USE OF RANGE AND QUANTITY FLEXIBILITY CONTRACTS IN MITIGATING SUPPLY CHAIN DISRUPTION

by

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AUTHOR'S DECLARATION

I, Binura Pasan Ranwala, declare that the research work carried out for this thesis was in accordance with the regulations of the Asian Institute of Technology. The work presented in it are my own and has been generated by me as the result of my own original research, and if external sources were used, such sources have been cited. It is original and has not been submitted to any other institution to obtain another degree or qualification. This is a true copy of the thesis, including final revisions.

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Lastly, I would like to dedicate this thesis to my parents, not only for funding me and giving me this opportunity but for always being there for me and supporting me all throughout my life. All my successes cannot be attained without them.

ABSTRACT

A retailer, a main supplier and backup supplier were examined in this proposed system. The two suppliers were considered under two separate contracts. Under a quantity flexibility contract, the main supplier was used, while the backup supplier was used under a range contract. It was stated that the main supplier was vulnerable to disruption and, as such, this contract configuration was proposed to minimize the impact of the stated disruption. A mathematical model was designed to simulate the mentioned system in this report. Using the statistical model, experiments were conducted using MATLAB to obtain the optimal order quantities for the retailer from the main supplier and the backup supplier to get optimal profit for him. A sensitivity analysis was also carried out to examine the impact on the order quantities of changing range fees, shortage price and penalty fee. Furthermore, to determine the efficiency of this contract configuration, a comparison was made between both the centralized and decentralized systems. The effect of the return quantity ratio is unclear, and it can be concluded that this contract configuration can coordinate the supply system.

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INTRODUCTION

1.1 Background

The supply chain is the linked network of parties from the raw material suppliers to the retailers which distributes end products to the customers (Simchi-levi, 2003). It is critical to deliver good quality products at a considerable price since the demand for most of the items is based on customer satisfaction. To facilitate the above mission the supply chain should be effective which means that it should deliver the desired output efficiently so that the maximum output is achieved by spending the minimum input.

Simchi-levi (2003) further stated that the observations made on the supply chain are too challenging to propose strategies (i.e., methods of managing the supply chain) for the whole chain, due to the uncertainties and the risks involved in forecasting the proper demand. Typically, strategies are applied to single links, i.e., the connections between two parties in the supply chain. Nevertheless, the strategies can also be applied to multiple links (Guo et al., 2017). It is important to have a proper strategy, as it would contribute to a smooth flow and sound coordination in the supply chain (Monczka et al., 1998).

Supply chain disruptions (i.e., disturbance or problems which interrupt the smooth flow of the supply chain) mainly occur due to demand uncertainty which is one of the main risks in production management. Lessard & Donald (2013) states that globalized companies face uncertainties due to geographic dispersion and organizational fragmentation. Whereas Wang & Michael (2018) states that uncertainties are occurring due to poor logistics performance. While Park & Kim (2016) stated that there are two main categories of disruption which are man-made and natural.

Man-made supply chain disruptions should be addressed in a three-step procedure. First, it is required to identify the causes of disruption (Mitchell, 1995; Zsidisin, 2003), followed by the development of the controlling technique to address the causes (Chopra

& Sodhi 2004; Hallikas et al., 2004; Harland et al., 2003; Ritchie & Brindley 2007), and finally to analyse the consequences of disruption on firm's performance (Norrman & Jansson, 2004; Wagner & Bode 2008; Hendricks & Singhal, 2003, 2005a, 2005b).

There are many tools in supply chain management to mitigate disruption, such as stockpile inventory, diversify the supply base, develop backup suppliers, manage product demand, and strengthen the core supply chain. Strategies that are implemented on one or more of these tools could help in mitigating the supply chain disruptions (Lee et al., 2014).

Simchi-levi (2003) also found that supply chain contracts can contribute to achieving coordination in the supply chain. According to Simchi-levi (2003) supply chain contracts are agreements between buyer and supplier on issues like pricing and volume discounts, minimum and maximum purchase quantities, delivery lead times, product or material quality, product return policies.

The concept of multi-sourcing was investigated by Tomlin (2006), and the literature on this article is based on his prior research. The body of the work conducted by Tomlin heavily focuses on the use of supply chain contracts, where a backup source of supply is employed. The coordination in the system is also required to attain additional profits for all members of the supply chain. For the adjustment of numerous actions implemented by multiple firms, the coordination plays an important role. Specifically, coordination is necessary to temper the downstream competition (Cachon, 2003).

In almost all the cases, a centralized system will outperform the decentralized system, in terms of supply chain profit (Chen et al., 2014). Therefore, to deal with the supply disruption through a contract agreement, retailers should have a long-term relationship with their suppliers. Agreeing with the supplier through a contract can help the buyers to reserve the capacity ahead to reduce inefficiency costs (Hou et al., 2017). The flexibility described favours the buyer. However, this may adversely affect the supplier as they may bear the risk of excess inventory. This can be mitigated by offering limited flexibility or prices based on the level of flexibility (Barnes-Schuster et al., 2002). Ultimately contracts are utilized to increase the coordination performance of the supply chain which means to achieve maximum profit for the whole supply chain as if the chain were operated under centralized decisions rather than decentralized decisions.

Some researchers examined agreements that have been considered as procurement contracts in conventional inventory management. Supply contract is a collaboration process in the supply chain that is structured to help the participants collaborate and aims to achieve exactly the same efficiency as the centralized structure. In addition, the procurement contract is used to enhance the efficiency of all members of the supply chain. An order to maximize the benefit of the participants of the supply chain relative to the decentralized system, and win-win condition would be core aspects of a contract (Giri et al., 2016).

1.2 Problem Statement

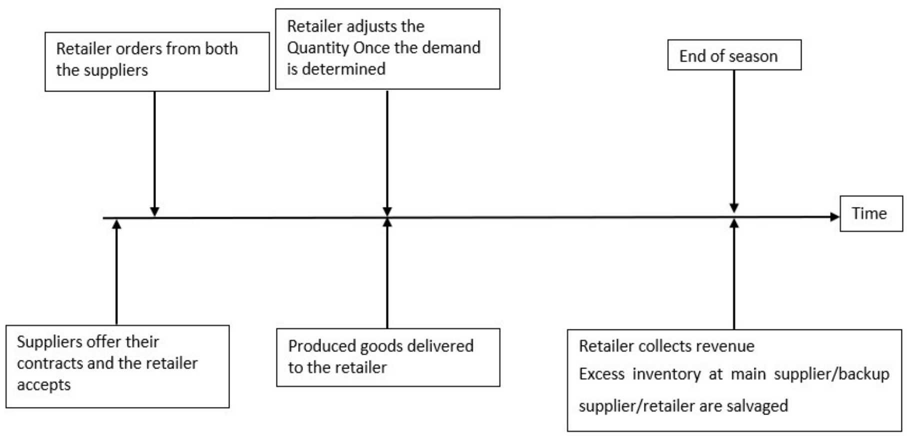
Review of the issues with regards to supply chains reveals supply chain disruptions as a critical issue. The unpredictable events cause disruptions in supply chains with a single supply source. (Barnes-Schuster et al., 2002). These disruptions result in inefficiencies, such as supply shortage, fluctuations, and delays (Togar et al., 2002). To avoid these issues, practitioners emphasize more on the use of flexibility as a solution. Flexibility is accomplished by promoting cooperation between all the different organizations that are suppliers, manufacturers, distributors, logistics providers, and retailers, with the goal of constantly enhancing all processes under increasingly evolving market conditions (Togar et al., 2002). Some analysts prefer to rely on using contracts to provide a flawless supply chain (Cachon, 2003). Further, dual sourcing is one such measure which helps to solve the above issue, and it focuses on using an additional supplier (Hou & Sun, 2016). Having more than one supplier can help improve reliability and avoid demand disruptions (Yu et al., 2009).

To mitigate the harmful effect of supply disruptions, this study focuses on developing a mathematical model for a system with one retailer and two suppliers which includes the main supplier, who might experience supply disruptions, with a quantity flexibility contract and a backup supplier with a range contract.

Figure 1.1 illustrates the timeline of the supply chain system from the production period to the end of the selling season. It is noted that the main supplier might have excess inventory due to the arrangement of the quantity flexibility contract. Excess inventory might also exist with both the retailer and the backup supplier. At the end of the period, all excess inventories will be salvaged at the same salvage price.

Figure 1.1

Timeline of the System



1.3 Objective

The objective of this research is to develop a contract model to deal with the supply disruption problem between a retailer and two suppliers, which comprises of one main supplier, and one backup supplier. The contract signed between the retailer and the main supplier is a quantity flexibility contract while the contract used between the retailer and the backup supplier is a range contract. The main contract parameters, i.e., order quantity and maximum return quantity from the retailer to the main supplier and the range of order quantity to the backup supplier will be the decision variables that need to be determined to maximize the profit of the retailer. Furthermore, the effectiveness of the proposed system will be tested by comparing the centralized and decentralized systems.

1.4 Scope and Limitations

The system examined in the study will be limited to the following characteristics.

- The supply chain will consist of one buyer and two suppliers. i.e., one main supplier and one backup supplier.
- The research only considers products with a single selling season.
- The main supplier will be subjected to supply chain disruption and may not deliver any ordered goods when disruption occurred.
- The main supplier will be under a quantity flexibility contract.
- The backup supplier will be under a ranged contract.

CHAPTER 2
LITERATURE REVIEW

The present study analyses the situation of a retailer where the main supplier with a quantity flexibility contract is under supply disruption. To mitigate the effect of supply disruption, a backup supplier with a range contract has been used by the retailer. Since the main objective is to avoid harmful effect of disruption and to achieve coordination, the literature related to the proposed contracts will be presented in this chapter. To be specific, the literature on quantity flexibility contracts, range contracts, and systems under disruption is discussed in the below sections.

Hèohn (2010) showed the existence of various types of contracts. He further stated that the simplest contract is the wholesale contract which simply describes the number of goods to be sold at specific wholesale prices. Another contract is the quantity discount contract which urges the buyer to purchase large volumes as the unit's wholesale price will be decreased as the buyer purchases above certain amounts. Some contracts allow the buyer to refund unsold goods such as the buyback contract and the quantity flexibility contract. In the buyback contract, the supplier agrees to buy back any unsold goods at a buyback price (the price can vary from salvage price and wholesale price). In the quantity flexibility contract, the buyer can refund unsold goods much like in the buyback contract. However, not all the unsold goods may be returned, rather only a previously established maximum quantity of the full order quantity may be returned at wholesale price.

Contracts such as the revenue sharing contracts are developed in a way that all the revenue generated by the buyer and the salvage is shared among the buyer and supplier in exchange for a favourable wholesale price. The sales rebate contract specifies that the supplier will pay the buyer a fixed amount for each unit sold above a given limit. Further there exist contracts such as the option contract that aim to provide flexibility to the buyer by allowing the buyer to adjust the order quantity when the demand is realized. Moreover, Emmons and Gilbert (1998) discovered how the profits of both parties are affected by the buyback contract under decentralized system with demand that fluctuates with price. (Bernstein and Federgruen (2005)) analyze the reliability actions of the decentralized supply chains in the sense of the two supply chains under demand volatility and the nature of contractual agreements between the parties. (Li et al. (2010)) to investigate a supply chain of manufacturers and vendors by disruption of supply and to recommend an appropriate situation for the decentralized system. Recent analysis has been suggested by (Li et al. (2017)), Research Capability Reconstruction to resolve disturbance in the decentralized assembly system consisting of a producer, and two suppliers that produce two components separately during development undertake that the main supplier may experience a supply disturbance situation, while another supplier may be completely efficient. They also present the scenario where, as damage happens, the main supplier will be able to resume the production volume, whatever the producer or trustworthy supplier is capable of supplying to the main supplier with a share revenue sharing contract. Eventually, supply delays are not uncommon, firms must get ahead of them. Thus, we model the contract structure formed between the manufacturer and the two suppliers under which it is usual and backup suppliers.

