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Study on the Impact of Supplier's Lead Time and Forecast Demand Updating on Retailer's Order Quantity Variability on Bullwhip Effect in Supply Chain Management

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Abstract

A supply chain consists of all parties involved, directly or indirectly, in fulfilling a customer request or demand. The supply chain not only includes the manufacturers and suppliers, but also transporters, warehouses, retailers, and finally the end consumers themselves. The objective of every supply chain is to maximize the overall value generated. The value a supply chain generates is the difference between what the final product is worth to the customer and the effort the supply chain expends in filling the customer's request. An important phenomenon in Supply Chain Management is known as bullwhip effect (BWE), which suggests that the demand variability increases as one moves up a supply chain. Bullwhip effect is an undesirable phenomenon in the supply chain which exacerbates the supply chain performance. The impact of BWE is to increase manufacturing cost, inventory cost, replenishment lead time, transportation cost, labor cost for shipping and receiving, cost for building surplus capacity and holding surplus inventories, and to decrease level of product availability and relationship across the supply chain. Various factors can cause bullwhip effect, one of which is customer demand forecasting. In this study, impact of forecasting methods on the bullwhip effect and mean square error has been considered.

The preceding study highlights the effect of forecasting technique, order processing cost and demand pattern on BWE and mean square error (MSE). The BWE and MSE have been evaluated using MATLAB coding. The results were analyzed using ANOVA and Fuzzy Logic, and finally the optimal parameters for minimum values of BWE and MSE have been determined

Key words - supply chain management, bullwhip effect, demand fluctuations, forecasting, manufacturing, and materials demand.

Introduction

Supply chain management (SCM) is a set of approaches utilized to efficiently integrate suppliers, manufactures, warehouses and stores so that merchandise is produced and distributed at the right quantities, to the right location and at the right time in order to minimize system wide cost while satisfying service level requirement. It can also be defined as the coordination of production, inventory, location and transportation among the participants in a supply chain to achieve the best mix of responsiveness and efficiency for the market being served. Supply chain management arose in late 1980s and came into widespread use in 1990s. Earlier it was known as "Logistics" and "Operations Management". There is a difference between the concept of supply chain management and traditional concept of logistic.

Effective supply chain management requires simultaneous improvement in both customer service level and the internal operating efficiencies of the companies in the supply chain. Customer service at its most basic level means consistently high order fill rates, high on-time delivery rates and very low rate of products returned by customers. Internal efficiency in an organization of a supply chain means that these organizations get an attractive rate of return on their investments in inventory and other assets, and also find ways to lower their operating and sales expenses.
A typical supply chain includes the following stages:

- Customer
- Retailer
- Wholesaler/distributor
- Manufacturer
- Component/raw material supplier

Objectives of Supply Chain

The main objective of the supply chain is to add value to a product or in other words to increase the throughput while simultaneously reducing both inventory and operating expenses. Throughput refers to the rate at which sales to the end customer occur. Supply chain management is a tool to accomplish following strategic objectives:-

- Reducing working capital
- Taking assets of the balance sheet
- Accelerating cash to cash cycles
- Increasing inventory turns

Bullwhip effect

Bullwhip effect is a problem which is related with the supply chain management. Supply chain management is related from the customer to raw material suppliers. The bullwhip effect is an observed phenomenon and forecast driven. The Bullwhip effect is mainly the fluctuation of the demand of product. When the information of demand order is distorted from stage to stage in the supply chain management, the demand order is fluctuated along the supply chain. Bullwhip effect is a trend of large and larger swing in inventory in response to changes in customer demand. The concept of Bullwhip effect was first appeared in *Industrial Dynamics* (1961) by "Jay Forrester"

Effect on the Supply Chain Performance

Lack of coordination in a supply chain occurs if each stage optimizes only its local objectives, without considering the impact on the complete chain. The performance of the entire supply chain is impaired if each stage of the chain tries to optimize its local objectives. Lack of coordination also results in information distortion within the supply chain. The performance measures which are directly affected by the lack of supply chain coordination are:-

- ➢ Manufacturing Cost
- ➢ Inventory Cost
- ➢ Replenishment Lead Time
- ➢ Transportation Cost
- ➢ Labor Cost for Shipping and Receiving
- ➢ Level of Product Availability
- ➢ Relationship Across the Supply Chain

➢ The lack of coordination reduces the profitability of a supply chain by making it more expensive to provide a given level of product availability.

