

Abstract Number: 025-1620

Abstract Title: Supply chain configuration design using design of experiment approach

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POMS 23<sup>rd</sup> Annual Conference

Chicago, Illinois, U.S.A.

April 20 to April 23, 2011

## **Abstract**

Due to the global competition, industries have to consider supply chain configuration before building their supply chain network. The configuration may include site allocation, supply chain layer design, logistics plan, lead time and etc. This paper exams the optimal setting to prevent bullwhip effect using design of experiment and simulation approaches. The regression analysis provides significant factors affecting supply chain bullwhip effect. Then,  $2^k$  design is developed for finding the optimal configuration. The EXCEL VBA is built for the supply chain simulation. The results shows short lead time, using moving average forecasting, and sharing inventory information can lead to minimize bullwhip effect in the supply chain.

**Key words:** Supply chain configuration, Design of Experiments,  $2^k$  designs

## **1 Introduction**

Due to global market forces, technological forces, economic considerations, industries move

towards globalization. Industries face challenges of global supply chain. They have to consider supply chain configuration before building their supply chain network. From upstream suppliers to downstream customers, most of those supply network members' entity relationship is not a simple linear connection. A supply chain consists of supply-side, production-side and customer-side that create a “multi-stage” environment; every stage has more than one site, which generate “multi-site” environment. The combination of “multi-stage” and “multi-site” produces the production environment of “supply network” (Figure 1). Supply chain can be explained as a complex system that is hard to understand, describe, predict or control.

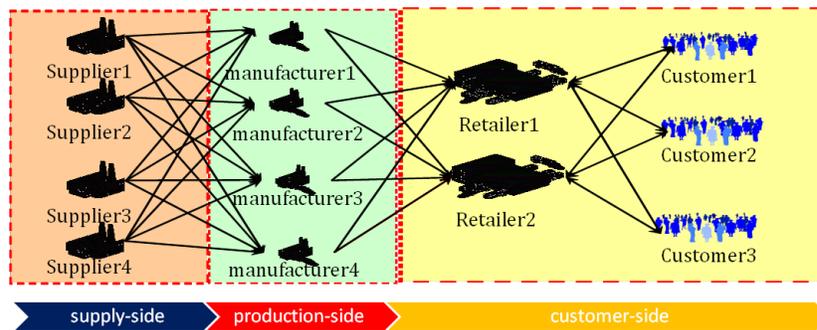


Figure 1 Supply network.

To achieve the optimum efficiency, there is a need to understand the role of members within the supply chain, the interactions among which members, and the method they interaction with each other, so the uncertainty of the supply network can be reduced. (Graves & Willems, 2005). In past, most studies based on inventory and costs to measure the performance of the supply chain configuration (Nepal, Monplaisir, & Famuyiwa, 2010). This study trying to use Bullwhip Effect to measure supply chain performance, because the Bullwhip Effect in supply chain has a great influence on operational effectiveness, including impact on production, inventory, cost, supply chain management

in important areas.

Most research of the Bullwhip Effect, mainly study on the phenomenon of Bullwhip Effect and its influencing factors. Such as Lee et al. mentioned the distortion of information will cause bullwhip effect when information transmitting (Lee, Padmanabhan, & Whang, 1997a, 1997b). There are some factors such as lead time, demand forecast, and order batch, price of production and shortage gaming, and these factors are the controllable factor of the bullwhip effect. However, the complex network structure of a supply chain or the multiple stages of a supply chain has been rarely considered in the existing literature, most research studies have considered only two-stage supply chain while developing their model (Bhattacharya & Bandyopadhyay, 2011). Therefore, this paper exams the optimal setting to prevent bullwhip effect using design of experiment and simulation approaches in multi-stage supply chain.

In the rest of this article, basic assumptions of model are outlined in section 2. The design of experiment, analysis and result are described in section 3. Finally, some concluding remarks are drawn in section 4.

