LogForum
> Scientific Journal of Logistics <
2018, 14 (2), 163-170
http://dx.doi.org/10.17270/J.LOG.2018.280
http://www.logforum.net p-ISSN 1895-2038 e-ISSN 1734-459X
ORIGINAL PAPER

THE ISSUE OF BULLWHIP-EFFECT EVALUATING IN SUPPLY CHAIN MANAGEMENT

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ABSTRACT. **Background**: This article deals with the quantitative evaluation of the bullwhip effect in supply chains. A literature review was carried out and it was revealed that there is no general approach to quantifying the bullwhip effect. In the article, a more precise concept of the bullwhip effect is proposed from the point of view of the natural-scientific approach.

Methods: A methodology for quantifying the bullwhip effect as a coefficient of linear regression was developed, characterising the dependence on the location of a link in supply chains, which can be used to adjust its operational work.

Results: The stability of the proposed model is confirmed by the results of its implementation in production in several sectors of the economy, distinguished by the number of units and number of study periods, which demonstrates its potential for use in the distribution system.

Conclusions: The main reason for the existence of the bullwhip effect is the unreliability of forecasts, which ultimately reduces the efficiency of inventory planning in supply chains and extensive logistics systems. Reducing the negative impact of the bullwhip effect can be achieved by using more advanced forecasting models and the quantitative assessment method used in this study, to adjust reserve stocks in supply chain links.

Key words: supply chain, uncertainty, bullwhip-effect, variation in order sizes, regression coefficient, t-statistics, order size dynamics.

INTRODUCTION

Supply chains are becoming more and more dynamic in a globalised society. Supply chain parameters are constantly changing, increasing uncertainty and the effect known as the "bullwhip effect".

The bullwhip effect is a phenomenon caused by high fluctuations in demand in various links of a logistics chain, and the more precisely it is determined, the more efficient the supply chain becomes.

In past research [Kot, Grondys, Szopa 2011], authors have noted that effective supply chain management consists of striving to minimize costs associated with connections between links. Therefore, cooperation between links is essential. Other authors [Kolinski, Sliwczynski 2015, Zhuravskaya 2017] proposed a method for evaluating the efficiency of the supply chain and options for improving it. However, researchers [Mesjasz-Lech 2014] have warned that the importance of small companies in the supply chain will grow because of their large share of the total number of companies (almost 80%). This situation, of course, will not help to reduce uncertainty in the supply chain and, therefore, the task of assessing the bullwhip effect will become more complicated. Various researchers [Wang, Disney 2016, Martynenko, Zhuravskaya, Qiao Cong 2016, Fredendall, Hill 2016; Lai, Ngai, Cheng 2002, Vokhmyanina, Zhuravskaya,

Citation: *Vokhmyanina A., Zhuravskaya M., Osmólski W., 2018. The issue of bullwhip-effect evaluating in supply chain management. LogForum 14 (2), 163-170, http://dx.doi.org/10.17270/J.LOG.2018.280*
Received: 09.01.2018, Accepted: 16.03.2018, on-line: 29.03.2018.

Qiao Cong 2015] have given an analysis of the causes and extent of the negative influence of the bullwhip effect on key indicators of the efficiency of supply chains, and approaches to eliminating or reducing its impact. The assessment of the uncertainty of the external market environment in which distribution logistics systems or supply chains function is still an important aspect of supply chain management [Wee, Blos, Yang 2012, Sirikasemsuk, Luong 2017, Madera 2014, Saaty 2013, Taha 2012].

There is no universal method for the quantitative assessment of the bullwhip effect, which would allow the volume and time indices of interaction of links to be coordinated and thereby reduce the negative consequences of uncertainty [Christopher 2016].

In quantitative assessment of the bullwhip effect, there is no general approach to the definition of variation. The bullwhip effect is determined on the basis of the variation expressed in natural units of material flow by the formula:

$$\text{Bullwhip effect} = \frac{\sigma^2_{ORATE} / \mu_{ORATE}}{\sigma^2_{CONS} / \mu_{CONS}}$$

where

- σ2 is the dispersion of orders placed to a supplier for a certain period (ORATE), and sales of the buyer for the same period (CONS);
- μ is the average value of orders placed by a buyer to a supplier for a certain period (ORATE), and the buyer's sales for the same period (CONS).