2.1 Quantity Flexibility Contracts

According to Simchi-levi (2003) a quantity flexibility contract is a contract where a retailer can refund the items as long as it does not exceed an agreed limit, and also it is different from the buy-back contracts because the buy-back contracts allow a partial refund amount for the whole quantity. Li et al. (2016) have developed a quantity flexibility contract between a cosmetic manufacturer and a retailer to help coordinate the supply chain. By this quantity-flexibility and supply chain coordination arrangement, the retailer commits an amount of quantity of newly-developed product, and in return the manufacturer allows the retailer to adjust the order quantities of the commitment quantities based on the inventory balance status and customer demand. It is expected that with this arrangement, both parties can attain maximum profit under the concept of the synergy effect by developing a two-period dynamic model. The optimal replenishment strategy for the retailer and the optimal pricing scheme for the manufacturer is obtained by comparing between models with and without the supply chain coordination or quantity adjustment. Numerical analysis and case application have been presented to support the theoretical model of Li et al. (2016) which focuses on attaining global (channel) optimal profit for both the manufacturer and the retailer. The findings of this study illustrate that there exists an improved supply chain coordination in the presence of quantity flexibility contract. Lian & Deshmukh (2009) indicated that such quantity flexibility contracts are common in automobile and contract manufacturers, as well as in fuel oil and natural gas delivery markets.

Sethi et al. (2003) studied single and multi-period quantity flexible contracts involving one demand forecast update in each period and a spot market. The optimum order quantities which used in the contract are obtained from the spot market. The amount that can be purchased on the contract is bounded by a given flexibility limit. The impact of the forecast quality and the level of flexibility on the optimal decisions and managerial insights were discussed behind the results.

Li et al., (2020) stated that the quantity flexibility contract is better than a capacity reservation contract when the demand and the price of the product are both uncertain, whereas capacity cost is high and capacity lead time is long . Li et al. (2020) has also shown how the quantity flexibility contract is more suitable as it can achieve higher coordination and higher profitability. Kim (2011) stated that the quantity flexibility contract can be a disadvantage to the buyer due to its mechanism and reduces the performance of the supply chain, i.e., where there are always unsold goods than the arranged limit.

2.2 Range Contracts

This type of contract is less explored in literature. According to Hochbaum & Wagner (2015) range contracts allow the buyer to procure goods from the supplier at a prescribed price within a specified range. In return, the supplier is compensated upfront with a range fee. This fee can be viewed as the buyer trading monetary value for reduced uncertainty. Hochbaum & Wagner (2015) further stated that the range contract is highly compatible with the quantity flexibility contract. Moreover, range contracts are more suitable for backup suppliers than for the main suppliers. Additionally, range contracts generalize existing contracts such as just in time, fixed price, option, and quantity-flexibility contracts, and can be adjusted to work alongside with other contracts.

2.3 Mitigating Disruption

According to Ambulkar et al. (2015), there are four types of supply chain disruptions that occur in firms. They are supply disruption, i.e., a late shipment of inbound materials from the supplier, logistics/delivery disruptions, i.e., truckload transportation provider did not pick up a load of the product as they said they would, in house/plant disruptions, i.e., plant shutdown due to major machine breakdown, and natural hazards/regulatory and political issues, i.e., disruption stemming from a country whose government cracked down on illegal re-sterilization of products only intended for single-use, after which those products saw high levels of unanticipated demand. Norrman & Jansson (2004) stated that it is vital to control the risks in partnership among other partners of the supply chain due to the supply disruptive effect. Zegordi (2011) stated that strategies for managing supply chain disruption can be categorized into two main types: preventive and recovery, and preventive solutions can be categorized as follows: robustness strategies; resiliency strategies; security-based strategies; agility strategies.

Disruption is a common thing for every system due to the existence of demand uncertainty. For instance, the fashion industry is an industry where demand is determined through fashion trends which solely depend on customer satisfaction. In the study of Zhao et al. (2020) such a system is analysed and a strategy is formulated to achieve coordination and also increase the quality of production. Riddalls & Bennett (2002) suggested that due to disruptions, the systems become costly with a variety of possible problems such as longer lead-times, stock-outs, not able to meet customer demand, and increasing costs.

Levy (1995) stated that when difficulties occur in a supply chain, people in charge try to solve them as a one-time event instead of considering that it could be the result of a lack of a robust supply chain. Zhang et al (2015) studied the difference between the buyback and revenue sharing contracts and stated that the critical ratio was the deciding factor. Critical ratio is the difference of wholesale price and production cost divided by wholesale price. If the critical ratio is high, then the revenue sharing contract would outperform the buyback contract. However, in a situation where the critical ratio is low the difference between the contracts become small and unclear as to which would yield better results.

The study conducted by Ghadge et al. (2017) showed the effect of the supplier and the retailer has on a supply chain and recommend that the risk can be minimized through risk-sharing contracts. Ramdas and Spekman (2000) showed that the outcomes of lack of coordination in a system are due to inaccurate forecasts, waste time, low capacity utilization, excessive inventory, inventory turns, and expensive inventory and logistic costs. Moreover, it was found that the impacts of the uncoordinated supply chain system have more damages to the performance of the whole supply chain (Lee et al., 1997). To alleviate the effects of overstock and understock in the inventory, the supply chain members coordinate by improving the efficiency of the supply chain operations and sharing information, which is one of the coordination methods to improve the performance of the whole supply chain (Lee et al, 1997).

Craighead & Blackhurst (2007) stated that supply chain disruptions and the associated operational and financial risks represent the most pressing concern facing firms that compete in today's global marketplace. Existing research has not only confirmed the costly nature of supply chain disruptions but has also contributed relevant insights on such related issues as supply chain risks, vulnerability, resilience, and continuity. In this conceptual note, Craighead & Blackhurst (2007) focus on a relatively unexplored issue, asking and answering the question of how and why one supply chain disruption would be more severe than another. In doing so, they argue that the supply chain disruptions are unavoidable and, consequently, that all supply chains are inherently risky. Employing a multiple-method, multiple-source empirical research design, they derive novel insights, presented propositions that relate the severity of supply chain disruptions (i) to the three supply chain design characteristics of density, complexity, and node criticality and (ii) to the two supply chain mitigation capabilities of recovery and warning. These findings not only augment existing knowledge related to supply chain risk, vulnerability, resilience, and business continuity planning but also call into question the wisdom of pursuing such practices as supply base reduction, global sourcing, and sourcing from supply clusters.

The paper presented by Tomlin, (2006) describes a few methods used in the past to minimize the effects of supply disruption. Firstly, inventory mitigation, which simply means having extra inventory in case of disruption. It is a simple but not very effective strategy as it has a high cost of its own. Secondly, sourcing mitigation, which can be illustrated as sourcing an additional supplier. There are a few considerations that need to be taken in this case. Having a backup supplier who has unlimited or infinite capacity would help in improving efficiency. Finally, for mitigation, we have financial mitigation, which simply is insurance policies against such disruption events that can cover the losses incurred. Contingency planning can be seen from the examples of sourcing and demand adjustments in the case of disruption. As for contingent sourcing, the backup suppliers are called on only when disruption occurs with the main supplier. This means that these backup suppliers must be able to increase their production rapidly in response to last-minute orders. For contingency planning, demand management have been used which refers to the firm experiencing disruption shifting their demand to other products in their catalogue and away from the product currently affected by the disruption. Furthermore, Yu et al., (2009) stated that dual sourcing is better than single sourcing by analysing a system where the disruption risk is captured by a probability, the non-stationary demand is modelled with an exponential function of the wholesale price multiplied by the maximum market scale, and the decision is analysed based on expected profit functions (the probability threshold is dependent on parameters of the system). Hence, a combination of both contingency planning and backup sourcing has been identified as best for a risk-averse buyer that wants to cover both mitigation and contingency planning (Tomlin, 2006).

2.4 Decentralized and Centralized Systems

According to Simchi-levi (2003) centralize system, decisions are taken by a central location for the entire network, whereas without considering other facilities, each facility determines the most efficient method in a decentralized system. It is also stated that centralized systems lead to global optimization and decentralized systems lead to local optimization.

Chiu and Kremer (2014) stated that the efficiency of various supply chain situations (i.e., centralized and decentralized) is compared and discussed. The findings reveal that the Decentralized Supply Chain scenario is advantageous for the cost effectiveness of the Supply Chain Network, whereas the Centralized Supply Chain scenario shows advantages for cost performance.

The study by Chen, Tian and Yang (2014) focusses on attributes of goods with extremely little salvage value include a short life span, short stock life, easy to lose, nearly zero salvage value and even disposal costs where almost all items need to be marketed in order to reduce inventory costs. Chen, Tian and Yang (2014) examines the optimum retail prices, and the retailer profit functions in the distributed control system and the supply chain profit function in the centralized control system. The optimum order quantity is then obtained. Their analysis indicates that lower wholesale costs can continue to optimize the advantages of the supply chain by decentralized decision-making.

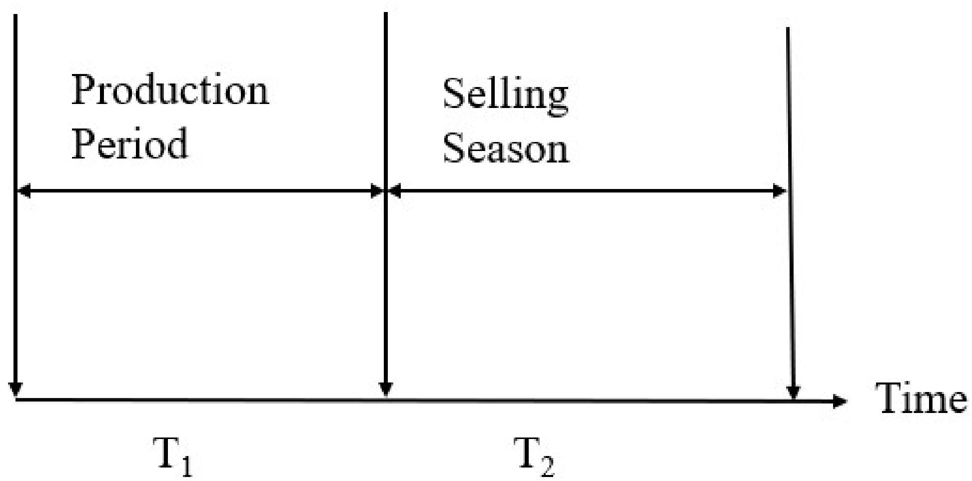
CHAPTER 3

MATHEMATICAL MODEL DEVELOPMENT

The mathematical model for the taken scenario in a supply chain which consists of 2 suppliers and a retailer where the main supplier is subjected to a quantity flexibility contract (who's under disruption) and the backup supplier is subjected to a range contract is as follows. The analysed time frame is from the beginning of the production period and until the end of the selling period. Only one selling season is considered in this case.

