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Benefits of CPFR Collaboration Strategy under Different Inventory Holding and Backorder Penalty Costs

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Abstract

This study uses discrete event simulation to investigate the benefits of Collaborative Planning, Forecasting and Replenishment (CPFR) strategy over Traditional Supply Chain (TSC) under different inventory holding costs and backorder penalty costs for both the manufacturer and retailer. A two-echelon production-inventory system with a retailer and manufacturer in a variable demand environment is considered for this study. No information is shared in TSC, while sales, forecast and inventory level information is shared in CPFR between a retailer and a manufacturer. The order quantity for retailer and the production quantity for manufacturer during each period are determined using periodic review order-up-to inventory policy. Lot-for-lot production policy is used by the manufacturer with a lead time of one period. The results suggest that CPFR performs better than TSC for both the manufacturer and retailer under all inventory holding costs. As inventory holding cost per unit per period increases, benefits of CPFR also increases for both the manufacturer and retailer. Also, when inventory holding cost is high, maximum benefits of CPFR is achieved for both the manufacturer and the retailerin an environment withhigh demand variability, high backorder penalty cost and long delivery lead time.

Keywords: CPFR strategy, inventory holding costs, backorder penalty costs

1. Introduction

In a traditional supply chain (TSC), the manufacturer has no visibility of their customer demand, and therefore production planning and inventory replenishment decisions are typically made from forecasts based on historical demand. In this situation, most manufacturers and their customers maintain high level of safety stock inventory, increasing the cost of inventory management in the supply chain.It has been estimated that out of $2.3 trillion in the retail supply chain, approximately $700 billion was in safety stock inventory, accounting for about 30% of the total cost of inventory in the retail supply chain (Lewis, 1998).

In recent years, many researchers have shown benefits of information sharing that helps reduce cost in the supply chain (Gavirneni et al., 1999; Lee et al., 2000; Kulp et al., 2004, Li et al., 2006). These research studies show that information sharing by customers (e.g., retailers) help the supplier (e.g., manufacturer) gain demand visibility, which in turn helps to reduce inventory levels and improve customer service levels. However, most of these studies also show that the supplier gains more benefits of information sharing compared to the retailer. With the supplier gaining more benefits, the retailer has less incentive to share information with the supplier.In order to encourage retailers to share information with their suppliers, many types of collaboration strategies have been developed and implemented in various industries with mixed results (Lapide, 2001; Baljko, 2003; Seifert, 2003). One such collaboration strategy is known as Collaborative Planning, Forecasting and Replenishment (CPFR).

CPFR is considered to be the latest strategy in the evolution of supply chain collaboration. Some of the earlier collaboration strategies like Continuous Replenishment Planning (CRP) and Vendor Managed Inventory (VMI) focused more on replenishment planning activities and did not give much consideration to the aspects of demand forecasting and production planning. In CRP and VMI agreements, the customer is usually not involved in decision making activities and it becomes difficult for supplier to make accurate demand forecasting, production planning and replenishment planning decisions, especially in a variable demand environment. However, CPFR is a comprehensive collaboration strategy that provides an excellent opportunity for both the customer and the supplier to jointly develop demand forecast and replenishment planning activities.Wal-Mart can be credited in initiating the development of CPFR. In 1995, first CPFR project, originally known as Collaborative Forecasting and Replenishment (CFAR) was initiated by Wal-Mart (retailer) with Warner-Lambert (manufacturer). Consulting company Benchmarking Partners and the software companies SAP and Manugistics supported them in this project. Listerine mouthwash products were used to test this collaboration strategy during the pilot project. Wal-Mart and Warner-Lambert independently developed their demand forecasts and compared them on a weekly basis. Any discrepancies between their forecasts were resolved which helped both companies to work with a single forecast. This initial project was considered a success and since then several companies have implemented CPFR with their suppliers and/or their customers (Esper & Williams, 2003; Seifert, 2003; Aviv, 2007).