## **2 BASIC ASSUMPTIONS**

Assume the supply chain is multi-stage (Figure 2), there are four stages, and each stage included three factories, in charge of production and sale. There are suppliers, manufacturers, distributors, retailers, customers from upstream to downstream. Each stage just only places the orders to forward stage.

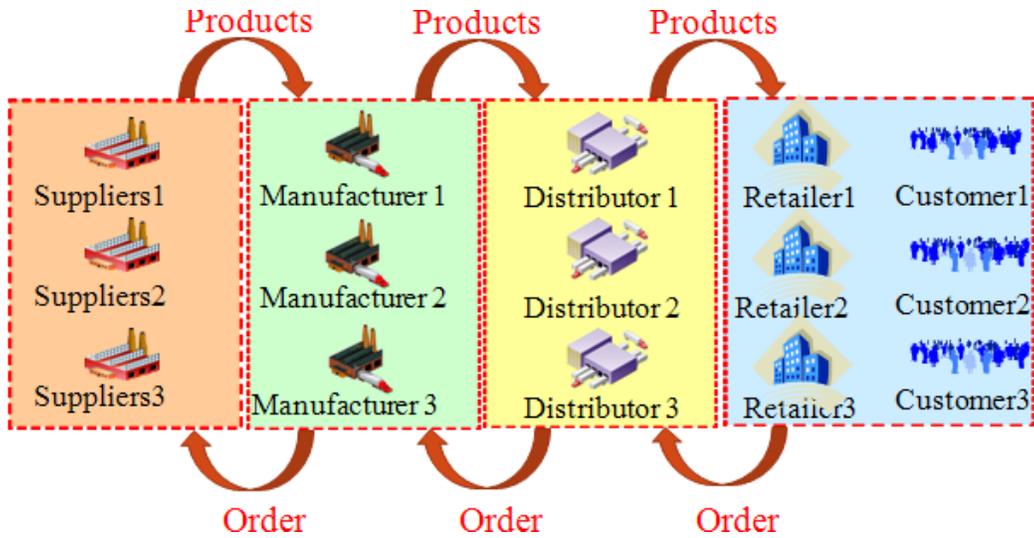


Figure 2 Supply chain network structure in this study

The design of experiment, need to simulate supply chain of a variety configurations to collect data on the state. This study wants to quantify the bullwhip effect, including the bullwhip effect factor in the configuration of a complex supply chain. Such as forecast method, inventory policies and the method of information sharing ◦ Scenario assumptions of simulation in each stage:

- (1) Market end-demand (customer) : Use (Kahn, 1987) model

$$D_t = d + \rho D_{t-1} + \varepsilon_t \quad \varepsilon_t \sim N(0, \sigma^2) \quad (1)$$

Where  $D_t$ , final of actual demand

$D_{t-1}$ , end of actual demand at time period  $t+1$

$d$ , expectation of demand (assuming 10)

$\rho$ , correlation coefficient, indicating the relevance of forward and backward period (assuming 0.1)

$\sigma$ , demand variability (assuming 5)

(2) Retailers assumption :

- a. Consumers directly.
- b. No backlog , if the customer demand is greater than the final inventory, it will not satisfied in the next period.
- c. Orders will be immediately passed to the upstream at time 0.
- d. Products will arrive in the beginning of period.
- e. Forecast method: Mentzer et al. pointed out the exponential smoothing method is the most familiar forecast method(Mentzer & Kahn, 1995). Therefore, this study uses the exponential smoothing and moving average forecast demand.
  - (i) Moving average method: the use of occurrence demand of forward 5 weeks forecast demand for the next period.

$$\widehat{D}_t = (D_{t-1} + D_{t-2} + D_{t-3} + \dots + D_{t-r})/r \quad (2)$$

Where  $\widehat{D}_t$ , prediction value

$D_{t-1}$ , actual value at time period  $t-1$

$D_{t-2}, D_{t-3}$  and  $D_{t-r}$ , actual value at time period  $t-2, t-3, t-r$

- (ii) Exponential Smoothing: the use of actual demand and forecast demand of linear combination to demand forecast for the next period.

$$\widehat{D}_t = \alpha D_{t-1} + (1 - \alpha) \widehat{D}_{t-1} \quad , 0 < \alpha = 0.5 \leq 1$$

Where  $\alpha$ , smoothing parameter, that is used to response to demand variation; the greater value is more sensitive.

