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Impact of Ordering Decisions on Performance of a Supply Chain – An Experimental and Simulation Study

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Abstract

A supply chain consists of a network of organizations. Each organization in it acts as either customer or supplier to others. Ordering and replenishment decisions of each organization or stage contribute to supply chain performance. A simulation study and experimentation were conducted in this study to determine the impact of ordering decisions on supply chain performance. The ordering decisions at each stage are taken by intuition for experimentation and are taken by inventory policies for simulation. Under customer demand distribution information sharing, the performance of a supply chain is evaluated and compared between those two conditions. A supply chain role play game software package is used to evaluate supply chain performance by intuition, and simulation is used to evaluate different inventory policies. Fixed order policy, Order Up-to Level (OUL), Modified OUL (MOUL), (r, Q) and (r, S) inventory policies are considered in this study. The performance measures used are the total supply chain inventory per period, bullwhip effect and supply chain fill rate. Grey Relational Analysis (GRA) is used to identify the best method to take decisions in supply chain. Results show that supply chain performance is best under MOUL policy. Based on the results of this study, supply chain members are encouraged to identify the best inventory policy and use that rather than making decisions based on intuition.

Keywords: *Supply chain, inventory policies, supply chain performance.*

1.0 Introduction

Supply chain includes all the organizations involved in fulfilling the customer requirements. They perform various business operations like procuring the raw material, producing and distributing the goods to customers etc. Coordinating activities among organizations is the function of supply chain management, which attempts to reduce supply chain costs. Supply chain management aims to increase customer satisfaction. Nowadays, competition is between the supply chains but not organizations. A supply chain's performance depends on the roles played and operations carried out at every stage in it. Various performance measures are used to evaluate supply chain performance, such as total cost of the supply chain, fill rate of the supply chain, bullwhip effect, etc.

In order to analyze the supply chain performance, analytical methods or experimental methods can be applied. Using the beer distribution game, Sterman (1989) was the first to experimentally analyze supply chain performance. There are four players involved in this experiment: a retailer, a wholesaler, a distributor, and a factory. The players receive orders from their downstream and independently decide on the quantity

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of orders and shipments without consulting each other. Players reported that they were unable to predict customer demand patterns, which resulted in large variances in their orders. Croson and Donohue (2003, 2006) examined the impact of demand distribution of customer, inventory information sharing, and point of sale data. Steckel et al. (2004) tested the effect of Point of Sale and lead time on supply chain performance using a beer distribution game. The results also show that a supply chain with information sharing performs better than one without it. A study by Wadhwa et al. (2009) and Pamulety and Pillai (2016) suggests that sharing mean demand information improves the supply chain's overall performance. Sunny et al. (2022) developed a blockchain-enabled beer game for the better supply chain management. Kumar et al. (2021) and Dony S.K et al. (2020) studied the performance of a serial supply chain.

In most of the experimental studies conducted for evaluating the supply chain performance, the ordering and shipment decisions are taken by participants without using any inventory policy or rule. The present study aims to analyze the performance of a four-stage single product serial supply chain with participants and inventory policy to determine how best to manage supply chain decisions. A multi-criteria decision-making method, Grey Relational Analysis (GRA), is used to identify the best way. Supply chain role play game software package is used for evaluating the performance of supply chain by taking decisions at each stage with participant's intuition. Simulation study is conducted for evaluating the supply chain performance by taking decisions at each stage with inventory policy. Various performance measures used are the total supply chain inventory per period, bullwhip effect and supply chain fill rate.

The organization of the paper is as follows: Sections 2 and 4 describes experimental procedure and simulation studies, respectively; Section 3 describes the performance measures used in this study. The discussion on results is given in Section 5. Section 6 concludes the present study.

2. Experimentation

Using supply chain role play game software, the experiments are conducted in the present study. In these experiments, each stage in a four-stage supply chain is managed by one participant. The four stages of the supply chain are retailer (i=1), wholesaler (i=2), distributor (i=3) and factory (i=4). Every period, the customer places the order with the retailer, who then ships the quantity (SQ) if it is available. Otherwise, the retailer will supply the available quantity. Throughout the supply chain, customer demand distribution details are shared to determine the size of the order to be placed with suppliers. In each stage, order decisions are taken periodically, and orders are placed when the customer's demand has been met. The experiments are conducted under lost sales business environment. Four participants constitute one supply chain and 36 participants participated in this experimental study. There were 9 supply chains under this supply chain setting. Most of the participants are from Industrial Engineering and Management specializations, and they are students from undergraduate, postgraduate, and MBA programs. The experiment was conducted for 55 periods and is not revealed to the players. At the end of period t, orders placed by stage i reach the stage (i+1) in period (t+1), and quantities shipped by stage (i+1) reach stage i in period (t+2). The factory is assumed to have an unlimited capacity for production and an unlimited amount of resources. As a result, the quantity of production from the factory stage for period t is available for distribution in the factory for period (t+1). Customer demand is also assumed to have arisen at retailers and follow a normal distribution with a mean of 20 units and a standard deviation of 5. The performance is calculated using the data from period 7 to 48 as in Steckel et al. (2004). If sufficient inventory is available (I), the quantity shipped will match the order quantity, otherwise it will match the available inventory. The distribution of customer demand is assumed to be N(20, 5), which is shared among the supply chain stages. In order to evaluate the supply chain performance, we consider the supply chain fill rate, the Bullwhip Effect (BWE), and the supply chain inventory per period. The assumptions of the present study are:

