CHAPTER 2

LITERATURE REVIEW

This chapter presents the scope of research which is primarily the broad area of study focused in this research. A detailed literature review related to the research scope is described. Based on the scope of research studied for possible extensions, research propositions are offered in this chapter. Also, managerial implications based on the literature review of the areas of focused study are provided.

2.1 Research Scope

The scope of the present work is in the following research areas: (i) Supply chain analysis for coordination, pricing, order quantity and investment decisions, (ii) JIT integrated inventory model for a buyer and a vendor (iii) Analysis of deteriorating production process lot sizing, number of inspections, investments for setup cost reduction and quality improvement, (iv) Optimal batch size and optimal number of kanbans in a single-stage and multi-stage JIT production system with rework of defective items, and (v) Lean manufacturing tools for productivity improvement.

2.1.1 Supply chain analysis for coordination, pricing, order quantity and investment decisions

Integration of manufacturer with the retailer reduces the cost, increases coordination and trust (Das et al., 2006). The manufacturer invests in the technology used to make the product and the retailer has the opportunity to influence final demand by choosing the appropriate selling/promotional efforts. The technology investment/quality-improvement costs are directly incurred by the manufacturer and the cost of selling/promotional efforts is directly incurred by the retailer only (Gurnani et al., 2007).

Hua et al., (2006) showed that coordination mechanism can improve the overall channel profits and cooperation can be implemented if the fluctuation of retail-market demand is relatively small. Chiadamrong and Prasertwattana (2006) studied the coordinating policy based on exchanging financial incentives that can improve the overall performance of whole chain as well as each member in chain. Li and Atkins (2005) found that coordination is more valuable when the demand information is unavailable and coordinating the replenishment and pricing strategies reduces the value of obtaining the demand information. Saccani and Perona (2007) proposed a contingency model for buyer-supplier relationships in order to maximize value creation for each specific exchange in manufacturing contexts. They concluded that scope and level of cooperation in buyer-supplier relationships stands as a critical factor to achieve success in market. Paulraj et al., (2008) asserted that inter-organizational communication is dominant factor in promoting strategic collaboration among buyers and suppliers.

There is a growing recognition by manufacturers and retailers towards the determination of product's selling price in order to achieve a maximum profit. Whitin (1955) incorporated pricing into the economic ordering quantity model through price-demand relation. Banerjee (1986) developed a joint economic lot size (JELS) model for a single buyer – single vendor system with a lot-for-lot policy that is not optimal if the setup cost of manufacturer is larger than ordering cost of buyer. Goyal (1988) extended the lot-for-lot production assumption (Banerjee, 1986) to show that economic production quantity is an integer multiple of buyer's ordering quantity. Monahan (1984) suggested a price discount approach in order to increase the supplier's profits for which the customer to deviate from its economical optimal policy. Lal and Staelin (1984) developed a price discount model so that a manufacturer using a properly designed quantity discounted scheme could increase his profits as well as increase a supply chain's total profit. Using the price sensitive deterministic demand, Viswanathan and Wang (2003) analyzed the influence of discount mechanisms, volume and quantity on the channel coordination. Detailed reviews of integrated buyer-supplier inventory models are given by Goyal and Gupta (1989), Joglekar and Thartare (1990).

Jeuland and Shugan (1983) found that inter-organizational coordination for marketing decisions leads to lower price for the consumer. Ingene and Parry (1995) extended Jeuland and Shugan's (1983) work to multiple retailers. Weng (1995a, 1995b) combined the marketing and operations and showed that coordinated decision making benefited both the supplier and buyer and maximized joint profit. Boyaci and Gallego (2002) analyzed the wholesaler-retailer coordination for price and order quantity decisions. Lau et al., (2007) extended the "stochastic and asymmetric information” framework proposed by Lau and Lau (2005) and showed that the manufacturer-imposed maximum retail price is more profitable to the dominant manufacturer.