- f. Inventory policies: Li et al. proposed the order-up-to inventory policies model for replenishment decisions making; retailer will review their own inventory when the actual inventory levels below the reorder point, then the retailer will place the order to manufacturer(Li, Wang, Yan, & Yu, 2005).

$$Z_{k+1,t} = Z_{k,t} + (S_{k,t} - S_{k,t-1}) \quad (3)$$

Where  $Z_{k,t}$ , the amount of retailers received the orders in phase  $k$  at end period  $t$

$Z_{k+1,t}$ , the amount of retailers place order to manufacturer at time period  $t$

$S_{k,t}$  the retailer is order-up-to level at time period  $t$ ,

$$S_{k,t} = M_{k,t} + z\sqrt{v_{k,t}}$$

$M_{k,t}$ , the conditional expectation of overall demand in lead time  $n$

$v_{k,t}$ , the conditional Variation of overall demand in lead time

$z$  represents order-up-to level(assuming 1.645).

- g. The method of information sharing :

- (i) Distribute: no information sharing to the manufacturer, the

manufacturer just only place the order from the order demand

(ii) Centralized: full information will shared with manufacturers. Addition to passing the order information, but also transfer market to manufacturers of final demand. The manufacturers can be predicted from the actual final demand, external demand.

h. The method of linking with forward stage : When design supply chain layer, need to choose the link with other stage. Therefore, this study want to understand the link with the previous stage how to configure the way of generated minimum bullwhip effect , assuming that is set as follows:

(i) 1 link 2: the retailer stage buy product from distribution stage of any two distributors.

(ii) 1 link 3: the retailer stage buy product from distribution stage of any three distributors.

i. Supply chain distribution: Set the supply chain, the need to account the logistics and information flow between stages, here assuming a simple way of two extreme cases.

(i) Average ratio: the number of products purchased from different factors is the same. such as manufacturer 1 buy the number of ratio is 0.5 , the manufacturer2 buy in the same ratio,0.5

(ii) Extreme ratio: the number of products purchased from different is not the same, but extreme; such as the manufacturer 1 buy the number of ratio is 0.1, the manufacturer2 purchase in extreme ratio, 0.9.

- (3) Distributors, manufacturers and suppliers are similar :
- a. No backlog, if the customer demand is greater than the final inventory, it will not meet in the next period.
  - b. Orders will be immediately passed to the upstream at time 0.
  - c. Products will arrive in the beginning of period.
  - d. Using the moving average or exponential smoothing to forecast demand.
  - e. Using order-up-to inventories policy to plan replenishment decisions.
  - f. Production model for MTS, based on demand forecast to plan production scheduling.
  - g. Information sharing approach is distributed or centralized.
  - h. The way for logistic link with forward stage is 1 link 2 or 1 link 3.
  - i. The supply chain logistic ratio is average or extreme.

Before experimental design need to choice factors, level, range, and response variables (Montgomery, 2009). The choices of factors are mentioned below:

(1) Factors from the above assumption scenario, the setting factors are shown in Table 1 and discuss following concepts:

- a. Forecasting methods: In a multi-level supply chain, sites may not be able to get end customer requirement, and can only forecast demands based on orders from the previous supply chain stage. However, due to all stages demands are estimated by previous stage's prediction. The forecasting error usually enlarges in the upper stream supply chain. As a result, the

demand and supply cannot be balance(Lee, et al., 1997a, 1997b). Therefore, this paper compares two forecasting approaches, moving average and exponential smoothing, for reducing the bullwhip effect.