- Each stage receives the quantity from its supplier at the beginning of each period.
- At the beginning of every period, shipment is made to meet the demand.
- An order is placed at the end of the period.
- No back orders are allowed.
- Customer demand for a single follows a normal distribution with parameters 20, 5.
- Each stage of the supply chain does not have capacity or storage constraints.
- Retailer stage only receives the customer orders.
- 40 units are the starting inventory for each stage.
- Each stage has a lead time of one week, but the factory has a zero lead time.
- One week is the review period.
- The factory has an infinite production capacity, and

raw materials are abundant.

The performance measures used for evaluation include BWE, total supply chain inventory per period and SC fill rate. The details of performance measures are given in Section 3. The supply chain performance under customer demand distribution information sharing is given in Table 1. These performance measures are the average values of nine identical supply chains.

Table 1: Supply chain performance under customer demand distribution information sharing

Information sharing	Performance measures		
	Total supply chain inventory per period	BWE	SC fill rate
Customer demand distribution	44.021	2.470	0.955

3. Performance Measures

Various performance measures used are total supply chain inventory per period, BWE and SC fill rate.

3.1. Total supply chain inventory per period:

End period inventory at stage i, in period t is as follows

$$\boldsymbol{I_t^i = \left(I_{t-1}^i + SQ_{t-1}^{i+1} - D_t\right)} \text{ for } \boldsymbol{i = 1}$$

$$I_t^i = \left(I_{t-1}^i + SQ_{t-1}^{i+1} - O_{t-1}^{i-1}\right) \text{ for } i = 2,3,4$$

Total inventory of the supply chain per period

$$= \frac{\sum_{i=1}^{4} I^i}{42}$$

$$\text{Total inventory at stage } i, I^i = \sum_{t=7}^{48} I_t^i, \forall i$$

3.2. Bullwhip Effect

There are several methods for quantifying it (Cachon et al., 2007 and Zang and Zang 2007). According to Shi and Bian (2010), it is an important performance indicator for supply chains. The following formulas were used in this study to measure it (Zhang and Zhang, 2007).

$$\text{BWE} = \frac{\text{last stage orders variance}}{\text{Customer demand variance at retailer stage}}$$

The following formulas are used to estimate the last stage variance of orders (factory).

$$\sigma_{i=4}^2 = \frac{\sum_{t=7}^{48} (O_t^{i=4} - \overline{O})^2}{42-1},$$

$$\text{where, } \overline{O} = \sum_{t=7}^{48} O_t^{i=4} \Big/ 42.$$

o_t^i is the order size placed by stage i in period t.

3.3. Supply Chain Fill Rate

The fill rate measures the percentage of demand met by on-hand inventory. Fill rate at retailers is a measure of the level of service provided by the supply chain to customer.

$$\text{Fill rate} = \frac{\text{Demand met}}{\text{Demand arose}}$$

$$\text{Supply chain fill rate} = \frac{\sum_{t=7}^{48} SQ_t^{i=1}}{\sum_{t=7}^{48} D_t}$$

SQ_t^i shipment Quantity by stage i in period t

D_t Customer demand in period t

4.0 Supply Chain Perrformance Under Inventory Policies: Simulation Study

In this study, the supply chain performance under the experimental conditions is evaluated considering inventory policies using simulation instead of participant. Inventory policies considered for this study includes Fixed Order Quantity, Order Up-to Level, Modified OUL (MOUL), (r, Q) and (r, S) where, Q, S, and r are fixed order quantity, order-up-to level and reorder point, respectively. All these policies come under the category of inventory position-based policies except FOQ. Throughout the supply chain, the same inventory policy is used to evaluate its performance. The performance of supply chain under the above inventory policies is evaluated. The simulation experiments are conducted with a run length of 104 periods in which the warmup period is the first 52 periods. The simulation contains 1200 replications. The average value of performance measures of 1200 replications is used to establish the conclusions. The simulation results are summarized in Table 2.

4.1. Details of Inventory Policies Used

Fixed order quantity policy and inventory position policies includes Order Up-to Level (*OUL*), Modified *OUL* (*MOUL*), (*r*, Q) and (*r*, *S*) are considered.

4.1.1. Fixed Order Quantity Policy (FOQ)

According to this policy, at each review period, a fixed size of order equals averaging demand per period is placed.

4.1.2. Order Up-to Level Policy (OUL)

An order is placed at each review period equal to the difference between the order up to level and the inventory position.

4.1.3. (r, S) Policy

A reorder point, *r*, represents the expected lead time demand. If inventory position is below or equal to *r* during a review period, an order is placed equal to the difference between inventory position and order up to level.

4.1.4. (r, Q) Policy

In this strategy, If the inventory position is below or equal to *r* during a review period, a fixed order *Q* equal to expected demand per period is placed.