Most research on CPFR are usually descriptive studies or case studies with very few analytical or simulation studies. Some of these research studies show the benefits of CPFR (or CFAR) over TSC in a two-level supply chain, while few other studies show the benefits of CPFR and VMI over TSC in a multi-echelon supply chain. Raghunathan (1999) developed an analytical model to study the impact of CFAR (Collaborative Forecasting) in a supply chain consisting of a manufacturer and two independent identical retailers. The model assumes that the manufacturer does not have any capacity constraints and knows the actual demand of the retailers. Based on their analysis they conclude that CFAR helps to reduce overall cost for manufacturer when compared to the traditional supply chain. Aviv (2007) developed an analytical model to study the impact of CFAR in a two-level supply chain with a retailer and a supplier. The supplier has unlimited source of supply and both the retailer and supplier replenish their inventory periodically.Based on numerical studies, it is indicated that CFAR reduces the supply chain costs in most cases and the benefits of CFAR depends on the relative forecasting skills of trading partners. Kazemi and Zhang (2013) develop an analytical model with one retailer and one manufacturer to determine the optimal decisions on retail price and order quantity under VMI and CPFR strategies. Simulation optimization procedure is also used to find the optimal decisions on order quantity and optimal price. Based on their analysis, CPFR generates higher overall profit and lower retail price than those of VMI under all circumstances considered in their study. However, the expected profit for the manufacturer and retailer reduces for larger demand variation.

Cigolini and Rossi (2006) consider a four-level supply chain consisting of factory, warehouse, distributor and retailers. They develop a simulation model to test and evaluate the most appropriate collaboration level within this supply chain. Three types of supply chain configurations are studied similar to traditional managed inventory (LCA), vendor managed inventory (VMI) and collaborative planning, forecasting and replenishment (CPFR).Using two demand patterns termed steady demand and nervous demand; they analyze the model to determine the effects on the performance measures. For steady demand scenario, they determine the difference among system performances between VMI and CPFR are not significant. However, for nervous demand scenario, the reduction in safety stock inventory for CPFR is significantly higher when compared to VMI. Sari (2008) considers a four-level supply chain with a manufacturer, warehouse, distributor and a retailer. They develop a simulation model to test and evaluate the most appropriate collaboration level within this supply chain. Three types of supply chain configurations are studied similar to traditional supply chain (TSS), vendor managed inventory (VMI) and collaborative planning forecasting and replenishment (CPFR). The analysis of simulation models determines that the benefits of CPFR are always higher than VMI. Additionally, when demand uncertainty is present the performance of CPFR is significantly better than VMI.Kamalapur et al. (2013) consider a two-echelon supply chain with a manufacturer and a retailer. Using discrete event simulation (Arena software from Rockwell Corp.) they investigate the benefits of CPFR and VMI over TSC on inventory managementcost for both the manufacturer and retailer. Along with three supply chain strategies, four other control variables: demand variability, production capacity, backorder penalty cost, and delivery lead time are considered. A fixed inventory holding cost per period is assumed for both the manufacturer and the retailer. Based on the results of the study, all factors considered in this study have a significant impact on inventory management cost forboth the manufacturer and the retailer. Also for all factor combinations, it is shown that CPFR achieves higher cost benefits when compared to VMI for both the manufacturer and the retailer.

While many benefits of information sharing in collaboration strategies like VMI and CPFR have been identified in the literature, however the benefits of CPFR collaboration strategy under different inventory holding costs in a variable demand environment has not been studied. Typically, the benefits of information sharing in CPFR collaboration strategy for both the manufacturer and the retailer can depend on many factors including inventory holding cost and backorder penalty cost of products. When determining cycle stock inventory or safety stock inventory for different products, the inventory holding cost of product is usually not considered. However, inventory holding cost per unit per period for different products can have a significant impact on the benefits of CPFR collaboration strategy for both the manufacturer and the retailer. When inventory holding cost of the product is low, both the manufacturer and the retailer may be able to hold more inventory and the benefits of information sharing in CPFR collaboration strategy may not be as significant compared to when inventory holding cost of the products are much higher. Similarly, when backorder penalty costs are low, both the manufacturer and retailer may tend to hold lower inventories and the benefits of CPFR collaboration strategy may not be as significant compared to when backorder penalty cost of the products are much higher.

