Exploring the relationship between inventory level and bullwhip effect in the supply chain

Lin Li*

School of Management, HeFei University of Technology, Anhui PR China

Anhui finance & trade vocational college, Anhui PR China

Received 1 July 2014, www.cmnt.lv

Abstract

This paper intends to work out an expected inventory level formula for the retailer in the two-stage supply chain. It aims at disclosing the quantitative relationship between bullwhip effect and expected inventory level and does analysis of simulation experiment. The model supposes the market demand faced by the retailer follows the autoregressive process AR(1) and that the retailer makes anticipation of the market demand during the replenishment lead time by mean square error method. Moreover, if the interference factor follows normal distribution with mean 0 and variance σ^2, market demand in every period, demand estimation during the replenishment lead time and the order quantity made by the retailer are all proved to follow normal distribution.

Keywords: bullwhip effect, first-order autoregressive model, supply chain management, inventory level, demand forecasting

1 Introduction

Bullwhip effect in the supply chain is called demand amplification effect [1-3]. When the demand variability increases as one move up the supply chain, the bullwhip effect occurs. Small variations in consumer demand can result in large variations in upstream orders and inventory. This process parallels to the bullwhip that swings much greater at the end than at the beginning. In some industries, bullwhip effect is also called “Forrester Wheel Effect” [4], “Whiplash” or “Whipsaw” effect.

Most of the previous researches on the bullwhip effect in the supply chain focus on demonstrating its existence, identifying its possible causes, quantifying the bullwhip effect and providing measures to reduce such effect. This paper considers a two-stage supply chain consisting of a single manufacturer and a single retailer, it differs from previous research in several ways. First, it supposes that the market demand faced by the retailer follows the autoregressive process AR(1) and the retailer makes anticipation of future market demand by mean square error method. Second, under the premises that the white noise follows normal distribution, market demand in every period, demand estimation of the replenishment lead time and order quantity are all proved to follow normal distribution. Finally, this paper intends to work out an expected inventory level by mathematical analysis and finds out a linear relationship between bullwhip effect and expected inventory level. As a result, it proposes the concept of ideal expected inventory level that serves as an indicator of measuring the optimal structure of the supply chain.

The rest of the paper is organized as follows. The next section provides a brief survey on the related literature. Section 3 describes the supply chain model and gives the main results of the paper. Section 4 presents analysis of experiment simulation. Section 5 concludes the paper and discusses the future research.

2 Literature Review

The literature on the bullwhip effect in the supply chain is extensive, so we only provide a description of major classes of models. Lee et al. [5] study the replenishment system in the supply chain where the bullwhip effect occurs. Enterprises in the downstream transmit information to enterprises in the upstream by making orders, which steers the latter’s production and inventory decisions. But the variance of orders is larger than that of the real market demand, causing that the information distortion is amplified from downstream to upstream. This paper accounts four causes of the bullwhip effect: demand forecast updating, rationing and shortage gaming, order batching and price fluctuation. Literature [6] quantifies the bullwhip effect in a simple two-stage supply chain consisting of a single manufacturer and a single retailer. It establishes a model that helps to explain two causes of the bullwhip effect, namely, demand forecasting and order lead times. It also expands these results to multi-stage supply chains with and without centralized customer demand information, and proves that the bullwhip effect can be reduced by centralizing demand information. However, it cannot be completely eliminated.

Cachon et al. [7] set up a two-stage supply chain model in which a single supplier and multiple independent

* ***Corresponding author*** e-mail: Lilin200492@163.com

retailers. In this model, the supplier has limited capacity, and retailers are privately informed of their optimal stocking levels. They show that some allocation mechanisms induce the retailers to place their optimal order and a manipulation mechanism may lead the supplier to build more capacity. Besides that, Kelle and Milne [8] study factors of order batching and examine the effect of (s,S) ordering policy on the order variability in a supply chain, they provide quantitative tools for the estimation of the variability increase. Lambert, Copper and Pagh [9] concentrate on operationalizing the supply chain management framework, they present that managing the supply chain involves three closely interrelated elements. Some other researchers as Ryan, Baganha, Cohen and Graves focus on how to optimize the technology of treating market demand information and information sharing mechanism [10-12]. Jaipuria et al. [13] propose an integrated approach of discrete wavelet transforms analysis and artificial neural network for demand forecasting, this model can improve the forecasting accuracy and be applicable to both linear and non-linear data series. Luong [14] studies the effect of autoregressive coefficients and lead time on bullwhip effect for a two stage supply chain, the retailer employs a base stock policy for inventory management using first order autoregressive model. Duc et al. [15] study the effect of existence of a third-party warehouse on bullwhip effect in a supply chain, and assume that the demand process as first order autoregressive model. For a list of updated results, the reader is referred to [16-18].

