

An impact analysis of forecasting methods and forecasting parameters on bullwhip effect

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Abstract. Bullwhip effect is an increase of variance of demand fluctuation from downstream to upstream of supply chain. Forecasting methods and forecasting parameters were recognized as some factors that affect bullwhip phenomena. To study these factors, we can develop simulations. There are several ways to simulate bullwhip effect in previous studies, such as mathematical equation modelling, information control modelling, computer program, and many more. In this study a spreadsheet program named Bullwhip Explorer was used to simulate bullwhip effect. Several scenarios were developed to show the change in bullwhip effect ratio because of the difference in forecasting methods and forecasting parameters. Forecasting methods used were mean demand, moving average, exponential smoothing, demand signalling, and minimum expected mean squared error. Forecasting parameters were moving average period, smoothing parameter, signalling factor, and safety stock factor. It showed that decreasing moving average period, increasing smoothing parameter, increasing signalling factor can create bigger bullwhip effect ratio. Meanwhile, safety stock factor had no impact to bullwhip effect.

1. Introduction

In this globalization era, supply chain growth become faster and competition among supply chains become tighter. Supply chain that can survive is the ones who have good quality in serving and fulfilling customer needs. One of the ways to increase customer service quality is managing supply chain efficiently and effectively. Supply chain system needs collaboration with many parties such as factory, warehouse, distributor, wholesaler, retailer, and customer [1]. Company management has to pay attention about supply chain arrangement because there are many parties and processes involved. There is also uncertainty in demand and fulfilment rate. The most important supply chain processes are ordering and delivering goods [1]. Excess inventory and backlog can happen if supply chain parties concerned only about their own profit and lack of coordination in ordering goods.

From Figure 1, it can be seen that orders quantity become more fluctuated from downstream to upstream of supply chain. It means that in the upstream of supply chain, the value of orders variance amplification become greater. Retailer, wholesaler, distributor, and even manufacturer purposely order more than necessary to their own upstream of supply chain. They do that to anticipate demand fluctuation from downstream of supply chain. This condition is known as bullwhip effect.



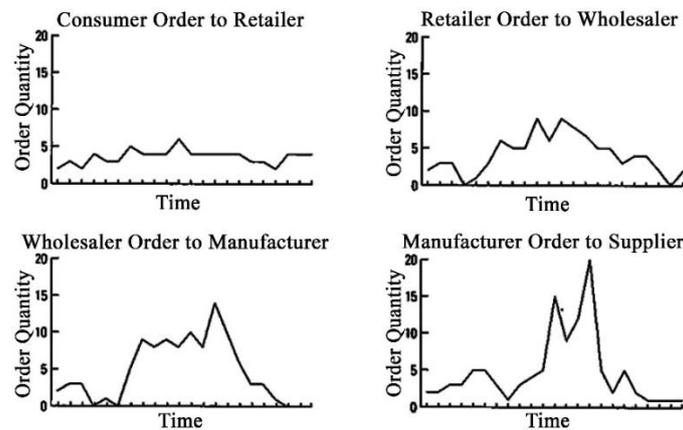


Figure 1. Increasing Orders Variance Amplification from Downstream to Upstream of Supply Chain .

Figure 1 showed that graph is one of the ways to represent bullwhip effect [2]. Bullwhip effect also can be understood and illustrated with physical model, computer program, mathematic equation, and combination of those models. Computer modelling is an effective, efficient, and up-to-date tool for simulation. Bullwhip effect modelling with computer program has been conducted by several previous studies such as Li [3], Lambrecht and Dejonckheere [4], and Boute and Lambrecht [5].

The purpose of the study is analysing impact of forecasting methods and forecasting parameters to the bullwhip effect using Bullwhip Explorer [5]. The remainder of this paper is organized as follows. Section 2 provides theoretical background about bullwhip effect, previous bullwhip effect studies, and Bullwhip Explorer program. Section 3 presents the research method. Section 4 discusses about input data and simulation result. Section 5 concludes the research and presents future research directions.

2. Theoretical Background

Lack of coordination in supply chain occurs either because of different stages of the supply chain have conflicting objectives or because of delayed and distorted information flows between stages [6]. This condition can cause bullwhip effect. Bullwhip effect is a phenomenon where order to the supplier tend to have larger variance than sales to buyer and the distortion propagates upstream of supply chain in amplified form [2]. Chen et al. in [5] stated the bullwhip effect equation as below:

$$\text{Bullwhip effect} = \frac{\text{Variance of Orders}}{\text{Variance of Demand}} \quad (1)$$

There are four causes of the bullwhip effect [2] :

1. Forecasting methods and parameters choice

If an upstream of supply chain relies only on the order data from its downstream, it will cause lose track of the real demand pattern. In this case there will be double forecasting that can lead to bullwhip effect. Wrong forecasting methods and parameters also can cause bullwhip effect.

