Specifying Inventory Policy Effects on Supply Chain Fill Rate Using Statistical Analysis

R.Sahraeian [1], M.Haghshenasi [2], E.dehghan [3]

1) Assistant professor in Department of Industrial engineering, Shahed University, Tehran, Iran
2) Department of Industrial engineering, Shahed University, Tehran, Iran
3) Department of Industrial engineering, Shahed University, Tehran, Iran
sahraeian@shahed.ac.ir
haghshenas@shahed.ac.ir
dehghan@shahed.ac.ir

Abstract

This paper investigates the effect of different inventory policies on a two stage supply chain's performance. Three inventory policies are considered as: r,Q (when inventory level reached to r, an order of size Q is placed); R,T (inventory is reviewed every T units of time, then enough value is ordered to bring the inventory level up to R); s,S (if the inventory level goes below s, then enough value is ordered to raise the inventory up to level S). Considered criteria for supply chain performance measurement are fill rate of retailers, suppliers and entire supply chain. These criteria are calculated under different cost structures and demand variations using simulation modelling. Simulation results are analysed using ANOVA (Analysis Of Variance) and DOE (Design of Experiment) approach. Results shows that inventory policies have significant effects on our considered response variables (fill rates).

Key words: **Simulation, Supply chain, Inventory policy, Fill rate, ANOVA**

1. Introduction

Each supply chain depending on its size is made of several members such as manufacturers, suppliers, distributors, retailers and customers. Each member has significant effect on entire supply chain. In other words decisions made by each member will influence on other members too.

Ordering decision and inventory policies are some of important and inevitable decisions in every supply chain. Selecting different inventory policies have different impacts on performance of members and entire supply chain. Our research is about two suppliers that provide one product for two retailers. Each of two retailers made their inventory decisions using simple ordering rules based on their demand. In this paper the impact of three different inventory policies used by the retailers is examined on the performance of the supply chain. Three inventory policies are considered as: r,Q (when inventory level reached to r, an order of size Q is placed); R,T (inventory is reviewed every T units of time, then enough value is ordered to bring the inventory level up to R); s,S (if the inventory level goes below s, then enough value is ordered to raise the inventory up to level S). Considered criteria for supply chain performance measurement are fill rates of retailers, suppliers and entire supply chain. Reference [1] define, fill rate measures the proportion of customer demand that is satisfied from available inventory. A simulation package is used for modeling supply chain considering different combinations of demand variation and cost structure. Then simulation results are analyzed using ANOVA (Analysis Of Variance) and DOE (Design of Experiment) approach.

2. Literature review

Performance measurement is an essential process in each supply chain. This evaluation must cover all internal and external organization activities. Each organization controls its strategy, goals and activities, using quantitative and qualitative criteria for performance measurement. Reference[2] said that "until recently , most businesses have primarily focused on improving their internal operations to better serve their immediate customers, and have paid little attention to performance of the entire supply chain by examining the impact of their decisions on other members along the supply chain". Reference [3] divided supply chain performance measures in two groups containing quantitative and qualitative. Reference [4] said, managers are faced to multi criteria problems and a small change in the strategic management can effect on entire supply chain performance. In addition they gathered the performance measures and explained them in details. Reference [5] described Performance metrics on the basis of balanced scorecard approach from following four perspectives: finance, customer, internal business process, and learning and growth. In regard to above subjects, appropriate criteria and measures for each supply chain can acquire easily.

Simulation is a tool that we can examine the impacts of different parameters on the supply chain performance. Reference [6] underlined that simulation is an essential and useful tool for modelling, designing and analysing. In fact simulation has advantages that analytical methods haven't it. It is clear that many different factors have influence on supply chain performance such as: demand intensity, lead time, inventory policy, demand forecasting method, cost structure, etc. Reference [7] studied the sensitivity of supply chain performance to three inventory planning parameters: (i) the forecast error, (ii) the mode of communication between echelons, and (iii) the planning frequency by using simulation. Reference [8] proposed one period review system with two replenishment methods, and then compared two methods by using simulation and heuristic algorithms. Reference [9] ranked four alternative replenishment policies that criteria values for each replenishment policy can be obtained either analytically or by using a simulation technique. Reference [10] improved the supply chain performance by coordinating inventory and capacity management. Different alternatives in this article are compared by using simulation. Reference [11] designed one simulation model for supporting supply chain management. Their proposed parametric and flexible simulator can examine different supply chain scenarios based of performance measures. They used DOE and ANOVA for experiments planning and simulation results analysis. Reference[2] investigate the effects of information sharing and early order commitment on the performance of four inventory policies used by retailers in a supply chain of one capacitated supplier and four retailers. In this article we investigate the effect of three inventory policies used by two retailers on fill rate as our considered performance criterion.