3 A Supply Chain Model

As many researches, this paper supposes that the retailer makes the decision of replenishment at the end of each fixed period and gives orders to the manufacturer in the upstream at the same time. The time interval between two neighbouring replenishment is same and replenishment occurs when $t = -\infty, \ldots, -1, 0, 1, n-1, n, n+1, \ldots, +\infty$. Suppose the replenishment lead time is l, indicating that the retailer will receive commodities from the manufacturer after a delay of l periods. Suppose the market demand faced by the retailer is characterized by the autoregressive process AR(1):

$$D_n = \mu + \rho D_{n-1} + \varepsilon_n , \tag{1}$$

where D_n refers to the market demand or sales in replenishment period n. μ is a non-negative constant, indicating the average level of the market demand. ρ is a correlation parameter with $|\rho| < 1$, indicating demand of two neighbouring replenishment periods. The closer ρ is to 1, the more correlation the demand of two neighbouring periods has. ε_n is the inference noise in period n and independent from demand D_n in period n. $\varepsilon_n, n = -\infty, \cdots, -1, 0, 1, \cdots, +\infty$ are independent from each other. ε_n includes all information in period n that cannot be explained by demand in past periods. In other words, it is only related to market environment. Thus, we think ε_n is independent from historical demand $D_{n-1}, D_{n-2}, D_{n-3}, \ldots$

3.1 FORECASTING METHOD AND THE INVENTORY POLICY

The retailer makes anticipation of market demand in future replenishment lead time by mean square error method. If replenishment decision is made at the end of period n, the retailer should make demand forecasting. Suppose the market demand of period $n+i$ is $D_{n+i} (i = 1, \ldots, l+1)$, respectively. Then the market demand during the replenishment lead time is:

$$\sum_{i=1}^{l+1} D_{n+i} = \frac{1}{1-\rho} \left\{ \mu \sum_{i=1}^{l+1} (1-\rho^i) + \rho(1-\rho^{l+1}) D_n \right\} + \sum_{i=1}^{l+1} \frac{1-\rho^i}{1-\rho} \varepsilon_{n+l+2-i} . \tag{2}$$

By mean square error method, we suppose the demand estimation is D_n^l, then $D_n^l = E\left(\sum_{i=1}^{l+1} D_{n+i} \mid D_n \right)$, where D_n^l is estimated by the conditional expectation of $\sum_{i=1}^{l+1} D_{n+i}$ based on D_n in period n. σ_n^l denotes the conditional variance of $\sum_{i=1}^{l+1} D_{n+i}$, then $\sigma_n^l = \operatorname{var}\left(\sum_{i=1}^{l+1} D_{n+i} \mid D_n \right)$. The inventory level in period $n+l+1$ decided at the end of period n is:

$$y_n = D_n + z\sqrt{\sigma_n^l} ,$$

where, z refers to service level factor or safety inventory factor. The bigger z is, the more safety inventory should be. Let q_n be the variance of the orders placed by the retailer to the manufacturer, then the order quantity q_n is denoted by $q_n = y_n - y_{n-1} + D_n$.

3.2 ANALYSIS OF THE PROBABILITY DISTRIBUTION

For inference factor ε_n in AR(1) process, we suppose it follows normal distribution with mean 0 and variance σ^2. We shall find out that market demand D_n in every period, demand estimation D_n^l and the order quantity q_n made by the retailer all follow normal distribution.

First, if we repeatedly employ Equation (1), D_n can be expressed as:

$$D_n = \mu + \rho D_{n-1} + \varepsilon_n = \mu \sum_{i=0}^{+\infty} \rho^i + \sum_{i=0}^{+\infty} \rho^i \varepsilon_{n-i} .$$

As ε_n is independent from each other, and $\varepsilon_n \sim N(0,\sigma^2)$, from the additive property of normal distribution:

$$\sum_{i=0}^{+\infty}\rho^i\varepsilon_{n-i}+\sum_{i=0}^{+\infty}\rho^i \sim N\left(\frac{\mu}{1-\rho},\frac{\sigma^2}{1-\rho^2}\right),$$

so $D_n \sim N\left(\frac{\mu}{1-\rho},\frac{\sigma^2}{1-\rho^2}\right)$.