2. The rationing and shortage gaming

Downstream of supply chain sometimes orders to upstream of supply chain more than the actual necessity to defend from lack of goods in the future. When the demand decrease again there will be many cancellations of order and this condition causes bullwhip effect.

3. Order batching

When inventory of a level of supply chain decreases, that level usually does not order directly because the order is based on batch or accumulated demand. Order batching is done to reduce order cost and transportation cost, but it can result on bullwhip effect because the orders from downstream represent accumulated demand, not the actual demand.

4. Price fluctuation

One level of supply chain can give promotion in form of discount, bonus, coupon, and many more. This can result on increasing purchase from downstream of supply chain in promotion period

although it has not needed the goods. When the price is returned to normal again, the demand decreases. This condition will cause bullwhip effect and piled-up inventory.

There are several kinds of bullwhip effect research such as empirical study, experiment, analytical study, and mathematical model [7]. Mathematical model can precisely quantify the bullwhip effect and its causes to predict system respond to several kinds of factor. One of the ways to create mathematical model is using simulation. There are some previous bullwhip effect studies using simulation. Li [3] made a controlling mathematical model that show inventory fluctuation resulted from information or connectivity availability rate difference among supply chain parties. Lambrecht and Dejonckhere [4] made a mathematical and graphical model in spreadsheet program for three echelon of supply chain. The input is inventory policy and parameter. The output is demand and order variance of supplier, order variance of wholesaler, total cost, and cycle service level and fill rate.

Boute and Lambrecht [5] made a mathematical and graphical model in a spreadsheet program. Demand parameters that must be defined are mean demand, variance of error, physical lead time, safety factor, unit holding cost per period, unit backlog cost per period, unit switching cost period, and safety stock factor. Forecasting methods that can be used are mean demand, moving average, exponential smoothing, demand signal processing, and minimum expected mean squared error. Forecasting parameters that can be defined are moving average period, smoothing parameter, signalling factor, and safety stock factor. The output is bullwhip effect ratio, net stock amplification, cycle service level, fill rate, average inventory cost per period, average switching cost per period, and bullwhip effect graphs.

3. Research Method

The study used Bullwhip Explorer spreadsheet program to analyse impact of forecasting methods and forecasting parameters to the bullwhip effect. We built two scenarios in this study. Scenario 1 was built to know impact of forecasting methods and their own parameters to bullwhip effect and other output. In this scenario, forecasting method was changed so we would know its impact to bullwhip effect. Some forecasting methods have its own forecasting parameter so the forecasting parameter was also changed to know its impact to bullwhip effect. Scenario 2 was built to know impact of safety stock factor to bullwhip effect and other output. In this scenario, safety stock factor was changed for each forecasting method. There were further explanations about the scenarios in section 4.

Total repetitions for each scenario with each method are thirty-five. Then, there was analysis impact of forecasting methods and parameters to bullwhip effect and other output such as net stock amplification, cycle service level, fill rate, average inventory cost/period, and average switching cost/period. Finally, the conclusion was drawn from result analysis.

4. Simulation and Analysis

4.1 Scenarios

Simulation of some scenarios is needed to understand impact of forecasting methods and forecasting parameters to bullwhip effect and other output. Each scenario and method is simulated thirty-five times. Demand data that are used are hypothetical data which are assumed as cassava chips demand at distributor. For each scenario, there are same input data as shown in Table 1:

Table 1. Same Input Data for Scenario 1 and 2.

Input Type	Input Data
Order policy	Standard Order-Up-To
Demand pattern	Independent and Identically Distributed (IID)
Mean demand	110 kg per day
Variance of error term	1 kg
Physical lead time	3 days
Unit holding cost per period	0.5 (0.5x1,000 = Rp 500)
Unit backlog cost per period	20 (20x1,000 = Rp 20,000)
Unit switching cost per period	2 (2x1,000 = Rp 2,000)

4.1.1. Scenario 1.

The purpose of scenario is to know impact of forecasting methods and their own parameters to bullwhip effect and other output. Safety stock factor that is used in scenario 1 is 1.645. Moving average period is a parameter of moving average. Smoothing parameter is a parameter of exponential smoothing and range from 0 to 1. Signaling factor is a parameter of demand signal processing and range from 0 to 1. Minimum expected mean squared error (MSE) also has autocorrelation coefficient as a forecasting parameter, but the value of that parameter is 0 if the demand pattern is IID. The input data for scenario 1 can be seen in Table 2.

