

A formulation for measuring the bullwhip effect within spreadsheets

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Abstract The bullwhip effect refers to the scenario in which orders to the supplier tend to present larger fluctuations than sales to the buyer, and the resulting distortion increasingly amplifies upstream in a supply chain. We propose a transformation of the known formulation by Chen et al. (2000) to calculate the bullwhip effect in a supply chain with the aim of being easily applied through spreadsheets without using VBA macros. We present this formulation modelled with Ms Excel© by using a numerical example.

Keywords: Bullwhip effect, measuring, spreadsheet.

1.1 Introduction

An integrated supply chain includes the purchasing of raw materials, the manufacturing with assembly or sometimes also disassembly, and the distribution and repackaging of produced goods sent to the end customers. Various operating stages in the logistic chain (nodes of the chain) can be represented by a simple model of some material-transformations or location-changes processing cells and arcs. In each processing cell, a value is added and some costs are incurred. At each processing cell there is a supply and a demand and often both are stochastic by nature. Inventories are insurance against the risk of shortage of goods in each cell of a logistic chain. They are limited by the given capacity of each processing node and also by the transportation capability of input and output flows.

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Bullwhip effect is a well-known phenomenon intensively studied already from the middle of the 20th century, known previously under the name of demand amplification or the Forrester effect (Forrester, 1961). It is often considered for the reduction of uncertainty in demand and because of a lead time stochastic behavior.

The Forrester effect is also encompassed in Sterman's bounded rationality (Sterman, 1989). Such an approach is particularly welcome when mathematical tools are not well developed or they are not well understood yet.

Most of the research works on the demand amplification have been focused on demonstrating its existence, identifying its possible causes, and developing methods for mitigating the negative effect of it. Lee et al. (1997a) identified four main causes of the bullwhip effect: wrong methods of demand forecasting, supply shortage anticipation, batch ordering and price variation. Demand amplification occurs mostly because of finite perturbations in final demand and in lead time all along the supply chain, which is always anticipated and in interaction with other causes. How the industry faces this phenomenon is broadly studied by Lee et al. (1997b), where some considerations of the bullwhip effect in supply chains are presented in detail. For an extension of the bullwhip effect concept in a supply chain, we refer readers to Campuzano and Mula (2011).

The main contribution of this paper is the proposal of a transformation of the formula by Chen et al. (2000) in order to measure the bullwhip effect in supply chains, with the aim of using easily it within spreadsheets and without developing VBA macros.

The rest of the paper is organized as follows. Section 1.2 reviews the main alternatives to measure the bullwhip effect. Section 1.3 proposes a transformation of the formulation by Chen et al. (2000) to measure the bullwhip effect. Section 1.4 presents the application of our proposal to spreadsheets through a numerical example. Finally, Section 1.5 provides the conclusions and further research.

1.2 Measuring the Bullwhip Effect

As mentioned above, bullwhip effect refers to the scenario where the orders to the supplier tend to have larger fluctuations than sales to the buyer and the distortion propagates up a supply chain in an amplified form. As distortion creates additional costs, the indicators of bullwhip are supposed to be in contingency with the costs or added value.

Ordering goods (input flow) in distribution centers can be studied as a multi-period dynamic problem. The demand during each period can be considered as a stochastic variable. The distribution of this variable is often described with a certain probability function. It is identically distributed in our proposal, which is based on the production and inventory control results, especially on the variability trade off study, presented by Dejonckheere et al. (2003), and the study of the impact of information enrichment on the bullwhip effect in supply chains (Dejonckheere et al. 2004), where some measures have been introduced.

The amplification upstream the supply chain can be measured through the variance of demand along the supply chain. Lee et al. (1997b) propose the changes of

the variance in demand σ^2 upstream as the measure of the bullwhip effect. It is a good measure only when the units of flow are not changing along the chain, which is not the case in many logistics problems. Chen et al. (2000) suggest that to avoid this problem the bullwhip effect should be measured by changing the ratio of σ^2/μ upstream of the supply chain, where μ is the expected value of the intensity of flows, but again it does not help to avoid the effect of changing the unit of measure. Chen et al. (2000) suggest that a measure of the bullwhip effect could be the ratio of these parameters between input and output flows at each activity cell in a supply chain upstream, when only one stage is considered, or the ratio of these parameters between final demand and first stage of manufacturing when total supply chain, having more stages, is to be evaluated.

$$Bullwhip = \frac{\sigma_o^2 / \mu_o}{\sigma_d^2 / \mu_d} = \frac{\sigma_o^2}{\sigma_d^2} \quad (1.1)$$

Unfortunately, σ^2/μ is not a measureless ratio and, therefore, it is difficult to understand the ratio of these measures between input and output flows, especially where assemblies and disassemblies are changing the unit of measure of μ between the input and output, and when we wish to compare this phenomenon in different supply chains. Therefore, we assume in this paper that the unit of measure is not changing in our supply chain.

