CHEMICAL ENGINEERING TRANSACTIONS
VOL. 62, 2017
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Fei Song, Haibo Wang, Fang He

ISBN 978-88-95608- 60-0; **ISSN** 2283-9216
DOI: 10.3303/CET1762239

Effect of Ordering Strategy of Chemical Enterprises on Supply Chain Stability

Yali Li[a], Bin Liu[b]

[a]Shijiazhuang Institute of Technology(SIT), Shijiazhuang 050228, China
[b]Baoding University,Baoding 071000, China
sjzzhyzzh@163.com

With the development of economic and social, problems of the stability of chemical supply chain appear. Fluctuation of chemical supply chain causes a huge impact on factories and consumers. Because of collapse of its supply chain, many companies come to failure and bankruptcy. Such accidents take severe harm not only to the chemical supply chain upstream and downstream enterprises, but also to the environment and life safety. It always brings immeasurable losses as well. Therefore, the study of chemical supply chain stability is practically significant to strengthen the safety of chemical supply chain operation, promote the sustainable development of chemical supply chain, improve the competitiveness of chemical industry, reduce global energy consumption, and protect social environment. At the same time, theoretical significance is to improve and perfect the theory of supply chain management. From the perspective of lead time, this paper analyses the influence of forecasting methods on supply chain bullwhip effect and supply chain stability. With the simulation and analysis, it can be found that no matter what kind of single prediction method we choose, bullwhip effect and the effect of its own shock will increase with the lead time increasing. This is an important factor affecting the size of the bullwhip effect. Therefore, chemical companies in supply chain should optimize the supply chain design, improve replenishment efficiency, enhance collaboration with other enterprises, and do efforts to reduce the lead time so as to enhance the stability of the supply chain. The results of the model simulation can help policy makers with better decision, as well as provide some management advice.

1. Introduction

The status of the chemical industry in the national economy is very important. It not only takes a significant position in people's lives, clothing, food and transportation, but also is important for in other high-tech industry development and technological progress.

Chemical industry is a special industry that is regarded as a typical chain system. The production chain can be extended deep and long. Upstream focuses on resource exploration and development, which is characteristic resource-dependence industry. The middle parts of the chain are mainly resource sales and petrochemical industries. Downstream products are more elaborate. Because the product differentiation is obvious, the added value of products is higher. Because of the diversification of materials and diversification of production methods in chemical industry, many raw materials, supporting materials and half-finished products can be recycled in various processes and products, which can lead to high product relevance.

Order decision-making of the chemical enterprises is often based on current and past historical information to predict future demand changes. Demand forecasting is also the basic process of enterprise production, inventory planning control and customer service level design. Different demand forecasting strategies will have different effects on chemical industry supply chain stability, so it is also important to study the stability of supply chain in chemical industry.

2. Related works

One of the main indicators of supply chain stability is the fluctuation of order quantity, so some scholars have studied the field from the angle of bullwhip effect.

Please cite this article as: Yali Li, Bin Liu, 2017, Effect of ordering strategy of chemical enterprises on supply chain stability, Chemical Engineering Transactions, 62, 1429-1434 DOI:10.3303/CET1762239

Zhang (2006) proves that when using the maximum inventory level strategy, a moving average, one index smoothing and the minimum mean square error in the demand forecast will bring different effects on supply bullwhip effect in the first-order autoregressive. It can be proved mathematically by the literatures that the variance of the total demand forecast error in the lead time is theoretically unchanged whatever the forecasting method we choose. However, in the real world, the chemical industry cannot predict the exact distribution of demand in advance, and usually it estimates the demand distribution through historical demand. Therefore, the variance of the total demand forecast error will inevitably change with time in the lead period. Ma et al., (2014) extends a retailer to two retailers on the basis of Zhang, and conducted similar studies on the three predictive methods.

Luong (2007) focuses on the effect of the lead time and the autocorrelation coefficient on the bullwhip effect when using the least mean square error prediction method. Gilbert (2005) presents a differential autoregressive moving average model for demand and deduces the bullwhip effect in the multi-level supply chain using the minimum mean square error demand forecast and the maximum inventory level replenishment strategy.