Table 2. Input Data for Scenario 1.

	Method 1	Method 2					Method 3					Method 4				Method 5	
Forecasting Method	Mean Demand	Moving Average					Exponential Smoothing					Demand Signal Processing				Minimum Expected MSE	
Forecasting Parameter	-	Moving Average Period (Tm)					Smoothing Parameter					Signalling Factor				Autocorrelation Coefficient	
		1	3	5	10	20	1	0.75	0.5	0.25	0.05	1	0.75	0.5	0.25	0.05	0

4.1.2. Scenario 2.

The purpose of this scenario is to know impact of safety stock factor to bullwhip effect and other output. Five forecasting methods with its own forecasting parameter are also used in this scenario. Each forecasting method is simulated with three different safety stock factor. The input data for scenario 2 can be seen in Table 3.

Table 3. Input Data for Scenario 2.

	Safety Stock Factor 1	Safety Stock Factor 2	Safety Stock Factor 3
Safety Stock Factor Value	2.326	1.645	0.842
Forecasting Method and Forecasting Parameter	1) Mean Demand 2) Moving Average (moving average period = 5) 3) Exponential Smoothing (smoothing parameter= 1) 4) Demand Signal Processing (signalling factor = 1) 5) Minimum Expected MSE		

4.2 Simulation Result

The average simulation output value of scenario 1 can be seen in Table 4. The average simulation output value of scenario 2 can be seen in Table 5.

Table 4(a). Average Simulation Output Value of Scenario 1.

Output	Method 1 Mean Demand	Method 2 Moving Average Parameter = Moving Average Period (Tm)					Method 3 Exponential Smoothing Parameter = Smoothing Parameter (α)				
		1	3	5	10	20	1	0.75	0.5	0.25	0.05
		Bullwhip (analytical)	1.00	41.00	7.22	3.88	2.12	1.48	41.00	21.40	10.33
Bullwhip (simulated)	1.00	40.64	7.37	4.00	2.27	1.59	41.51	21.54	10.46	4.29	1.55
NSA (analytical)	4.00	20.00	9.33	7.20	5.60	4.80	20.00	13.60	9.33	6.29	4.41
NSA (simulated)	3.93	19.90	9.42	7.13	5.72	4.82	19.95	13.57	9.61	6.30	4.47
Cycle Service Level (%)	98.60	83.59	90.43	93.81	96.05	97.41	83.40	87.39	90.97	94.90	97.54
Fill Rate (%)	99.98	99.56	99.83	99.90	99.94	99.96	99.56	99.72	99.83	99.92	99.97

Average Inventory Cost/period	2.37	12.01	5.81	4.12	3.18	2.66	12.09	8.36	5.74	3.71	2.59
Average Switching Cost/period	2.24	17.91	6.35	4.67	3.48	2.85	18.32	12.58	8.34	5.12	2.84

Table 4(b). Average Simulation Output Value of Scenario 1.

Output	Method 4 Demand Signal Processing Parameter = Signalling Factor (γ)					Method 5 Minimum Expected MSE Parameter = Autocorrelation Coefficient (ρ)
	1	0.75	0.5	0.25	0.05	$\rho=0$
	Bullwhip (analytical)	5.00	3.63	2.50	1.63	1.11
Bullwhip (simulated)	5.00	4.26	2.63	1.42	1.00	1.00
NSA (analytical)	5.00	4.56	4.25	4.06	4.00	4.00
NSA (simulated)	5.01	4.74	4.23	3.99	4.02	3.96
Cycle Service Level (%)	97.26	97.58	97.80	98.35	98.38	95.30
Fill Rate (%)	99.96	99.97	99.97	99.98	99.98	99.93
Average Inventory Cost/period	2.84	2.72	2.55	2.45	2.46	2.87
Average Switching Cost/period	6.20	5.75	4.22	2.71	2.28	2.26

Table 5(a). Average Simulation Output Value of Scenario 2 (Part 1).