In statistical analysis, the actual variation described by the variance or standard deviation is often replaced by the measure of the relative dispersion. If the absolute dispersion is measured by the standard deviation σ as the root mean square of the deviation from the mean, and if the average is the mean intensity of supply chain flows μ , then the relative dispersion usually used in basic statistics is the coefficient of variation $V = \sigma/\mu$ and the estimation is generally expressed as a percentage, which would also be a good indicator here. But following the approaches of previous authors we keep the bullwhip measure as suggested by Chen et al. (2000) and we shall not change the units upstream of flows.

1.3. Formulation Proposal

We propose the following transformation of the formula (1.1), provided by Chen et al. (2000) to measure the bullwhip effect, with the aim of easily using it within spreadsheets.

In order to compute the measure proposed by Chen et al. (2000) and considering the importance of calculating performance measures to the supply chain behavior, we build a spreadsheet based in their measure.

The calculus of the bullwhip effect is based in the variance of both variables: sales and orders. As the bullwhip effect is an amplification of orders in the supply chain as consequence of unshared information in all levels of the supply chain, we analyze these variables as it follows.

First, the calculus of the variance of sales is done with the spreadsheet variance formula because it must be calculated by using all dates available, i.e. the dates associated to each period, from zero to the t period.

Moreover, the variance associated to the variable of orders must be calculated only to each period which presents some difference between sales and orders, with the assumption that it depends only on the current period (periods where the difference between orders and sales is different to zero), it can be interpreted as follows: the vector of orders to the period n is a vector of n elements which the first $n-1$ elements are equal to zero and the n -th term is the value of orders to the t period. As a consequence of this assumption, the calculus of the variance of orders is based in the general formula of the variance that is shown in the equation (1.2.). This formula considers $n-1$ elements, because it is a sample variance, generally for a limited number of data.

$$Var(x) = \frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1} \quad (1.2)$$

Because of the assumption that the vector of orders is composed by $n-1$ terms which are equal to zero, the variance calculus implies a sum of t terms that has $n-1$ identical terms and one term is associated to the n -th period. As a consequence of the structure of the vector of orders we can express the variance formula as it is shown in the equations (1.3) and (1.4).

$$Var(x) = \frac{\left(\sum_{i=1}^{n-1} (x_i - \bar{x})^2 \right) + (x_n - \bar{x})^2}{n-1} \quad (1.3)$$

$$Var(x) = \frac{(n-1)\left(-\bar{x}\right)^2 + (x_n - \bar{x})^2}{n-1} \quad (1.4)$$

According to the assumption with respect to the vector of orders, the mean of orders can be calculated as the orders in n periods divided by n . As a result of the replacement of the mean of orders in the equation (1.4), we can express the formula of the variance of orders as follows:

$$Var(x) = \frac{(n-1)\left(-\frac{x_n}{n}\right)^2 + \left(x_n - \frac{x_n}{n}\right)^2}{n-1} \quad (1.5)$$

The expression that is shown in the equation (1.5) can be easily implemented in a spreadsheet because it only depends of the data quantity (n) and the last information of orders.

Then, we implement the expression of the bullwhip effect measure (BEM) to the t period, BEM_t , as a cumulative expression of the effect of individual period distortions, by using a conditional expression presented in the equation (1.6).

$$BEM_t = \begin{cases} BEM_{t-1} & \text{if } orders_t - sales_t = 0 \\ BEM_{t-1} + \frac{Var(Orders)}{Var(Sales)} & \text{in other wise} \end{cases} \quad (1.6)$$

Note that the BEM can be calculated as a cumulative value to each period. Formulas in equations (1.5) and (1.6) were implemented by using a numerical example in order to evaluate their performance. In the next section, we present a numerical example and the spreadsheets used to calculate the bullwhip effect.

1.4 Numerical example within spreadsheets

The example presented in the Fig. 1.1 shows the BEM, which was calculated by using the expressions presented in the equations (1.5) and (1.6). The demands were generated by a discrete uniform distribution between x and y , i.e. they are identically distributed.

t	Sales	Orders	Receptions	Differences	Orders Variances	Sales Variances	BEM
0	0	0,00	0,00	0,00			0,00000
1	1	1,60	0,00	0,60	1,28000	0,50000	2,56000
2	1	1,48	0,00	0,48	0,73013	0,33333	4,75040
3	2	2,98	1,60	0,98	2,22606	0,66667	8,08950
4	2	2,79	1,48	0,79	1,55370	0,70000	10,30906
5	1	1,03	2,98	0,03	0,17673	0,56667	10,62095
6	2	4,37	2,79	2,37	2,72693	0,57143	15,39307
7	1	0,25	1,03	-0,75	0,00781	0,50000	15,40870
8	1	0,25	4,37	-0,75	0,00694	0,44444	15,42432
9	2	2,75	0,25	0,75	0,75625	0,45556	17,08439
10	1	0,25	0,25	-0,75	0,00568	0,41818	17,09797

Fig. 1.1 Spreadsheet implementation of the BEM formula.

The spreadsheet formulation used to calculate the BEM should be carried out as detailed below.