Figure 3.1

Timeline of the Model



The disruption will happen only to the normal supplier and as a result the model will study based on both scenarios of disruption and without disruption. Both cases will have the same initial period where the retailer will place orders to both suppliers at the beginning of the period (before selling season). The retailer will order Q_M by paying at whole sale price W_M to the normal supplier. With the backup supplier, the retailer will decide the order range [Q_{BU}, Q_{BL}] by paying the range fee R_F.

At the beginning of the selling season when the demand is realized, the retailer will place order within the agreed-upon range to the backup supplier working under the

range contract. The probability of disruption at the normal supplier to occur will be denoted as P_D and the demand is assumed to be a random variable which is uniformly distributed between $[\gamma - n]$ and $[\gamma + n]$.
The notations for the analysis are as follows.

x= demand

R_p= retailer's sales price

Q_M= initial order placed with the main supplier

W_M= whole sale price offered by main supplier

C_M= cost to manufacture one unit for main supplier

r= return quantity to main supplier

r_{max}= maximum allowed return to main supplier

P= penalty per unit for failing to deliver

R_F = Unit Range fees

Q_{BL} = Lower Order Quantity for Backup Supplier

Q_{BU} = Higher Order Quantity for Backup Supplier

W_B = Unit Wholesale Price of backup supplier

C_B= cost to manufacture one unit for backup supplier

P_d= probability that disruption occurs

S_c = Unit Shortage Cost

S = Unit Salvage Cost

3.1 Profit Function Without Disruption in the Production Period

T_1 Period;

Profit of the Retailer = - cost of the initial order from the normal supplier - cost of the order range fees from the backup supplier

$\prod_{R}^{T1}(Q_M, Q_{BU}, Q_{BL}) = -W_M Q_M - R_F(Q_{BU} - Q_{BL})$

Profit of the main supplier = revenue from the initial order - cost of production

$\prod_{M}^{T1}(Q_M, Q_{BU}, Q_{BL}) = W_M Q_M - C_M Q_M$

Profit of the backup supplier = revenue for making order range fees - cost of production

$\prod_{B}^{T1}(Q_M, Q_{BU}, Q_{BL}) = R_F(Q_{BU} - Q_{BL}) - C_B Q_{BU}$

3.2 Profit Function Without Disruption During the Selling Season

T_2 Period;

Case1; $x \leq Q_M - r_{max} + Q_{BL}$

Case2; $Q_M - r_{max} + Q_{BL} < x \leq Q_M + Q_{BL}$

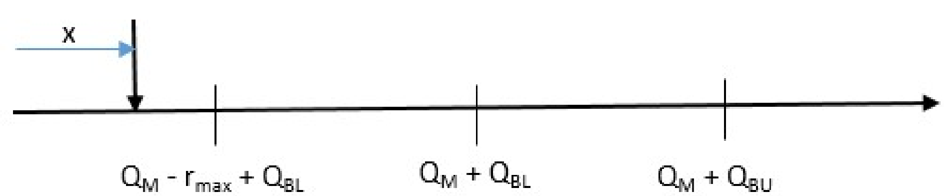
Case3; $Q_M + Q_{BL} < x \leq Q_M + Q_{BU}$

Case4; $x > Q_M + Q_{BU}$

Case1; $x \leq Q_M - r_{max} + Q_{BL}$

Figure 3.2

Without Disruption Case 1 – Demand Less than $Q_M - r_{max} + Q_{BL}$



Retailer returns r = r_{max} to the main supplier. The retailer has to order Q_{BL} from the backup supplier and salvage the remaining inventory. The main supplier will salvage the returned quantity to him, and the backup supplier will salvage (Q_{BU} - Q_{BL}).

Profit of the retailer = sales revenue – cost of order quantity from backup supplier + refund from normal supplier + salvage + payment to backup supplier

$\prod_{R2}^{T2}(Q_M, Q_{BU}, Q_{BL}, r, x) = R_P x - S(Q_M - r_{max} + Q_{BL} - x) +$
$W_M(r_{max}) - W_B(Q_{BL})$

Profit of the normal supplier = - repaying the retailer + salvage

$$\prod_{M2}^{T2}(Q_M, Q_{BU}, Q_{BL}, r, x) = -W_M r_{max} + S(r_{max})$$

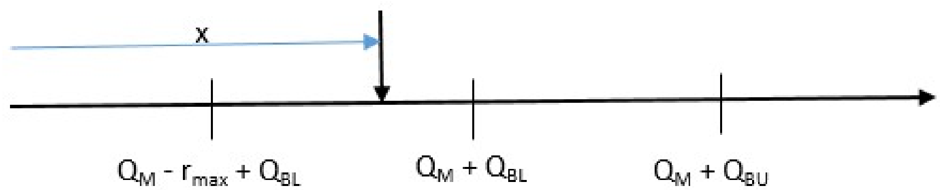
Profit of the backup supplier = revenue of the order quantity from retailer – Salvage

$$\prod_{B2}^{T2}(Q_M, Q_{BU}, Q_{BL}, r, x) = W_B(Q_{BL}) + S(Q_{BU} - Q_{BL})$$

Case2; Q_M - r_{max} + Q_{BL} < x ≤ Q_M + Q_{BL}

Figure 3.3

Without Disruption Case 2 – Demand between Q_M - r_{max} + Q_{BL} and Q_M + Q_{BL}



The retailer has to order Q_{BL} from the backup supplier. The quantity that the retailer returns to the main supplier is; r = (Q_M+Q_{BL}-x). The backup supplier salvages $(Q_{BU} - Q_{BL})$

Profit of the retailer = sales revenue – cost of order quantity from backup supplier

$$\prod_{R3}^{T2}(Q_M, Q_{BU}, Q_{BL}, r, x) = R_P x - W_B(Q_{BL})$$

Profit of the normal supplier = - repaying the retailer + salvage

$$\prod_{M3}^{T2}(Q_M, Q_{BU}, Q_{BL}, r, x) = -W_M(Q_M - x + Q_{BL}) + S(Q_M - x + Q_{BL})$$

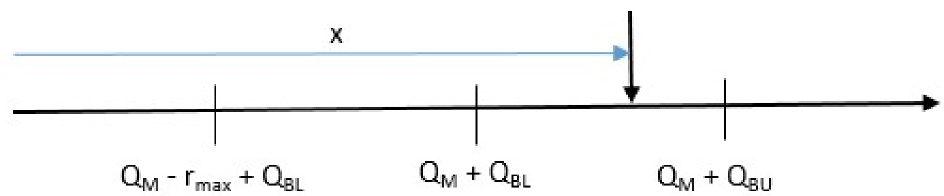
Profit of the backup supplier = revenue of the order quantity from retailer + Salvage

$$\prod_{B3}^{T2}(Q_M, Q_{BU}, Q_{BL}, r, x) = W_B(Q_{BL}) + S(Q_{BU} - Q_{BL})$$

Case3; $Q_M + Q_{BL} < x \leq Q_M + Q_{BU}$

Figure 3.4

Without Disruption Case 3 – Demand between $Q_M + Q_{BL}$ and $Q_M + Q_{BU}$



The retailer orders Q_M from the main supplier and orders (x-Q_M) from the backup supplier. No salvage for the Retailer and the main supplier. The backup supplier has a salvage quantity of $\left(Q_{BU} - (x - Q_M)\right)$.

Profit of the retailer = sales revenue – cost of order quantity from backup supplier

$$\prod_{R4}^{T2}(Q_M, Q_{BU}, Q_{BL}, r, x) = R_P x - W_B(x - Q_M)$$

Profit of the normal supplier = 0

$$\prod_{M4}^{T2}(Q_M, Q_{BU}, Q_{BL}, r, x) = 0$$

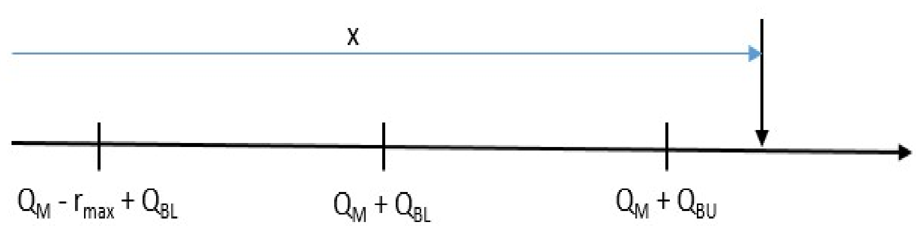
Profit of the backup supplier = revenue of the order quantity from retailer + Salvage

$$\prod_{B4}^{T2}(Q_M, Q_{BU}, Q_{BL}, r, x) = W_B(x - Q_M) + S\left(Q_{BU} - (x - Q_M)\right)$$

Case4; $x > Q_M + Q_{BU}$

Figure 3.5

Without Disruption Case 3 – Demand is Greater than $Q_M + Q_{BU}$



The retailer orders Q_{BU} from the backup supplier. No salvage for all three parties. Shortage quantity at the retailer is (x- Q_M - Q_{BU}).

Profit of the retailer = sales revenue – cost of order quantity from backup supplier – shortage cost

$$\prod_{R5}^{T2}(Q_M, Q_{BU}, Q_{BL}, r, x) = R_P x - W_B(Q_{BU}) - S_C(x - (Q_{BU} + Q_M))$$

Profit of the normal supplier = 0

$$\prod_{M5}^{T2}(Q_M, Q_{BU}, Q_{BL}, r, x) = 0$$

Profit of the backup supplier = revenue of the order quantity from retailer

$$\prod_{B5}^{T2}(Q_M, Q_{BU}, Q_{BL}, r, x) = W_B(Q_{BU})$$

3.3 Profit Function with Disruption at the During the Production Period

T_1 Period;

Profit of the Retailer = - cost of the initial order from the normal supplier - cost of the order range fees from the backup supplier

$$\prod_{R}^{T1}(Q_M, Q_{BU}, Q_{BL}) = -W_M Q_M - R_F(Q_{BU} - Q_{BL})$$

Profit of the main supplier = revenue from the initial order

$$\prod_{M}^{T1}(Q_M, Q_{BU}, Q_{BL}) = W_M Q_M$$

Profit of the backup supplier = revenue for making order range fees - cost of production

$$\prod_{B}^{T1}(Q_M, Q_{BU}, Q_{BL}) = R_F(Q_{BU} - Q_{BL}) - C_B Q_{BU}$$

3.4 Profit Functions During Selling Season with Disruption

T_2 Period;

Case1; $x \leq Q_{BL}$

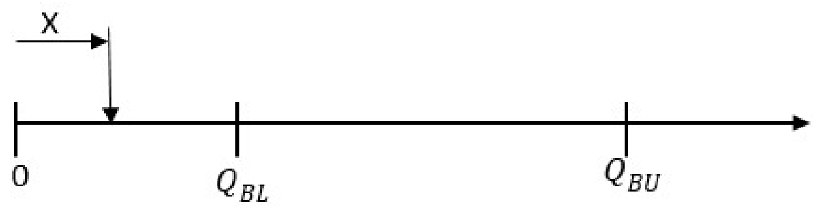
Case2; $Q_{BL} < x \leq Q_{BU}$

Case3; $x > Q_{BU}$

Case 1 $x \le Q_{BL}$

Figure 3.6

With Disruption Case 1 – Demand is Less than Q_{BL}



Retailer order Q_{BL} from backup supplier, receive penalty payment from normal supplier due to failure of delivery and have excess inventory of $(Q_{BL}-x)$. The backup supplier has an excess inventory of$(Q_{BU} - Q_{BL})$.

