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, ...] have noted that effective supply chain management consists of striving to
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:

\[
\text{Bullwhip effect} = \frac{\sigma_{\text{RATE}}}{\mu_{\text{CONS}}} / \frac{\sigma_{\text{CONS}}}{\mu_{\text{CONS}}}
\]

where

- \( \sigma_{\text{RATE}} \) is the dispersion of orders placed to a supplier for a certain period (ORATE), and sales of the buyer for the same period (CONS);
- \( \mu \) 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](image)

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

$$V_{abs} = \frac{\sigma_{qk}^2}{\bar{q}_k}$$  \hspace{1cm} (1)

Let’s also calculate the relative variation

$$V_{rel} = \frac{\sigma_{qk}}{\bar{q}_k}$$  \hspace{1cm} (1a)

where $k = 1, K$ 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:

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

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

\[
\bar{q}_k = \frac{\sum_{t=1}^{T} q_{kt}}{T} \quad (2)
\]

\[\sigma_{qk}^2 \text{ – variance of the order quantity:}
\]

\[
\sigma_{qk}^2 = \frac{\sum_{t=1}^{T} (\bar{q}_k - q_{kt})^2}{T} \quad (3)
\]

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

<table>
<thead>
<tr>
<th>Supply chain link number</th>
<th>Number of orders placed by the link</th>
<th>Average order value in the link, cargo units.</th>
<th>Dispersion</th>
<th>Absolute variation, cargo units</th>
<th>Standard deviation, cargo units</th>
<th>Relative variation, coefficient.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40</td>
<td>8.50</td>
<td>1.75</td>
<td>0.206</td>
<td>1.323</td>
<td>0.156</td>
</tr>
<tr>
<td>2</td>
<td>36</td>
<td>9.25</td>
<td>24.41</td>
<td>2.619</td>
<td>4.941</td>
<td>0.534</td>
</tr>
<tr>
<td>3</td>
<td>33</td>
<td>10.21</td>
<td>67.02</td>
<td>6.562</td>
<td>8.186</td>
<td>0.802</td>
</tr>
<tr>
<td>4</td>
<td>21</td>
<td>15.00</td>
<td>118.00</td>
<td>7.867</td>
<td>10.863</td>
<td>0.724</td>
</tr>
<tr>
<td>5</td>
<td>22</td>
<td>18.10</td>
<td>227.78</td>
<td>12.590</td>
<td>15.092</td>
<td>0.834</td>
</tr>
</tbody>
</table>

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.
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):

$$
\rho = \frac{\sum_{k=1}^{K} (k \cdot V_{abs}) - \frac{\sum_{k=1}^{K} V_{abs}}{K} \cdot \sum_{k=1}^{K} k}{\left(\sum_{k=1}^{K} k^2 - \frac{\sum_{k=1}^{K} k}{K}\right)^{1/2} \left(\sum_{k=1}^{K} V_{abs}^2 - \frac{\sum_{k=1}^{K} V_{abs}}{K} \cdot \sum_{k=1}^{K} V_{abs}^2 \right)^{1/2}}
$$

(6)

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:

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

The obtained parameters were checked using t-statistics. The results of the analysis are given in Table 3.
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 $a_1$, 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 $a_1(k - 1)$ 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.

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REFERENCES


OCENA EFEKTU BYCZEGO BICZA W ZARZĄDZANIU ŁAŃCUCHEM DOSTAW

STRESZCZENIE. Wstęp: W pracy zostały postawione pytania dotyczące przeprowadzania oceny ilościowej efektu byczego bicza występującego w obrębie łańcucha dostaw. Wykonano przegląd 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 liczącą 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