) is always entirely fulfilled. Exceptions occur extremely rarely in case of serious geopolitical international conflict, wars or natural disasters. This is due to way of functioning of natural gas transmission system where gas final consumers are actually physically connected with gas producers, and where the pipeline system functions not only as transportation mode, but also as a warehouse / storage with huge capacity.

MEASURING BULLWHIP EFFECTS IN NATURAL GAS SUPPLY CHAIN

For this research, flow of communication in form of orders and/or nominations (order announcements) is even more important than physical flow. Order flow in natural gas supply chain of Croatia is presented at Figure 3.



Source: Šebalj, D., Mesarić, J. & Dujak, D., 2018

Fig. 3. Order flow of natural gas supply chain

Suppliers act a role of retailers towards final consumers (either households or industry) – they sell gas to them and, more or less precisely, measure their consumption of natural gas. Based on historical consumption data and other variables (e.g. weather forecast, seasonality character, other industry or regional specifics) they are making their own predictions and send them as daily nominations (for the following day on hourly level) to the so called balanced group manager – one of suppliers who represents a group of connected suppliers that are buying and withdrawing gas from the same transmission system operator. Balanced group manager collects all nominations from the members of his balance group and sends the total nomination to the transmission system operator, via trading platform.

As the transmission system (i.e. pipeline system) of natural gas in Croatia has to be balanced, it is important to insert same amount of gas into transmission system as the amount that is spend / withdrawn from it. And this is main role of nominations that represent main direction for inserting gas into the system. Nominations are just predictions and they are usually more or less wrong - errors are happening. If there was more gas inserted into the transmission system than it was spent / withdrawn – positive imbalance occurs. In opposite case, negative imbalance of the transmission system follows. Obviously, system needs to be balanced again with additional amount of gas or some not spend gas has to be stored (this amount is called "balancing energy"), and cost of this balancing has to be paid by gas suppliers who were making nominations. The more accurate the nominations are, the lower is the supplier's cost.

METHODOLOGY AND RESEARCH RESULTS

For the purposes of this research authors use data for 2017 year of one of main natural gas supplier in Croatia (natural gas supplier "X") to calculate BEratio and check if there is a bullwhip effect occurring on this natural gas supplier level. For calculating bullwhip effect purposes we used a formula that indicates distortion of information flow as a ratio of variance of orders and variance of demand (due to data availability). Orders are presented with nominations that are send regularly (daily) to transmission system operator, and demand is actual natural gas consumption (because whole demand is satisfied). All data are coming from one measuring-reduction station of supplier "X" that has the largest gas flow (the largest households' consumption) and all data are expressed in kilowatt hours (kwh) of natural gas.

Figure 4 represents the differences between orders and actual consumption during January 2017 (daily level distortion). January is traditionally a month with highest natural gas consumption in Croatia, and it can be seen from figure 4 that differences between nominations and consumption sometimes reach even 22% (like on 10th January). But, than BEratio was calculated:

$$BEratio_{monthly} = \frac{Variance[Orders]}{Variance\,[Demand]} = \frac{46112687894{,}09}{182127159591{,}65} = 0{,}25319$$

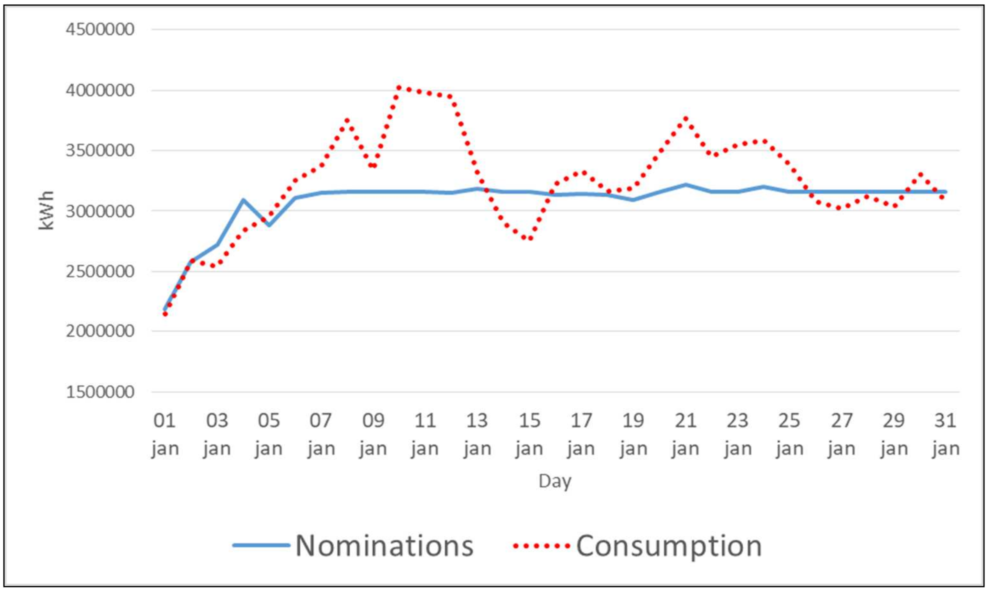
As BEratio is only 0,25319 it can be conclude that on monthly level in January, there is no bullwhip effect at supplier "X".