It is also proved that the longer the total lead time is, the greater the autocorrelation coefficient is, and the more obvious the bullwhip effect is. Meanwhile, the number of supply chain level and whether sharing information of sale point or not have little effect on the bullwhip effect (Dejonckheere et al., 2005).

Alizadeh (2012) studies an actual four-stage supply chain, and gets the conclusion that the greater the smoothing parameters is ,the greater the bullwhip effect is by constantly adjusting the smoothing parameters in the exponential smoothing method.

Some scholars have also studied the content related to the forecast replenishment strategy. Jaksic et al. (2008) study the effects of multiple replenishment strategies on the bullwhip effect based on the exponential smoothing prediction method by using the transfer function in cybernetics. It is found that some will lead to bullwhip effect, but some can weaken the demand fluctuations. Consequently, the choice of appropriate forecast replenishment strategy can completely eliminate the bullwhip effect.

Hussain et al., (2012) extend the study of Zhang and reach a similar conclusion in the bullwhip effect. At the same time, the concept of inventory variance ratio is proposed, which refers to the ratio of net inventory variance to demand variance. The results show that the exponential smoothing prediction method has a higher inventory variance ratio than the least mean square error method, and the gap between the two ratios increases with the increase of the lead time.

Najafi et al. use simulation methods to compare the advantages among single moving average, one-index smoothing and linear regression from the perspective of bullwhip effect in the multi-level supply chain. However, when the demand obeys the normalized distribution, the ordering strategies from the literatures are relatively simple. Its order quantity is equal to the demand forecast minus the existing stock, without considering the delay in transport and the safety stock. After study the bullwhip effect of closed-loop supply chain, Wan et al., (2012) believe that reverse logistics can reduce the forward logistics bullwhip effect. The predictive method used in the literature is an exponential smoothing method. Sun (2013) also studies the effects of existing inventory adjustment factors and in-transit inventory adjustment coefficients on the bullwhip effect based on an exponential smoothing method.

These scholars mainly use the simulation modeling method or the control theory modeling method to study the corresponding forecasting replenishment strategy (Makui et al., 2007). They basically combine the single moving average method and the first exponential smoothing method with the independent normal distribution demand to do prediction, or combine the first exponential smoothing method with the first-order autoregressive demand to do prediction. Other scholars use the anchor adjusts replenishment strategy to meet the step demand. Scholars have studied many methods including heuristic algorithms. Kimbrough et al., (2012) establish a multi-agent simulation model for beer games, which combines with genetic algorithm (GA) to arrive at the optimal ordering strategy for each firm. Then he confirms that Agent can efficiently complete the distribution process of beer and reduce the bullwhip effect. But the model requires all enterprises to share full information and coordinate decision-making in the supply chain (Mackelprang et al., 2015), which participants is not feasible with multi- participants in more realistic environment.

3. Ordering Strategy Model and Analysis

In this paper, the multi-level single-node chemical enterprise supply chain model is established to study the stability. The boundary of the system is defined and the role of the chemical enterprise in the supply chain is refined. The chemical supply chain consists of one retailer, one wholesaler, one distributor and one manufacturer from the downstream to the upstream, and the terminal customer and the external supplier is the entity.

Stability is measured by the bullwhip effect. After calculating the degree of freedom in this model, the formula for the bullwhip effect is calculated as follows,

$$\frac{\sum_{t=u}^{T}(q_t - \frac{1}{T-u+1}\sum_{t=u}^{T} q_t)^2}{\sum_{t=u}^{T}(I_t - \frac{1}{T-u+1}\sum_{t=u}^{T} I_t)^2} \tag{1}$$

In the above formula, q_t represents the order quantity of the retailer, wholesaler, distributor, or manufacturer in $t$period. I_t represents the terminal customer's demand in the $t$period. u represents the initial simulation period for the bullwhip effect calculation, and Trepresents the termination period of the simulation. It is generally necessary to select a reasonable range$u$so that the period interval [u, T] for calculation is large enough as well as the data are stable in the period of [u, T].