Profit of the retailer = sales revenue - cost of order quantity from backup supplier + penalty cost for fail delivery + salvage

$$\prod_{R1}^{DT} (Q_M, Q_{BU}, Q_{BL}, r, x) = R_P x - S(Q_{BL} - x) - W_B(Q_{BL}) + P(Q_M)$$

Profit of the normal supplier = – penalty cost for fail delivery

$$\prod_{M1}^{DT} (Q_M, Q_{BU}, Q_{BL}, r, x) = - PQ_M$$

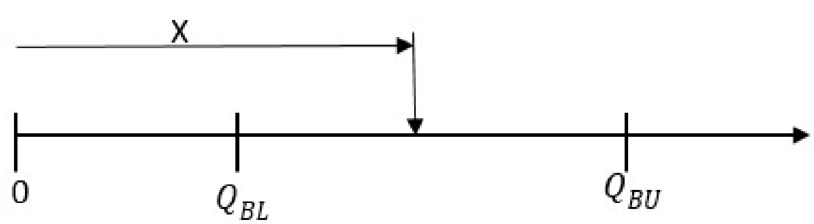
Profit of the backup supplier = revenue of order quantity from retailer + salvage

$$\prod_{B1}^{DT1}(Q_M, Q_{BU}, Q_{BL}, r, x) = S(Q_{BU} - Q_{BL}) + W_B Q_{BL}$$

Case2; $Q_{BL} < x \le Q_{BU}$

Figure 3.7

With Disruption Case 2 – Demand is in Between Q_{BL} and Q_{BU}



Retailer order x from backup supplier, receive penalty payment from normal supplier due to failure of delivery and, no excess inventory.

Profit of the retailer = sales revenue - cost of order quantity from backup supplier + penalty cost for fail delivery

$\prod_{R2}^{DT2}(Q_M, Q_{BU}, Q_{BL}, r, x) = R_P x - W_B(Q_{BU}) + P(Q_M)$

Profit of the normal supplier = – penalty cost for fail delivery

$\prod_{M2}^{DT2}(Q_M, Q_{BU}, Q_{BL}, r, x) = -PQ_M$

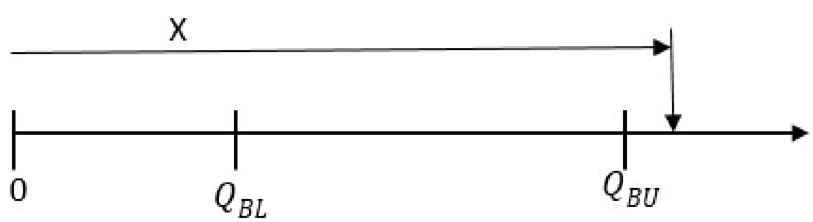
Profit of the backup supplier = revenue of order quantity from retailer + salvage

$\prod_{B2}^{DT1}(Q_M, Q_{BU}, Q_{BL}, r, x) = S(Q_{BU} - x) + W_B x$

Case3; x > Q_{BU}

Figure 3.8

With Disruption Case 2 – Demand is Greater than Q_{BU}



Retailer order Q_{BU} from the backup supplier, receive penalty pay from normal supplier due to failure of delivery and has an amount of shortage ($x - Q_{BU}$).

Profit of the retailer = sales revenue - cost of order quantity from backup supplier + penalty cost for fail delivery + shortage cost

$\prod_{R3}^{DT}(Q_M, Q_{BU}, Q_{BL}, r, x) = R_P Q_{BU} - W_B(Q_{BU}) - S_C(x - Q_{BU}) + P(Q_M)$

Profit of the normal supplier = – penalty cost for fail delivery

$\prod_{M3}^{DT2}(Q_M, Q_{BU}, Q_{BL}, r, x) = -PQ_M$

Profit of the backup supplier = revenue of order quantity from retailer

$\prod_{B3}^{DT}(Q_M, Q_{BU}, Q_{BL}, r, x) = W_B(Q_{BU})$

3.5 Expected Profits

When calculating the expected profit, the scenarios of with disruption and no disruption are considered separately. Each of the above situations have two time periods; i.e., the production period and the selling season. When the profits during the selling season is considered all the cases which are shown above in the previous sections should be considered. Here the demand is assumed to be uniformly distributed between $[\gamma - n]$ and $[\gamma + n]$

3.5.1 Expected Profits Without Disruption

Expected profit without disruption = [production period] + [selling season]

Retailer's profit function without disruption

$\prod_R^T(Q_M, Q_{BU}, Q_{BL})$ = profit function before the selling season + expected profit function during the selling season

$$\prod_R^T(Q_M, Q_{BU}, Q_{BL}) = -W_M Q_M - R_F(Q_{BU} - Q_{BL}) +$$
$$\int_{\gamma-n}^{Q_M - \text{rma} + Q_{BL}} \prod_{R2}^{T2}(Q_M, Q_{BU}, Q_{BL}, r, x)\, f(x)dx +$$
$$\int_{Q_M - \text{rmax} + Q_{BL}}^{Q_M + Q_{BL}} \prod_{R3}^{T2}(Q_M, Q_{BU}, Q_{BL}, r, x)\, f(x)dx +$$
$$\int_{Q_M + Q_{BL}}^{Q_M + Q_{BU}} \prod_{R4}^{T2}(Q_M, Q_{BU}, Q_{BL}, r, x)\, f(x)dx +$$
$$\int_{Q_M + Q_{BU}}^{\gamma+n} \prod_{R5}^{T2}(Q_M, Q_{BU}, Q_{BL}, r, x)\, f(x)dx +$$

Main supplier's profit function without disruption

$\prod_M^T(Q_M, Q_{BU}, Q_{BL}) =$ Profit function before the selling season + expected profit function during the selling season

$$\prod_M^T(Q_M, Q_{BU}, Q_{BL}) = W_M Q_M - C_M Q_M +$$
$$\int_{\gamma-n}^{Q_M - \text{rmax} + Q_{BL}} \prod_{M2}^{T2}(Q_M, Q_{BU}, Q_{BL}, r, x)\, f(x)dx +$$
$$\int_{Q_M - \text{rmax} + Q_{BL}}^{Q_M + Q_{BL}} \prod_{M3}^{T2}(Q_M, Q_{BU}, Q_{BL}, r, x)\, f(x)dx +$$

$\int_{Q_M + Q_{BL}}^{Q_M + Q_{BU}} \prod_{M4}^{T2}(Q_M, Q_{BU}, Q_{BL}, r, x)\, f(x)dx +$

$\int_{Q_M + Q_{BU}}^{\gamma+n} \prod_{M5}^{T2}(Q_M, Q_{BU}, Q_{BL}, r, x)\, f(x)dx$

Backup supplier's profit function without disruption

$\prod_M^T(Q_M, Q_{BU}, Q_{BL}) =$ Profit function before the selling season + expected profit function during the selling season

$\prod_B^T(Q_M, Q_{BU}, Q_{BL}) \; = R_F(Q_{BU} - Q_{BL}) \; - \; C_B Q_{BU} +$

$\int_{\gamma-n}^{Q_M - \text{rmax} + Q_{BL}} \prod_{B2}^{T2}(Q_M, Q_{BU}, Q_{BL}, r, x)\, f(x)dx +$

$\int_{Q_M - \text{rmax} + Q_{BL}}^{Q_M + Q_{BL}} \prod_{B3}^{T2}(Q_M, Q_{BU}, Q_{BL}, r, x)\, f(x)dx +$

$\int_{Q_M + Q_{BL}}^{Q_M + Q_{BU}} \prod_{B4}^{T2}(Q_M, Q_{BU}, Q_{BL}, r, x)\, f(x)dx +$

$\int_{Q_M + Q_{BU}}^{\gamma+n} \prod_{B5}^{T2}(Q_M, Q_{BU}, Q_{BL}, r, x)\, f(x)dx$

3.5.2 Expected Profits with Disruption

Expected profit with disruption = [production period] + [selling season]

Retailer's profit function with disruption

$\prod_R^{DT}(Q_M, Q_{BU}, Q_{BL})$ = profit function before the selling season + expected profit function during the selling season

$\prod_R^{DT}(Q_M, Q_{BU}, Q_{BL}) \; = -W_M Q_M \; - \; R_F(Q_{BU} - Q_{BL}) +$

$\int_{\gamma-n}^{Q_{BL}} \prod_{R1}^{DT} \; (Q_M, Q_{BU}, Q_{BL}, r, x)\, f(x)dx + \int_{Q_{BL}}^{Q_{BU}} \prod_{R2}^{DT2}(Q_M, Q_{BU}, Q_{BL}, r, x)\, f(x)dx +$

$\int_{Q_{BU}}^{\gamma+n} \prod_{R3}^{DT2}(Q_M, Q_{BU}, Q_{BL}, r, x)\, f(x)dx +$

Main supplier's profit function with disruption

$\prod_M^{DT}(Q_M, Q_{BU}, Q_{BL}) =$ Profit function before the selling season + expected profit function during the selling season

$\prod_M^{DT}(Q_M, Q_{BU}, Q_{BL}) \; = W_M Q_M \; - \; P Q_M$

Backup supplier's profit function with disruption

$\prod_M^{DT}(Q_M, Q_{BU}, Q_{BL}) =$ Profit function before the selling season + expected profit function during the selling season

$$\prod_B^{DT}(Q_M, Q_{BU}, Q_{BL}) = R_F(Q_{BU} - Q_{BL}) - C_B Q_{BU} + \int_{\gamma-n}^{Q_{BL}} \prod_{B1}^{DT2}(Q_M, Q_{BU}, Q_{BL}, r, x)\, f(x)dx + \int_{Q_{BL}}^{Q_{BU}} \prod_{B2}^{DT2}(Q_M, Q_{BU}, Q_{BL}, r, x)\, f(x)dx + \int_{Q_{BU}}^{\gamma+n} \prod_{B3}^{DT2}(Q_M, Q_{BU}, Q_{BL}, r, x)\, f(x)dx +$$

When combining the above functions into a final profit function the probability that a disruption is taken into consideration. The probability of disruption occurring is denoted as P_d.

Final Expected Profit = [Expected Profit with Disruption * Probability of disruption] + [Expected Profit without Disruption * Probability of no disruption]

Retailer Final Expected Profit = [Retailer Expected Profit with Disruption * Probability of disruption] + [Retailer Expected Profit without Disruption * Probability of no disruption]

$$\prod_R (Q_M, Q_{BU}, Q_{BL}) = (\prod_R^{DT}(Q_M, Q_{BU}, Q_{BL}) \ . P_d\ ) + (\prod_R^{T}(Q_M, Q_{BU}, Q_{BL}) \ . (1 - P_d))$$

Normal Supplier Final Expected Profit = [Normal Supplier Expected Profit with Disruption * Probability of disruption] + [Normal Supplier Expected Profit without Disruption * Probability of no disruption]

$$\prod_M (Q_M, Q_{BU}, Q_{BL}) = (\prod_M^{DT}(Q_M, Q_{BU}, Q_{BL}) \ . P_d\ ) + (\prod_M^{T}(Q_M, Q_{BU}, Q_{BL}) \ . (1 - P_d))$$

Backup Supplier Final Expected Profit = [Backup Supplier Expected Profit with Disruption] + [Backup Supplier Expected Profit without Disruption * Probability of no disruption]

$$\prod_B (Q_M, Q_{BU}, Q_{BL}) = (\prod_B^{DT}(Q_M, Q_{BU}, Q_{BL}) \ . P_d\ ) + (\prod_B^{T}(Q_M, Q_{BU}, Q_{BL}) \ . (1 - P_d))$$

CHAPTER 4
NUMERICAL EXPERIMENTS

This chapter explains the experiments conducted to identify the results (i.e., the profits of the parties involved and the optimum order quantities of both the suppliers) given by the system when numerical values are introduced, and the behavior of the key parameters in the system.