- b. Lead time ( $n$ ) of inventory policies: The longer lead time, safety stock, order number, the greater the accumulation of the number. Range of variation will therefore increase, leading to enlarge the bullwhip effect (Warburton RDH, Disney SM ,2007).
- c. Information sharing: Some study pointed out that the bullwhip effect can be lower due to information sharing. But even if all of the information is publicly transparent, supply chain still cannot completely avoid the phenomenon of magnification variation.
- d. The method of linking with forward stage: Lambert and Cooper suggests this factor is the primary aspects of supply chain structure. Therefore, this study wants to find the optimal configuration of different linking in the supply chain(Lambert & Cooper, 2000).
- e. Supply chain distribution: Lambert and Cooper also suggests this factor is the primary aspects of supply chain structure. He pointed out that the more important customers will be more interactive, management and control. Base on this assessment, the more important customer may have more interactions, information flow, and material flow. When configuring supply chain, it is important to know the proportional of each link among all providers from the previous stage. (Lambert & Cooper, 2000).

Table 1 The level of independent variables

Factors	Level 1 (1)	Level 2 (-1)
Forecasting methods	Moving Average r=5	Exponential Smoothing $\alpha=0.5$
Lead time (n)	n=1	n=10
Information sharing	Distributed	Centralized
The method of linking with forward stage	1link 2	1link 3
Supply chain distribution	Average	Extreme

(2) Response variable: this paper use bullwhip effect to be response variable. Bullwhip effect can be measured in two dimensions: Partial bullwhip effect (PBWE) and Total bullwhip effect (TBWE). Both equations quantify the bullwhip effect in term of a ratio of order variance(Wangphanich, Kara, & Kayis, 2007).

$$PBWE_k = \frac{\text{Var}(q_k)/\text{Mean}(q_k)}{\text{Var}(D_k)/\text{Mean}(D_k)} \quad (4)$$

$$TBWE_k = \frac{\text{Var}(q_k)/\text{Mean}(q_k)}{\text{Var}(\sum_{i=1}^n EC_i)/\text{Mean}(\sum_{i=1}^n EC_i)} \quad (5)$$

Where  $q_k$ , order placed at SC unit  $k$

$EC_i$ , end customer demand  $i$

$k$ , supply chain unit in a supply chain (  $k = 1, 2, \dots, n$ )

$i$ , number of end customer in the same chain

$D_k$ , demand from downstream partner at SC unit  $k$

### 3 ANALYSIS AND RESULT

The experiment was divided into two steps: Parameter selection and  $2^k$  Design. Parameter selection is use Regression Analysis to select. After that, using important parameters to performance  $2^k$  Design to find optimal setting.

The Minitab is statistical analysis software and in common use in academic and industrial. Because it including a complete analysis tools and easy to use. This research use Minitab for executed design of experiments.

### 3.1 Parameter selection

The factors from the model assumption scenario, the setting factors are: A: ratio, B: link, C: lead time, D: Forecasting method, E: information sharing. The response variable Y is total bullwhip effect (TBWE).

Regression analysis of five factors is shown in Table 2. P-value of A: ratio and B: link are large than 0.05, thus, here select C: lead time, D: Forecasting method, and E: information sharing to be main significant factors.

Table 2 Input factors selected by Regression Analysis

Term	Effe	Coef	SE Coef	T	P
Constant		12.349	0.4331	28.51	0.000
A:ratio	-	-0.248	0.4331	-0.57	0.567
B:link	1.54	0.770	0.4331	1.78	0.077
C:lead time	-	-1.365	0.4331	-3.15	0.002
D: Forecasting method	-	-4.796	0.4331	-11.07	0.000
E: information sharing	20.0	10.016	0.4331	23.13	0.000
S = 6.00125 R-Sq = 78.29% R-Sq(adj) = 77.71%					

### 3.2 $2^k$ Design

After select significant factor, we executed the experiment of 23 factorial design and 6 replicates. The interaction analysis result shown in Table 3, we could found the P-value

of C 、 D 、 E 、 CD 、 CE 、 DE less than 0.05. And it is significant of 2-way interactions.