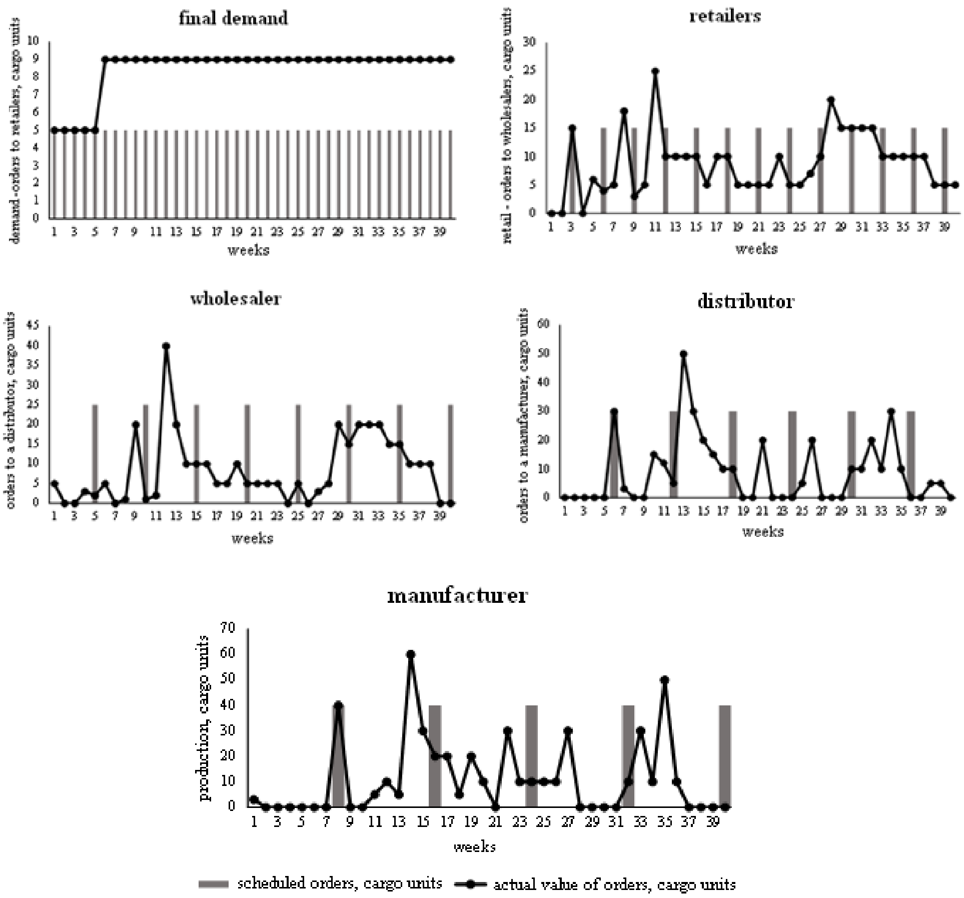

Fig. 1. Dynamics of the size of orders in the supply chain, cargo units

The main problem of attempts to quantify the bullwhip effect in the sources considered is the locality of the result obtained: the bullwhip effect is calculated for two adjacent links, which does not allow the scale of its influence on the remaining links in the supply chain to be assessed.

Thus, the term bullwhip effect can be formulated as follows:bullwhip effect - the pattern of change - increase - the variation in the size of orders through the supply chain, depending on the location of the link in relation to the link in which there were failures and deviations between the actual values of the sizes of orders and what was planned or expected.If it is defined in this way, a quantitative estimate of the bullwhip effect can be expressed as the regression coefficient of the variations in demand ordered in accordance with the location of the link in the supply chain.

In this case, a pattern can be measured by revealing the dependencies of cause-effect relationships, while the main factor determining the magnitude of fluctuations in the size of orders is the location of the link in the supply chain.For example, let us consider the algorithm for determining the magnitude of the bullwhip effect in supply chains for data on the sale of a food company's products, for which we analyse the fluctuations in the actual size of the order relative to the planned level (Figure 1).