This research study investigates the impact of different inventory holding costs, backorder penalty costs; demand variability and delivery lead time on the cost benefits of information sharing in CPFR collaboration strategy compared to TSC for both the retailer and manufacturer. Two simulation models (TSC and CPFR), are developed using discrete-event simulation (Arena software from Rockwell Automation)where no information is shared in TSC, while sales, forecast and inventory level information is shared in CPFR collaboration model. Using these simulation models, we investigate the cost benefits (i.e. cost reduction) in inventory management of CPFR over TSC for both the manufacturer and retailer under different factor combinations considered in this study.

2. Research Methodology

This section describes the conceptual model and research methodology used in this study. The conceptual model has a make-to-stock manufacturer (plant and warehouse) and a retailer in a two-echelon production-inventory system. The decisions made and information shared in TSC and CPFR supply chain strategies are shown in Figure 1 and Figure 2. Demand forecast for both the retailer and the manufacturer is developed using exponential smoothing forecast technique. The production quantity for the manufacturer and order quantity for retailer during each period is determined using periodic review order-up-to inventory level. Review period is one week and all decisions by the retailer and manufacturer are made beginning of each period. The production quantity and the order quantity during each period is the difference between order-up-to level and the current inventory position at their respective locations. Safety stock for the retailer and the manufacturer is calculated using service level, standard deviation of forecast error and the lead time.

Customer demand for retailer is generated beginning of each period in both the simulation models. The customer demand for retailer and demand forecast for both retailer and manufacturer are updated during each period. During each period of the simulation run, the order-up-to inventory level is updated to determine order quantity for retailer and production quantity for manufacturer. The customer demand, production quantity and order quantity are non-negative. A lot-for-lot production policy with a production lead time of one period is used by the manufacturer. The transportation lead time from production plant to manufacturer's warehouse is assumed to be negligible. During each period, both the retailer and manufacturer fulfill their demands from their available inventory and any demand not met is backordered with a backorder penalty cost.

2.1 Sequence of Events in TSC Strategy

The retailer and manufacturer use traditional supply chain (TSC) before any collaboration agreement is reached between them. In TSC, orders are placed by the retailer and no other information is shared with the manufacturer as shown in Figure 1. In this situation, the retailer and the manufacturer make inventory replenishment decisions independently, with the manufacturer in a less favorable position regarding demand information. During each period of the simulation run, the sequence of events is as follows. Beginning of each period, the manufacturer's warehouse receives shipments from manufacturer's production plant. The manufacturer fulfills the retailer order (plus any backorder) from their available inventory at warehouse. Similarly, after receiving shipments from the manufacturer, the retailer fulfills customer demand (plus any backorder) from their available inventory. Any unfulfilled demand for both the manufacturer and retailer is backordered with a backorder penalty cost. Next, both the retailer and manufacturer develop their demand forecast independently and calculate their order-up-to inventory level. Using this information along with inventory levels (or backorders) at their respective locations, the order quantity for retailer and production quantity for manufacturer is determined. These actions are taken by the retailer and the manufacturer simultaneously during each period. Finally, at the end of each period, the retailer cost and the manufacturer cost per period are calculated based on inventory level or backorder quantity at their respective locations.