3. Research design

Previous researches and articles showed that supply chain performance has a close relation with different inventory policies. This article is interested in reviewing the impact of three inventory policies on supply chain performance. In order to have practical simulation results for other supply chains, different combinations of demand variation and cost structure are used throughout the simulation.

3.1. Supply chain simulation model

Our simulation model is related to a supply chain that has two stages. In this supply chain two suppliers provide one standard product for two retailers. For each retailer, customer demand per day follows normal distribution with mean of 1,000. Each retailer at the ordering time selects one of suppliers randomly. Inventory policies and production rules used by suppliers based on their limitation is constant. When the inventory level in the suppliers' warehouses become less than or equal to 9,000 then enough value is produced to bring the inventory level up to 18,000.

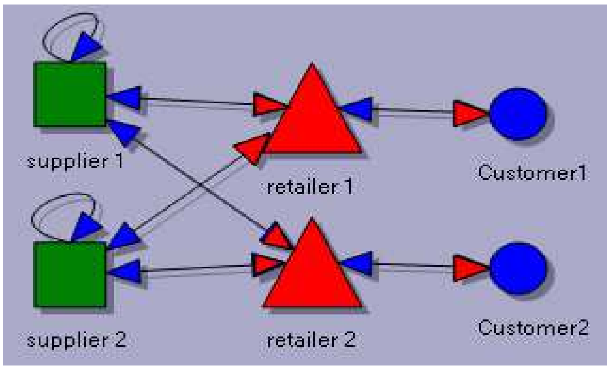

Figure 1: Visual modeler

Fixed order cost is 1000$ for each retailer when places an order. Production set up cost for each supplier is 500$ and production cost per unit is 1 $. Fixed and variable cost of transportation becomes distinct. Cost values are used for computing inventory policies parameters.
Transportation time from two suppliers to retailers 1 and 2 are respectively 25 and 50 hours. Production time for each order is constantly 15 hours. Time independent shortage cost per unit is 1$. Initial inventory for 4 sites is 2500 units.

3.2. Inventory policies

Three inventory policies considered in this research are:
1-(r,Q): as shown in Figure 2, when inventory level reached to r, an order of size Q is placed. Since average of customer demand per day is 1000, customer demand per year will be 365,000 units on the average.

Fixed order quantity $=Q=\sqrt{\dfrac{2DA}{h}}$; where D is annual demand, A is fixed ordering cost and h is rate of inventory carrying cost.

To compute reorder point and safety stock it is required to identify the distribution of customer demand during the lead time. Because customer demand has normal distribution and lead time is constant thus total demand during lead time is normally distributed with a mean of μ_L and standard deviation of σ_L, where the following is true:

$\mu_L = D \times L$; $\sigma_L = \sqrt{L} \times \sigma_D$; SS=K σ_L ;

$\sigma_D =$ Standard deviation of daily demand

Service level = Probability (demand during lead time =< reorder point).
K, safety stock and reorder point can be computed using above formulas and required service level.

$r = \mu_L + SS$; r = reorder point

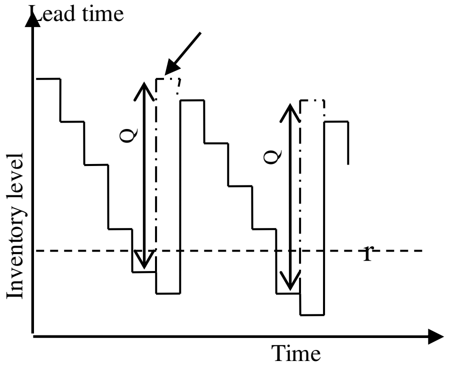

Figure 2: (r,Q) inventory policy

2- (R,T): inventory is reviewed every T units of time, then enough value is ordered to bring the inventory level up to R.