4.1.5. Modified OUL (MOUL) Policy

This works as OUL policy but the minimum order size is fixed as expected demand in review (EDR).

$$O_t = \begin{cases} 0, \text{if } (IP_t > S) \\ (S - IP_t), \text{if } (IP_t < S) \,\&\, (S - IP_t) > EDR \\ EDR, \text{if } (IP_t < S) \,\&\, (S - IP_t) < EDR \end{cases}$$

where

IPt = Inventory Position at period (*t*).

4.2. Parameters Setting for inventory policies

Each policy parameters are designed in such a way that a certain degree of synchronization of supply and demand can be achieved at the earliest in the supply chain stages. The order is placed periodically (each period). First three stages in the supply chain will receive the order at the beginning of the third period. At the end of period one, the fourth-stage placed an order which will be received in the beginning of period two. Various parameters set under each policy are given below.

4.2.1. Fixed Order Quantity Policy

In this policy, an order is placed irrespective of the size of the demand arisen. The initial inventory set for 1st stage is 40 units, 2nd and 3rd stages is 20 units and zero for 4th stage.

4.2.2 Inventory Position Based Policies

The inventory position-based policies considered in this study includes Order Up-to Level (*OUL*), Modified *OUL* (*MOUL*), (*r*, *Q*) and (*r*, *S*).

(r, Q) and (r, S) policies place orders at the end of each period based on re-order point *r*, whereas OUL and MOUL policies place orders if inventory position is less than or equal to order up-to level. So, there is a chance of placing an order in each period. Hence, the first three-stage requires initial inventory to meet the demand in first two periods. The fourth-stage requires initial inventory to meet the first period demand, only because of less lead time than other stages. The initial inventory for the first three stages is 40 units and it is 20 units for the fourth-stage. The order up-to level for the first three stages is 40 and 20 for the fourth stage. The order up-to level is equal to (T+k+L) period demand. T is the time between reviews, k is the order lead time and L is the delivery lead time.

The reorder point, *r*, is equal to expected demand during ($k + L$) period. It is fixed as 20 for the first three stages and zero for the fourth stage. The *Q* value is the fixed as 20 units equal to average demand per period for the present study.

Table 2: Supply chain performance under inventory policies

Policy	Performance measures		
	Total supply chain Inventory per period	BWE	SC fill rate
FOQ	17.720	0.000	0.975
OUL	07.762	0.359	0.858
(r, Q)	25.013	2.876	0.751
(r, S)	10.873	4.078	0.488
MOUL	08.897	0.436	0.949

5.0 Results and Discussion

The supply chain performance under experimental condition and inventory policies are given in Tables 1 and 2, respectively. GRA is used to rank the

Table 3: Performance of each alternative under N(20, 5)

Policy	Performance measures		
	Total supply chain Inventory per period	BWE	SC fill rate
FOQ	17.720	0.000	0.975
OUL	7.762	0.359	0.858
(*r*, *Q*)	25.013	2.876	0.751
(*r*, *S*)	10.873	4.078	0.488
MOUL	8.897	0.436	0.949
customer demand distribution(expt.)	44.021	2.470	0.955

Table 4.Comparison of supply chain performance under experimentation and inventory policies N(20, 5)

Policy	Grey relational coefficient				
	Total SC inventory per period	BWE	SC fill rate	Grey relational grade	Rank
FOQ	0.645	1.000	1.000	0.881	2
OUL	1.000	0.850	0.675	0.841	3
(*r*, *Q*)	0.512	0.414	0.520	0.482	6
(*r*, *S*)	0.853	0.333	0.333	0.506	5
MOUL	0.941	0.823	0.903	0.889	1
Customer demand distribution (expt.)	0.333	0.452	0.924	0.569	4

alternatives based on the three performance measures. The details of GRA are given in Mathew and Rajendrakumar 2011 and Pamulety et al. 2017. For comparing the supply chains under experimental case and inventory policies, the performance measures of them are given in Table 3. The rank assigned to each alternative is given in Table 4. MOUL is ranked first and FOQ is next by GRA. The grey relational grade is the basis for ranking and the grade values of the first two policies are almost the same. Hence, it is possible to identify MOUL and FOQ as the best policies for the supply chain considered. Managers' (manger of supply chain stages) intuition-based ordering ranked 4th among the six alternatives.

6.0 Conclusions

The performance of a single product four- stage serial supply chain under customer demand distribution information sharing (experimentation) is compared with the performance of supply chain under FOQ, OUL, MOUL, (*r*, *Q*) and (*r*, *S*) inventory policies. GRA method is used to rank the alternatives and it is found that the performance of MOUL is the best.

In customer demand distribution information sharing (experimentation), each participant knows the average customer demand per period, and the order size decision is taken by intuition. The participants have taken order decision in every period without using any particular ordering policy. Result of this study shows that the performance of supply chain is better under MOUL than under order decision taken by intuition. The performance of MOUL is better than all other inventory position-based policies tested because the minimum order size is fixed as expected demand in review period. Hence, this study encourages managers to use MOUL inventory policy for better performance.

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