The graph shows that in the "final demand" link, which determines the effective demand of customers, an increase in the order size from 5 to 9 cargo units is observed at week 6. This leads to a change in the size of orders in all subsequent links.

Based on the observations obtained (Figure 1), a general graph of the dynamics of the size of orders in the supply chain has been constructed (Figure 2).

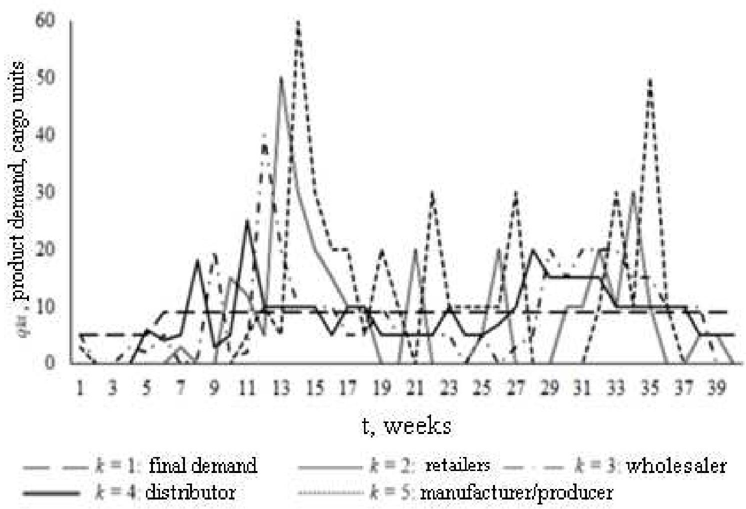

Fig. 2. Dynamics of orders sizes in the supply chain of food products, cargo units

In [Ivanov 2009; Volkova 2015], to determine the bullwhip effect, the absolute value of the order size measured in cargo units is used:

$$V_{\text{abs}} = \frac{\sigma_{qk}^{2}}{\bar{q}_{kt}} \qquad (1)$$

Let's also calculate the relative variation

$$V_{\text{rel}} = \frac{\sigma_{qk}}{\bar{q}_{kt}} \qquad (1a)$$

where $k = \overline{1, K}$ is the ordinal number of the supply chain link that places orders to the supply chain, starting with demand, K is the number of links in the supply chain;

$t = \overline{1,T}$ is the sequence number of the period, T - the full interval of the periods under study;

$\overline{q}_k$ – is the average value of the order placed by the ordering link to the delivering link for a certain period, cargo units;

$$\overline{q}_k = \frac{\sum_{t=1}^{T} q_{kt}}{T} \qquad (2)$$

σ_{qk}^2 – variance of the order quantity:

$$\sigma_{qk}^2 = \frac{\sum_{t=1}^{T} (\overline{q}_k - q_{kt})^2}{T} \qquad (3)$$

Table 1 shows the results of intermediate calculations characterizing the variation in the size of orders for the supply chain.

Table 1. Indicators of variation in order sizes in the supply chain links

Supply chain link number	Number of orders placed by the link	Average order value in the link, *cargo units.*	Dispersion	Absolute variation, *cargo units.*	Standard deviation, *cargo units.*	Relative variation, *coefficient.*
k	n	$\overline{q}_k$	σ_{qk}^2	V_{abs}	σ_{qk}	V_{rel}
1	40	8,50	1,75	0,206	1,323	0,156
2	36	9,25	24,41	2,619	4,941	0,534
3	33	10,21	67,02	6,562	8,186	0,802
4	21	15,00	118,00	7,867	10,863	0,724
5	22	18,10	227,78	12,590	15,092	0,834