R2 measures the proportion of total variability explained by the model. From Table 3, we could found R-Sq is highly to 94.17% .But it always increases as factors are added to the model, even if these factors are not significant. The R-Sq (adj) statistic is adjusted for the “size” of the model. The R-Sq (adj) can actually decrease if no significant terms are added to a model. Accordingly, the R-Sq(adj) of 93.15% has highly explanation ability.

Table 3 Interaction analysis

Term	Effect	Coef	SE Coef	T	P
Constant		12.349	0.5391	24.0	0.000
C:lead time	-	-2.687	0.5391	-4.98	0.000
D: Forecasting method	-	-5.230	0.5391	-9.7	0.000
E: information sharing	21.80	10.900	0.5391	20.2	0.000
C:lead time*D: Forecasting method	2.235	1.117	0.5391	2.07	0.045
C:lead time*E: information sharing	-	-2.999	0.5391	-5.56	0.000
D: Forecasting method*E: information sharing	-	-4.729	0.5391	-8.77	0.000
C:lead time*D: Forecasting method*E: information	2.573	1.286	0.5391	2.39	0.022
S = 3.73501 R-Sq = 94.17% R-Sq(adj) = 93.15%					

The ANOVA shown in Table 4, we could figure out the p-value of main effects and 2-way interactions are less than 0.05. Therefore, man effects and interactions are significant. The result is as same as Table 3.

Table 4 Analysis of Variance

Source	D	Seq SS	Adj SS	Adj	F	P
Main Effects	3	7362.65	7362.65	2454.	175.	0.0
2-Way Interactions	3	1565.32	1565.32	521.7	37.4	0.0
3-Way Interactions	1	79.42	79.42	79.42	5.69	0.0
Residual Error	40	558.01	558.01	13.95		
Pure Error	40	558.01	558.01	13.95		
Total	47	9565.41				

Figure 3 shows the main effects plot for TBWK. There has minimum TBWK when C:

lead time set 1, or D: Forecasting method set moving average, or E: information sharing set centralized.