4.1 Numerical Experiments

Numerical experiments were conducted using MATLAB software. The following parameters were used in the test which was conducted to find the optimum order quantities which give the maximum profit of the two suppliers and the retailer. The profit of the whole supply chain is then calculated for the proposed contracts. The results are then compared with a system that has a similar setup of two suppliers and a retailer that uses buy-back and range contracts. The following parameters are used for the base case:

x= demand uniformly distributed between $[\gamma - n]$ and $[\gamma + n]$,

$R_p = 25$, $W_M = 10$, $C_M = 5$, $r_{max} = Q_M*0.25$, $P = 12$, $R_F = 2$, $W_B = 12$, $C_B = 7$, $P_d = 0.05$, $S_c = 28$, $S = 2$, $\gamma = 800$, n = 250

The optimal results of the base case are presented in table 4.1.

Table 4.1

Comparison Between the Proposed System with a Similar System Using a Buyback Contract.

Variables	Optimal result of the proposed system	Optimal results of system with buyback contract			
		Buyback price			
		5	5.2	5.4	5.6
Q_M	150	278	285	292	299
Q_{BL}	60	201	201	201	201
Q_{BU}	892	475	468	462	456
Retailer's profit	7164	5876	5888	5901	5914
Normal supplier's profit	902	1076	1086	1095	1103
Backup supplier's profit	4997	1150	1134	1117	1100
Supply chain's profit	13062	8102	8109	8113	8117

In table 4.1, the proposed system is compared with a previous study which dealt with a system that has a retailer, the main supplier which uses a buyback contract, and a backup supplier that uses a range contract. When comparing with the previous study, the order quantity from the main supplier has decreased. The range of the backup supplier (Q_{BU}-Q_{BL}) has increased. The profit of the retailer has increased. The profit of the backup supplier also increased but the profit of the main supplier has decreased. Also, the total profit of the supply chain has increased. So, it can be concluded that the proposed system is better for the retailer, the backup supplier, and the whole supply chain.

4.2 Sensitivity Analysis

In this part, the behavior of the key input parameters which are the range fee, shortage cost, penalty cost, and the probability of disruption are examined to identify their impact on the order quantities and the profits of the parties involved in the proposed supply chain. Further, the coordination of the supply chain is determined by calculating the efficiency of the total supply chain profit. In the decentralized system, (i.e., the decision-maker in the decentralized system is the retailer) the retailer's profit function is optimized so that maximum profit is achieved, and in the centralized system, (i.e., the decision-maker in the centralized system is an unbiased one) the total profit function is optimized so that the whole supply chain achieves the maximum profit.

4.2.1 Sensitivity Analysis with Respect To R_F

In this section, the effect of the range fees on the system is taken into consideration. The analysis is conducted by increasing and decreasing the base value used in the scenario and observe the changes in the order quantities of the two suppliers, the profits of the retailer, the two suppliers, and the profit of the whole supply chain. The results for both the centralized and decentralized systems are shown in table 4.2 and table 4.3 respectively.

Table 4.2

Effect of Changing Range Fees (R_F) in a Decentralized System

R_F	Q_M	Q_{BL}	Q_{BU}	Retailer's profit	Normal supplier's profit	Backup supplier's profit	Supply chain's profit
0.8	150	60	892	8162	902	3998	13062
1	150	60	892	7996	902	4165	13062
1.2	150	60	892	7829	902	4331	13062
1.4	150	60	892	7663	902	4497	13062
1.6	150	60	892	7496	902	4664	13062
1.8	150	60	892	7330	902	4830	13062
2	150	60	892	7164	902	4997	13062
2.2	150	60	892	6997	902	5163	13062
2.4	150	60	892	6831	902	5329	13062
2.6	150	60	892	6664	902	5896	13062
2.8	150	60	892	6498	902	5829	13062
3	150	60	892	6332	902	6230	13062

From the results shown in table 4.2 when the range fee is increased in the decentralized system, the order quantities of the main supplier and the backup supplier remain the same and so is the total supply chain profit. However, the profit of the retailer is decreased, and the profit of the backup supplier is increased. This happens because the range fee affects only the retailer and the backup supplier in the decentralized system.

Table 4.3

Effect of Changing Range Fees (R_F) in a Centralized System

R_F	Q_M	Q_{BL}	Q_{BU}	Retailer's profit	Normal supplier's profit	Backup supplier's profit	Supply chain's profit
0.8	251	670	773	9693	772	3205	13671
1	251	670	773	9672	772	3226	13671
1.2	251	670	773	9651	772	3247	13671
1.4	251	670	773	9631	772	3267	13671
1.6	251	670	773	9610	772	3288	13671
1.8	251	670	773	9590	772	3308	13671
2	251	670	773	9569	772	3329	13671
2.2	251	670	773	9548	772	3350	13671
2.4	251	670	773	9528	772	3370	13671
2.6	251	670	773	9507	772	3391	13671
2.8	251	670	773	9487	772	3411	13671
3	251	670	773	9466	772	3432	13671

From the results presented in table 4.3, when the range fee is gradually increased in the centralized system, the order quantities of the main supplier and the backup supplier remain the same and so does the total supply chain profit. However, the profit of the retailer has decreased, and the profit of the backup supplier has increased. This is due to the fact that the range fee affects only the retailer and the backup supplier in the centralized system.

Figure 4.1

Order Quantities Over with Respect to R_F in the Decentralized System

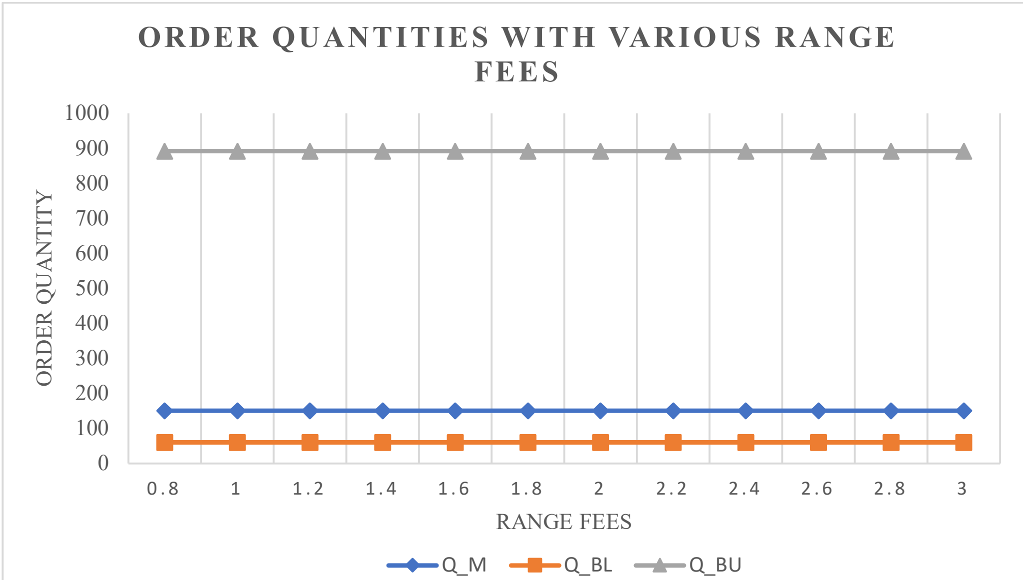
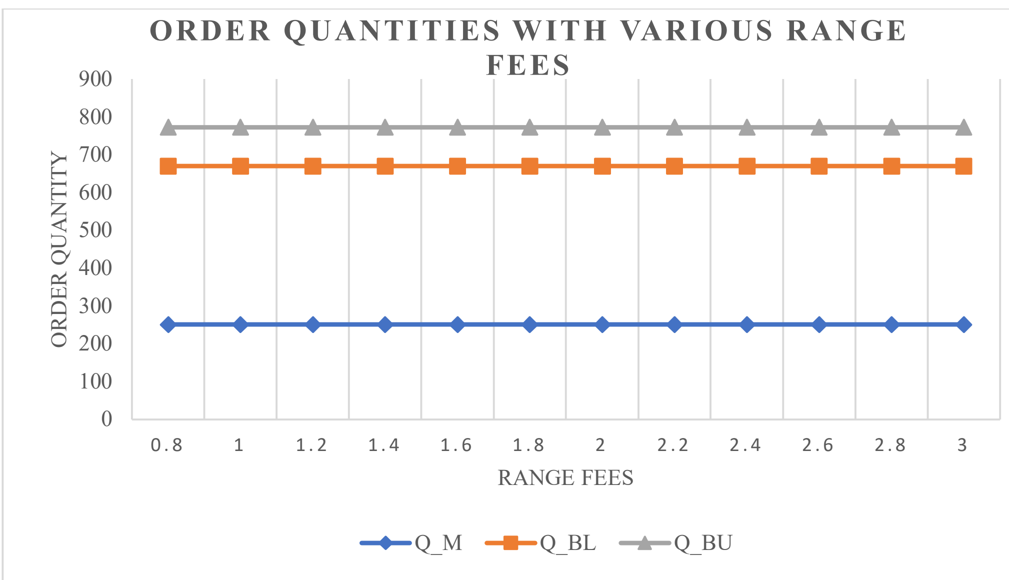


Figure 4.2

Order Quantities Over with Respect to R_F in the Centralized System.



The trends of the parameter, as shown in Figures 4.1 and 4.2, are similar in both the systems for the increment in R_F. Therefore, we can conclude that both the centralized and decentralized systems react in the same way for the changes made for R_F. However, the values of the order quantities of both the suppliers and their profits have changed.

The order quantity of the main supplier remains the same in the decentralized system and the centralized system. In terms of the backup supplier, the lower order quantity and the upper order quantity is also constant. Hence, the range of the backup supplier (Q_{BU}-Q_{BL}) has not changed in the decentralized and centralized systems. The profit of the retailer has decreased in both the systems where the profit of the backup supplier in both the systems has increased. The profits of the whole supply chain and the normal supplier is constant in both systems as well.

4.2.2 Coordination Analysis with Respect to Changes In R_F

In this section, the coordination of the supply chain is examined by calculating the efficiency (i.e., the percentage ratio of the total profit of the decentralized system over the total profit of the centralized system) from the total profit of the supply chain in both the centralized and the decentralized systems according to the changes of the range fee in the supply chain.

Table 4.4

Comparison Between Supply Chain Profits under Centralized and Decentralized Systems as R_F Changes

R_F	Decentralized	centralized	% efficiency
0.8	13062	13671	95.55
1	13062	13671	95.55
1.2	13062	13671	95.55
1.4	13062	13671	95.55
1.6	13062	13671	95.55
1.8	13062	13671	95.55
2	13062	13671	95.55
2.2	13062	13671	95.55
2.4	13062	13671	95.55
2.6	13062	13671	95.55
2.8	13062	13671	95.55
3	13062	13671	95.55

From the results revealed in table 4.4, it is clear that the total supply chain profit of the decentralized system is very near to the total supply chain profit of the centralized system. Therefore, the efficiency while R_F is changed is very high and the proposed system achieves good coordination.

4.2.3 Sensitivity Analysis with Respect to (S_C)

In this section, the impact of the shortage cost is taken into consideration. The base value is altered in the same manner as the range fees. The results for both the centralized and decentralized systems are shown in table 4.5 and table 4.6, respectively.