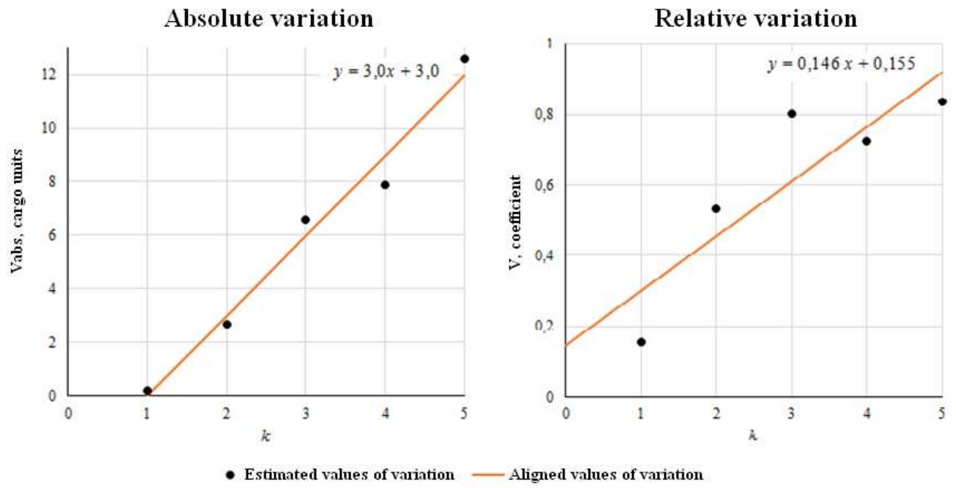

Fig. 1. Correlation field for the dependence of variation on the location of the link of the supply chain

Figure 3 shows the correlation field, which illustrates the dependence of the magnitude of the absolute variation on the location of the link of the supply chain.

The analysis of Fig. 3 leads to the assumption of the linear nature of the dependence, hence the quantitative estimate of the "bullwhip effect" can be represented as the value of the linear regression coefficient. Let's define the parameters of the regression equation for changing the absolute variation for the data under consideration.

$$a_0 = \frac{\sum_{k=1}^{K} V_{abs} \sum_{k=1}^{K} k^2 - \sum_{k=1}^{K} V_{abs} k \sum_{k=1}^{K} k}{K \sum_{k=1}^{K} k^2 - \left(\sum_{k=1}^{K} k \right)^2}; \quad (4)$$

$$a_1 = \frac{K \sum_{k=1}^{K} V_{abs} k - \sum_{k=1}^{K} V_{abs} \sum_{k=1}^{K} k}{K \sum_{k=1}^{K} k^2 - \left(\sum_{k=1}^{K} k \right)^2} \quad (5)$$

Interim calculations necessary to determine the parameters of the regression equation are presented in Table 2.

$$a_0 = \frac{29{,}9 \cdot 55 - 119{,}6 \cdot 15}{5 \cdot 55 - 15^2} = -3{,}026$$

$$a_1 = \frac{5 \cdot 119{,}6 - 15 \cdot 29{,}9}{5 \cdot 55 - 15^2} = 2{,}996$$

Thus, the change in the absolute variation of demand in the supply chain links can be represented as a linear relationship; an increase of an average of 3 cargo units per link:

$$V_{abs}(k) = 2{,}996 \cdot k - 3{,}026$$

Table 2. Interim calculations

k	V_{abs}	$k \cdot V_{abs}$	k^2	V_{abs}^2	$V_{abs}(k)$	$(V_{abs}(k) - V_{abs})^2$	$(k-\bar{k})^2$	$(V_k - \bar{V})^2$
1	0,206	0,206	1	0,042	-0,026	0,054	4	33,256
2	2,639	5,278	4	6,964	2,973	0,112	1	11,114
3	6,562	19,686	9	43,060	5,973	0,347	0	0,347
4	7,867	31,468	16	61,890	8,972	1,222	1	3,588
5	12,590	62,950	25	158,508	11,972	0,382	4	43,787
∑=15	**29,864**	**119,588**	**55**	**270,464**	**29,864**	**2,117**	**10**	**92,093**