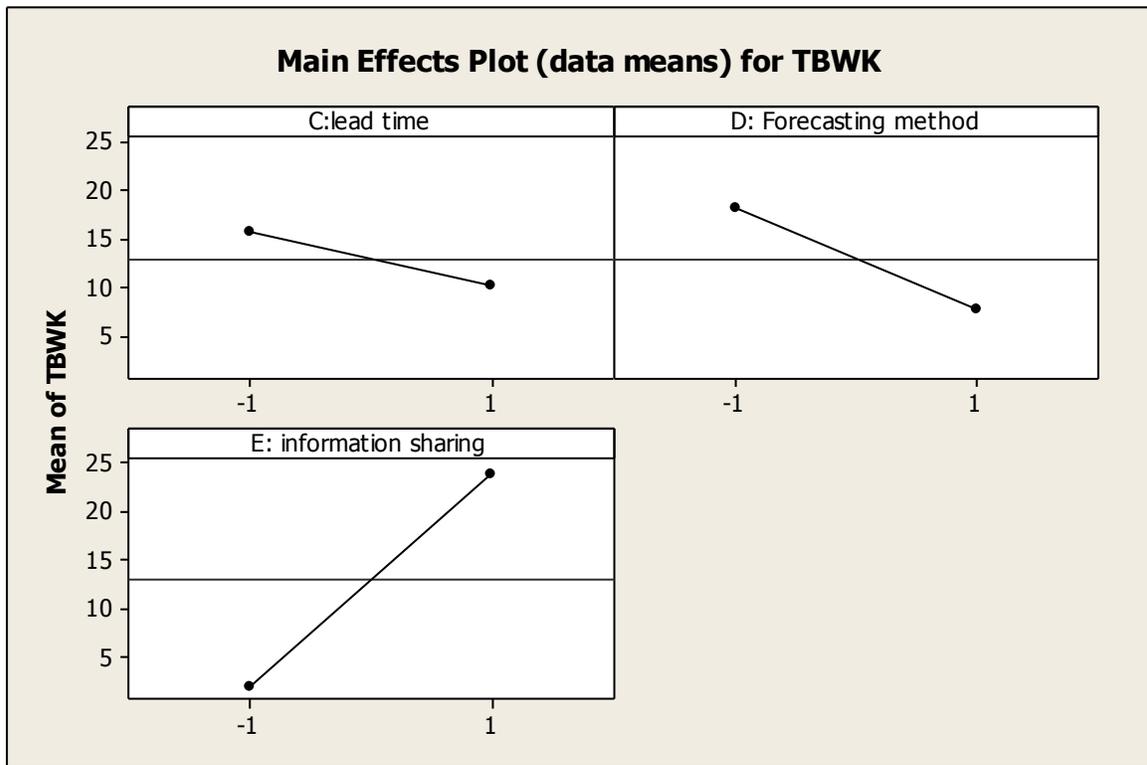


Figure 3 Main Effects Plot for TBWK

Figure 4 shows the interaction plot for TBWK. The picture of upper-left part show the C: lead time set 1 and D: Forecasting method set 1(moving average) has minimum TBWK. The picture of upper-right part show the C: lead time set 1 and E: information sharing set -1(centralized) has minimum TBWK. And lead time and information sharing is positive correlation. The picture of upper-right part show the C: lead time set 1 and E: information sharing set -1(centralized) has minimum TBWK. The picture of lower-right part show the D: Forecasting method set 1(moving average) and E: information sharing set -1(centralized) has minimum TBWK.