If the whole year 2017 is analysed (monthly level distortion), it can be seen that the differences between orders and consumption are not significant (see Figure 5). From this figure it can be seen that those differences, especially in summer months, are not so significant – the biggest is around 5% in January. In this case, total nominations are only 2% lower than consumption.

Based on monthly orders and demand data, a BEratio for the whole year 2017 was calculated:

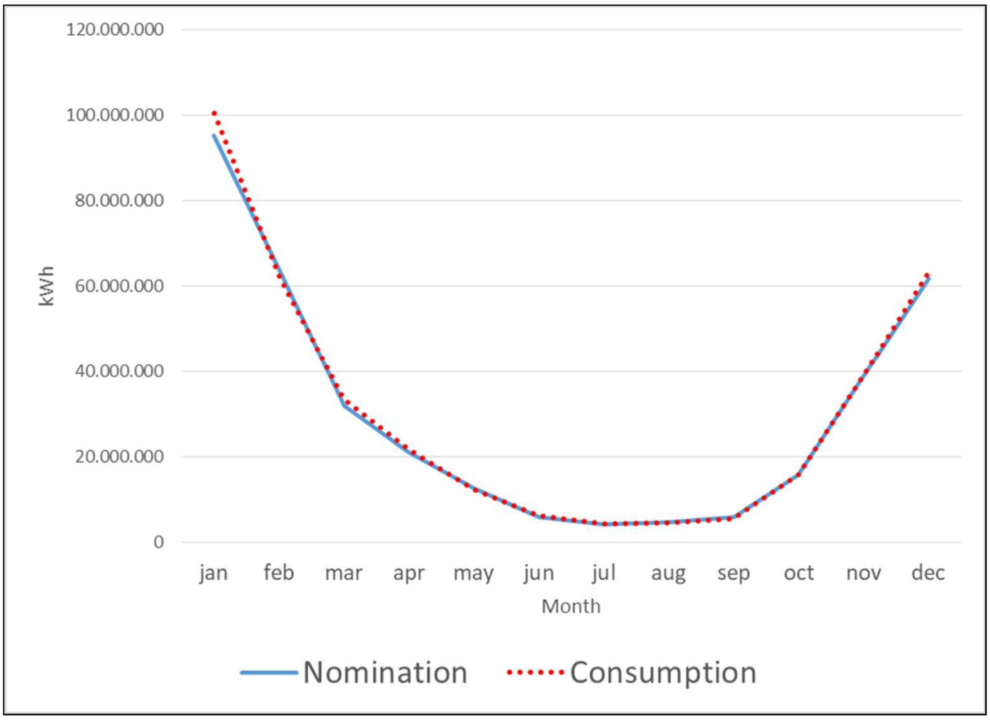
$$BEratio_{yearly} = \frac{Variance[Orders]}{Variance\,[Demand]} = \frac{873972324885971}{932231778637331} = 0{,}937505$$

In this case, BEratio value is much higher and close to 1, but still not higher than 1. Although it can be stated that there is no bullwhip effect at supplier "X" at yearly level, it can be noticed that BEratio value is increasing on longer periods of analysis.



Source: Authors' calculation based on internal data of supplier "X"

Fig. 4. Difference between nominations and actual consumption on a monthly basis



Source: Authors' calculation based on internal data of supplier "X"

Fig. 5. Difference between nominations and actual consumption on a yearly basis

DISCUSSION AND CONCLUSION

Natural gas supply chain is huge and complex system with enormous amount of gas flowing through its transmission system every day. As this system is functioning on balancing principle that penalize differences between nominated quantities (orders) and real consumption, accuracy in forecasting needs for gas for next day accounts for significant share of companies costs. As one of rear studies which analyse specifics of only natural gas supply chain, this research have shown functioning of natural gas supply chain with special emphasis on relationship and communication between lower part members of natural gas supply chain - gas end consumers, suppliers and wholesalers. Research results confirm Azhar's [2013] claim that on lower level of supply chain there is no bullwhip effect or its value is really small – this is the case for natural gas supply chain as well. Even though differences between orders and nominations are noticed in all analysed periods, on the last downstream level of natural gas supply chain there is no bullwhip effect. However, research has shown considerably higher level of BEratio on yearly level (0,937505) then BEratio on monthly level (0,25319). One of the reasons of such low level of BEratio is really short lead time in natural gas supply chain which is enabled with pipeline system of gas delivery, as well as rare changes of consumer prices for gas.