Table 4.5

Effect of Changing Shortage Cost (S_C) in a Decentralized System

S_C	Q_M	Q_{BL}	Q_{BU}	Retailer's profit	Normal supplier's profit	Backup supplier's profit	Supply chain's profit
14	141	63	905	7108	850	5075	13034
16	142	63	903	7119	856	5065	13040
18	144	62	901	7127	868	5048	13043
20	145	62	899	7138	873	5038	13049
22	146	61	897	7138	879	5037	13054
24	148	61	896	7154	890	5008	13052
26	149	60	894	7153	896	5007	13057
28	150	60	892	7164	902	4997	13062
30	152	59	891	7168	914	4977	13059
32	153	58	889	7168	920	4976	13063
34	155	58	887	7185	931	4950	13065
36	156	57	886	7182	937	4946	13064
38	158	57	884	7199	948	4920	13067
40	159	56	882	7197	954	4919	13070

According to the results in table 4.4, when the shortage cost increases in the decentralized system, the order quantity from the main supplier increases, the lower order quantity and upper order quantity from the backup supplier decreases. Also, the range of the backup supplier (Q_{BU}-Q_{BL}) slightly decreases. The backup supplier's profit has decreased, and the profit of the main supplier has increased. It is also observed that the trend in the retailer's profit and the profit of the whole supply chain profit is not very clear because of the fluctuations shown above. The fluctuations occur because there are local maximums and minimums in the profit functions of the retailer and the whole supply chain when the value of the shortage cost is changed. Hence, it can be concluded that the effect of the shortage cost is not significant.

Table 4.6

Effect of Changing Shortage Cost (S_C) in a Centralized System

S_C	Q_M	Q_{BL}	Q_{BU}	Retailer's profit	Normal supplier's profit	Backup supplier's profit	Supply chain's profit
14	400	427	590	10325	1393	2449	14167
16	369	478	629	10186	1253	2611	14050
18	343	522	662	10057	1139	2759	13955
20	320	560	691	9940	1042	2894	13875
22	299	593	715	9835	958	3021	13814
24	282	622	737	9736	889	3131	13756
26	266	647	756	9649	828	3232	13710
28	251	670	773	9569	772	3329	13671
30	238	690	788	9497	725	3414	13636
32	227	709	801	9424	684	3498	13606
34	216	725	814	9364	646	3567	13577
36	206	740	825	9307	611	3635	13554
38	198	754	835	9250	582	3698	13531
40	189	767	844	9200	553	3761	13514

According to the results in table 4.5, the total profit of the supply chain has decreased. The profits of the normal supplier and also the retailer have decreased where the profit of the backup supplier increased. The order quantity of the main supplier has reduced but the upper order quantity and the lower order quantity of the backup supplier have increased. However, the range (Q_{BU}-Q_{BL}) of the backup supplier has decreased.

Figure 4.3

Order Quantities with Respect to S_C in the Decentralized System.

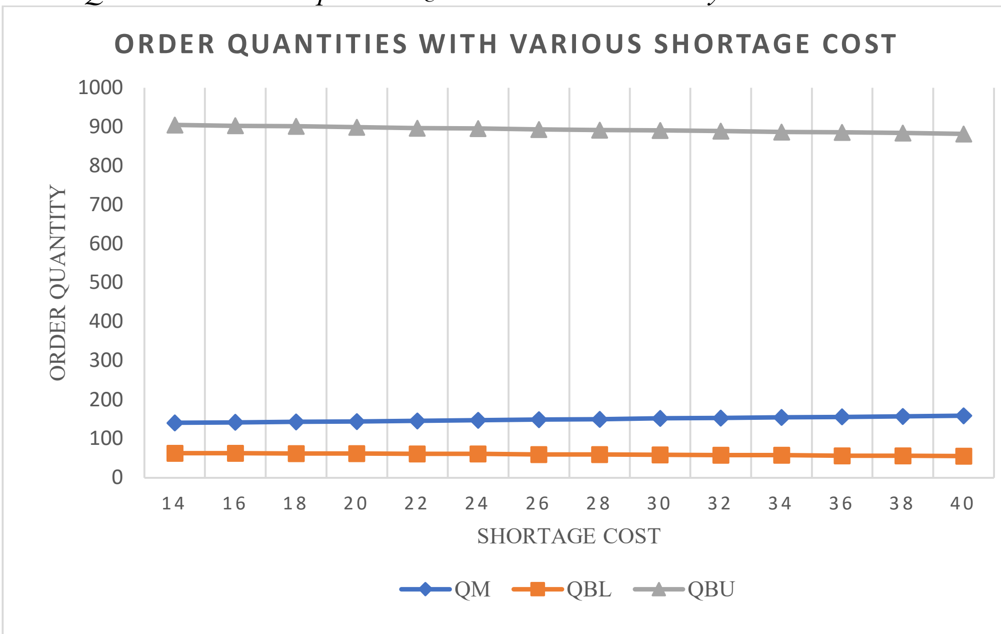
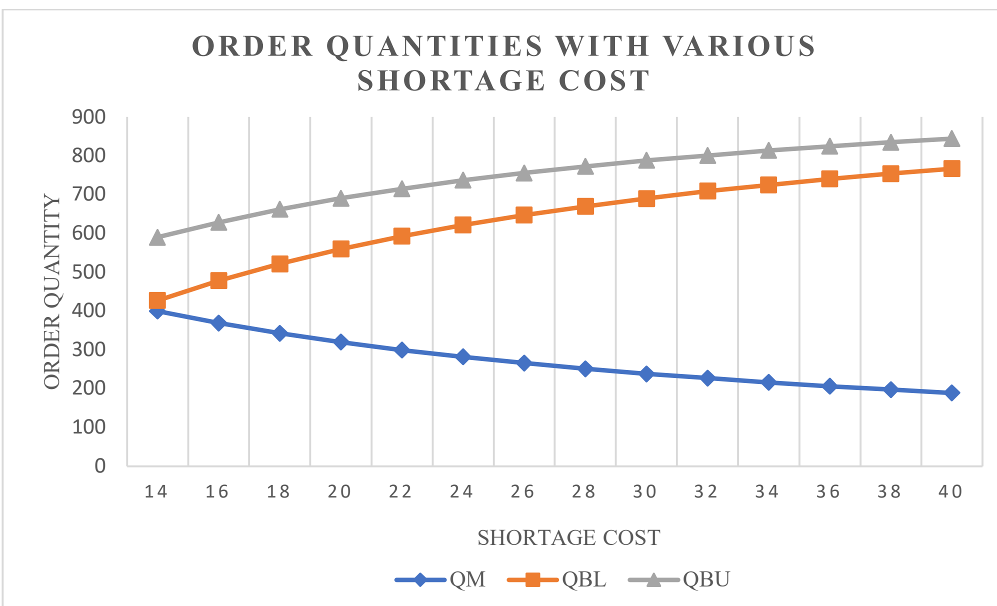


Figure 4.4

Order Quantities with Respect to S_C in the Centralized System.



As seen in figures 4.3 and 4.4, there are no fluctuations in the centralized system when compared with the decentralized system. The order quantity of the main supplier in the decentralized system increases when the shortage cost increases but the order quantity of the main supplier in the centralized system has decreased when the shortage cost increases. It is also notable that the lower order quantity of the backup supplier decreases in the decentralized system and increases in the centralized system. Further, it is also noted that the range of the backup supplier (Q_{BU}-Q_{BL}) decreases in both centralized and decentralized systems.

4.2.4 Coordination Analysis with Respect to Changes In S_C

In this section, the coordination of the supply chain is examined by calculating the efficiency from the total profits of the supply chain in both the centralized and the decentralized systems.

Table 4.7

Comparison Between Supply Chain Profits under Centralized and Decentralized Systems as S_C Changes

S_C	Decentralized	centralized	% efficiency
14	13034	14167	92.00
16	13040	14050	92.81
18	13043	13955	93.46
20	13049	13875	94.05
22	13054	13814	94.50
24	13052	13756	94.88
26	13057	13710	95.24
28	13062	13671	95.55
30	13059	13636	95.77
32	13063	13606	96.01
34	13065	13577	96.23
36	13064	13554	96.38
38	13067	13531	96.57
40	13070	13514	96.71

From the results shown in table 4.7, it is clear that the total supply chain profit of the decentralized system is very near to the total supply chain profit of the centralized system and it is also noted that the efficiency increases when the shortage cost increases. Therefore, it is evident that the efficiency is very high and that the proposed system achieves good coordination.

4.2.5 Sensitivity Analysis with Respect to (P)

The impact of the penalty fee is analyzed in this section. The method of analysis is the same as for the previous parameters. The results for both the centralized and decentralized systems are shown in table 4.8 and table 4.9, respectively.

Table 4.8

Effect of Changing Penalty Fees (P) in a Decentralized System

P	Q_M	Q_{BL}	Q_{BU}	Retailer's profit	Normal supplier's profit	Backup supplier's profit	Supply chain's profit
8.5	150	60	892	7137	928	4997	13062
9	150	60	892	7141	924	4997	13062
9.5	150	60	892	7145	921	4997	13062
10	150	60	892	7149	917	4997	13062
10.5	150	60	892	7152	913	4997	13062
11	150	60	892	7156	909	4997	13062
11.5	150	60	892	7160	906	4997	13062
12	150	60	892	7164	902	4997	13062
12.5	150	60	892	7167	898	4997	13062
13	150	60	892	7171	894	4997	13062
13.5	150	60	892	7175	891	4997	13062
14	150	60	892	7179	887	4997	13062
14.5	150	60	892	7182	883	4997	13062
15	150	60	892	7186	879	4997	13062

From the results in table 4.6, when the penalty fee increases in the decentralized system, the order quantities of the main and the backup suppliers remain the same and so is the total supply chain profit. The profit of the backup supplier is also not constant. However, the profit of the retailer has increased, and the profit of the main supplier has decreased. This is because the penalty fee affects only the retailer and the main supplier in the decentralized system.

Table 4.9

Effect of Changing Penalty Fees (P) in a Centralized System

P	Q_M	Q_{BL}	Q_{BU}	Retailer's profit	Normal supplier's profit	Backup supplier's profit	Supply chain's profit
8.5	251	670	773	9481	860	3329	13671
9	251	670	773	9494	848	3329	13671
9.5	251	670	773	9506	835	3329	13671
10	251	670	773	9519	823	3329	13671
10.5	251	670	773	9531	810	3329	13671
11	251	670	773	9544	798	3329	13671
11.5	251	670	773	9556	785	3329	13671
12	251	670	773	9569	772	3329	13671
12.5	251	670	773	9582	760	3329	13671
13	251	670	773	9594	747	3329	13671
13.5	251	670	773	9607	735	3329	13671
14	251	670	773	9619	722	3329	13671
14.5	251	670	773	9632	710	3329	13671
15	251	670	773	9644	697	3329	13671

As per the results in table 4.7, when the penalty fee increases in the centralized system, the order quantities of both the suppliers remain the same and so does the total supply chain profit. The profit of the backup supplier has also not changed. However, the profit of the retailer has increased, and the profit of the main supplier has decreased. This is because that the penalty fee affects only the retailer and the main supplier in the centralized system.

Figure 4.5

Order Quantities with Respect to P in the Decentralized System.