Zou et al., (2004) proposed a model to synchronize the assembly process with the simultaneous consideration of order processing time and order quantity determination. Sirias and Mehra (2005) compared quantity versus lead time dependent discount incentive systems, which are the main mechanisms used to coordinate the efforts of an inter-organizational supply chain. Zhou and Li (2007) dealt with the coordinating quantity decision problem in a supply chain contract to meet the random demand of single product with short life cycle. Boute et al., (2007) showed that by integrating the order decision on lead times, the order pattern and production pattern can be smoothened to a considerable extent without increasing stock levels. Chen et al., (2006) considered a supply chain in which the manufacturer decides the initial production quantity and the retailer specifies order quantity after the demand forecast is improved. Hwarng et al., (2005) evaluated the impact of simplifying demand assumptions in a relatively complex supply chain. Simplifying demand distribution usually results in under or overestimation of total inventory costs. Abad (2006) examined the purchase lot size decision of a retailer responsible for paying for freight of a single season style good with an uncertain demand and concluded that if the buyer is responsible for paying for the freight, then the freight cost is relevant to the decision concerning the purchase lot size.

2.1.2 JIT integrated inventory model for a buyer and a vendor

Just-in-time (JIT) philosophy can be defined as the ideal of having the necessary amount of material available where it is needed and when it is needed. The concept of just-in-time production is that materials should flow throughout the entire production sequence without being stopped or accumulated at an intermediate stage. The advantages of JIT production include reduced inventories, reduced lead times, higher quality, reduced scrap and rework rates, ability to keep schedules, increased flexibility, easier automation, and better utilization of workers and equipment. In a production process, eliminating waste which is the underlying goal of JIT, could be attained through smaller batch sizes and reduction of in-process inventory, where concepts such as shortening lead time, setup cost reduction and increased quality are fundamental. For a production system, a reduced inventory translates into reduced inventory holding costs and, eventually, savings in total cost. Inventories are one of the main sources of inefficiency in industrial companies. Generally, the storage does not add value to the product and it should be eliminated whenever possible. Small lot sizes contribute to lower levels of inventory and scrap, high product quality, lower inspection costs for incoming parts, increased flexibility and earlier detection of defects, etc (Banerjee and Kim, 1995).

The basis of the JIT philosophy is that setup times and costs may be reduced, resulting in smaller lot sizes and greater flexibility. Setup reduction program is an important manufacturing strategy in business environment and is identified as one of the key facilitating factors for just-in-time manufacturing. The impact of investing in reduced setup cost has been observed in many manufacturing settings including job shops, batch shops, and flow shops. Setup cost is a critical determinant of the lot size. A reduction in the setup cost leads to reduction in lot size, and a reduction in lot size would lead to a reduction in inventory costs (Nasri et al., 1990). Process quality improvement usually results in costs associated with the purchase of new technology, modification of existing equipment, training employees, hiring new employees and investment in information technology infrastructure. JIT system improves product quality and eliminates waste by frequent manufacturing and shipment of products in small lots. One of the major tasks of maintaining the competitive advantages of JIT production is to compress the lead time needed to perform activities associated with delivering high quality products to customers. To achieve just-in-time, it is also necessary to reduce order lead time (Karlsson and Åhlström, 1996). The lead time can be reduced by an additional crashing cost (Pan and Yang, 2002).

For the full benefits of JIT to be realized, suppliers are required to match JIT delivery with their JIT production. It is essential that supply chain inventory models incorporate the relationship between inventory and quality. Ignoring the relationship between quality and lot size has contributed to overestimating the optimal production lot sizes in inventory models. In today's supply chain management environment, companies are using the JIT production to gain and maintain a competitive advantage (Pan and Yang, 2002). Helper's (1991) survey results indicate that in order to enhance long-term competitiveness, it is important to encourage suppliers and customers to develop capabilities of JIT production as well as JIT delivery. Customers can obtain improvements in quality and delivery by motivating suppliers to adopt JIT production and JIT delivery. One of the implications of JIT production and delivery is the reduction of lot sizes because it contributes to the reduction inventories and lead times (Sánchez and Pérez, 2001).

