11th International Conference on Modern Research in
MANAGEMENT, ECONOMICS and ACCOUNTING
18 – 20 December, 2020 Oxford, United Kingdom

Measurement and Reduction of the Bullwhip Effect

Tamás Faludi[1],

University of Miskolc, Hungary,

Abstract.

In the 21st century, supply chain management has a big challenge: decrease the bullwhip effect, which is derived from the coordination problems of the extended chains. Because nowadays the chain members have many other partners, and the supply chain is not a simple chain according to the traditional approach; chains more look like big networks. And the cooperation is getting to be more difficult than ever. Companies define each other as competitors rather than cooperating partners. That is the reason why the information flow is not satisfactory and the information-sharing mechanisms do not exist. Partners do not be aware of the market demand and even of each other's needs. Thus, the inventory management is focusing on safety, therefore they have big stocks, which causes costs. This is the bullwhip effect. The purpose of this paper is to introduce the bullwhip effect and to show how to measure the effect. There are solutions for the bullwhip effect that could be eliminated or at least decreased. These management tools are also presented in the paper. A case study with two cases shows what happens if the supply chain members realize the bullwhip effect and try to improve their processes to decrease the effect with some management tools.

Keywords: Supply Chain Management, Supply Chain Coordination, Bullwhip Effect, Bullwhip Ratio

1. Introduction

Supply chain management is one of the fastest developing fields nowadays. Its importance increased at the turn of the millennium. This was the time when the supply chains were beginning to grow and expand rapidly. To manage, organise, or coordinate these chains were getting to be a big challenge for the companies because the chain members had many other partners. The reason why this growth is globalisation mainly. When the world became open, the economic borders were eliminated, companies got the chance to grow – to outsource some processes into another country, to expand abroad, to make a global network. The information-flow and thereby the information-sharing mechanisms were difficult because of the many partners. The nature of relationships was also changed; some members establish long-term cooperation with the direct partners and strategic alliances have appeared. But other members determined partners as competitors. Members like this have no willingness to share information about the demand, or the customer's needs. This attitude leads to inefficient operation. It is not just the problem of the parties but a problem for the whole supply chain. The disinformation helps to increase the biggest issue of the supply chains, which is called the bullwhip effect.

These changes support the development of supply chains and supply chain management; the significance of this field has increased. Supply chain management, especially the supply

chain coordination recommends solutions for efficient cooperation between the partners to avoid or at least minimise the effects of the bullwhip effect.

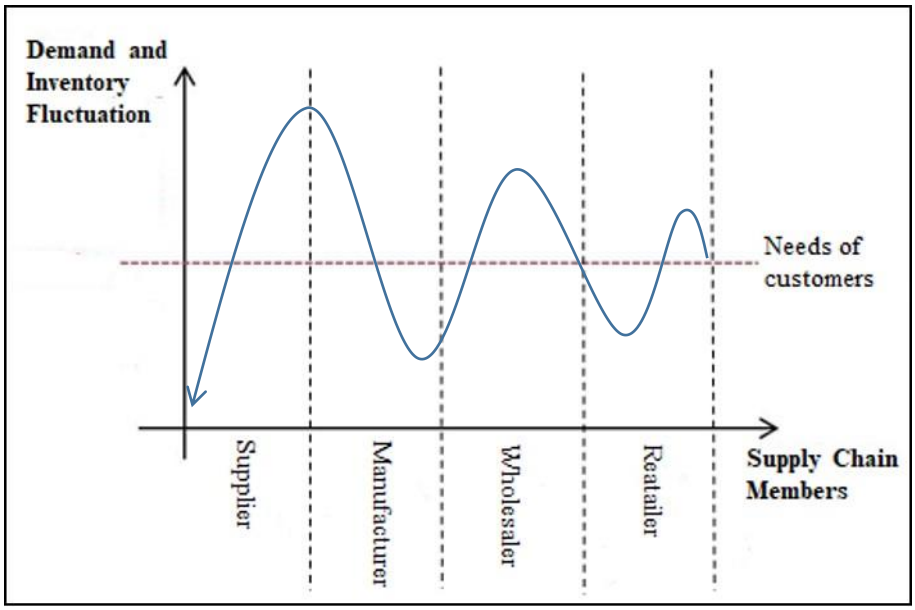
The paper focused on the measurement of the bullwhip effect because the companies need to know the rate of the bullwhip effect. The research also presents and recommends management tools to reduce the negative effects of the bullwhip effect.