2.2 Sequence of Events in CPFR Strategy

In CPFR strategy, the retailer shares sales, forecast and inventory level information with the manufacturer as shown in Figure 2. Manufacturer does not forecast and uses this information to determine their production quantity during each period. All decisions for the manufacturer and retailer are made at the beginning of each period. During each period of the simulation run, the sequence of events is as follows. Beginning of each period, the manufacturer's warehouse receives shipments from manufacturer's production plant. The manufacturer fulfills the retailer order (plus any backorder) from their available inventory at warehouse. Similarly, after receiving shipments from the manufacturer, the retailer fulfills customer demand (plus any backorder) from their available inventory. Any unfulfilled demand for both the manufacturer and retailer is backordered with a backorder penalty cost. Next, the retailer develops the demand forecast (which is shared with manufacturer) and both the retailer and manufacturer calculate their order-up-to inventory level. An echelon-based inventory policy is used by the manufacturer intheir production planning and inventory replenishment decisions. Under echelon-based inventory policy, the inventory level of the manufacturer plus inventory level of retailer and any backorder quantity at both locations are used to determine the production quantity (Axsater & Rosling, 1993). These actions are taken by the retailer and the manufacturer simultaneously during each period. Finally, at the end of each period, the retailer cost and the manufacturer cost per period are calculated based on inventory level or backorder quantity at their respective locations.

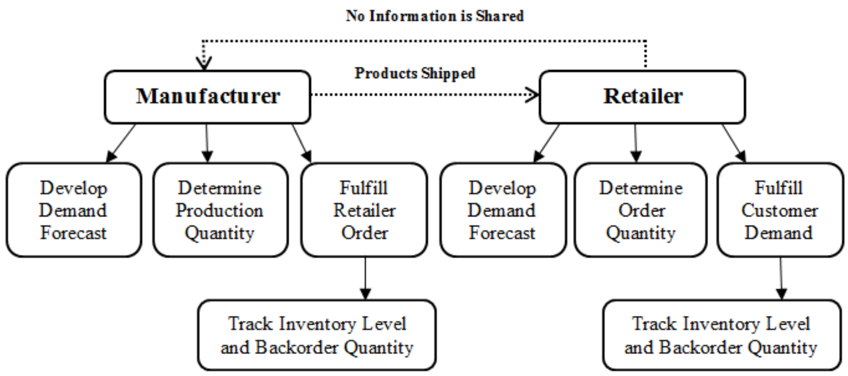

Figure 1. Decisions made and information shared in traditional supply chain

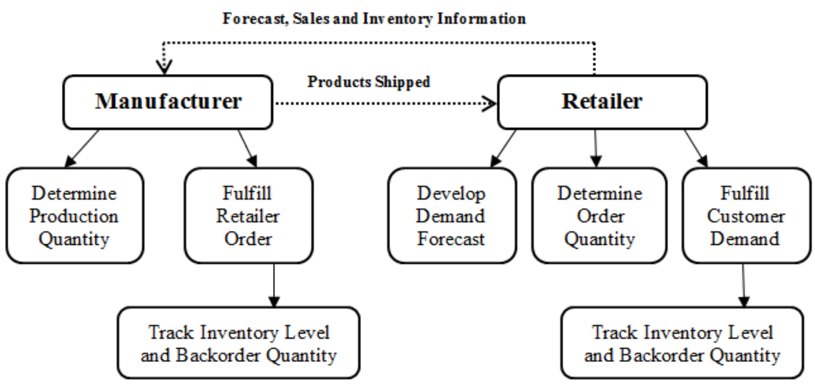

Figure 2. Decisions made and information shared in CPFR collaboration strategy

2.3 Supply Chain Factors

Four control variables and two performance measures as shown in Table 1 and Table 2 are used to investigate the benefits of CPFR collaboration strategy over Traditional Supply Chain (TSC). Demand variability, inventory holding costs and backorder penalty costs are environmental factors which generally are not in the control of supply chain members. Also, delivery lead time plays an important role in determining the safety stock inventory needed for both supply chain partners, which in turn impacts the total cost of inventory management. Many studies in information sharing and collaboration strategies have used auto-correlated demand type.

At a major supermarket in the United States, the weekly sales data of 150 products over a two year period was examined and the sales pattern was found to be significantly auto-correlated (Lee et al., 2000). So the auto-correlated demand pattern with three levels of demand variability is considered for this study. The customer demand during each period of the simulation run is generated as shown below

$$D_t = d + \rho D_{t-1} + \varepsilon_t$$

ρ = correlation factor, d = initial mean, and ε_t = error that is normally distributed with mean zero and standard deviation σ. The average customer demand for retailer is 100 units per period with a correlation factor of 0.5. Three levels of demand variability are generated by varying σ in the above equation. Production capacity is assumed 1.5 times the average customer demand and the customer service level used to determine safety stock is 95% for both the manufacturer and the retailer. The manufacturer cost and retailer cost per period are used as the performance measures and are determined based on inventory level and backorder quantity at end of each period.