Although, bullwhip is not recorded with this research, differences between orders and demand are noticed (reaching sometimes to even 20%). Recommendations for decreasing this differences and avoiding possible development of bullwhip effect are:

- Organisations should use more information sharing in supply chain with aim of making more accurate forecast and orders (nominations) for gas.
- In future, organisations on different levels of natural gas supply chain should make one joint demand forecast, based on original demand and larger number of other variables collected from more supply chain members. This should be easily feasible especially in supply chain from this research in which in some cases even three levels of natural gas supply chain are vertically integrated by ownership.
- Organisations should use different and forecasting methods with higher accuracy like neural networks, ANFIS, genetic algorithms, grey model or some other mathematical and statistical models [Šebalj et al., 2019].

In further researches, authors plan to measure BEratio on at least one more upstream level in natural gas supply chain, as well as to expand measuring by including larger number of companies on each supply chain level. This way we would be able to conclude about existence and magnitude of bullwhip effect in natural gas supply chain, as well as to discuss about its reasons and ways of avoiding it.

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WYKORZYSTANIE ALGORYTMU HEURYSTYCZNEGO DO ROZWIĄZANIA PROBLEMU SYNCHRONIZACJI DOSTAW CYKLICZNYCH DO CENTRÓW PRZEŁADUNKOWYCH

STRESZCZENIE. **Wstęp:** W pracy przedstawiono problem synchronizowania dostaw cyklicznych do centrów przeładunkowych. Dostawy realizowane są na stałych trasach: pojazd, obsługujący daną trasę ma dostarczyć towar do centrum przeładunkowego, załadować tam inny towar i przewieźć go do kolejnego punktu trasy lub wykonać pusty przejazd do punktu załadunku. Punktami synchronizacji obsługi tras są centra logistyczne, w których niejednokrotnie towar przywieziony przez jeden pojazd, wyrusza w dalszą drogę innym. Dostawy na każdej trasie realizowane są ze stałą częstotliwością. Trasy dostaw oraz ilości przewożonego towaru są znane. Celem w problemie synchronizacji dostaw cyklicznych jest maksymalizacja liczby synchronizacji przyjazdów i pobytu pojazdów w centrach logistycznych tak, aby możliwe było grupowanie ich obsługi w bloki rozładunkowo-załadunkowe.

Metody: Na podstawie opracowanego wcześniej modelu matematycznego dla problemu synchronizowania dostaw cyklicznych do centrów przeładunkowych został zbudowano algorytm heurystyczny poszukujący rozwiązań poprzez ukierunkowane losowanie. W artykule przedstawiono opracowany algorytm losowego przeszukiwania.

Wyniki: Eksperyment obliczeniowy polegał na rozwiązaniu zestawu zadań synchronizowania dostaw cyklicznych przy pomocy opracowanego algorytmu i porównaniu uzyskanych wyników ze znanymi rozwiązaniami dokładnymi.

Wnioski: Przedstawiony algorytm heurystyczny dla zadania synchronizowania dostaw cyklicznych pozwala na uzyskanie rozwiązań zbliżonych do wyników otrzymanych przy zastosowaniu modelu programowania matematycznego. Zaletą zastosowanego algorytmu jest znaczne skrócenie czasu poszukiwania rozwiązania, co może mieć znaczenie dla praktycznego wykorzystania zaproponowanej metody.

Słowa kluczowe: harmonogramowanie dostaw cyklicznych, programowanie całkowitoliczbowe mieszane, optymalizacja, synchronizacja, algorytmy heurystyczne

Davor Dujak ORCID ID: https://orcid.org/0000-0003-2663-8849
Josip Juraj Strossmayer University of Osijek
Faculty of Economics in Osijek
Ljudevit Gaj Square 7, 31000 Osijek, Croatia
e-mail: davor.dujak@efos.hr

Dario Šebalj ORCID ID: https://orcid.org/0000-0002-8295-7847
Josip Juraj Strossmayer University of Osijek
Faculty of Economics in Osijek
Ljudevit Gaj Square 7, 31000 Osijek, Croatia
e-mail: dario.sebalj@efos.hr

Adam Koliński ORCID ID: https://orcid.org/0000-0002-0467-4673
Poznań School of Logistics
Department of controlling and information systems
Estkowskiego 6, 61-755 Poznań, Poland
e-mail: adam.kolinski@wsl.com.pl