2. Interpretation of the bullwhip effect

The purpose of supply chain coordination is ensuring efficient operation through the interactions between people and processes and defines a collective goal for the whole chain (Gupta & Weerawat 2006, Kaipia 2007). Thus the lack of coordination generates insecurity within the chain, which can bring the upset of the balance of power, or the prioritize of the own interest, and the overshadowing of the cooperation. These phenomenons are potential losses, which cause increased costs.

Due to the weaker cooperation, caused by the low level of information flow, chain members have inaccurate or insufficient information about the real needs of the next chain member, or the direct partners. Because of the companies' rational behavior, the ordered quantity is based on a forecast. The forecast is usually inaccurate, in some cases, the inaccuracy is intentional, because companies would like to have the stock to be able to react to the changing needs of customers or partners. This kind of behavior can be appeared by other members within the chain. A chain member monitors the needs – and probably the other's orders – of the direct partners, and if a higher-ordered quantity is experienced, the chain member also takes order with a higher quantity. This phenomenon can extend to the whole chain. In this case, there are increasing fluctuations in the volumes of stock and the demand while moving back in the supply chain from the final customer (Szegedi 2017). This is the bullwhip effect (Figure 1.)

Figure 1: Representation of the bullwhip effect



Source: Own construction based on Szegedi (2017)

Figure 1 represents an ideal case when the customer's need is constant. The retailer the one who is the closest to the market, thereby the final customer. It assumes that the retailer has the most accurate information about the demand and its changes. If the retailer has no willingness to share the information, or in a worse case the company decides to give irrelevant and false information for the other partners, their forecasts will be inaccurate, which influences the quantities of the orders; growing stock inventories will be the consequence which is followed by the increased cost of retaining inventory. This process can be also derived from the insufficient level of communication (Arshinder & Deshmukh 2008). Companies have more quantity than it is needed according to the needs, therefore in the next period less ordered quantity will be realized. But the dynamic changes of the needs can cause an increased demand and possibly companies do not have enough quantity from the products. Now they have to make it up, which includes also higher costs. This fluctuation causes the bullwhip-like trend in Figure 1 – the blue line represents it – because the changing needs induced by demand and inventory fluctuation affects the whole supply chain.

Therefore, the bullwhip effect is primarily based on insufficient information flow and it causes several serious problems. According to the literature, this is mainly due to the rational behavior of companies, but there are many other reasons for the contribution of the effect. Humans, as a fault factor, can be the source of administrative mistakes. Multinational companies use other measurement units or because of the different countries. Due to the same reason, the problem can be the foreign exchange. Furthermore, sometimes companies indicate the fluctuation of the demand with some sale promotions (Constantino et al. 2013).

These processes, factors, phenomenons confirm the effects of the bullwhip effect. It is worth quantifying the effect because the presence and the rate of the phenomenon can be

determined. If the bullwhip effect is realized by the companies and the whole chain, some changes are needed in the management.

3. Recommended management solutions for reducing the bullwhip effect

The key is ensuring a satisfactory level of information flow and that the partners have the willingness to share the important information, especially focused on the demand and its changes. It may help the forecasts to be more accurate. But there is a need for members to trust each other.

Thus, the first recommendation is to establish strategic alliances. It synchronises the purposes of the partners. A better result can be reached if the supply chain conception and orientation are also implemented in the companies' philosophy. It helps to be seen the flows of material, services, information; the roles are determined clearly within the chain, all of which help to develop the relationships (Mentzer et al. 2001).