T = $\dfrac{Q}{D}$ that Q is computed in (r,Q) section and D is average annual demand.

$$R = \mu_{T+L} + SS \quad , \quad \mu_{T+L} = D \times (L+T) \quad ,$$
$$SS = K\sigma_{T+L} \ , \ \sigma_{T+L} = \sqrt{T+L} \times \sigma_D$$

K can be computed with service level in the same way explained in (r,Q).

3- (s,S): if the inventory level goes below s then enough value is ordered to raise the inventory up to level S.
We supposed that review period is continuous therefore:

$$s = SS + D \times L; \qquad SS = K\,\sigma_L;\ \sigma_L = \sqrt{L} \times \sigma_D;$$
$$S = \sqrt{\frac{2DA}{h}} + s$$

Using the formulas that explained in previous section we can compute the best quantity for the parameters such as r, R, s, S, etc. then we begin to simulate supply chain. To plot Figure 2 we used [11].

3.3. Simulation model factors

Model simulating using computer help us to vary many parameters or factors through the simulation. Two environmental parameters called cost structure and demand variation are considered in this research. Anyhow the decision parameter in this research is inventory policy that we want to find the best policy using simulation. It is necessary to mention that σ_D in the low and high state of demand variation is respectively 25 and 150 for two retailers and in medium state is 25 for one retailer and 150 for next retailer.

To reduce the effect of random variates, five simulation runs were conducted. Since the parameters have 3, 2 and 3 levels, totally $3 \times 2 \times 3 \times 5 = 90$ simulation runs are conducted in this research.

Table1: Simulation factors

Parameter name	label	level	Values	numeric
Demand variation	SD	3	Low, medium, high	1,2,3
Cost structure	CS	2	i=0.2,0.05	0. 2,0.05
Inventory policy	IP	3	r, Q; R, T; s, S	1,2,3

4. Simulation results analysis

We used the Minitab software to apply DOE and ANOVA for simulation results analysis. To use DOE approach, at first it is required to determine response variables. Next step is choosing factors and their levels and ranges. It is supposed that simulation results of this research are an experiment's data such that fill rate of retailer (fr), fill rate of supplier (fs) and total fill rate (tf) play response variable role. In addition environmental and decision making parameters (demand variation (SD), cost structure (CS) and inventory policy (IP)) are considered as controllable factors with levels showed in table 1. It is noteworthy that since CS is dependent to holding cost, it is also labelled as h.

To apply ANOVA it is required to test adequacy conditions of the observations. These conditions are having normal distribution, equal variances and independency of observation from order of data. Using normality test in Minitab software shows that our data isn't normal. So our observations are in need of transformation to be normal. Considering type I error (α) equal to 0.005, fr is transformed to $fr_2 = 1/\exp(fr)$ to make it normal. To normalize fs and tf, we used Johnson transformation in Minitab. After normalization, Minitab confirmed other adequacy conditions for transformed data. For example figure 3and 4show these conditions for fr_2.