Banerjee (1986) presented a joint economic lot size model where the order quantity of retailer and production lot size of producer are equal (on a lot-for-lot basis) and found the joint optimal lot size under deterministic conditions. Goyal (1988) generalized Banerjee's (1986) lot-for-lot production assumption model by allowing the producer's lot size to be an integer multiple of the retailer's order quantity. Goyal (1995) investigated a policy in which the size of successive shipments from the producer to the retailer increases by a factor equal to the ratio of production rate to demand rate. Hill (1997) provided a policy for the shipment sizes. Goyal and Nebebe(2000) considered a policy in which the successive shipments are equal to the size of the first shipment multiplied by the ratio of production to the demand rate.

Defective items are inevitably produced in real production systems due to which costs are incurred. Rosenblatt and Lee (1986) and Porteus (1986) first presented the significant relationship between quality imperfection and lot size. Rosenblatt and Lee (1986) investigated the effect of process quality on lot size in the classical economic manufacturing quantity model. Porteus (1986) introduced a modified economic manufacturing quantity model and assumed that the number of conforming units in a lot is a random variable that depends on the transition probability and the lot size. Keller and Noori (1988) extended Porteus' work (1986) considering the demand during lead time is probabilistic and shortages are allowed.

Ben-Daya and Rahim (2003) showed that multistage lot sizing models for imperfect production processes, lower costs are incurred and larger lot sizes are produced due to introduction of inspection and restoration costs, which result in the reduction in quality control costs. Affisco et al., (2002) proposed a quality adjusted joint economic lot size model and considered the impact of economic investments in vendor's quality improvement and setup cost reduction on the system wide costs for a single-vendor single-buyer deterministic demand economic lot sizing problem. Paknejad et al., (2005) considered finite range stochastic lead time for a random number of defective units in a lot and showed that investment in quality improvement results in significant cost savings. Huang (2002) developed an integrated vendor-buyer inventory policy for flawed items in just-in-time manufacturing environment, with an aim to minimize the total joint annual costs. Goyal et al., (2003) developed a simple approach for determining an optimal integrated vendor- buyer inventory policy for an item with imperfect quality with an objective to minimize the total joint annual costs. Yang and Wee (2000) developed an economic ordering policy of deteriorating items using integrated approach results in a cost reduction compared with independent decision by buyer. Rau et al., (2003) derived an optimal joint total cost in a multi-echelon inventory model for a deteriorating item and showed that the integrated approach results in lower joint total cost as compared with independent decision approaches. Ouyang and chang (2000) extended the work of Moon and Choi (1988) to include the possible relationship between lot size and quality.

The length of lead time directly affects the customer service level, inventory investment in safety stock, and the competitive abilities of business (Pan and Yang, 2002). The crashing of lead time consists of mainly of the following components: order preparation, order transit, supplier lead time, and delivery lead time (Tersine, 1982). Liao and Shyu (1991) presented a continuous review model in which order quantity is predetermined and lead time is a unique decision variable. Ben-Daya and Raouf (1994) extended the Liao and Shyu model (1991) and derived the optimal lead time and optimal ordering quantity to minimize the sum of the ordering cost, holding cost, and lead time crashing cost. Ben-daya and Hariga (2003) developed a continuous review inventory model with lead time is decomposed into setup time, processing time and non productive time. These components reflect the setup cost reduction, lot size lead time reduction, and lead time crashing respectively. Manufacturers have often faced a challenge to reduce production lead time and cost simultaneously. Effort is devoted to reduce the setup time which is directly related to setup cost (Moon, 1994, Ben-Daya and Hariga, 2003, and Kreng and Wu, 2000).