To avoid big stocks, some supply chain strategies can help to forecast the demand as accurately as possible. Supply chain management offers to use the push, pull, the mixture of push and pull, and the lean strategies. The push strategy is typically used by manufacturing. The manufacturer pushes the goods and products upon the other chain members, which causes big stocks by the members, so the usage of this strategy is not recommended. Pull strategy can be better because in this case the real needs of final customers indicate the manufacturing. Stocks can be almost eliminated absolutely, but it is the opposite of rational behavior. Companies need at least a minimum level of safety stock, thus pull strategy is not either recommended. However, the blend of the push and pull strategies can be a good solution. The mixed strategy uses the push strategy from the manufacturer till the distribution, and the products or goods are delivered for the wholesalers and retailers according to the real needs of customers. Thus pull strategy is used from the distribution, the wholesaling, and the retailing. Another good strategy is the lean, where besides the determination of the market demand the strategy tries to eliminate the non-value-creating processes (Szegedi 2017).

Demand management can support forecasting. It determines the factors, which influence the demand in the past. It gives trends, which help to make more accurate forecasts (Nagy & Bódi-Schubert 2014). Demand management wants a high level of cooperation because just in this way can be shared the needed information (Hill et al 2018). One of the best tools to use in favor of demand management is the CPFR. It is an acronym; the words of CPFR represents the essence of the tool. It means the concentration on the collaborative planning and forecasting and the replenishment of these data – sharing on a platform where every partner can check them.

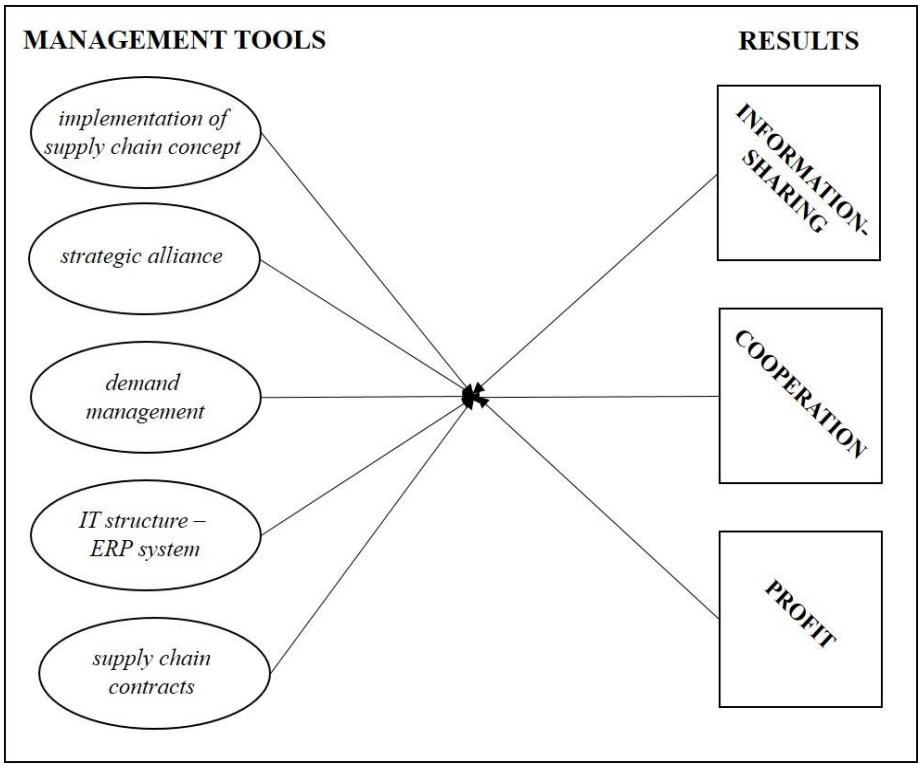
Nowadays, a very important issue is to have a modern IT background. For example, the CPFR also uses cloud-based technology for real-time data and information-sharing. ERP systems, such as SAP can also make easier communication and information-sharing mechanisms.

Contracts can control and manage the relationship and the cooperation between the chain members. They determine the sharing mechanism of risks, costs, profits, benefits (Coltman et al. 2009). The literature distinguishes many different contract types, but the right choice

should be specified by the characteristics of the relationship, which includes the different attitudes of companies. If partners are in a strategic alliance, the choice can be easier and a mutually advantageous type of contract can be chosen or even a unique contract can be created (Katok & Pavlov 2013).