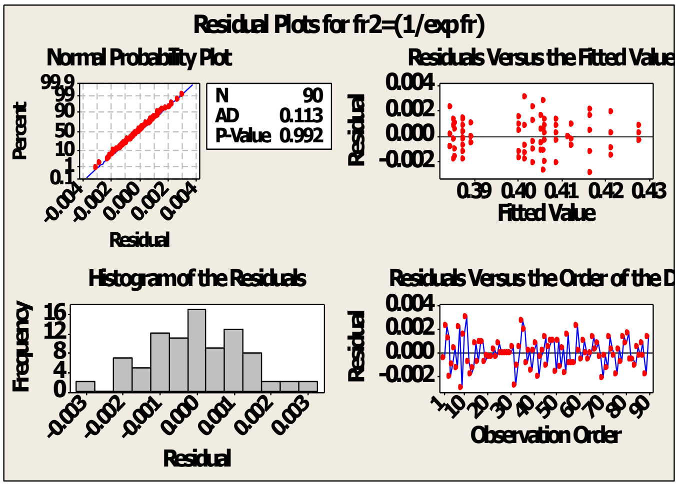

Figure3: Adequacy checking for transformed fr

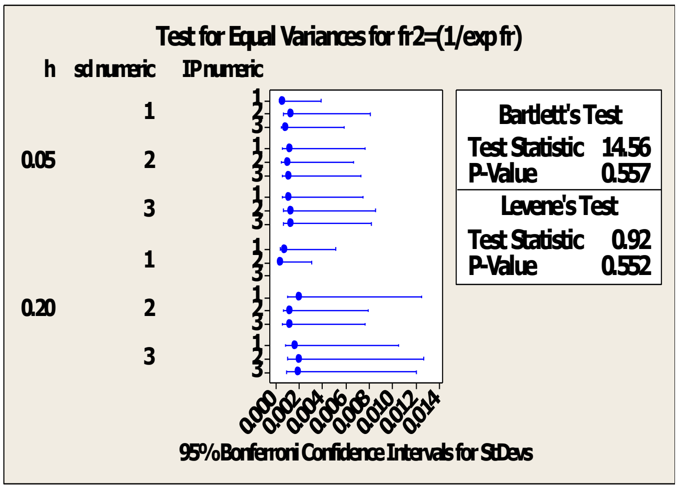

Figure4: Test for equal variances for transformed fr

So analysis of variance is done on these new transformed data. Table 2 shows ANOVA results for transformed fill rate of retailer (fr_2).

Since P-values presented in table 2 are less than supposed type I error ($\alpha = 0.1$), the effects of h, sd and IP on fr_2 are significant. Further the achieved R-sq and R-sq (adj) are suitable means that the fitted model is proper. Figure 5shows the plot of factors' main effect on fr_2. It is clear that in h=0.2, IP numeric=2 and sd numeric=1 the first response variable (fr2) has the maximum value. It is qualified to say that because of the negative correlation ($\rho=-1$) between fr and fr2, fr (fill rate of retailers) has its minimum value on the aforesaid settings.

In the same way ANOVA results for fs_2 are obtained. As P-values indicate, h and IP has significant effect on fs_2. Although P-value of sd is larger than $\alpha=0.1$ but because of significance of h and sd interaction effect (h*sd), the main effect of sd can not be ignored. R-sq and R-sq (adj) also indicate the well fitted model.

The main effect plots for fs2 (shown in figure 6) indicate that the second response variable (fs) has its maximum value in

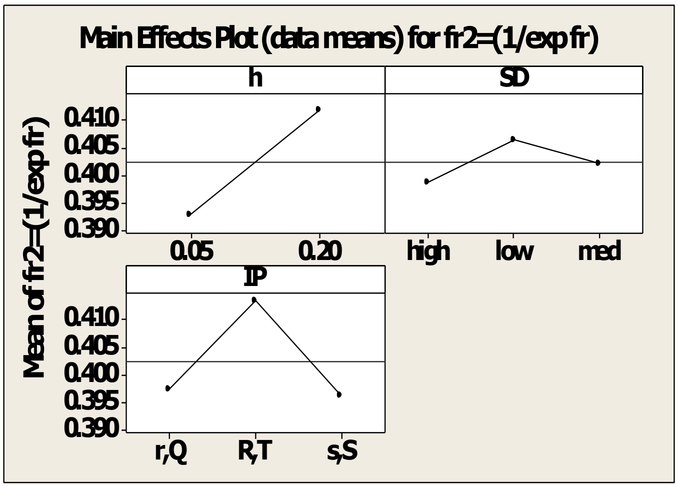

Figure 5: Main effect plot for fr2

h=0.2 and IP numeric=1. Besides the desirable level for sd factor is sd=1 or sd=2 (by a little difference). Since the correlation between fs and fs2 is positive ($\rho=0.97$), this result is confirmed for fill rate of supplier too.