Objectives of the Project

The objectives of the present research work are as follows:

1. Understanding the basic structure of supply chain network and the concept of BWE.
2. Determination of BWE and MSE through demand generated using different demand patterns.
3. Analysis of the results using statistical methods.
4. Optimization of parameters for minimum BWE and MSE.

Literature Review

Marlene Silva Marchena (2010) showed that for certain types of demand processes, the use of the optimal forecasting procedure that minimizes the mean squared forecasting error leads to significant reduction in the safety stock level. This highlights the potential economic benefits resulting from the use of this time series analysis.

Ling-Tzu Tseng et al. (2011) proposed a prediction system based on an evolutionary least-mean-square algorithm to estimate the downstream demand, which consequently enables the batch ordering of manufacturer to close the estimated inventory level to cope with the bullwhip effect by taking into account the holding and backorder costs.

Sunong Wua et al. (2011) applied ABMS (Agent-based model and simulation), as one of the scientific and dynamic research methods for complex system, to establish a supply chain model and determine its abundant bullwhip effect phenomenon under swarm platform. It proves the ABMS is the effective way to study the bullwhip effect in complex supply chain.

Ahmed Shaban et al. (2012) investigated the impact of various classical ordering policies on ordering and inventories in a multi-echelon supply chain through a simulation study. In addition a proposed ordering policy that relies on information sharing in a decentralized way is proposed to mitigate the bullwhip effect.

Dean C. Chatfield and Alan M. Pritchard Prabhu (2013) build a hybrid agent/discrete-event simulation model of a supply chain and execute it under various conditions of demand variance, lead-time variance, information sharing, and return allowance. They find that permitting returns significantly increases the bullwhip effect.

Borut Buchmeistera et al. (2014) simulated a simple three-stage supply chain using seasonal (SM) and de-seasonal (DSM) time series of the market demand data in order to identify, illustrate and discuss the impacts of different level constraints on the BE. The results are shown that at higher OEE level manufacturers have less variability in production processes; the BE is stronger in DSM than in SM.

Marly Mizue Kaibara de Almeida et al. (2014) provided results of trust and collaboration that lead to the mitigation of the bullwhip effect in supply chain management through a systematic literature review. The analysis found that few studies focused on addressing behavioural aspects to reduce the bullwhip effect. Most of them focused on operational and quantitative aspects.

Xiangyu Li (2015) put forward some weakening measures aimed at reasons of Bullwhip Effect including strengthening information sharing, adjusting structure of supply chain, preventing shortage game and strengthening inventory control.

Ahmad Sadeghi (2016) done a comparison of the bullwhip effect measure when two main forecasting methods i.e. exponential smoothing and moving average are used and empirical results are provided. At last, a cost analysis is conducted based on shortage and holding cost under different bullwhip effect measures.

Matloub Hussain et al. (2017) investigated the impact of capacity constraints and safety stock on the backlog bullwhip effect in a model of a two-tier supply chain. This research gives supply chain operations managers and designers a practical way to develop a trade-off between capacity and safety stock at different echelons and to take better decisions about their capacity and safety stocks.

B. Sravani and Dr. G. Padmanabhan (2018) investigated the selection of appropriate forecasting parameters in reducing bullwhip effect. The results revealed that increase of smoothing parameter levels had significant impact on bullwhip effect.

Junhai Ma and Xiaogang Ma (2018) established the supply chain model with two retailers which followed the different first-order autoregressive models and employed the order- up-to inventory policy in order to consider the market competition. It is interesting to note that market competition and the consistency of demand volatility between two retailers are also two important factors leading to the bullwhip effect apart from autoregressive coefficient, lead time and the span of forecast.