The relationship between the indices that characterize the bullwhip effect is direct and very close, which is confirmed by the calculation of the linear correlation coefficient (r):

$$r = \frac{\sum_{k=1}^{K} (k \cdot V_{abs}) - \frac{\sum_{k=1}^{K} k \sum_{k=1}^{K} V_{abs}}{K}}{\sqrt{\left(\sum_{k=1}^{K} k^2 - \frac{\left(\sum_{k=1}^{K} k \right)^2}{K} \right) \cdot \left(\sum_{k=1}^{K} V_{abs}^2 - \frac{\left(\sum_{k=1}^{K} V_{abs} \right)^2}{K} \right)}} \quad (6)$$

$$r = \frac{119{,}6 - \frac{15 \cdot 29{,}9}{5}}{\sqrt{\left(55 - \frac{15^2}{5} \right) \cdot \left(270{,}5 - \frac{29{,}9^2}{5} \right)}} = 0{,}988$$

The obtained parameters were checked using t-statistics. The results of the analysis are given in Table 3.

Table 3. Parameters of regression equations for absolute and relative variations in order sizes in the supply chain

Index	Absolute variation	Relative variation
a_1 – bullwhip effect	2,996	0,146
a_0	–3,026	0,155
r	0,988	0,876
σ_ε	0,650	0,121
σ_k	1,414	1,414
σ_V	4,29	0,25
t_{crit}	$t_{crit}(3;0{,}005)$= 5,841	$t_{crit}(3;0{,}07)$= 1,995
t_{a1}	19,6	2,090
t_{a0}	6,5 > 5,841	3,136
t_r	27,3	3,136
t_{a1}	27,8	3,136

The critical value of Student's t-test is less than calculated ones, and it means that the obtained parameters characterizing the relationship between the magnitude of the variation and the location of the link in the supply chain are recognized as significant.

All calculated values of the t-criteria are greater than the critical value (than tabular value: The values of the parameters of the regression equation for the relative variation in order sizes can be considered typical at the significance level). Thus, the relative variation in the links of the supply chain increases by an average of 15.5%.

To test the method for stability, the proposed procedure for quantifying the "bullwhip effect" was used for other types of goods. The "bullwhip effect" for various companies and industries based on statistical information is analyzed in [Disney, Towill 2003; Ivanov 2009; Baltagi 2011]. Analysis showed its negative impact on the efficiency of supply chains.

The obtained parameters a1, describing the required regularity between the location of the link of the supply chain and the intensity of the fluctuations of orders in it, can be treated as the "bullwhip effect" and used to adjust the size of orders by the amount a1(k – 1) if the size of the change in the very first link is known. Also, the obtained value of the "bullwhip effect" can be taken into account when planning reserve stocks at supplying units.

CONCLUSIONS

It is clear, that using the proposed method of determining the "bullwhip effect" based on the correlation-regression analysis will not completely eliminate the fluctuations in the size of orders, but will significantly reduce them, and therefore reduce the unproductive expenditure of resources associated with environmental uncertainty and market risks.

The main reason for the appearance of the "bullwhip effect", according to most researchers in this area, is the lack of reliability of forecasts [Wang, Disney 2016, Holmstrom 1997, Lee et al. 1997, Kumar and Haleem 2016, Vokhmyanina 2017], which ultimately reduces the efficiency of inventory planning in supply chains and extensive logistic systems. Reducing the negative impact of the "bullwhip effect" can be achieved by using more advanced forecasting models [Dooley, et al. 2010, Vokhmyanina, Zhuravskaya and Qiao 2015] and the quantitative assessment method used in this study to adjust reserve stocks in the supply chain links.

ACKNOWLEDGEMENTS

The work was carried out with the partial financial support of the Russian Foundation for Basic Research, project No. 16-06-00464.

REFERENCES

Baltagi B.H., 2011. Econometrics, Springer Science & Business Media.

Christopher M., 2016. Logistics & supply chain management. Pearson UK.

Disney S.M., Towill D.R., 2003. The effect of vendor managed inventory (VMI) dynamics of bullwhip effect in supply chains. International Journal of Production Economics 85 (2), 199-215, http://dx.doi.org/10.1016/S0925-5273(03)00110-5

Dooley K.J., Yan T., Mohan S., Gopalakrishnan M., 2010. Inventory management and the bullwhip effect during the 2007–2009 recession: evidence from the manufacturing sector. Journal of Supply Chain Management 46 (1), 12-18, http://dx.doi.org/10.1111/j.1745-493X.2009.03183.x

Fredendall L. D., Hill E., 2016. Basics of supply chain management. CRC Press.