Figure 2 summarizes the recommended management tools to companies make their relationship better, the information-flow and information-sharing – through the communication – are more efficient, which help to reduce the bullwhip effect.

Figure 2: Recommended management tools



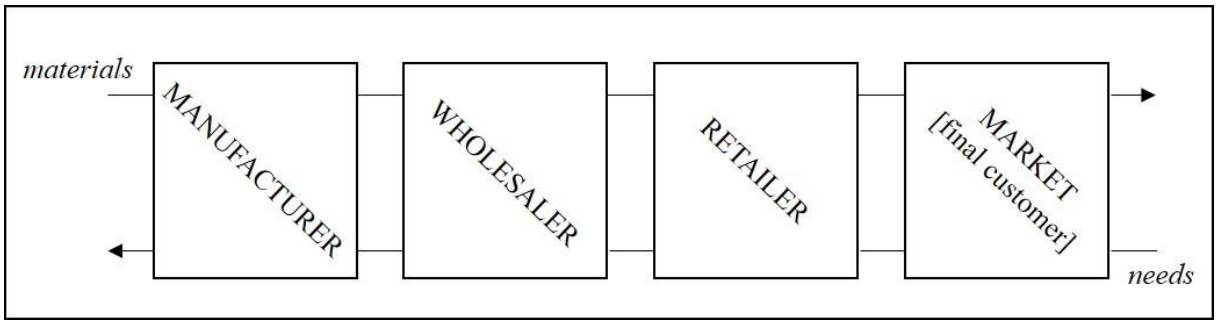
Source: Own construction

The next chapter introduces a case study to represent the importance of the measurement of the bullwhip effect and the usage of the introduced management tools.

4. Case study

A case study for the measurement of the bullwhip effect is included in the paper. For the calculation, a simple model of the supply chain is given (Figure 3).

Figure 3: The supply chain model



Source: Own construction

The chain contains three members; the manufacturer sells the products to the wholesaler, who sells the goods to the retailer. According to the market demand, the retailer satisfies the needs of the final customers. In the case of this supply chain, the bullwhip effect will be analysed.

Two cases will be discussed. In the first case, the chain members do not use any kind of management tools to increase the efficiency of their partnership and to reduce the bullwhip effect. It means that every chain member has imperfect information about market demand. In the second case, the management tools will be used by the chain members, information is available for the members. A comparative analysis is also included in the paper.

4.1 Methodology of the measurement of bullwhip effect

Uneven resource utilization is very costly for companies in the long-term. Thus, the monitoring is necessary to know how well the needs of the chain members are aligned with the real needs of customers and the needs of each member.

Relative standard deviations are used for the calculations because the analysed factors are the demand and inventory fluctuations, which are based on the mean and standard deviation. The name of the indicator is Bullwhip Ratio, derived from the quotient of the relative standard deviation of the chain member's ordered quantity and the relative standard deviation of the previous chain member's needs or ordered quantity (Chen et al. 2000).

Other values must be calculated to get the Bullwhip Ratio. Table 1 summarizes these factors.

Table 1: Notations

NAME	***SYMBOL***
mean	$\bar{x}$
standard deviation	s_x
relative standard deviation (order of chain member)	$O\left[s_x/\bar{x}\right]$
relative standard deviation (needs of final customer)	$D\left[s_x/\bar{x}\right]$
relative standard deviation (order/needs of previous chain member)	$D^{-1}\left[s_x/\bar{x}\right]$
Bullwhip Ratio – whole supply chain	BWR^0
Bullwhip Ratio – previous chain member	BWR^{-1}

Source: own construction

The paper includes two types of the Bullwhip Ratio. First, the standard one shows the bullwhip effect from the point of the whole supply chain; the benchmark will be the needs of final customer (Eq. 1). The second will show how accurately could be the matching of the direct partners' needs in terms of the ordered quantity (Eq. 2).

$$BWR^0 = \frac{O\left[s_x/\bar{x}\right]}{D\left[s_x/\bar{x}\right]} \tag{1}$$

$$BWR^{-1} = \frac{O\left[s_x/\bar{x}\right]}{D^{-1}\left[s_x/\bar{x}\right]} \tag{2}$$

Inventory policy is also necessary to define because it influences the periodicity and the quantity of the orders.