Bullwhip Effect Analysis

Bullwhip effect is a wasteful phenomenon that occurs due to lack of information across the supply chain. This phenomenon is one of the current challenges that a supply chain faces. This makes it essential to understand the performance of supply chain on the basis of bullwhip effect and mean square error (MSE) with the variation of process parameters. In this study bullwhip effect and mean square error are considered as measures of supply chain performance. To achieve this, the present chapter describes process parameters used for analyzing the two staged supply chain and also presents detailed methodology related to design of experiment technique based on ANOVA method

Selection of accurate forecasting method

Charts only give the interaction of all forecasting with actual demand and also give accuracy and stability measure approximately. However for choosing best forecasting method for the Product related to accuracy of forecasting as discussed it is required to consider for all the forecasting methods.

Demand Forecasting in a Supply Chain

Forecasting of future demand is essential for taking decisions related to supply chain. Demand forecasting is the activity of estimating the quantity of a product or service that consumers will purchase in future. It involves techniques including both informal and quantitative methods. Informal methods include educated guess, prediction, intuition etc whereas quantitative methods are based on the use of past sales data or current data from test markets. It may be used in making pricing decisions, in assessing future capacity requirements, or in making decisions on whether to enter a new market not.

Characteristics of Forecast

These are the characteristics of forecast which supply chain managers should be aware of:-

- Forecasts are always inaccurate and should thus include both the expected values of forecast and measure of forecast error.
- Long-term forecast is usually less accurate than short-term forecast as it has a larger standard deviation of error relative to that in short-term forecast.
- Aggregate forecasts are usually more accurate than disaggregate forecasts, as they tend to have smaller standard deviation of error.
- As we move up the supply chain away from the end consumer, the companies suffer greater information distortion. But collaborative forecasting based on sales to end customer helps upstream enterprise reduce forecast error. Collaborative forecasting is the process of setting up a continual line of communication between distributors and those customers with the ability to predict the future needs of the products they buy from the distributors.

Components of a Forecast and Forecasting Methods

A company should identify the factors that influence the future demand and should ascertain the relationship between these factors and future demand. Some of these factors are:-

- Past demand
- Lead time of product replenishment
- Planned advertising or marketing efforts
- State of the economy
- Planned price discounts
- Actions that competitors have taken

The companies should understand the factors first and then select an appropriate forecasting methodology.

Basic Categories of Forecasting Method

Forecasting methods can be divided into the following four main categories:-

- Qualitative or judgmental methods
- Extrapolative or time series methods
- Causal or explanatory methods
- Simulation

- *Judgmental or qualitative methods* rely on expert's opinion in making a prediction for the future. They are most appropriate when little historical data is available or when experts have market intelligence that may affect the forecast.
- *Extrapolative or time series methods* use the past history of demand in making a forecast for the future. The objective of these methods is to identify the pattern in historic data and extrapolate this pattern for the future. They are based on the assumption that the past demand history is a good indicator of future demand.
- *Causal methods* of forecasting assume that the demand for an item depends on one or more independent factors (like price, advertising, competitor's price etc.). These methods seek to establish a relationship between the variable to be forecasted and independent variables. Once this relationship is established, future values can be forecasted by simply plugging in the appropriate values for the independent variables.
- *Simulation* forecasting method imitates the consumer choices that give rise to demand to arrive at a forecast. Using simulation, a firm can combine time-series and causal methods to answer questions like: What will be the impact of a price promotion? What will be the impact of a competitor opening a store nearby?

The observed demand always consists of two components that is a systematic component and random component. It is represented as:

Observed demand (O) = Systematic component(S) + Random component(R)

Systematic component measures the expected value of demand and consists of:-

- Base or current deseasonalized demand
- Trend or rate of growth or decline in demand for the next period
- Seasonality or the predictable seasonal fluctuation in demand

The random component is that part of the forecast that deviates from the systematic part.