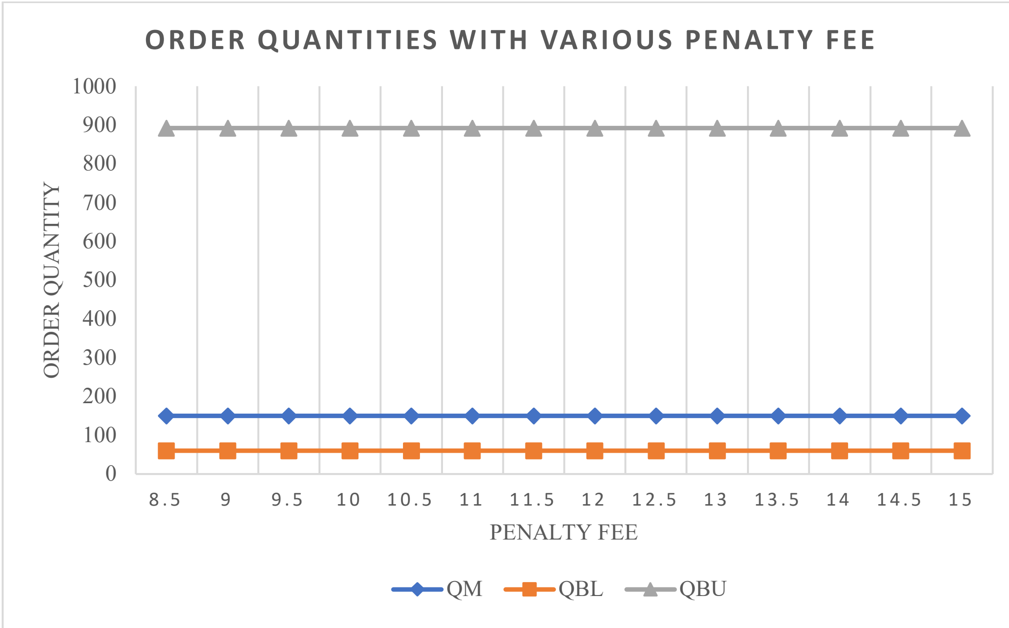
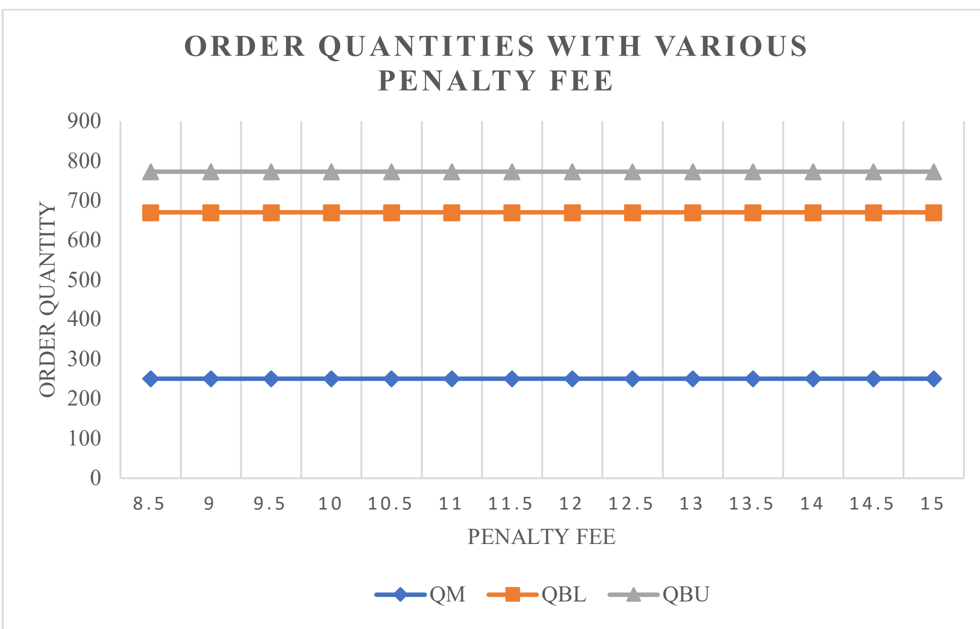


Figure 4.6

Order Quantities with Respect to P in the Centralized System.



As per figures 4.5 and 4.6, all the trends in both the systems are the same except for the order quantity increase of the main supplier and also the decline in the range of the backup supplier in the centralized system in comparison with the decentralized system.

4.2.6 Coordination Analysis with Respect to Changes In P

In this section, the coordination of the supply chain is examined by calculating the efficiency from the total profit of the supply chain in both the centralized and the decentralized systems according to the changes of the penalty cost in the supply chain.

Table 4.10

Comparison Between Supply Chain Profits under Centralized and Decentralized Systems as P Changes

P	Decentralized	centralized	% efficiency
8.5	13062	13671	95.55
9	13062	13671	95.55
9.5	13062	13671	95.55
10	13062	13671	95.55
10.5	13062	13671	95.55
11	13062	13671	95.55
11.5	13062	13671	95.55
12	13062	13671	95.55
12.5	13062	13671	95.55
13	13062	13671	95.55
13.5	13062	13671	95.55
14	13062	13671	95.55
14.5	13062	13671	95.55
15	13062	13671	95.55

From the results shown in table 4.10, it is clear that the total supply chain profit of the decentralized system is very near to the total supply chain profit of the centralized system. Therefore, the efficiency is very high and the proposed system achieves good coordination.

4.2.7 Sensitivity Analysis with Respect to (P_D)

The impact of the probability of disruption is analyzed by using the same method mentioned before. The results for both the centralized and decentralized systems are shown in table 4.11 and table 4.12, respectively.

Table 4.11

Effect of Changing the Probability of Disruption (P_D) in a Decentralized System

P_D	Q_M	Q_{BL}	Q_{BU}	Retailer's profit	Normal supplier's profit	Backup supplier's profit	Supply chain's profit
0.05	150	60	892	7164	902	4997	13062
0.06	139	64	908	6982	827	5115	12924
0.07	127	70	925	6809	747	5224	12780
0.08	114	76	944	6617	663	5339	12619
0.09	100	82	965	6405	576	5458	12439
0.1	84	89	989	6170	630	5586	12234
0.11	65	97	1016	5902	367	5737	12005
0.12	45	106	1046	5611	251	5553	11739
0.13	22	116	1081	5267	122	6031	11419

Results in Table 4.11 illustrates that when the probability of disruption increases, in the decentralized system, the order quantity of the main supplier decreases. This trend is reasonable. When considering the order quantity of the backup supplier, both the order quantities have increased, and the range (Q_{BU}-Q_{BL}) has increased. The profits of the retailer, the main supplier, and the whole supply chain have decreased while the profit of the backup supplier increased.

Table 4.12

Effect of Changing the Probability of Disruption (P_D) in a Centralized System

P_D	Q_M	Q_{BL}	Q_{BU}	Retailer's profit	Normal supplier's profit	Backup supplier's profit	Supply chain's profit
0.05	258	656	769	9648	857	3204	13709
0.06	257	659	770	9631	839	3230	13700
0.07	255	661	771	9618	823	3251	13692
0.08	254	664	771	9602	806	3279	13687
0.09	253	667	772	9585	789	3304	13678
0.1	251	670	773	9569	772	3329	13671
0.11	250	673	773	9554	756	3357	13666
0.12	249	675	774	9542	740	3377	13658
0.13	247	678	775	9526	723	3401	13651

Results in Table 4.12 illustrates that when the probability of disruption increases in the centralized system, the order quantity of the main supplier decreases. This trend is reasonable. When considering the order quantity of the backup supplier, both the order quantities have increased but the range (Q_{BU}-Q_{BL}) has decreased. The profits of the retailer, the main supplier, and the whole supply chain have decreased while the profit of the backup supplier increased.

Figure 4.7

Order Quantities over Different Stages of P_D in the Decentralized System.

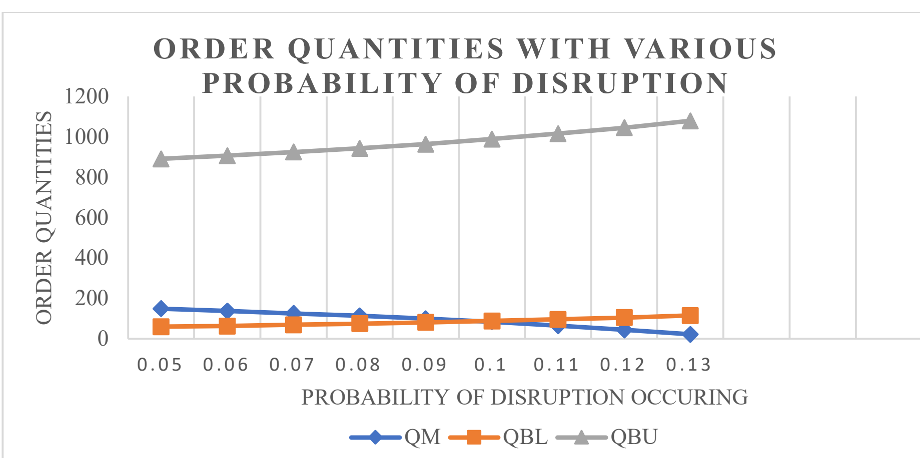
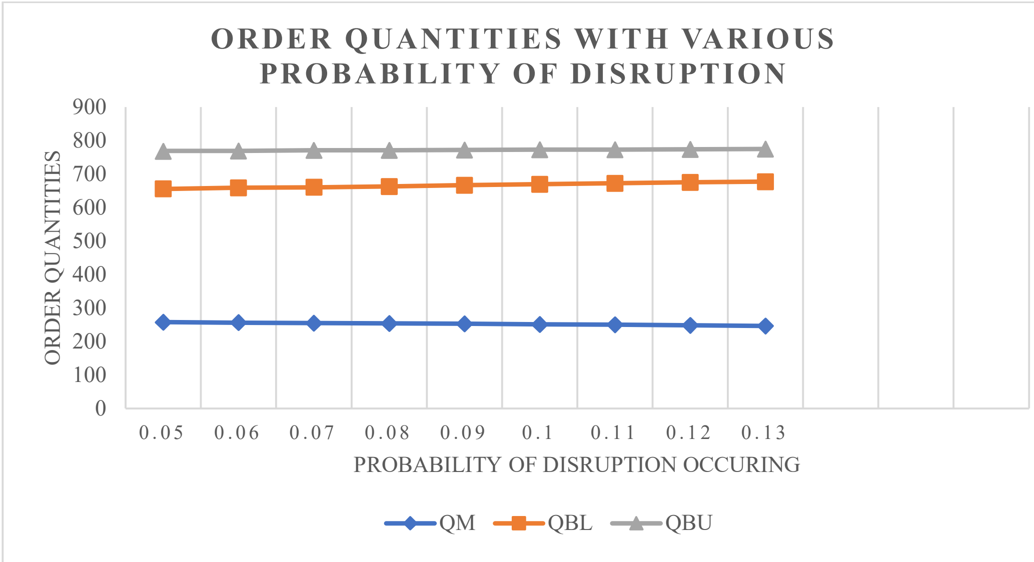


Figure 4.8

Order Quantities over Different Stages of P_D in the Centralized System.



According to figures 4.7 and 4.8, the profit trends of the retailer and the two suppliers are the same in both the centralized and decentralized systems where using the main supplier becomes riskier. In terms of order quantities, the range of the backup supplier (Q_{BU}-Q_{BL}) increases in the decentralized system but decreases in the centralized system. Hence, it is evident that it gets riskier to order from the main supplier when the probability of disruption is increased.

4.2.8 Coordination Analysis with Respect to Changes in P_D

In this section, the coordination of the supply chain is examined by calculating the efficiency from the total profits of the supply chain in both the centralized and the decentralized systems according to the changes of the probability of disruption in the supply chain.