4.2 Case 1

Rational behavior is assumed, therefore chain members strive to have a certain quantity of security stock. The information flow is not perfect, because of the competitive attitudes of the members. It means that the information-sharing mechanisms are also imperfect. Thus, members try to maintain their inventory at a quarter of the current demand. So they try to keep the closing stock of the different periods at a quarter of the demand because they want to keep surplus – as a safety stock – for the next periods to satisfy any needs of the customer. The case study includes 3 periods. The initial inventories of 1st period are equal to 1.5x of the

customer‘s needs. Based on this information, Table 2 summarizes the data, which are needed to calculate the bullwhip effect.

Table 2: The results of applied inventory management in Case 1

PERIODS	CUSTOMER'S NEEDS [1000 pcs]	RETAILER			WHOLESALER			MANUFACTURER		
		Initial inventory	*Order*	*Closing stock*	*Initial inventory*	*Order*	*Closing stock*	*Initial inventory*	*Order*	*Closing stock*
1	8	12	6	10	12	3	7,5	12	2,25	3,75
2	12	10	17	15	7,5	30,75	21,25	3,75	65,44	38,44
3	18	15	25,5	22,5	21,25	36,13	31,88	38,44	42,85	45,16

Source: own construction

With the help of Table 2 the BWR and the associated values can be calculated (Table 3).

Table 3: The BWR values in Case 1

	CUSTOMER'S NEEDS	RETAILER	WHOLESALER	MANUFACTURER
$\bar{x}$	12,67	16,17	23,29	36,85
s_x	5,03	9,78	17,78	32,02
$s_x/\bar{x}$	0,40	0,60	0,76	0,87
BWR^0	-	**1,50**	**1,90**	**2,20**
BWR^{-1}	-	**1,50**	**1,30**	**1,10**

Source: own construction

According to Table 3, the bullwhip effect is ascertainable. The values of BWR^0 show a monotonically increasing trend, which means the members' orders move away from the real needs of the customer. Thus, they will have a surplus of stock. However, the values of BWR^{-1} show a tendency to decrease. It means that the needs of the members are getting closer to each other if we move from the retailer to the direction of the manufacturer. This tendency is due to the increasing quantities of the orders period by period.

4.3 Case 2

The members have perfect information about the demand and each other's needs. Information-sharing mechanisms are also realized in the chain. Members use the recommended management tools – such as demand management, strategic alliance – to make their cooperation efficient. The inventory management is based on the puffers, it is a kind of

rationalised safety stock. Puffer defends companies against the random changes of the demand but does not allow to have a big surplus in the stock. The base of the puffer is given by the standard deviation of needs. In this case, the closing stock must be 2x of the standard deviation of needs. The initial inventories of the first period – thanks to the better cooperation and communication – are the 0.25x of needs – orders – of the previous chain member.

Table 4: The results of applied inventory management in Case 1

PERIOD	CUSTOMER'S NEEDS [1000 pcs]	RETAILER			WHOLESALER			MANUFACTURER		
		Initial inventory	*Order*	*Closing stock*	*Initial inventory*	*Order*	*Closing stock*	*Initial inventory*	*Order*	*Closing stock*
1	8	10	6,86	8,86	8,58	12,24	13,96	15,3	21,18	24,24
2	12	8,86	12	8,86	13,96	12	13,96	24,24	12	24,24
3	18	8,86	18	8,86	13,96	18	13,96	24,24	18	24,24

Source: own construction

Table 5 summarizes the BWR values.