The performance measures (i.e. output data) from both the simulation models (TSC and CPFR) are used to investigate the benefits of CPFR over TSC under different inventory holding cost along with other control variables. To determine the impact of control variables on performance measures and facilitate valid comparison, the production policy and inventory policy remain the same for all factor combinations in both TSC and CPFR strategies. Also, the same random number sequence is utilized to reduce the impact of random variations of input data that will help to generate the same customer demand for all factor combinations. The number of replications for both simulation models is 30 and the length of simulation run is 1150 periods. A warm-up of 150 periods is used to initialize the system and remaining 1000 periods is used for the analysis. The statistical software "Minitab 16" is used for the analysis.

Table 1. Control variables for the experimental design

Control Variables	Control Variables Details	Other Details
Demand Variability (DVR)	Low Demand Variability, σ = 5 Med Demand Variability, σ = 15 High Demand Variability, σ = 25	Average Demand is100 units per period
Inventory Holding Cost (IHC)	Low Inventory Holding Cost, 1.0 Med Inventory Holding Cost, 2.0 High Inventory Holding Cost, 3.0	Inventory Holding Cost is per unit per period
Backorder Penalty Cost (BOP)	Low Backorder Penalty Cost, 10 Med Backorder Penalty Cost, 20 High Backorder Penalty Cost, 30	Backorder cost is times inventory holding cost
Delivery Lead Time (DLT)	Low Delivery Lead Time, 1.0 Med Delivery Lead Time, 2.0 High Delivery Lead Time, 3.0	Lead Time is number of review periods

Table 2. Performance measures for the experimental design

Performance Measures	Performance Measure Details
Retailer Cost (per period)	Inventory Holding Cost for the Retailer plus Backorder Cost for the Retailer
Manufacturer Cost (per period)	Inventory Holding Cost for Manufacturer plus Backorder Cost for Manufacturer

3. Results and Discussion

The output data from both the simulation models are analyzed to determine the cost benefits of CPFR over TSC under different inventory holding costs, backorder penalty costs, delivery lead timeand demand variability. First, the cost benefits of CPFR compared to TSC under different inventory holding costs for both the manufacturer and the retailer aredetermined. Next, the cost benefits of CPFR compared to TSC under different inventory holding costs along with other control factors for both the manufacturer and the retailer are determined. Some of the main results of this research study are shown below.

3.1 Impact of Different Inventory Holding Costs in CPFR Strategy

The cost benefits of CPFR over TSC under different inventory holding cost for both the manufacturer and retailer are shown in Figure 3. It can be seen that as inventory holding cost per unit per period increases, the cost benefits of CPFR strategy for both the manufacturer and the retailer also increases. This is due to the fact that information shared in CPFR collaboration strategy helps in reducing inventory and backorder costs,which in turn helps to increase the cost benefits of CPFR collaboration strategy for both the manufacturer and the retailer. So when inventory holding cost per unit per period is high, then CPFR strategy can generate significant benefits for both the manufacturer and retailer. Next, we investigate benefits of CPFR for different inventory holding cost along with demand variability, backorder penalty cost and delivery lead time for both the manufacturer and retailer.