3.1 Single Moving Average

In the demand forecast, the participants have been informed of the current demand. If the number of moving averages is *m*, the participant predicts the demand based on the observation of recent *m* demands (including current demand). In *t* period, the participants' expectations of the demand of each period are equal, which is shown as follows,

$$\bar{d}_{t+1} = \bar{d}_{t+2} = \ldots = \bar{d}_{t+L} = \frac{1}{m}\sum_{i=0}^{m-1} d_{t-1} \tag{2}$$

From the above formula, the expectation of total demand forecast for the entire lead period $\bar{D}_t$ is shown in formula (3),

$$\bar{D}_t = \sum_{i=0}^{L} \bar{d}_{t+i} = \frac{L}{M}\sum_{i=0}^{m-1} d_{t-i} \tag{3}$$

Table 1: Bullwhip Effect When L=2

Times	Retailer	Wholesaler	Distributor	Manufacturer
1	1.1573	1.4493	1.8844	2.4150
2	1.1117	1.3223	1.6648	2.1313
3	1.1907	1.5149	1.9504	2.4017
4	1.1700	1.4872	1.8718	2.2802
5	1.0932	1.3589	1.7468	2.2524
6	1.1561	1.4570	1.8968	2.3784
7	1.1659	1.4269	1.8070	2.2908
8	1.2110	1.6067	2.1368	2.6786
9	1.1782	1.5312	1.9994	2.5521
10	1.1159	1.3702	1.7558	2.2240
11	1.1735	1.5323	2.0569	2.6443
12	1.3728	2.0200	2.9888	4.0150
13	1.1523	1.5084	1.9753	2.6334
14	1.1304	1.4023	1.7891	2.2806
15	1.1090	1.3543	1.6913	2.1429
16	1.1185	1.3551	1.7179	2.1625
17	1.1519	1.4368	1.9012	2.4870
18	1.2884	1.8407	2.6786	3.5947
19	1.1589	1.4821	1.9444	2.4471
20	1.1717	1.4794	1.8863	2.4521
Expectation	1.1689	1.4968	1.9672	2.5232
Standard Deviation	0.0643	0.1678	0.3245	0.4728

Table 2: Bullwhip Effect When L=3

Times	Retailer	Wholesaler	Distributor	Manufacturer
Expectation	1.3584	2.3065	4.4292	7.0454
Standard Deviation	0.1479	0.7337	2.7480	5.3160

Table 3: Bullwhip Effect When L=4

Times	Retailer	Wholesaler	Distributor	Manufacturer
Expectation	1.5930	3.8848	12.0073	25.0813
Standard Deviation	0.2239	1.9289	10.1549	22.8596

We analyze the influence of lead time Lon supply chain stability. Assume that the values of all the participants' L are *2, 3* and *4*, respectively. We set the initial stock amount $h0$ that is corresponding to L is *447,657,866*. A total of three groups of parameters are to minimize the impact of the initial value on the model, so that the model tends to stabilize as soon as possible.
The value, the total mean and standard deviation of bullwhip effect of each participant that are calculated according to formula (1) are shown in Table 1 to Table 3.
In Table 1, we take the results of the first time as an example. It can be clearly seen that the bullwhip effect in the chemical industry increases. Retailers are close to the market. The volatility amplification effect on order is small, and the bullwhip effect is only 1.1573. But manufacturers are far away from the terminal customer, which leads to more obvious amplification effect, and the bullwhip effect value 2.4150. The ratios of orders of between each level are *1.4493 / 1.1573 = 1.2523*, *1.8844 / 1.4493 = 1.3002*, and *2.4150 / 1.8844 = 1.2816*. These three ratios are closer. From the three tables above, we can conclude that no matter how much *L is*, the bullwhip effect always increases from the downstream to the upstream of the supply chain to in all the different run times, which is actually determined by the inherent mechanism of the forecast replenishment strategy.