2.1.3 Analysis of deteriorating production processes lot sizing, number of inspections, investments for setup cost reduction and quality improvement

In batch production systems, small lot sizes offer benefits such as lower inventory carrying cost, reduced space requirements, increased machine availability and increased system flexibility

(Banerjee et al., 1996). Lot sizing arises when the machine switches from one product to another. Setup cost is the cost of changing over production equipment, the cost due to cleaning or to scrap losses when machine is set for the next product (Moon et al., 2002). Setup cost can be controlled and reduced through worker training, procedural changes and specialized equipment. Quick setups are also considered an important element for successfully implementing just-in-time (JIT) production. The product quality is depends on the state of the production process and defective items are produced due to imperfect production processes. The defective items must be rejected, repaired and reworked, and thus incur substantial costs (Hou, 2007). Instead of controlling the parts produced, the process is kept under control, through discovering errors that can lead to defects (Karlsson and Åhlström, 1996). In order to attain production system efficiency, reduced lot sizes should be accompanied by corresponding setup cost reduction and quality improvement (Hou, 2007). In particular, level scheduling combined with the elimination of muda (waste) has successfully delivered a wide range of products (Aitken et al., 2002).

The basic economic production quantity model (EPQ) determines the optimal lot size when demand and production rates have known, deterministic values. Rosenblatt and Lee (1986) presented a model where the process goes out of control and thus produces defective items. They assumed that deterioration of the production process from in-control state to out-of-control state is exponentially distributed. Porteus (1986) described a system that begins each production run in control, and the process may shift out-of-control and it stays that way while the remainder of the lot is produced. The production system is restored to perfect quality when it is setup again. Based on this assumption, the number of conforming units in a lot is a random variable that depends on the transition probability and the lot size. Both Rosenblatt and Lee (1986) and Porteus (1986) found that the optimal economic production quantity (EPQ) is smaller than the classical EPQ model because shorter production run (smaller lot) produces fewer defective items. Lee and Rosenblatt (1987) derived an optimal production run length and optimal inspection schedules simultaneously assuming the elapsed time until the shift is exponentially distributed with a known mean, and by approximating the average cost function using McClaurin Series. Khouja and Mehrez (1994) formulated an economic production lot size model that assumes the percentage of conforming components in a lot decreases as the production rate increases. Porteus (1986), Rosenblatt and Lee (1986) and Khouja and Mehrez (1994) initially provided the framework to extend the classical economic production quantity model considering the effect of imperfect production processes.

Cheng (1993) showed that normal prerequisites and benefits of JIT production can be identified from the analysis of EPQ system in which the production rate is close to demand rate. Dong (1997) considered the investment in setup reduction and quality improvement for a production system with imperfect production process and derived optimal production cycle time and total relevant cost. Affisco et al., (2002) proposed a joint economic lot size model that considers the impact of economic investments in the vendor's quality improvement and setup cost reduction. Affisco et al., (2002) derived models for setup cost reduction, quality improvement and simultaneous setup cost reduction and quality improvement for quality adjusted joint economic lot size model. Their results indicate that focus on setup cost reduction and quality improvement results in lower costs and smaller lot sizes. Liu and Çetinkaya (2007) have noted that investment function for setup cost reduction and quality improvement in the work of Affisco et al., (2002) does not follow practice in industries and obtained different results in comparison to Affisco et al., (2002). Sarker and Coates (1997) extended the EOQ model with setup cost reduction in the variable lead time environment and investigated the opportunities for setup cost reduction investment. Chand (1989) investigated the benefits of small lot sizes in total cost to be minimized. Pakkala and Rahim (1999) presented the optimal process mean and production run using Taguchi's loss function. Lin and Gong (2006) studied the impact of random machine breakdowns on the classical EPQ model and determined the optimal production uptime that minimizes the expected total cost per unit time. Chiu et al., (2007) determined the optimal run time for an economic production quantity model with scrap, rework, and stochastic machine breakdowns. Chen (2006) considered the advantages of preventive maintenance to analyze the impact of inspection errors, permitted shortage conditions and minimal repair on cost. Rahim and Al-Hajailan (2006) determined the optimal production run for a deteriorating production system, with allowable shortages. Leung (2007) proposed a general power function to model the relationship between production setup cost and process reliability as independent variables and interest and depreciation cost as dependent variable.