Table 5: The BWR values in Case 2

	CUSTOMER'S NEEDS	RETAILER	WHOLESALER	MANUFACTURER
$\bar{x}$	12,67	12,29	14,08	17,06
s_x	5,03	5,58	3,40	4,66
$s_x/\bar{x}$	0,40	0,45	0,24	0,27
BWR^0	-	**1,13**	**0,60**	**0,68**
BWR^{-1}	-	**1,13**	**0,53**	**1,13**

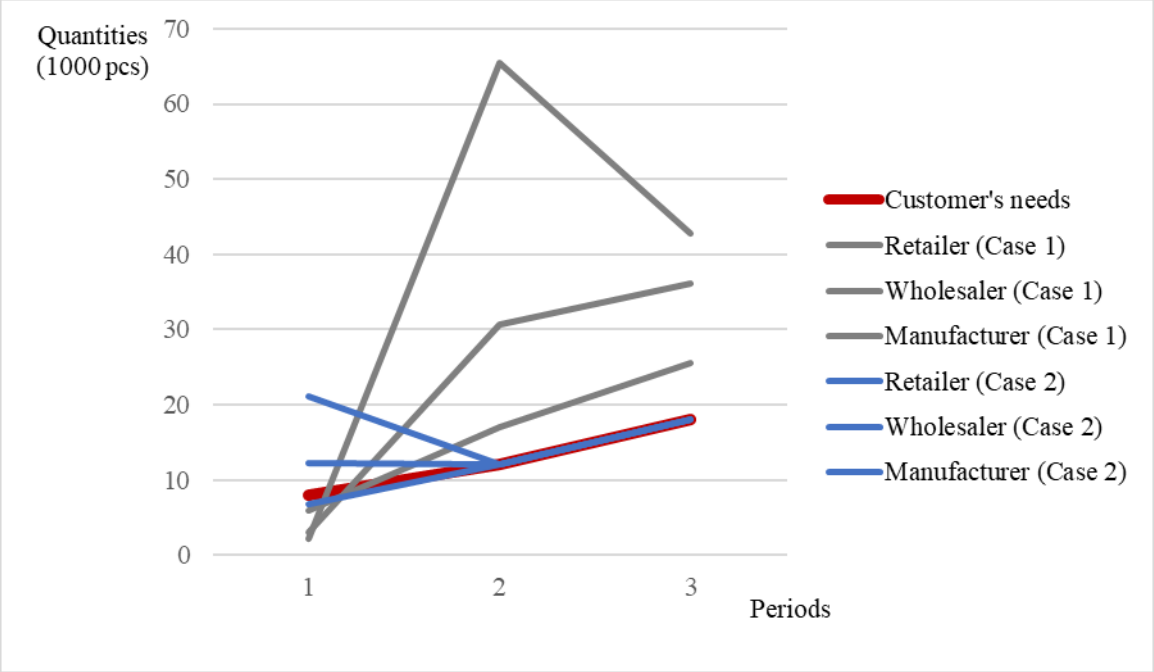
Source: own construction

The new inventory management results in the minimisation of the bullwhip effect. There are no monotonically increasing trends in the case of the BWR values, it means that the bullwhip effect could be decreased and almost eliminated from the chain. An interesting fact that the values of BWR^{-1} show large fluctuations. According to the results, wholesaler could adapt to the needs of the previous member, the retailer.

4.4 Comparison

Figure 4 shows the comparison of the two cases focused on the change of ordered quantities.

Figure 4: Comparison of the ordered quantities from the point of the different inventory management



Source: Own construction

There is a big difference between the curves. The first group, which represents the inventory management of Case 1 and marked with grey colour has big fluctuations. It means the presence of the bullwhip effect. But in the second group – with blue colour – only in the first period has some differences between the orders, from the second period the orders are normalised, and they follow the needs. Thus, there is no bullwhip effect in this case.

Figure 4 proves the assumption that the different management tools could help the companies to increase their efficiency, which begins with the selecting of the appropriate inventory policy regarding the specifics of the market, industry, the chain, or the members' attitudes. On the other hand, they could also help to decrease the bullwhip effect. If the level of cooperation allows the information-sharing, the relationship could be more effective.