3.2 Single Exponential Smoothing

When participants forecast demand, if we use single exponential smoothing method, and the smoothing parameter is β and the lead period is L, the demands of each period that the participants forecast are equal in the period t, shown as follows,

$$\bar{d}_{t+1} = \bar{d}_{t+2} = ... = \bar{d}_{t+L} = \bar{d}_t + \beta(d_t - \bar{d}_t) \tag{4}$$

From the above formula, the expectation of total demand forecast for the entire lead period $\bar{D}_t$ is shown in formula (5),

$$\bar{D}_t = \sum_{i=0}^{L} \bar{d}_{t+i} = L[\bar{d}_t + \beta(d_t - \bar{d}_t)] \tag{5}$$

It is necessary to give the initial condition of the exponential smoothing method, so the initial forecast demand is the mean of all historical requirements, as shown in formula (6).

$$\bar{d}_{t+1} = \frac{1}{t}\sum_{t=1}^{t} d_i, t = \max(m, n) \tag{6}$$

In this research, we set β=1/(1+*m*)=0.095.
We analyse the influence of lead time L on supply chain stability. Assume that the values of all the participants' L are *2, 3* and *4*, respectively. We set the initial stock amount $h0$ that is corresponding to L is *447, 657, 866*. By using a different random number of seeds for each times, we get the mean and standard deviation of the bullwhip effect of each participant as shown in Table 4.

Table 4: Bullwhip Effect When using Single Exponential Smoothing

	Expectation				Standard Deviation			
L	Retailer	Wholesaler	Distributor	Manufacturer	Retailer	Wholesaler	Distributor	Manufacturer
2	1.3431	1.9213	2.8016	4.0572	0.0423	0.1273	0.2728	0.4676
3	1.6281	2.9888	5.8474	10.1775	0.1239	0.6666	2.5704	3.4873
4	1.9411	4.6832	13.6678	30.9592	0.1408	1.3322	10.0471	23.3274

3.3 Minimum Mean Square Error

Participants use minimum mean square error to forecast demand. In *t* period, demand of each period for Llead period is shown as formula (7).

$$\bar{d}_{t+i} = \frac{\bar{\mu}_t}{1-\bar{\rho}_t} + \bar{\rho}_t^{\,i}\left(d_t - \frac{\bar{\mu}_t}{1-\bar{\rho}_t}\right), i = 1, 2, ..., L \tag{7}$$

From the above formula, the expectation of total demand forecast for the entire lead period $\bar{D}_t$ is shown in formula (8).

$$\bar{D}_t = \sum_{i=0}^{L} \bar{d}_{t+i} = \frac{L\bar{\mu}_t}{1-\bar{\rho}_t} + \left(\frac{\bar{\rho}_t - \bar{\rho}_t^{\,L+1}}{1-\bar{\rho}_t}\right)\left(d_t - \frac{\bar{\mu}_t}{1-\bar{\rho}_t}\right) \tag{8}$$

We analyse the influence of lead time Lon supply chain stability. Assume that the values of all the participants' *L* are *2, 3* and *4*, respectively. We set the initial stock amount $h0$ that is corresponding to *L* is *447, 657, 866*. By using a different random number of seeds for each times, we get the mean and standard deviation of the bullwhip effect of each participant as shown in Table 5.

Table 5: Bullwhip Effect When using Minimum Mean Square Error

	Expectation				Standard Deviation			
L	Retailer	Wholesaler	Distributor	Manufacturer	Retailer	Wholesaler	Distributor	Manufacturer
2	1.6625	2.4128	3.4964	5.0666	0.2098	0.641	1.3098	2.5955
3	1.9085	3.5012	9.1887	18.1962	0.3529	1.5747	12.7945	17.6809
4	2.1934	5.586	26.4731	87.4238	0.3949	2.6438	23.0061	98.2246

It can be seen from Table 4 and Table 5 that the mean and standard deviation of the bullwhip effect increases with the increase of *L*. The rules of changes of Stability are similar regardless of different order strategy. This article thinks that for the various roles in chemical industry supply, phenomenon that *L* increasing brings about the bullwhip effect increasing is significant.