Time-Series Forecasting Methods

The goal of any forecasting method is to predict the systematic component of demand and estimate the random component. In its most general form, the systematic component of demand contains a level, a trend, and a seasonal factor. The equation for calculating the systematic component may take form as shown below:-

Multiplicative: Systematic component = level × trend × seasonal factor Additive: Systematic component = level + trend + seasonal factor Mixed: Systematic component = (level + trend) × seasonal factor

Experimental Design

In conventional experiments, effect of only one factor is investigated independently at a time keeping all other factors at fixed levels. Therefore, visualization of impact of various factors in an interacting environment really becomes difficult. Thus, more experimental runs are required for the precision in effect estimation, general conclusions cannot be drawn and the optimal factor settings are difficult to obtain. To overcome this problem, design of experiment (DOE) approach is used to effectively plan and perform experiments, using statistics and is commonly used to improve the quality of products or processes. Design of experiments is a robust analysis tool for modeling and analyzing the influence of control factors on performance output.

Bullwhip effect in supply chain is controlled by number of parameters which collectively determine the performance output. Hence, in the present work ANOVA's parameter design can be adopted to optimize the process parameters leading to reduction of bullwhip effect and mean square error. The most important stage in the DOE lies in the selection of the control parameters and their level. In the experimental design three factors that are holding cost (Cp), method and demand pattern (Pp) with four, ten and four levels are considered respectively. The levels of the factors are represented as shown in Tables

Table 1: Representation of levels for the factor method

Level		Representation
Moving Average	n=50	1
	n=100	2
	n=200	3
	n=300	4
Exponential Smoothing	n=7, α=0.25	5
	n=7, α=0.5	6
	n=7, α=0.75	7
	n=15, α=0.25	8
	n=15, α=0.5	9
	n=15, α=0.75	10

MATLAB Codes

MATLAB is a numerical computing environment and a fourth-generation programming language developed by Math Works. This programming language allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages like C, C++, Java and FORTRAN. Using MATLAB, we can solve technical computing problems faster than with traditional programming languages, such as C, C++, and FORTRAN.

MATLAB codes were first written to generate demand for different conditions and then forecasting was done using the two previously mentioned methods and finally their respective bullwhip effect and mean square error were calculated.

Results and Discussion

The experimental design was created using ANOVA and then the MATLAB codes were run in that order to generate their respective bullwhip effect and mean square error which is shown. When the responses were analyzed, it was observed that there is a large variation amongst them, so it was necessary to normalize the responses. Depending upon the characteristics of the data sequence various methods have been used for data analysis of data preprocessing i.e. normalization. The normalization is taken by the following equations.

1) Lower-the-better (LB):
2) EQUATION
3) Higher-the-better (HB):
4) EQUATION

ANOVA is applicable for single objective criteria, so multi-objective criteria is converted to single objective criteria using Fuzzy Inference System to generate Multi performance characteristic index (MPCI). The MPCI values are shown in Table 2. The MPCI values are then analyzed and then the main effect plot for it is drawn in Minitab software.