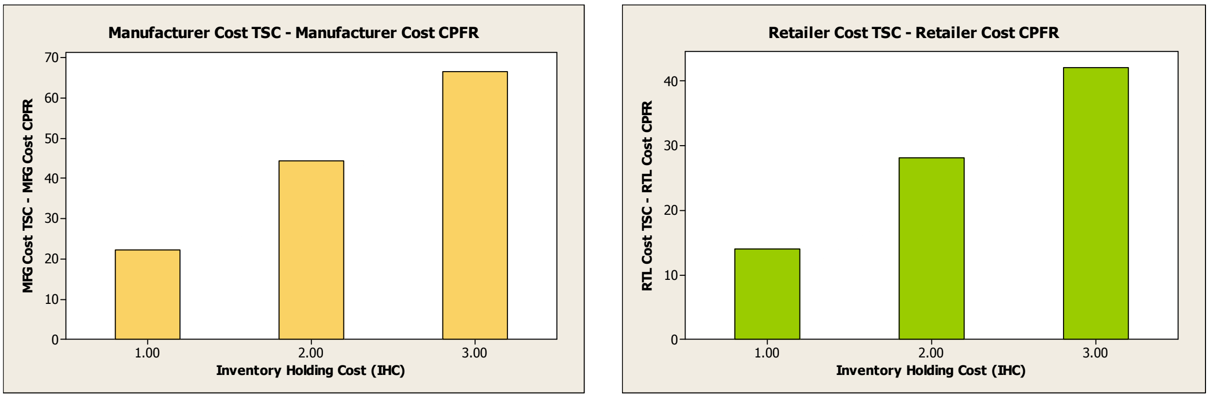

Figure 3. Cost benefits of CPFR under different inventory holding cost

3.2 Impact of Different Inventory Holding Cost and Demand Variability

The impact of different inventory holding cost and demand variability on the cost benefits of CPFR for both the manufacturer and retailer are shown in Figure 4. It can be seen that demand variability and inventory holding cost does have a significant impact on the cost benefits of CPFR strategy for both the manufacturer and retailer. As demand variability and inventory holding cost increases, the cost benefits of CPFR for both the manufacturer and retailer increases. When demand variability is low, the impact of inventory holding cost per unit per period on the cost benefits of CPFR is considerably lower.However, when demand variability is high and inventory holding cost is changed from $1.0 to $3.0 per unit per period, the cost benefits of CPFR increases significantly from $44.22 to$132.64 per period for the manufacturer and from $21.93 to $65.75 per period for the retailer.This suggests that when demand variability is high, the impact of increased inventory holding cost on the cost benefits of CPFR is significantly higher for both the manufacturer and the retailer. This is due to the fact that when demand variability is high, the safety stock and backorder penalty cost in TSC is usuallyhigher for both the manufacturer and the retailer. However, the availability of forecast and inventory level information in CPFR strategy helps in improving the forecast, production planning and inventory replenishment activities, which in turn helps to significantly reduce safety stock and backorder cost for both themanufacturer and the retailer.

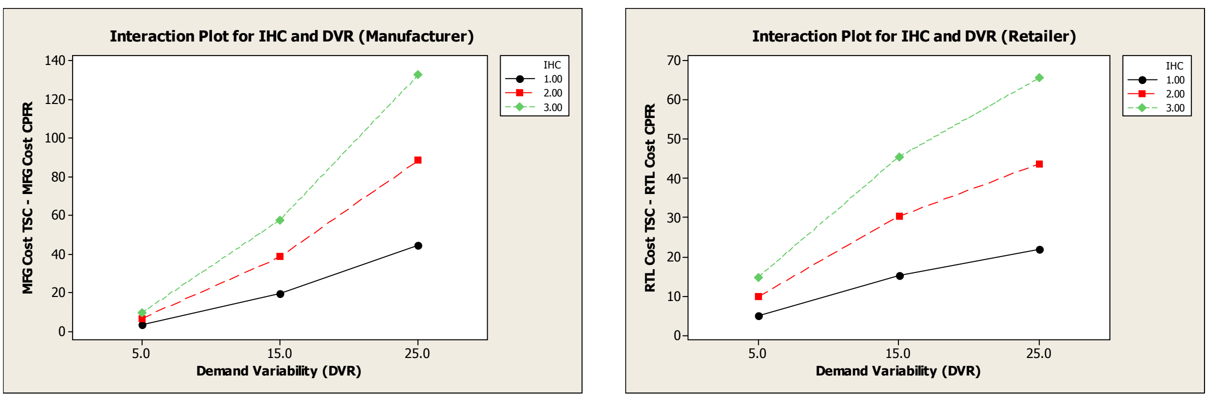

Figure 4. Impact of inventory holding cost (IHC) and demand variability (DVR)