Differences formula in Cell N8

=L8-B8

Variance orders formula in Cell O8

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=(IF(N8>0;(A8)*POWER(L8/(A8+1);2)+POWER(L8-(L8/(A8+1));2);0))/A8
Variance sales formula in Cell P8
=VAR(B$7:B8)
Bullwhip Effect Measure formula in Cell Q8
=Q7+IF(N8=0;0;(O8/P8))

```

The first expression corresponds to the difference between the values of orders and sales to the period one. The sales and orders are presented in the Fig. 1.2.

The second expression shows the form in which the current relationship to the variance of orders is calculated. Here, the formula is only calculated when the difference between orders and sales is different of zero (N8); n is the period in that the variance of orders is calculated, and it is the value in the cell A8 plus 1 (because of the period zero is included in the data quantity), $n-1$ is the value of the cell A8; L8 represents the orders in the period, that is used to calculate the mean of orders.

The formula of the variance of sales is just a spreadsheet formula of the variance which is calculated to the sales from period zero to the current period (the period is in the A column).

Last column is the BEM, it is the cumulative value of the variance of orders divided by the variance of sales, and the implementation of this measure is presented in the Fig. 1.3.

All the expressions can be extended to the period in which we need to calculate the BEM.

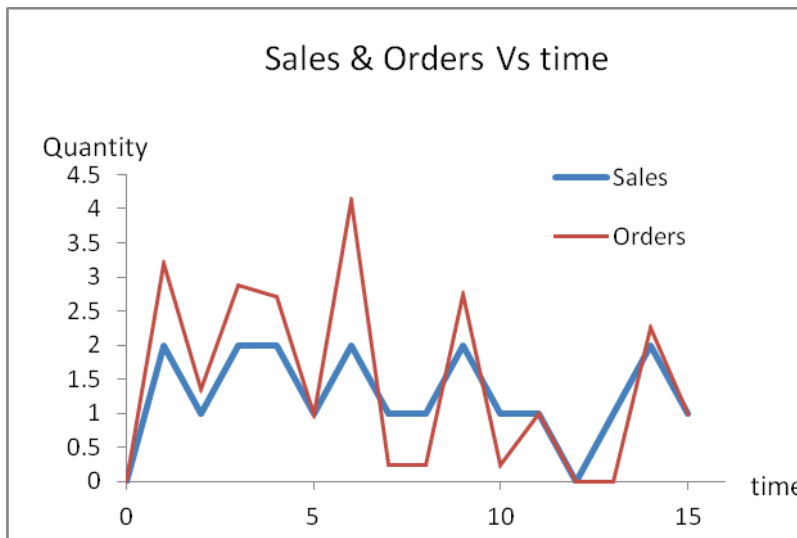


Fig. 1.2 Sales and orders versus time, a numerical example.

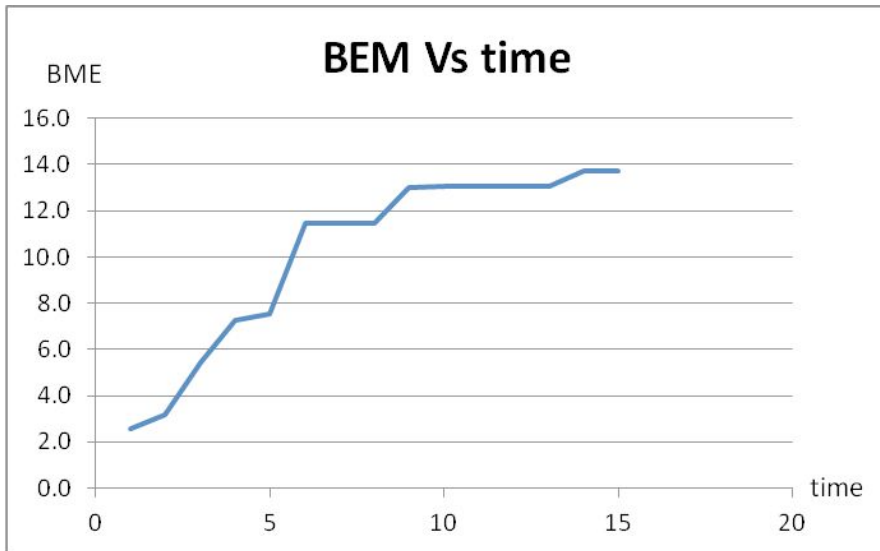


Fig. 1.3 Bullwhip effect measure (BEM), a numerical example.

1.5 Conclusions

In this paper, we have presented a transformation of the formula by Chen et al. (2000) to measure the bullwhip effect in supply chains with the aim of being easily implemented within spreadsheets and without developing VBA macros. Then, we have shown the detail of the implementation of this modified formula to calculate the bullwhip effect in supply chains via spreadsheets.

A forthcoming work is related to the transformation of the formula by Fransoo and Wouters (2000), which measures the bullwhip effect at a particular level in a multi-level supply chain as the quotient of the coefficient of the demand variance generated by this level, and as the coefficient of the demand variance received by this level, with the same objective of easily implementing it through spreadsheets.

1.6 References

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