5. Conclusion

The bullwhip effect is one of the most influencing factors of the efficient operation of supply chains, especially in the 21st century. It causes inventory disruptions, can increase the costs, and decrease the level of customer services. That is the reason why companies need to deal with the measurement of the bullwhip effect.

With the help of the Bullwhip Ratio, companies could monitor their orders and check how accurately pass their information about the demand with the real needs. If the ordered quantities do not meet the real needs, there will be inventory problems. The BWR points to this problem. Companies could use various kinds of management tools to improve their processes. In the era of Industry 4.0, it is needed to companies have an advanced, modern IT infrastructure. This background can be the basis of many improving management tools, such

as the CPFR or some other cloud-based relationship-managing systems. Other important things the information-flow and information-sharing. If there is a cooperative relationship – for example, a strategic alliance –, the parties prefer common goals instead of individual purposes. Thus, they will support each other with information-sharing mechanisms. It also helps the forecasting, so they could order a similar quantity to the real customer's needs.

A case study is represented how the different attitudes influence the basic operational processes. If there is wrong inventory management caused by the insufficient cooperation, many costs could be increased. But if companies or chain members have the willingness to cooperate at a higher level, better conditions and results will be realized.

Acknowledgment

This research was supported by the project no. EFOP-3.6.2-16-2017-00007, titled "Aspects on the development of intelligent, sustainable and inclusive society: social, technological, innovation networks in employment and digital economy". The project has been supported by the European Union, co-financed by the European Social Fund and the budget of Hungary.

References

Arshinder, A., K., Deshmukh, S., G. (2008): Supply chain coordination: Perspectives, empirical studies and research directions, *International Journal of Production Economics* 115, pp. 316-335.

Chen, F. & Drezner, Z. & Ryan, J. K. & Simchi-Levi, D. (2000): Quantifying the bullwhip effect in a simple supply chain: The impact of forecasting, lead times, and information. *Management Science*, Vol. 46, No. 3, pp. 436-443.

Coltman, T. & Bru, K. & Perm-Ajchariyawong, N. & Devinney, T. M. & Benito, G. R. (2009): Supply Chain Contract Evolution, *European Management Journal*, Vol. 27, Issue 6, pp. 388-401.

Costantino, F. & Di Gravio, G. & Shaban, A. & Tronci, M. (2013): Exploring the Bullwhip Effect and Inventory Stability in a Seasonal Supply Chain, *International Journal of Engineering Business Management* 5, 10.5772/56833 [Online], available: https://journals.sagepub.com/doi/epub/10.5772/56833 (downloaded: 2020. 11. 02.)

Gupta, D. & Weerawat, W. (2006): Supplier-manufacturer coordination in capacitated two-stage supply chains, *European Journal of Operational Research*, Vol. 175., Issue 1., pp. 67-89.

Hill, C. A. & Zhang, G. P. & Miller, K. E. (2018): Collaborative planning, forecasting, and replenishment & firm performance: An empirical evaluation, *International Journal of Production Economics*, Vol. 196, pp. 12-23.

Kaipia, R (2007): Supply Chain Coordination – Studies on planning and information sharing mechanisms, *Helsinki University of Technology Laboratory of Industrial Management Doctoral dissertation series* 2007 / 2, Espoo

Katok, E. & Pavlov, V. (2013): Fairness In Supply Chain contracts: A laboratory study, *Journal Of Operations Management*, Volume 31, Issue 3, pp. 129-137

Mentzer, J., T. & DeWitt, W. & Keebler, J., S. & Min, S. & Nix, N., W. & Smith, C., D. & Zacharia, Z. G. (2001): Defining Supply Chain Management, *Journal of Business Logistics*, Vol. 22., No. 2., pp. 1-25.

Nagy, J. & Bódi-Schubert, A. (2014): Keresletmenedzsment (Demand-management), In: Termelés, szolgáltatás, logisztika – Az értékteremtés folyamatai (szerk.: Demeter Krisztina), Complex, Budapest

Szegedi, Z. (2017): *Ellátásilánc-menedzsment*, (Supply chain management) Kossuth Kiadó, HU, Budapest