Output	Method 1 Mean Demand			Method 2 Moving Average			Method 3 Smoothing		
	2.326	1.645	0.842	2.326	1.645	0.842	2.326	1.645	0.842
	Bullwhip (analytical)	1.00	1.00	1.00	3.88	3.88	3.88	41.00	41.00
Bullwhip (simulated)	1.00	1.00	1.00	3.98	4.00	4.00	40.97	41.51	41.21
NSA (analytical)	4.00	4.00	4.00	7.20	7.20	7.20	20.00	20.00	20.00
NSA (simulated)	3.98	3.93	3.94	7.31	7.13	7.19	19.86	19.95	19.70
Cycle Service Level (%)	99.61	98.60	89.32	96.46	93.81	78.07	88.39	83.40	70.34
Fill Rate (%)	100	99.98	99.85	99.93	99.90	99.57	99.70	99.56	99.07
Average Inventory Cost/period	2.59	2.37	4.44	3.56	4.12	10.44	9.24	12.09	21.97
Average Switching Cost/period	2.23	2.24	2.25	4.68	4.67	4.63	18.22	18.32	18.39

Table 5(b). Average Simulation Output Value of Scenario 2.

Output	Method 4 Demand Signal Processing			Method 5 Minimum Expected MSE		
	2.326	1.645	0.842	2.326	1.645	0.842
	Bullwhip (analytical)	5.00	5.00	5.00	1.00	1.00
Bullwhip (simulated)	4.97	5.04	5.02	1.00	1.00	1.00
NSA (analytical)	5.00	5.00	5.00	4.00	4.00	4.00
NSA (simulated)	4.98	4.94	4.98	3.87	3.96	3.84
Cycle Service Level (%)	99.16	97.50	86.05	99.65	95.30	89.38
Fill Rate (%)	99.99	99.97	99.78	100.00	99.93	99.86
Average Inventory Cost/period	2.76	2.80	6.02	2.60	2.87	4.28
Average Switching Cost/period	6.10	6.18	6.25	2.25	2.26	2.31

From scenario 1 result, it can be seen that if the forecasting method is mean demand, bullwhip ratio is one means that there is no bullwhip effect. It is because of the steadiness of the forecasting result, which is average of past demand. The quantity is only added if there is unfulfilled demand. Because of that, variance of order and variance of demand have same value and do not result on bullwhip effect.

Moving average forecasting method has impact to bullwhip effect. Bigger moving average period cause smaller bullwhip effect ratio, smaller net stock amplification, bigger cycle service level, bigger fill rate, smaller average inventory and switching cost per period. It is because forecasting uses more past demand data when the moving average period is bigger so forecasting result will approach mean demand. Exponential smoothing method has impact to bullwhip effect. Smaller smoothing parameter cause smaller bullwhip effect, smaller net stock amplification, bigger cycle service level, bigger fill rate, smaller average inventory and switching cost per period. It is because if the smoothing parameter value near zero, it will give less weight to single past demand.

Demand signal processing method has impact to bullwhip effect. Smaller signalling parameter cause smaller bullwhip effect, smaller net stock amplification, bigger cycle service level, bigger fill rate, smaller average inventory and switching cost per period. It is because if signalling factor value near zero, the order will not be set by the change of demand. Minimum expected mean squared error with zero autocorrelation coefficient does not have impact on bullwhip effect because customer demand variability is reduced, not amplified.

From scenario 2, it can be seen that smaller signalling parameter cause no significant effect to bullwhip effect, no significant effect to net stock amplification, smaller cycle service level, smaller fill rate, bigger average inventory per period and no significant effect to switching cost per period. It is because safety stock factor only affects safety stock quantity and does not affect forecasting result.

5. Conclusion and Future Research

Forecasting methods and forecasting parameters have impact on bullwhip effect. Mean demand forecasting method does not have impact on bullwhip effect because the forecasting result is always steady. Moving average forecasting method has impact on bullwhip effect but can be reduced by using bigger moving average period or more past demand data. Exponential smoothing forecasting method has impact on bullwhip effect but can be reduced by using smaller smoothing parameter because it will give less weight to single past demand. Demand signal processing has impact to bullwhip effect but can be reduced by using smaller signalling factor because the order will not be set by the change of demand. Minimum expected mean squared error with zero autocorrelation coefficient does not have impact on bullwhip effect because customer demand variability is reduced.

Future research about bullwhip effect in more than two echelon using Bullwhip Explorer or other simulation model can be conducted to learn more about the phenomenon. This research only considered one of four bullwhip effect causes which is forecasting methods and parameters choice so in the future, the three other causes should be included. In the future, raw data can also be the input so demand pattern between different situations can be observed and differentiated even though the mean and variance of those situations are the same.

6. References

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