Holmstrom J., 1997. Product range management: a case study of supply chain operations in the European grocery industry. Supply Chain Management 2 (3), 107-115, http://dx.doi.org/10.1108/13598549710178291.

Ivanov D.A., 2009. Supply chain management. Publishing House of St. Petersburg State University.

Kolinski A., Sliwczynski B., 2015. Evaluation problem and assessment method of warehouse process efficiency. Business Logistics in Modern Management, 175-188.

Kot S., Grondys K., Szopa R., 2011. Theory of inventory management based on demand Forecasting. Polish Journal of Management Studies 3, 148-156.

Kumar S., Haleem A., 2016, . Benchmarking using an index for bullwhip effect mitigation. Uncertain Supply Chain Management 4, 161-170, http://dx.doi.org/10.5267/j.uscm.2015.10.002

Lai K.H., Ngai E. W.T., Cheng T.C.E., 2002. Measures for evaluating supply chain performance in transport logistics. Transportation Research Part E: Logistics and Transportation Review 38 (6), 439-456, http://dx.doi.org/10.1016/S1366-5545(02)00019-4.

Lee H.L., Padmanabhan P., Wang S., 1997. The bullwhip effect in supply chains. Sloan Management Review 38 (3), 93-102.

Madera A.G., 2014. Risks and chances: uncertainty, forecasting and evaluation. Krasand, Moscow.

Martynenko A.V., Zhuravskaya M.A., Qiao C., 2016. Assessment of cargo transportation time in logistics supply chain. Herald of the Ural State University of Railway Transport 3, 73-81.

Mesjasz-Lech A., 2014. The use of it systems supporting the realization of business processes in enterprises and supply chains in Poland. Polish Journal of Management Studies 10 (2), 94-103.

Saaty T.L., 2013. Decision making with dependence and feedback: The Analytic Network Process. Springer, New York.

Sirikasemsuk K., Luong H. T., 2017. Measure of bullwhip effect in supply chains with first-order bivariate vector autoregression time-series demand model. Computers & Operations Research 78, 59-79, http://dx.doi.org/10.1016/j.cor.2016.08.005.

Taha H.A., 2012. Operations research: an introduction. Pearson Education Inc, New Jersey.

Vokhmyanina A.V., 2017. Forecasting logistic indicators in conditions of annual irregularity. Transport: Science, Technology, Management 5, 13-20.

Vokhmyanina A.V., Zhuravskaya M.A., Qiao C., 2015. The Analysis of Bullwhip «Effect Influence» on the Level Service in the Supply Chain Management. Transport: Science, Technology, Management 9, 38-45.

Volkova S.A., 2015. Logistics of transportation in supply chains. Integrated Logistics 6, 8-10.

Wang X., Disney S. M., 2016. The bullwhip effect: Progress, trends and directions. European Journal of Operational Research, 250(3), 691-701, http://dx.doi.org/10.1016/j.ejor.2015.07.022

Wee H.M., Blos M.F., Yang W.H., 2012. Risk management in logistics. In Handbook on Decision Making. Springer, Berlin-Heidelberg, 285-305, http://dx.doi.org/10.1007/978-3-642-25755-1_15.

Zhuravskaya M.A. (2017) Green Logistics as the Basis for Improving Environmental Efficiency of Transport. In: Golinska-Dawson P., Kolinski A. (eds) Efficiency in Sustainable Supply Chain. EcoProduction. Springer, Cham, 99-115, http://dx.doi.org/10.1007/978-3-319-46451-0_7.