Table 2: The observed values of BWE and MSE of each experimental run

Sr. No.	Responses		Sr. No.	Responses		Sr. No.	Responses		Sr. No.	Responses	
	BWE	**MSE**		**BWE**	**MSE**		**BWE**	**MSE**		**BWE**	**MSE**
1	0.1296	0.1684	21	2.3136	12.8301	41	0.3289	0.0903	61	0.3928	20.0764
2	0.509	18.2945	22	0.1046	1.1896	42	0.1486	0	62	0.3941	0.0402
3	0.1109	0	23	0.3923	0.086	43	0.1956	28.3577	63	0.1211	22.5869
4	0.5414	0	24	0.1169	0.1252	44	0.0234	0	64	0.644	14.7199
5	0.0446	0.2313	25	0.6676	0.0922	45	0.2119	0	65	0.1902	0
6	0.1063	0.0104	26	0.3368	22.4595	46	0.2677	29.1909	66	0.1943	21.3983
7	0.1209	26.0307	27	0.1752	0	47	0.6322	0.0432	67	0.1893	0
8	0.2262	0.1684	28	0.2529	0	48	0.0976	24.9277	68	0.1724	0.2655
9	0.1393	0	29	0.2056	29.538	49	0.5625	0.0098	69	0.8255	48.6484
10	0.2752	0	30	1.6504	16.3935	50	1.0196	19.1914	70	0.2358	0.0896
11	0.21	0.0876	31	1.7682	13.2703	51	1.0782	0.023	71	0.1372	31.5779
12	0.2224	24.1858	32	1.3962	13.0719	52	0.6367	0.1628	72	0.4164	28.9279
13	0.2014	0	33	0.2196	28.0224	53	0.1432	23.8526	73	0.5259	0
14	0.2581	19.1649	34	1.2637	18.1141	54	0.1529	0	74	0.7996	21.4335
15	0.158	0	35	0.0799	0.0664	55	0.5855	31.5779	75	0.4612	0
16	0.1611	23.6115	36	0.5073	47.9046	56	0.4203	0	76	0.1522	29.4007
17	0.9891	31.5229	37	0.1667	27.8624	57	1.1834	0.0341	77	0.5481	0.0016
18	0.1377	0	38	0.2083	24.5823	58	1.1085	46.0635	78	0.4122	0.159
19	0.1117	0	39	0.1206	0	59	0.2839	12.5504	79	1.263	63.0715
20	0.4115	26.1085	40	0.1898	0.1619	60	0.2245	0	80	0.0532	22.0875

Sr. No.	Responses		Sr. No.	Responses		Sr. No.	Responses		Sr. No.	Responses	
	BWE	MSE		BWE	MSE		BWE	MSE		BWE	MSE
81	0.0618	29.2464	101	0.137	0	121	0.3302	0	141	0.6985	38.8934
82	0.3392	0.017	102	0.0451	0.217	122	0.6724	32.2195	142	0.2024	0.0282
83	0.1489	0	103	0.033	0.2716	123	0.2796	29.0917	143	0.1025	0.0464
84	0.1875	0.0302	104	0.0597	0	124	0.0594	0.0876	144	0.0889	0
85	0.2462	0	105	0.1109	0	125	0.1556	0	145	0.4743	33.1291
86	0.3162	39.8289	106	0.3246	0.0117	126	2.9435	13.1172	146	0.46476	32.3566
87	0.2653	24.1224	107	0.6439	18.8508	127	0.2696	0	147	0.2614	0
88	0.5558	0	108	0.8656	0.0569	128	2.3707	91.6344	148	0.1579	24.675
89	0.5093	0	109	0.3386	0	129	0.1045	25.0139	149	0.4669	19.4359
90	0.3269	0	110	0.5083	0.0076	130	0.3147	0.0037	150	0.6657	27.7763
91	0.1536	0.2085	111	0.3752	0	131	0.5518	0.0399	151	0.976	0
92	0.31	0.1743	112	0.4483	0	132	0.2148	0.0073	152	0.293	0.0383
93	0.4959	0	113	0.1975	0	133	0.1844	0.036	153	1.1113	50.8351
94	0.0799	0.0127	114	0.4243	30.5566	134	1.2564	23.9599	154	0.2516	0.004
95	0.6291	0	115	0.5525	0	135	0.546	0.0145	155	0.3662	0
96	0.162	0	116	0.8279	20.9302	136	1.8589	64.5195	156	0.204	24.0227
97	0.0439	0	117	0.9651	42.5371	137	0.2078	28.1341	157	1.8237	0.0071
98	0.1645	0.2074	118	0.1636	0.0397	138	0.1436	21.3951	158	0.518	0
99	0.3587	0.0425	119	0.0601	0	139	0.4611	29.4007	159	0.2835	23.5904
100	0.19	0.0418	120	0.3643	23.3757	140	0.1522	26.0049	160	0.1148	0

Figure 1 shows the residual plot for MPCI where MPCI values are very close to the straight line and the histogram appears to be bell-shaped. This indicates that the MPCI values are normally distributed.