For demand estimation D_n^l, from Equation (2) and the expression $D_n^l = E\left(\sum_{i=1}^{l+1} D_{n+i} \mid D_n\right)$, by simple calculation we can get:

$$D_n^l = \frac{\mu}{1-\rho}\left\{(l+1)-\sum_{j=1}^{l+1}\rho^j\right\}+\frac{\rho\left(1-\rho^{l+1}\right)}{1-\rho}D_n. \qquad (3)$$

It has been proved that $D_n \sim N(\frac{\mu}{1-\rho},\frac{\sigma^2}{1-\rho^2})$. Observe Equation (3), there is only one normal random variable D_n and the rest are all constants. So D_n^l is also a normal random variable.

For q_n, after calculation we can get:

$$\sigma_n^l = \operatorname{var}\left(\sum_{i=1}^{l+1} D_{n+i} \mid D_n\right)=\frac{1}{(1-\rho)^2}\sum_{j=1}^{l+1}\left(1-\rho^j\right)^2\sigma^2.$$

Thus, the fluctuation σ_n^l of market demand during the lead time has no correlation with period *n*. So substitute $y_n = D_n + z\sqrt{\sigma_n^l}$ to the expression of q_n and get:

$$q_n = y_n - y_{n-1} + D_n = D_{n-1} + \frac{1-\rho^{l+2}}{1-\rho}\varepsilon_n .$$

As ε_n is independent from D_{n-1} and both are normal distribution, so q_n is also normal distribution. Calculate the expectation and variance of q_n:

$$q_n \sim N\left(\frac{\mu}{1-\rho},\left(\frac{1}{1-\rho^2}+\left(\frac{1-\rho^{l+2}}{1-\rho}\right)^2\right)\sigma^2\right).$$

From the above mentioned, we can see the normal random property of the order quantity q_n by the retailer in every period is derived from that of ε_n.

3.3 EXPECTED INVENTORY LEVEL OF THE RETAILER

Next, we will deduce the expected inventory level by mean square error analysis. As we have already known, q_n is a random variable that is a normal distribution with mean $\frac{\mu}{1-\rho}$ and variance $\left(\frac{1}{1-\rho^2}+\left(\frac{1-\rho^{l+2}}{1-\rho}\right)^2\right)\sigma^2$.

The retailer gives an order q_n at the end of each period and receives commodities after the interval of l periods. Suppose the consumption speed per time is v, and we use expectation $E(v)$ to replace v. Under $E(v)$, there are three states of inventory: just running up, surplus and shortage. To obtain the expected inventory level at the end of each period, we should get the probability distribution function of commodity consumption time T_v with the amount of q_n in every period.

$$T_v = \frac{q_n}{E(v)} = \frac{q_n}{\frac{E(D_n)}{T}} = \frac{T(1-\rho)}{\mu}\cdot q_n,$$

where T refers to the length of time in every period. q_n is known to follow normal distribution, T_v is also the same. Calculate the expectation and variance, and we can get:

$$T_v \sim N\left(T,\left(1+\frac{(1+\rho)\left(1-\rho^{l+2}\right)^2}{1-\rho}\right)\frac{T^2\sigma^2}{\mu^2}\right).$$

Let $f(T_v)$ denotes the probability density function of T_v. We can get the product expression of expected inventory level and the time:

$$\begin{aligned}
IT &= \int_0^T\int_0^{T_v}(T_v-t)\frac{\mu}{(1-\rho)T}dt\cdot f(T_v)dT_v + \\
&\int_T^{+\infty}\int_0^T(T-t)\frac{\mu}{(1-\rho)T}dt\cdot f(T_v)dT_v = \\
&\frac{\mu}{2(1-\rho)T}\int_0^T(T_v-T)^2 f(T_v)dT_v + \\
&\frac{\mu}{(1-\rho)}\cdot\int_0^T T_v f(T_v)dT_v - \frac{\mu T}{2(1-\rho)}\int_0^T f(T_v)dT_v + \\
&\frac{\mu T}{2(1-\rho)}\int_T^{+\infty} f(T_v)dT_v.
\end{aligned} \qquad (4)$$

In this expression:

$$T_v \sim N\left(T,\left(1+\frac{(1+\rho)\left(1-\rho^{l+2}\right)^2}{1-\rho}\right)\frac{T^2\sigma^2}{\mu^2}\right).$$