OCENA EFEKTU BYCZEGO BICZA W ZARZĄDZANIU ŁAŃCUCHEM DOSTAW

STRESZCZENIE. Wstęp: W pracy zostały postawione pytania dotyczące przeprowadzania oceny ilościowe efektu byczego bicza występującego w obrębie łańcucha dostaw. Wykonano przeglądu literatury, na podstawie którego stwierdzono, że nie ma jednorodnego podejścia do ujęcia ilościowego efektu byczego bicza. W związku z tym, zaproponowano bardziej precyzyjne podejście do tego efektu.

Metody: W celu oceny ilościowej efektu byczego bicza stworzono metodę współczynnika regresji liniowej, charakteryzującą się zależnością między lokalizacjami ogniw w łańcuchu dostaw i która może być użyta do poprawy jego działania operacyjnego.
Wyniki: Stabilność proponowanych modeli jest potwierdzona w postaci wyników ich wdrożenia do produkcji w różnych obszarach gospodarczych, różniących się liczbą jednostek oraz liczbą okresów poddanych badaniu, które dowodzą możliwości ich użycia w praktycznych działaniach firmy w obrębie systemu dystrybucyjnego.
Wnioski: Głównym powodem występowania efektu byczego bicza jest brak trafności estymacji, która to wpływa na obniżenie efektywności zarządzania zapasem w obrębie łańcucha dostaw oraz dużych systemów logistycznych. Redukcję negatywnego wpływu efektu byczego bicza można osiągnąć przez zastosowanie bardziej zaawansowanych metod prognostycznych oraz metody oceny ilościowej, użytej w tej pracy w celu bardziej optymalnego zarządzania zapasami w obrębie łańcucha dostaw.

Słowa kluczowe: łańcuch dostaw, niepewność, efekt byczego bicza, zmiany wielkości zamówienia, współczynnik regresji, statystyka t, dynamiczna wielkość partii

DIE BEWERTUNG DES BULLWHIP-EFFEKTS IM MANAGEMENT DER LIEFERKETTE

ZUSAMMENFASSUNG. Einleitung: Im Rahmen der vorliegenden Arbeit wurden Fragen bezüglich der Durchführung einer quantitativen Bewertung des innerhalb der Lieferkette auftretenden Bullwhip-Effektes gestellt. Es wurde einleitend eine Literaturübersicht vorgenommen. Auf deren Grundlage stellte man fest, dass es keine universelle Vorgehensweise bei der quantitativen Bewertung des Bullwhip-Effektes besteht. Im Zusammenhang damit schlug man eine mehr präzise Behandlung dieses Effektes vor.
Methoden: Zwecks der quantitativen Bewertung des Bullwhip-Effektes erstellte man eine Methode des Koeffizienten einer linearen Regression, die sich durch eine Abhängigkeit zwischen den einzelnen Lokalisierungsgliedern in der Lieferkette charakterisiert und zur Verbesserung der operativen Handlung angewendet werden kann.
Ergebnisse: Die Stabilität der vorgeschlagenen Modelle ist bestätigt in Form von Resultaten deren Einführung innerhalb der Fertigungsaktivitäten unterschiedlicher Wirtschaftsbereiche. Die Resultate unterscheiden sich durch die Anzahl von Einheiten und der erforschten Zeitperioden und daher weisen auf die Möglichkeit deren Inanspruchnahme in praktischen Handlungen einer Firma innerhalb ihres Distributionssystems hin.
Fazit: Die grundlegende Ursache für das Auftreten des Peitscheneffektes ist der Mangel an Treffsicherheit der betreffenden Schätzung, was die Herabsetzung der Effizienz des Bestandsmanagements innerhalb der Lieferkette und größerer Logistiksysteme mit beeinflusst. Eine Minimalisierung des negativen Einflusses des Bullwhip-Effektes kann mittels der Anwendung von mehr fortgeschrittenen Prognostizierungsmethoden und der Methode zur quantitativen Bewertung, die in dieser Arbeit zwecks eines optimierten Bestandsmanagements innerhalb der Lieferkette in Anspruch genommen worden ist, erzielt werden.

Codewörter: Lieferkette, Unsicherheit, Bullwhip-Effekt, Veränderungen von Bestellungsgrößen, Koeffizient der Regression, Statistik, dynamische Losgröße

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