Table: 3 Mean Response

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cp	**3**	**0.062703**	**0.062703**	**0.020901**	**31.24**	**0.000**
Method	**9**	**1.497719**	**1.497719**	**0.166413**	**248.73**	**0.000**
DP	**3**	**0.153478**	**0.153478**	**0.051159**	**76.47**	**0.000**
Cp* Method	**27**	**0.047300**	**0.047300**	**0.001752**	**2.62**	**0.000**
Cp* DP	**9**	**0.012465**	**0.012465**	**0.001385**	**2.07**	**0.042**
Method* DP	**27**	**0.012465**	**0.210875**	**0.007810**	**11.67**	**0.000**
Error	**81**	**0.054192**	**0.054192**	**0.000669**		
Total	**159**	**2.038732**				

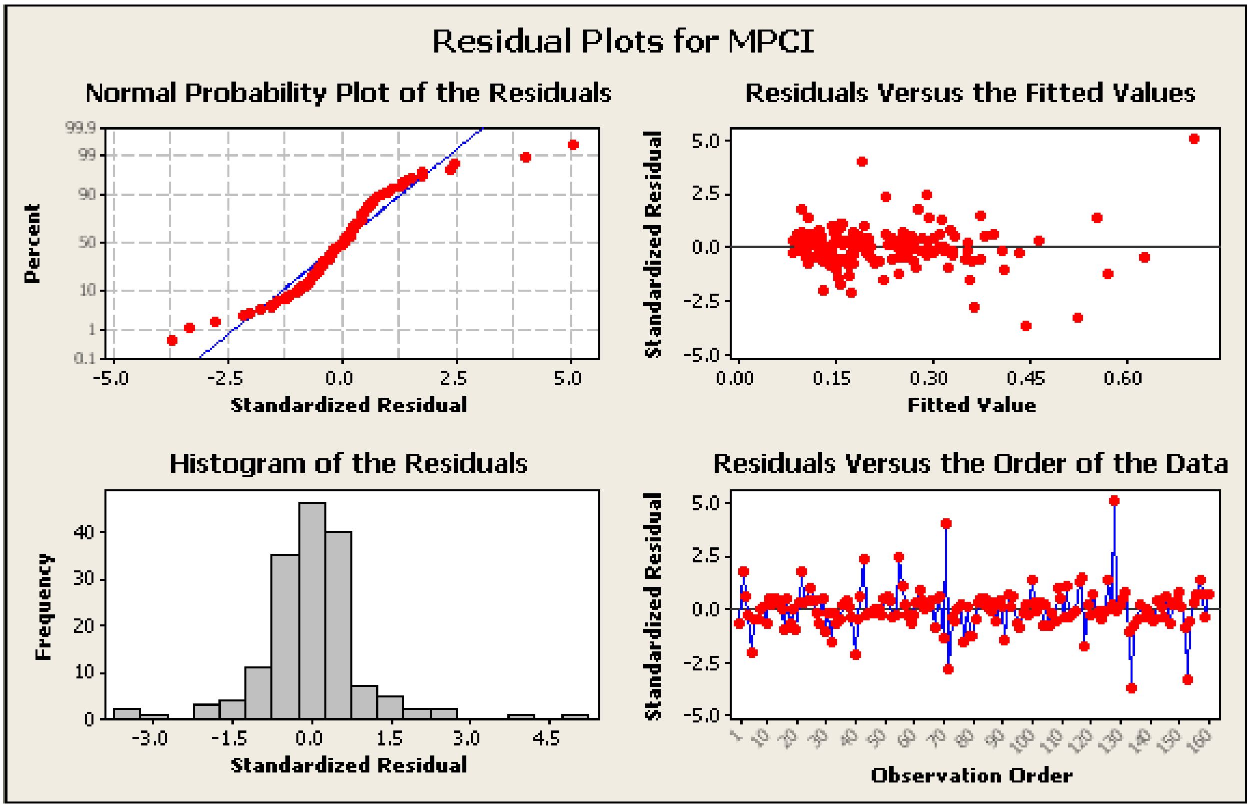

Figure 1: Residual plots for MPCI

In Figure 2 the main effect plot for MPCI has been shown which depicts the mean of the data of the multiple factors involved. The points in the plot are the means of the response variable at the various levels of each factor, with a reference line drawn at the grand mean of the response data. The main effects plot shows the magnitudes of main effects and the level of the factors which satisfy the higher the better criterion. From the main effect plot it has been observed that the MPCI is optimum at order processing cost Cp = $285, Method = 4 (i.e., moving average method for n = 300), and Pp = Pp3 (i.e., demand pattern with seasonality and increasing trend).

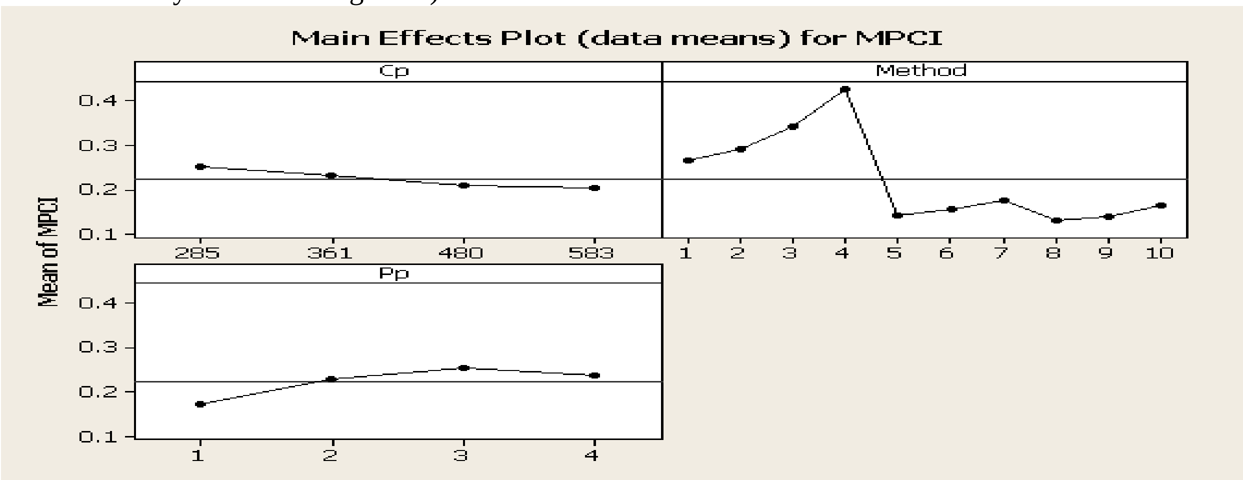

Figure 2: Main Effect Plot for MPCI

Conclusion

It is observed from the above study that forecasting based demand variability is a major factor negatively influencing stability of supply chain network. In the present study, application of fuzzy logic reasoning using the ANOVA method for improvement of supply chain performance by reducing BWE and MSE has been studied. The optimization of the process parameters for minimum BWE and MSE were performed individually. Different forecasting methods have been compared from bullwhip effect and mean square error points of view by using simulation program written in MATLAB code, and then subsequently analyzed by fuzzy coupled with ANOVA for determining the optimal factors.

- The study uses ANOVA and a fuzzy-rule based inference system, which forms a robust and practical methodology in tackling multiple response optimization problems.
- It has been demonstrated that a multiple response optimization problem can be eeffectively tackled by using fuzzy reasoning to generate a single MPCI as a performance indicator.
- Statistical analysis is then carried out on the MPCI to identify the key factors, which affect process performance and then determine the optimal factor settings to optimize process performance.
- It was ascertained from the experimentation and analysis that minimum BWE and MSE have been obtained at order processing cost of $285 with moving average forecasting method taking 300 past demand data, and when demand pattern is with seasonality and increasing trend.

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