It means that the range of T_v is the entire abscissa axis from $-\infty$ to $+\infty$. But in real situation, the consumption time must be greater than 0. So we deduce that the main range of T_v is from 0 to $+\infty$ and the rest can be overlooked. As $f(T_v)$ is a normal density function, the image of $f(T_v)$ is symmetrical about $T_v = T$. So we can get:

$$\int_0^T T_v f(T_v)dT_v \approx \frac{1}{2}\int_{-\infty}^{+\infty} T_v f(T_v)dT_v = \frac{1}{2}\mu_{T_v} = \frac{1}{2}T,$$

$$\int_0^T f(T_v)dT_v \approx \int_T^{+\infty} f(T_v)dT_v = \frac{1}{2}\int_{-\infty}^{+\infty} f(T_v)dT_v = \frac{1}{2},$$

$$\int_0^T (T_v - T)^2 f(T_v)dT_v \approx \frac{1}{2}\int_{-\infty}^{+\infty} (T_v - T)^2 f(T_v)dT_v =$$

$$\frac{1}{2}\sigma_{T_v}^2 = \frac{1}{2}\left(1+\frac{(1+\rho)(1-\rho^{l+2})^2}{1-\rho}\right)\frac{T^2\sigma^2}{\mu^2}.$$

Substitute the results to Equation (4) and get the expression for expected inventory level $\times$time:

$$IT = \left\{[1+\frac{(1+\rho)(1-\rho^{l+2})^2}{1-\rho}]\cdot\frac{\sigma^2}{4\mu(1-\rho)}+\frac{\mu}{2(1-\rho)}\right\}T.$$

So the expected inventory level of the retailer in every period is:

$$I = \left[1+\frac{(1+\rho)(1-\rho^{l+2})^2}{1-\rho}\right]\cdot\frac{\sigma^2}{4\mu(1-\rho)}+\frac{\mu}{2(1-\rho)}.$$

3.4 ANALYSIS OF THE RELATIONSHIP BETWEEN BULLWHIP EFFECT AND EXPECTED INVENTORY LEVEL

In this subsection, we first give the expression of the bullwhip effect in the two-stage supply chain, where the market demand follows the autoregressive process AR(1) and the retailer uses mean square error method to estimate market demand. Based on the definition of the bullwhip effect, we have:

$$B = \frac{\operatorname{var}(q_n)}{\operatorname{var}(D_n)} = \frac{\left(\frac{1}{1-\rho^2}+\left(\frac{1-\rho^{l+2}}{1-\rho}\right)^2\right)\sigma^2}{\frac{\sigma^2}{1-\rho^2}} = .$$

$$1+\frac{(1+\rho)(1-\rho^{l+2})^2}{1-\rho}.$$

In the previous section, we derive the expected inventory level of the retailer in every period:

$$I = \left[1+\frac{(1+\rho)(1-\rho^{l+2})^2}{1-\rho}\right]\cdot\frac{\sigma^2}{4\mu(1-\rho)}+\frac{\mu}{2(1-\rho)}.$$

Next we will analyse this expression. Recall the definition of bullwhip effect B. If B =1, then the variance of order quantity is not amplified, and the expression will turn to be $I^* = \frac{\sigma^2}{4\mu(1-\rho)}+\frac{\mu}{2(1-\rho)}$. This is the ideal expected inventory level. It is the lowest inventory level. But as $\frac{(1+\rho)(1-\rho^{l+2})^2}{1-\rho} > 0$, which means there is always $I > \frac{\sigma^2}{4\mu(1-\rho)}+\frac{\mu}{2(1-\rho)}$, so we can never reach the ideal expected level. However, this concept is significant in that it helps the retailer to measure if there is space to optimize the structure of the supply chain.

Let us take a look at the first term $\left[1+\frac{(1+\rho)(1-\rho^{l+2})^2}{1-\rho}\right]\cdot\frac{\sigma^2}{4\mu(1-\rho)}$. It is in fact the product of the bullwhip effect B and the fluctuation $\frac{\sigma^2}{4\mu(1-\rho)}$. Then the expected inventory level can be expressed as:

$$I = B\cdot\frac{\sigma^2}{4\mu(1-\rho)}+\frac{\mu}{2(1-\rho)},\ B \ge 1.$$

When the market demand follows first-order autoregressive model AR(1) and the retailer uses mean square error method to forecast the demand during the replenishment lead-time, there is a linear correlation between the expected inventory level and the bullwhip effect. μ, ρ and σ are parameters in the market demand process. The bigger ρ and σ is, the higher the expected inventory level and the greater the bullwhip effect will be, the expected inventory level will be linearly steeper. Actually, this explains why the bullwhip effect can cause a large amount of overstock in enterprise and why reducing the bullwhip effect can reduce the expected inventory level and the inventory cost.