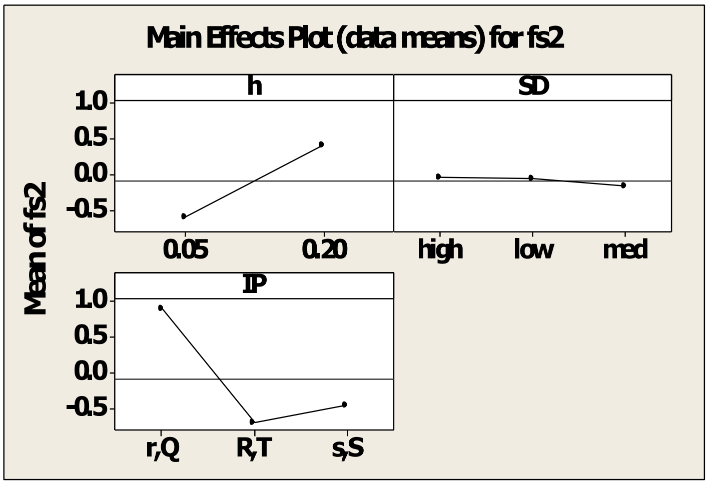

Figure6: Main effect plot for transformed fs

Table2: Analysis of Variance for fr2= (1/exp fr)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
h	1	0.0081982	0.0081982	0.0081982	4427.25	0.000
sd numeric	2	0.0008500	0.0008500	0.0004250	229.52	0.000
IP numeric	2	0.0055902	0.0055902	0.0027951	1509.44	0.000
h*sd numeric	2	0.0000923	0.0000923	0.0000461	24.92	0.000
h*IP numeric	2	0.0000468	0.0000468	0.0000234	12.65	0.000
sd numeric*IP numeric	4	0.0000452	0.0000452	0.0000113	6.10	0.000
h*sd numeric*IP numeric	4	0.0000144	0.0000144	0.0000036	1.94	0.113
Error	72	0.0001333	0.0001333	0.0000019		
Total	89	0.0149704				

S = 0.00136079   R-Sq = 99.11%   R-Sq(adj) = 98.90%

Finally, the ANOVA table for transformed total fill rate (tf_2) is computed. Comparing P-values with α=0.1 indicates that all main and interaction effects of h, sd an IP are significant except sd*IP. Proportionally high R-sq and R-sq (adj) expresses that the fitted model is proper.

Based on main effect plots shown in figure 7and the positive correlation between tf and tf2 ($\rho=0.97$) the third response variable (total fill rate) has its best (highest) value in h=0.2, IP numeric=1 and sd numeric=3.

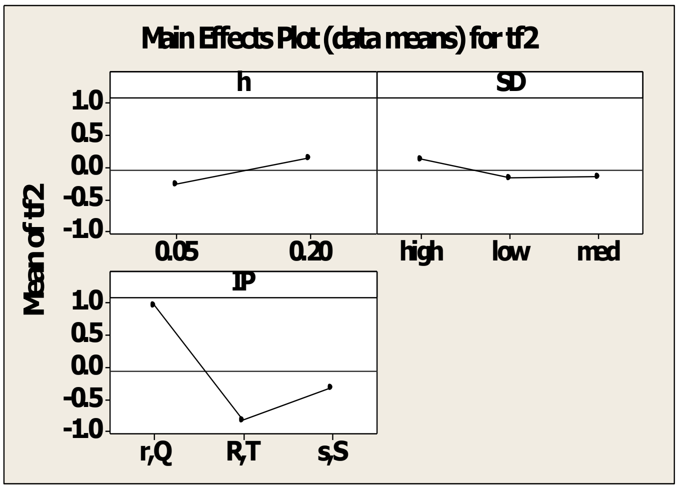

Figure7: Main effect plot for transformed tf

5. Conclusions

This research aims to improve the performance of a supply chain by focusing on inventory policies. The considered performance measurement criterion is fill rate. In addition two environmental factors (demand variation and cost structure) are considered in this examination. In order to have practical results for other supply chains, different combinations of environmental factors and supposed inventory policies (r,Q; s,S; R,T) are investigated. We use simulation for modelling the problem. Then DOE approach is used to analyse simulation results. Our final goal is to select the best inventory policy. By a good approximation results show that for each combination of cost structure and demand variation, the (r, Q) inventory policy leads to the highest fill rate.

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