Table 4.13

Comparison Between Supply Chain Profits under Centralized and Decentralized Systems as P_D Changes

P_D	Total profit in a centralized system	Total profit in a decentralized system	% efficiency
0.05	13709	13062	95.23
0.06	13700	12924	94.34
0.07	13692	12780	93.34
0.08	13687	12619	92.20
0.09	13678	12439	90.94
0.1	13671	12234	89.49
0.11	13666	12005	87.85
0.12	13658	11739	85.95
0.13	13651	11419	83.65

According to the results shown in Table 4.13, it is evident that at all values of disruption probability, the centralized system has a higher supply chain profit than the decentralized system. However, the total supply chain profit in the decentralized system using the proposed contracts is not too far from that of the centralized system when the probability of disruption is low. Therefore, the use of the proposed contracts provides the capability to coordinate the supply chain efficiently. Further when the probability of disruption increases, the coordination efficiency of the supply chain decreases.

4.2.9 Sensitivity Analysis with Respect to Return Quantity Ratio (θ)

Finally, the impact of the Return Quantity Ratio is analyzed by using the same method mentioned before. The results for both the centralized and decentralized systems are shown in table 4.14 and table 4.15, respectively.

Table 4.14

Effect of Changing the Return Quantity Ratio (θ) in a Decentralized System.

θ	Q_M	Q_{BL}	Q_{BU}	Retailer's profit	Normal supplier's profit	Backup supplier's profit	Supply chain's profit
0.21	105	82	928	6503	570	5509	12583
0.23	105	84	928	6514	581	5490	12583
0.25	104	85	928	6505	587	5496	12589
0.27	104	86	928	6505	598	5487	12590
0.29	103	87	929	6493	604	5490	12587
0.31	103	89	929	6504	615	5471	12590
0.33	102	90	929	6496	620	5477	12593
0.35	101	91	929	6487	626	5483	12596
0.37	100	93	930	6488	630	5476	12595
0.39	99	94	931	6477	635	5479	12592

Results in Table 4.14 illustrates that when the Return Quantity Ratio increases, in the decentralized system, the order quantity of the main supplier decreases. This trend is reasonable. When considering the order quantity of the backup supplier, the lower order quantity increases, the upper order quantity also increases but the range (Q_{BU}-Q_{BL}) decreases. The profits of the retailer, the backup supplier and the whole supply chain have fluctuations while the profit of the normal supplier increases.

Table 4.15

Effect of Changing the Return Quantity Ratio (θ) in a Centralized System

θ	Q_M	Q_{BL}	Q_{BU}	Retailer's profit	Normal supplier's profit	Backup supplier's profit	Supply chain's profit
0.21	100	943	1190	5884	217	7220	13330
0.23	100	943	1190	5905	198	7229	13332
0.25	100	943	1190	5926	179	7229	13334
0.27	100	943	1190	5946	161	7229	13335
0.29	100	943	1190	5967	142	7229	13337
0.31	100	943	1190	5987	124	7229	13340
0.33	100	943	1189	6020	106	5416	13343
0.35	100	943	1189	6041	88	5416	13345
0.37	100	943	1189	6061	71	5416	13348
0.39	100	943	1189	6081	53	5416	13350

Results in Table 4.15 illustrates that when the Return Quantity Ratio increases in the centralized system, the order quantity of the main supplier remains unchanged. When considering the order quantity of the backup supplier, the lower order quantity does not change, but the upper order quantity decreases, therefore, the range (Q_{BU}-Q_{BL}) decreases. The profits of the retailer, and the whole supply chain have increased while the profit of the main supplier deceases and the profit of the backup supplier is fluctuated.

Figure 4.9
Order Quantities over Different Stages of (θ) in the Decentralized System.

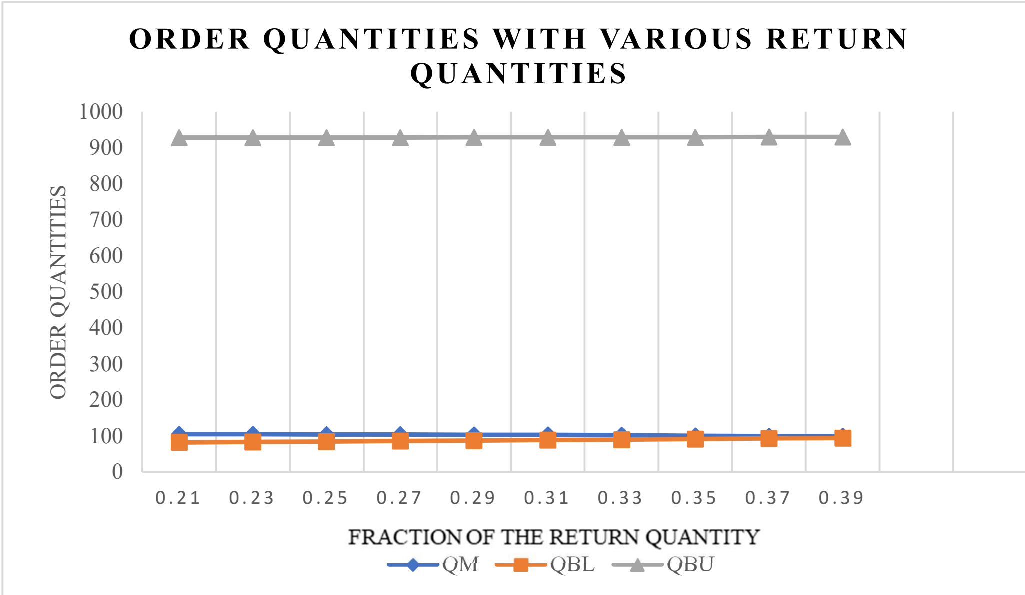
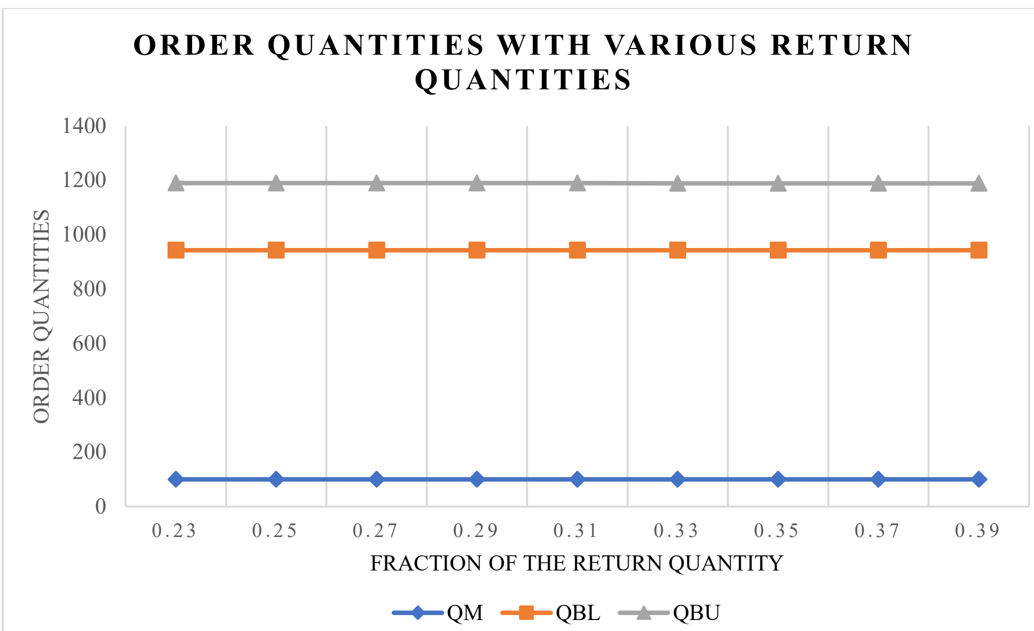


Figure 4.10
Order Quantities over Different Stages of (θ) in the Centralized System.



According to figures 4.9 and 4.10, the profit trends of the main supplier is the same in both the centralized and decentralized systems whereas the backup supplier's profit in the centralized system is clearer. The profits of the retailer and the total supply chains' profits the trend in the centralize system is clear whereas they are fluctuated in the decentralized system. The main supplier's quantity increases in the decentralized system and is unchanged in the centralized system. The backup supplier's lower order quantity decreases in the decentralized system and constant in the centralized system. The upper order quantity stays constant in the decentralized system but decreased in the centralized system.

4.2.10 Coordination Analysis with Respect to Return Quantity Ratio (θ)

In this section, the coordination of the supply chain is examined by calculating the efficiency from the total profits of the supply chain in both the centralized and the decentralized systems according to the changes of the Return Quantity in the supply chain.

Table 4.16

Comparison Between Supply Chain Profits under Centralized and Decentralized Systems as (θ) Changes

θ	Total profit in a centralized system	Total profit in a decentralized system	% efficiency
0.21	13350	12583	94.25
0.23	13350	12583	94.25
0.25	13350	12589	94.30
0.27	13350	12590	94.31
0.29	13350	12587	94.28
0.31	13350	12590	94.31
0.33	13350	12593	94.33
0.35	13350	12596	94.35
0.37	13350	12595	94.34
0.39	13350	12592	94.32

According to the results shown in Table 4.16, it is evident that at all values of return quantity ratio, the centralized system has a higher supply chain profit than the decentralized system. However, the total supply chain profit in the decentralized system using the proposed contracts is not too far from that of the centralized system. Therefore, the use of the proposed contracts provides the capability to coordinate the supply chain efficiently.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

In this research, a system with a retailer purchasing from two suppliers, i.e., the main supplier which is vulnerable to disruption, and a backup supplier which has been incorporated to minimize the harmful effect of disruption, was investigated. The main supplier was kept under a quantity flexibility contract and the backup supplier under a range contract. These contracts were chosen based on their demonstrated ability to coordinate the supply chain in a normal non-disruptive situation, as well as their ability to provide flexibility to the retailer when disruption occurs. In this research, the order quantities to be placed by the retailer with both suppliers have been analysed to maximize his profit. From the numerical analysis, it can be concluded that the proposed system is better for the retailer, the backup supplier, and the whole supply chain than a system that has a similar setup of two suppliers and a retailer that uses buy-back and range contracts. Then from the sensitivity analysis, it is observed that R_F has the effect only on the backup supplier and the retailer and P has an effect on the main supplier and the retailer. The decline in the range (Q_{UL}-Q_{BL}) of the backup supplier is another major difference. The efficiency at which this configuration of contracts performs was tested by comparing the centralized and decentralized systems and was shown to be closed to the maximum efficiency at various levels of supply disruption probability which certifies that this system can help achieve coordination.

When considering the results for the analysis of the return quantity, the profits of the total supply chain, the profit of the backup supplier and the retailer have unclear trends in the decentralized system whereas in the centralized system, except for the backup suppliers profit the trends for the other profits are clear. The trend for the main supplier is the same in both systems. The order quantity of the main supplier has decreased in the decentralized system but constant in the centralized system. The lower order quantity of the backup supplier has increased where the upper order quantity is constant in the decentralized system. In the centralized system, the lower order quantity is constant where the upper order quantity is constant. The range (Q_{UL}-Q_{BL}) of the backup supplier is decreased in both the system. The impact of the return quantity is unclear due to the fluctuations.

This system can be implemented to manage supply chains with high demand so that the use of the quantity flexibility contract is appropriate. This study can be extended by adding more suppliers to the system and analyzing their usefulness or by investigating the system for multiple periods.

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