Let's see the quantifying expression $B = \frac{\operatorname{var}(q_n)}{\operatorname{var}(D_n)} = 1+\frac{(1+\rho)(1-\rho^{l+2})^2}{1-\rho}$ again. It shows that the bullwhip effect expands along with the increase of the replenishment lead-time. If the manufacturer in supply chain can reduce this lead-time, he can lower the bullwhip effect and reduce the expected inventory level so as to optimize the supply chain structure. This conclusion is reached in many related literatures. But this paper firstly points out the quantifying model that the retailer can reduce the expected inventory level if the bullwhip effect can be lowered.

4 Experiment Simulation and Results

To verify the reasonability of the model in supply chain, we apply Visual C++ to it and analyse the results based on parameter adjustment validation.

Suppose the supply chain consists of an automobile part producer and a professional automobile repair shop. According to sales statistics, the demand of part faced by the repair shop follows the first-order autoregressive model AR (1): $d_{NT} = 100 + \rho d_{(N-1)T} + \varepsilon_{NT}$, $\varepsilon_{NT} \sim N(0, \sigma^2)$. The repair shop uses mean square error method to estimate the future demand, and the replenishment lead-time is 4.

Table 1, Table 2 and Table 3 are the results of expected inventory level of the retailer, ideal expected inventory level and the bullwhip effect level from the expressions:

$$I = B \cdot \frac{\sigma^2}{4\mu(1-\rho)} + \frac{\mu}{2(1-\rho)},$$

$$I^* = \frac{\sigma^2}{4\mu(1-\rho)} + \frac{\mu}{2(1-\rho)} \text{ and } B = 1 + \frac{(1+\rho)\left(1-\rho^{l+2}\right)^2}{1-\rho}.$$

The abscissa parameter refers to dynamic adjustment of correlation parameter ρ with the fixed step 0.1 in the AR (1) process. The longitudinal parameter refers to the standard variance σ of white noise with the value of 2, 4, 9, 16, 25, 36, 49, 64.

TABLE 1 Expected inventory level of the retailer

σ \ ρ	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
2	55.580	62.531	71.469	83.389	100.078	125.116	166.847	250.295	500.517
4	55.654	62.625	71.592	83.554	100.313	125.464	167.388	251.180	502.069
9	56.056	63.133	72.254	84.452	101.582	127.347	170.320	255.974	510.472
16	57.136	64.500	74.038	86.869	105.001	132.417	178.212	268.880	533.097
25	59.414	67.382	77.800	91.964	112.209	143.107	194.853	296.093	580.803
36	63.556	72.624	84.641	101.230	125.317	162.547	225.114	345.578	667.554
49	70.377	81.256	95.905	116.490	146.903	194.561	274.947	427.070	810.414
64	80.839	94.498	113.185	139.897	180.015	243.668	351.388	552.074	1029.552

As is shown in Table 1, with the increase of correlation parameter ρ and white noise standard variance σ, the expected inventory level rises up. In addition, experimental simulation analysis also proves that *I* is more sensitive to σ than ρ does. In other words, the difference between the expected inventory level and the ideal one is not significant when ρ and σ are at a low level. But this becomes significant when ρ and σ increase.

TABLE 2 Ideal expected inventory level

σ \ ρ	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
2	55.567	62.513	71.443	83.350	100.020	125.025	166.700	250.050	500.100
4	55.600	62.550	71.486	83.400	100.080	125.100	166.800	250.200	500.400
9	55.781	62.753	71.718	83.671	100.405	125.506	167.342	251.013	502.025
16	56.267	63.300	72.343	84.400	101.280	126.600	168.800	253.200	506.400
25	57.292	64.453	73.661	85.938	103.125	128.906	171.875	257.813	515.625
36	59.156	66.550	76.057	88.733	106.480	133.100	177.467	266.200	532.400
49	62.225	70.003	80.004	93.338	112.005	140.006	186.675	280.013	560.025
64	66.933	75.300	86.057	100.400	120.480	150.600	200.800	301.200	602.400

As is shown in Table 2, with the increase of correlation parameter ρ and white noise standard variance σ, the ideal expected inventory level I^* rises up. I^* is more sensitive to σ^2 than ρ does. Considering Table 1 and Table 2, we can see that the difference between the expected inventory level and the ideal one is not significant with the growth of ρ but significant with the growth of σ, indicating that it is more sensitive to σ.