3.3 Impact of Different Inventory Holding Cost and Backorder Penalty Costs

The impact of different inventory holding cost and backorder penalty costs on the cost benefits of CPFR for both the manufacturer and retailer are shown in Figure 5. It can be seen that both backorder penalty cost and inventory holding cost does have a significant impact on the cost benefits of CPFR strategy for both the manufacturer and retailer. As backorder penalty cost and inventory holding cost increases, the cost benefits of CPFR for both the manufacturer and retailer increases. When backorder penalty cost is low and inventory holding cost is changed from $1.0 to $3.0 per unit per period, the cost benefits of CPFR increases from $11.65 to $34.13 per period for the manufacturer and from $4.73 to $14.22 per period for the retailer. However, when backorder penalty cost is high and inventory holding cost is changed from $1.0 to $3.0 per unit per period, the cost benefits of CPFR increases significantly from $30.73 to $98.95 per period for manufacturer and from $23.32 to $69.40 per period for the retailer. This suggests that when backorder penalty cost is high, the impact of increased inventory holding cost on the cost benefits of CPFR is significantly higher for both the manufacturer and the retailer. Generally, when backorder penalty cost is high, reducing backorders without significantly increasing inventory is important for efficient inventory management. Therefore the benefits of CPFR increases as backorder penalty costs and inventory holding cost increases due to the availability of forecast and inventory level information in CPFR strategy. This helps in improving the forecast, production planning and inventory replenishment activities, which in turn helps to significantly reduce safety stock and backorders for both the manufacturer and the retailer.

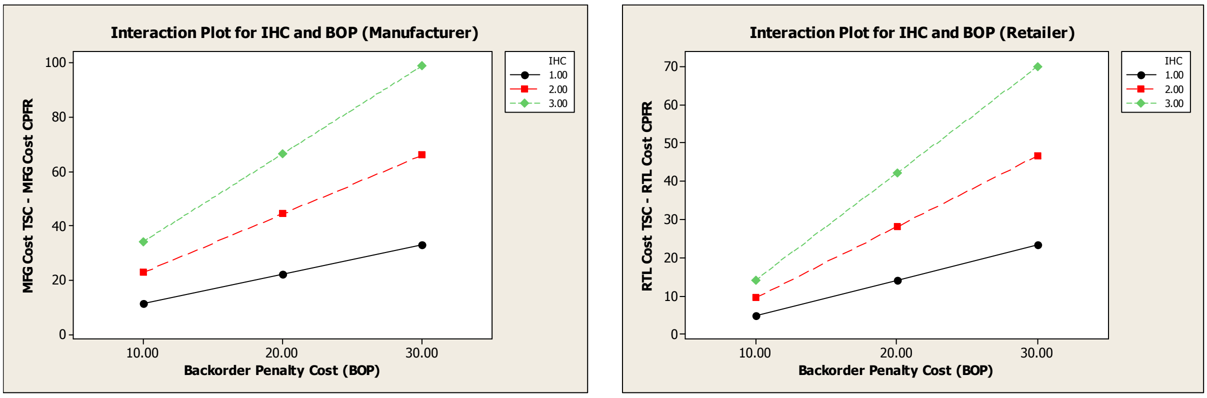

Figure 5. Impact of inventory holding cost (IHC) and backorder penalty cost (BOP)