4. Conclusion

In this paper, we study that the influence of three different single prediction methods on the stability of supply chain from the perspective of bullwhip effect. The three kinds of single prediction methods are single moving average method, single exponential smoothing method and minimum mean square error method. Under the condition of dynamic decision-making based on the recent observation, the supply chain of multi-level single node can be simulated. From the perspective of lead time, this paper analyses the influence of forecasting methods on supply chain bullwhip effect and supply chain stability. With the simulation and analysis, it can be found that no matter what kind of single prediction method we choose, bullwhip effect and the effect of its own shock will increase with the lead time increasing. This is an important factor affecting the size of the bullwhip effect. Therefore, chemical companies in supply chain should optimize the supply chain design, improve replenishment efficiency, enhance collaboration with other enterprises, and do efforts to reduce the lead time so as to enhance the stability of the supply chain.

References

Alizadeh P., 2012, The Role of Forecasting Parameters in Reducing Bullwhip Effect, Advances in Production Engineering and Management, 7(3), 177-186, DOI: http://dx.doi.org/10.14743/apem2012.3.140

Dejonckheere J., Disney S.M., Lambrecht M.R., 2003, Measuring and Avoiding the Bullwhip Effect, A control Theoretic Approach, European Journal of Operational Research, 147(3), 567-590, DOI: https://doi.org/10.1016/S0377-2217(02)00369-7

Gilbert K., 2005, An ARIMA Supply Chain Model, Management Science, 51(2), 305-310, DOI: 10.1287/mnsc.1040.0308 · Source: DBLP

Hussain M., Shome A., Lee D.M., 2012, Impact of Forecasting Methods on Variance Ratio in Order-up-to Level Policy, The International Journal of Advanced Manufacturing Technology, 59(1-4), 413-420, DOI: 10.1007/s00170-011-3485-1

Jakšič M., Rusjan B., 2008, The Effect of Replenishment Policies on the Bullwhip Effect, A Transfer Function Approach, European Journal of Operational Research, 184(3), 946-961, DOI: 10.1016/j.ejor.2006.12.018 · Source: DBLP

Kimbrough S.O., Wu D.J., Zhong F., 2002, Computers Play the Beer Game, Can Artificial Agents Manage Supply Chains, Decision Support Systems, 33(3), 323-333, DOI: 10.1016/S0167-9236(02)00019-2 · Source: DBLP

Luong H.T.,2007, Measure of Bullwhip Effect in Supply Chains with Autoregressive Demand Process, European Journal of Operational Research, 180(3), 1086-1097, DOI: 10.1016/j.ejor.2006.02.050 · Source: DBLP

Mackelprang A.W., Malhotra M.K., 2015, The Impact of Bullwhip on Supply Chains, Performance Pathways, Control Mechanisms, and Managerial Levers, Journal of Operations Management, 36, 15, DOI: 10.1016/j.jom.2015.02.003

Makui A., Madadi A., 2007, The Bullwhip Effect and Lyapunov Exponent, Applied Mathematics and Computation, 189(1), 35-40, DOI: 10.1016/j.amc.2006.11.069 · Source: DBLP

Ma J.H., Bao B.S., Ma X.G., 2014, Inherent Complexity Research on the Bullwhip Effect in Supply Chains with Two Retailers, The Impact of Three Forecasting Methods Considering Market Share, Abstract and Applied Analysis, 2014, 1-13, DOI: 10.1155/2014/306907

Sun W.Q., 2013, Supply Chain System Simulation and Cost Optimization Based on APIOBPCS Adjustment Coefficient, Industrial Engineering Journal, 16(6), 134-140.

Wan Z., Li C. H.B., 2012, Bullwhip effect in closed-loop supply chain based on system dynamics, Computer Integrated Manufacturing Systems, 18 (5), 1093-1098.

Zhang X.L., 2004, The Impact of Forecasting Methods on the Bullwhip Effect, International Journal of Production Economics, 88 (1), 15-27, DOI: 10.1016/S0925-5273(03)00128-2 · Source: RePEc