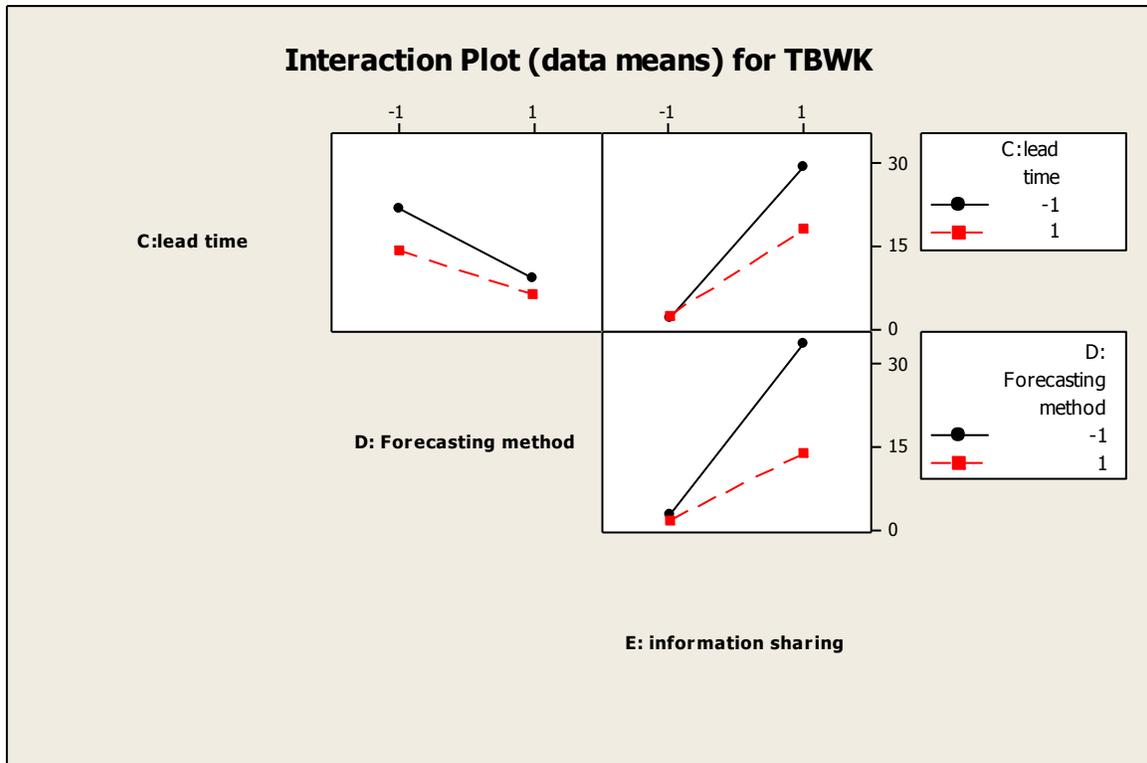


Figure 4 Interaction Plot for TBWK

Figure 5 shows the cube plot for TBWK. There has minimum TBWK 1.3987 if C: lead time set -1(10), and D: Forecasting method set 1(moving average), and E: information sharing set -1(centralized). Even though the results of lead time are different among cube plot and main effects and interaction plot, it does not affect the accuracy of the experiment. In the ANOVA of Table 4, 3-Way Interactions is non-significant. The interaction between the three factors that affect the bullwhip effect is not significant. In the figure, the values are little difference between 1.3981 and 1.6857. Only when the situation of D: Forecasting method set 1(moving average) and E: information sharing set -1(centralized), lead time 10 better then lead time 1. That's mean, if the supply chain use forecasting method of moving average and all information will shared with manufacturers, lead time is not important factor.