TABLE 3 Bullwhip effect level

ρ	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
B	2.222	2.500	2.854	3.314	3.907	4.636	5.412	5.900	5.171

Bullwhip effect model $B = 1 + \frac{(1+\rho)\left(1-\rho^{l+2}\right)^2}{1-\rho}$ has no correlation with the fluctuation standard variation σ. So there is one row of data in Table 3. The value of *B* increases along with ρ. From Table 1, Table 2 and 3, we can see that the expected inventory level will be up with the increase of *B*, it is characterized by positive linear correlation. This proves that the model in supply chain is reasonable.

5 Conclusions

This paper bases itself on the two-stage supply chain consisting of a single supplier and a single retailer. It supposes that the market demand follows the first-order autoregressive model AR (1) and future market demand forecasting made by the retailer with the mean square error method. It reveals that there is a linear correlation between the expected inventory level and the bullwhip effect, which establishes quantity link between the two. It also proposes the concept of ideal expected inventory level to measure the optimized degree of the supply chain structure. Moreover, it also analyses how parameters of the market demand process affect the inventor`y level. In future research, we can further study the cases that the market demand follows other demand process or the retailer uses other demand forecasting methods.

References

[1] Lee H L, Admanabhan V, Whang S 1997 The bullwhip effect in supply Chains *Sloan Management review* **38**(3) 93-102

[2] Wilding R 1998 The supply chain complexity triangle: uncertainty generation in the supply chain *International Journal of Physical Distribution & Logistics Management* **2**(8) 599-616

[3] Taylor D H 2000 Demand amplification: has it got us beat? *International Journal of Physical Distribution & Logistics Management* 30(6) 515-33

[4] Forrester J W 1968 Industrial dynamics *Management Science* **14**(7) 398-415

[5] Lee H L, Padmanabhan V, Whang S 1997 Information distortion in a supply chain: the bullwhip effect *Management science* **43**(4) 546-58

[6] 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* **46**(3) 436-43

[7] Cachon G P, Lariviere M A 1999 Capacity choice and allocation: strategic behavior and supply chain performance *Management Science* **45**(8) 1091-1108

[8] Kelle P, Milne A 1999 The effect of (s, S) ordering policy on the supply chain *International Journal of Production Economics* **59**(1) 113-22

[9] Lambert D M, Cooper M C, Pagh J D 1998 Supply chain management: implementation issues and research opportunities *International Journal of Logistics Management* **9**(2) 1-20

[10] Ryan J K 1998 Analysis of inventory models with limited demand information *Ph.D Dissertation Department of Industrial Engineering and Management Science Northwestern University* Evanston IL USA

[11] Baganha M P, Cohen M A 1998 The stabilizing effect of inventory in supply chains *Operations Research* **46**(3-supplement) S72-S83

[12] Graves S C 1999 A single-item inventory model for a nonstationary demand process *Manufacturing & Service Operations Management* **1**(1) 50-61

[13] Jaipuria S, Mahapatra S S 2014 An improved demand forecasting method to reduce bullwhip effect in supply chains *Expert Systems with Applications* **41**(5) 2395-2408

[14] Luong H T 2007 Measure of bullwhip effect in supply chains with autoregressive demand process *European Journal of Operational Research* **180**(3) 1086-97

[15] Duc T T, Luong H T, Kim Y D 2010 Effect of the third-party warehouse on bullwhip effect and inventory cost in supply chain *International Journal of Production Economics* **124**(2) 395-407

[16] Li Q, Disney S M, Gaalman G 2014 Avoiding the bullwhip effect using damped trend forecasting and the order-up-to replenishment policy *International Journal of Production Economics* **149**(3) 3-16

[17] Li C 2013 Controlling the bullwhip effect in a supply chain system with constrained information flows *Applied Mathematical Modelling* **37**(4) 1897-1909

[18] Cigolini R, Pero M, Rossi T, Sianesi A 2014 Linking supply chain configuration to supply chain performance: A discrete event simulation model *Simulation Modelling Practice and Theory* 40(1) 1-11

Author

Lin Li, born in March, 1967, Hefei, Anhui, China

Current position, grades: Doctoral student at the School of Management, Hefei University of Technology. Lecturer in Anhui finance &trade vocational college, Hefei Anhui, China.

University studies: B.S. degree from Hefei University of Technology, Hefei, China in 1996.

Scientific interest: cloud computing, capital operation and management.