Sarker and Yu (1996) considered a production-inventory system in which optimal batch sizes are determined for all products having the same processing cycle time that are processed on different machines in a flow shop. Lin et al., (2003) considered various cases for a single product imperfect manufacturing system where the defect rate is a function of the setup cost, the proportion of defective items is not constant, or the inventory system has a limited capacity for raw materials. Jaber (2006) investigated the lot sizing problem for reduction in setups, with reworks, and interruptions to restore process quality, with an assumption that the rate of generating defects reduces with each quality restoration action. Buscher and Lindner (2007) determined the economic production and rework quantity as well as the corresponding batch sizes. Darwish and Ben-Daya (2007) proposed a production inventory model that takes into account the effect of imperfect production processes, preventive maintenance and inspection errors. Giri and Dohi (2007) considered scheduling of inspections for imperfect production processes where the process shift is assumed to follow an arbitrary probability distribution with an increasing failure rate. Hadjinicola and Soteriou (2003) addressed the issue of budget allocation in order to improve the yield of the various stages and minimize the annual cost incurred from defects observed in all production stages. More capital resources should be allocated to a production stage which processes a large number of products, and low cost for implementing the yield improvement, low mean yield and high cost incurred from defects.

Freeland et al., (1990) found that items with greater variability tend to have high priority for setup reduction. Managerial insights form the work of Li et al., (2008) show that with the variation in the investment budget shift in the setup cost vs quality improvement strategies are necessary to maximize return on investment (ROI). Giri and Moon (2004) provided efficient solution algorithms on capital investment in setup reduction on an economic lot scheduling problem with limited budget. Kreng and Wu (2000) discussed an optimal policy of set-up time reduction in an economic production quantity model. They assumed that the set-up cost is linearly related to set-up time and the setup cost in a classical EPQ model is modified in terms of unit setup cost and setup time. Ouyang et al., (2002) investigated the options of investing in process quality improvement, setup cost reduction, shortened lead time at an extra crashing cost for an imperfect production process.

Lin and Hou (2004) investigated the effects of quality improvement by capital investment and their results indicate that considerable cost savings could be realized through the process quality improvement. Gallego and Moon (1992) determined the multiple product, single facility cyclic schedule to minimize holding and setup costs, at the expense of setup costs by externalizing setup operations. Gallego and Moon (1995) considered economic lot scheduling problem to determine multiple item single facility cyclic schedule. Hwang et al., (1993), Moon (1994) and Hong (1997) assumed that both setup reduction and quality improvement can be achieved for a production system with imperfect production process through investment. Cheng et al., (1998) determined the setup schedule and production rate for each product that minimize average total costs. Ben-Daya and Hariga (2000) developed mathematical models for the economic lot scheduling problem taking into account the effect of imperfect quality and process inspection during the production run. Eynan (2003) investigated the economic lot scheduling problem within the common cycle framework under flexible production approach which allows alteration of production rates during a production run.

2.1.4 Optimal batch size and optimal number of kanbans in a single-stage and multi-stage JIT production system with rework of defective items