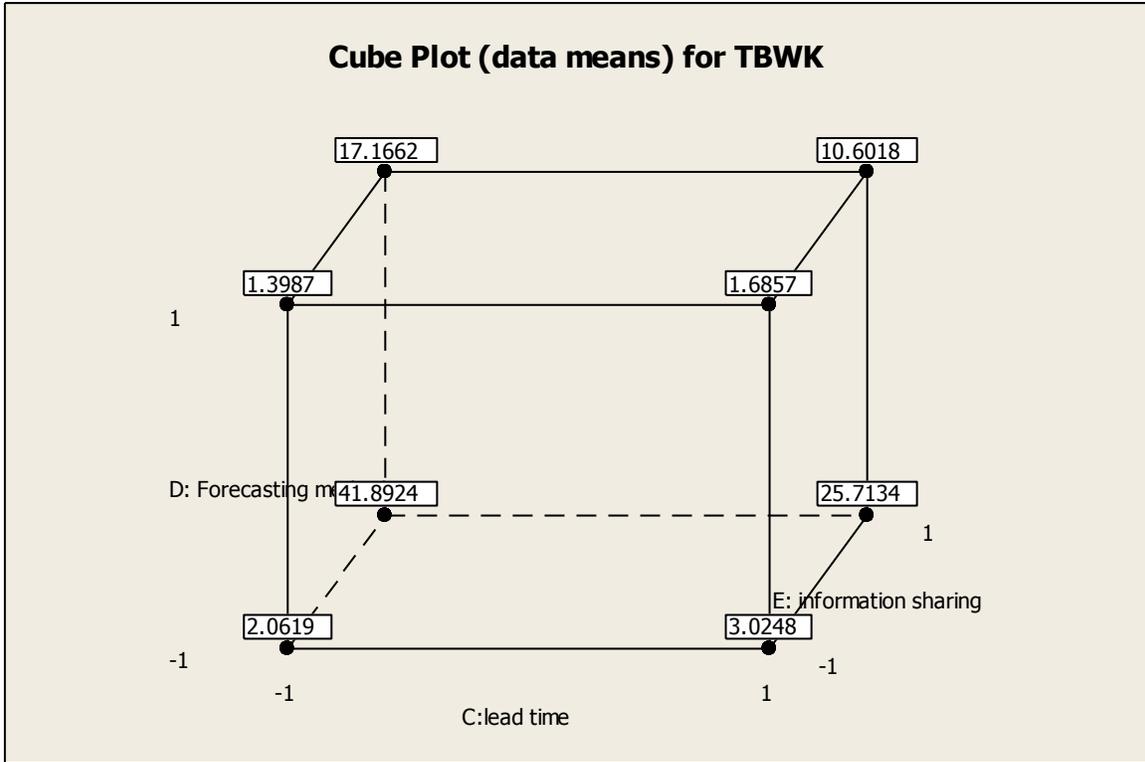


Figure 5 Cube Plot for TBWK

#### 4 CONCLUSIONS

In a global market, the performance of supply chain could be measured via the bullwhip effect. This research constructs a supply chain of four-stage, every stage has three sites. This model has five basic factors such as ratio, link, lead time, forecasting method, and information sharing. We use design of experiment (DOE) and discuss the optimal configuration of supply chain with minimum bullwhip effect.

At first, this study selects significant factors by regression analysis. The main factors are lead time, forecasting method, and information sharing. The method of linking with forward stage and supply chain distribution are not significant factors. It means configuration of supply chain structure would not significantly affect the bullwhip effect.

Then, use analysis of  $2^k$  design to find the optimal configuration of supply chain. The

result of main factors, lead time setting as 1, and forecasting method setting as moving average, and information sharing setting centralized has minimum TBWK. Otherwise, if the supply chain use forecasting method of moving average and all information will shared with manufacturers, lead time is not important factor.

This study contains only a few basic factors of supply chain. Future research can be added to the supply chain bullwhip effect of different factors to be explored in a comprehensive study of all factors, it may be more comprehensive results.

## References

- Bhattacharya, R., & Bandyopadhyay, S. (2011). A review of the causes of bullwhip effect in a supply chain. *The International Journal of Advanced Manufacturing Technology*, 54, 1245-1261. doi: 10.1007
- Graves, S. C., & Willems, S. P. (2005). Optimizing the supply chain configuration for new products. *Management Science* 51(8), 1165-1180.
- Kahn, J. A. (1987). Inventory and the Volatility of Production. *American Economic Review*, 77(4), 667-679.
- Lambert, D. M., & Cooper, M. C. (2000). Issues in Supply Chain Management. *Industrial Marketing Management*, 29, 65-83.
- Lee, H. L., Padmanabhan, V., & Whang, S. (1997a). The Bullwhip Effect In Supply Chains. *Sloan Management Review*, 38(3), 93-102.
- Lee, H. L., Padmanabhan, V., & Whang, S. (1997b). Information Distortion in a Supply Chain: The Bullwhip Effect. *Management Science*, 43(4), 546-558.
- Li, G., Wang, S., Yan, H., & Yu, G. (2005). Information transformation in a supply chain: a simulation study. *Computers and Operations Research* 32(3), 707-725.

Mentzer, J. T., & Kahn, K. B. (1995). Forecasting technique familiarity, satisfaction, usage, and application. *Journal of Forecasting*, 14, 465-476.

Montgomery, D. C. (2009). *Design and Analysis of Experiments, 7th Edition*. New York: John Wiley and Sons.

Nepal, B., Monplaisir, L., & Famuyiwa, F. (2010). *Supply Chain Configuration Model for New Product Development: A Multi-objective Approach*. Paper presented at the POMS 21th Annual Conference, Canada.

Wangphanich, P., Kara, S., & Kayis, B. (2007). *A Simulation Model of Bullwhip Effect in a Multi-Stage Supply Chain*. Paper presented at the Industrial Engineering and Engineering Management, 2007 IEEE International Conference