3.4 Impact of Different Inventory Holding Cost and Delivery Lead Time

The impact of different inventory holding cost and delivery lead time on the cost benefits of CPFR for both the manufacturer and retailer are shown in Figure 6. It can be seen that delivery lead time does have a bigger impact on the cost benefits of CPFR strategy for both the manufacturer and retailer. As inventory holding cost and delivery lead time increases, the cost benefits of CPFR for both the manufacturer and retailer increases. When delivery lead time is low and inventory holding cost is changed from $1.0 to $3.0 per unit per period, the cost benefits of CPFR increases from $12.47 to $37.31 per period for the manufacturer and from $3.87 to $11.52 per period for the retailer. However, when delivery lead time is high and inventory holding cost is changed from $1.0 to $3.0 per unit per period, the cost benefits of CPFR increases significantly from $36.66 to $109.83 per period for the manufacturer and from $25.98 to $77.73 per period for the retailer. This suggests that when delivery lead time is lower, there is considerably lower impact of increased inventory holding cost per unit per period on the benefits of CPFR strategy, especially for the retailer. However, when delivery lead is high, the impact of increased inventory holding cost on the cost benefits of CPFR is significantly higher for both the manufacturer and the retailer. This is due to the fact that when delivery lead time is high, significantly higher safety stock is maintained in TSC by both the manufacturer and the retailer. However, the availability of forecast and inventory level information in CPFR strategy helps in improving inventory fillrate and significantly reduce the safety stock and backorder cost for both the manufacturer and the retailer.

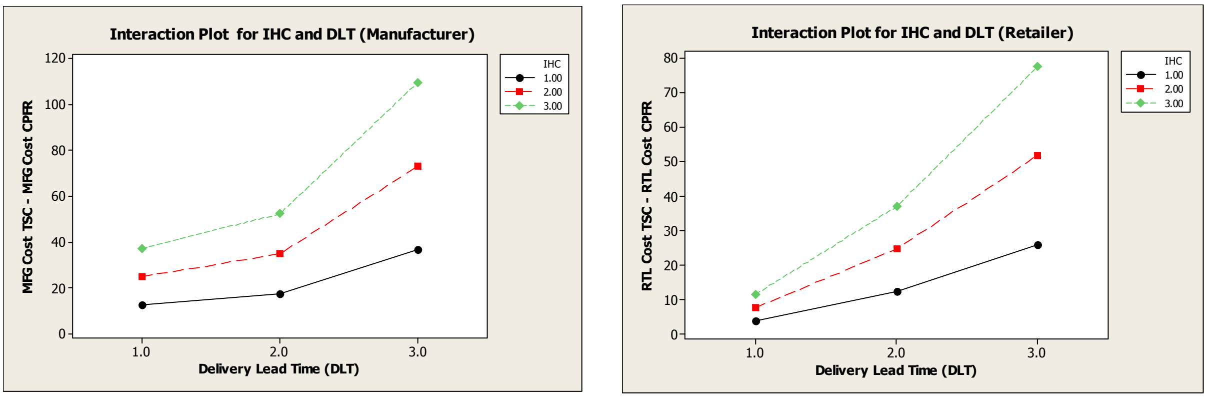

Figure 6. Impact of inventory holding cost (IHC) and delivery lead time (DLT)

4. Conclusions

This research study investigated the benefits of sharing sales, forecast and inventory level information in CPFR collaboration strategy compared to no information sharing in TSC under different inventory holding costs, backorder penalty costs; demand variability and delivery lead timefor both the manufacturer and the retailer using simulation methodology. Generally, different products have different inventory holding costs which can have a significant impact on the total cost of inventory management. In addition, back order penalty costs can also have a significant impact on the benefits of information sharing in CPFR strategy. The conceptual model is a two-echelon production-inventory system with a make-to-stock manufacturer (plant and warehouse) and a retailer. Periodic review order-up-to inventory policy (R, S) is used to determine the order quantity for retailer and production quantity for manufacturer during each period. Manufacturer uses lot-for-lot production policy with production lead time of one period. The results suggest that when inventory holding cost per unit per period increases, the cost benefits of CPFR strategy also increases for both the manufacturer and retailer. Based on the cost measures considered in this study, the manufacturer gains more cost benefits of CPFR compared to the retailer. Also, cost benefits of CPFR strategy is significantly higher when demand variability is high, inventory holding cost is high, backorder penalty cost is high and the delivery lead time is long. However when demand variability is low and delivery lead time is short; the benefits of CPFR collaboration strategy is much lower for both the manufacturer and the retailer.

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