JIT has a pull system of coordination between stages of production. In a pull system, a production activity at a stage is initiated to replace a part used by the succeeding stage. The primary advantage of the pull system is the reduced inventory and hence the associated cost of inventory reduction. JIT philosophy can be accomplished using kanban technique with the improvements in reduction of inventory and wasted labor, and enhancement of customer service. Kanban system plays a significant role in the JIT production system. The use of kanbans in controlling production and in-process inventory has proven to be a simple and effective method for implementing the JIT philosophy. Kanbans have been adopted in just-in-time (JIT) production systems as a means of material transportation and production information exchange between workstations. Kanbans pass information about what and how much to produce from one station to another. The kanban pulls parts from one station to another to meet the demand at each station at the right time. If no withdrawal is requested by the succeeding station, the preceding station will not produce at all and hence no excess items are made. A subsequent process withdraws necessary parts from a preceding process at a necessary point in time, and then the preceding process produces the parts withdrawn by the subsequent process. Figure 2.1 illustrates the kanban operations in a multi-stage production system. The types of Kanbans can be divided into two major categories: withdrawal kanban and production-ordering kanban. The production-ordering and withdrawal kanbans are used in a Just-in-Time (JIT) production system. The withdrawal kanban specifies the kind and quantity of parts which the subsequent process should withdraw from the preceding process, while the production-ordering kanban specifies the kind and quantity of parts which the preceding process must produce.

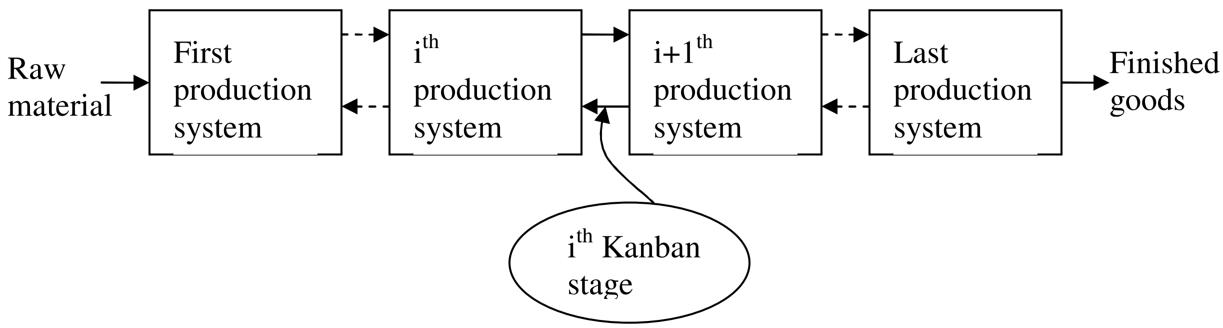

Fig. 2.1 Multi-stage production system with kanban operations

Manufacturing parts and products that are defective and therefore need rework are wasteful. Closely associated with zero defects is the principle of just-in-time, since accomplishing fault free parts is a prerequisite to achieving just-in-time deliveries (Karlsson and Åhlström, 1996). Suppliers need to deliver frequently as required to the point of use, in small quantities with total quality guaranteed, eliminating the need for incoming inspection. Aigbedo (2004) investigated how well supplier plants are capable of meeting assembly requirements under different supply frequency schedules. The appropriate inventory levels for each part are determined that will reduce supply chain costs and increase profits for members of the supply chain. The need for early detection of defects in minimal inventory for low cost and high quality requires a kanban supply arrangement (McIvor, 2001). Kanban mechanism ensures the organizations to run their supply chain systems in JIT policy (Wang and Sarker, 2006).

Rosenblatt and Lee (1986) studied the effect of deteriorating process on lot-sizing decisions. Further, Lee and Rosenblatt (1987, 1989) found that by monitoring the process through inspections larger lots sizes at lower costs can be obtained. Hayek and Salameh (2001) derived an optimal operating policy for the finite production model under the assumption that all the defective items are reworked and allowed backorders. Chiu (2003) considered the reworking of defective items on the economic production quantity with backlogging allowed. Wang and Sheu (2001) investigated the effect of warranty cost on the optimization of economic manufacturing quantity. Alfares et al., (2005) integrated item and process deterioration, varying demand and production rates, quality, inspection and maintenance into a production-inventory system for deteriorating items.

Monden (1983) mentioned that the number of kanbans between two adjacent stations represents the maximum inventory level and, therefore, should be kept minimum. Bitran and Chang (1987) presented a model for a Kanban system in a deterministic, multi-stage capacitated, assembly-tree-structure JIT production system. Rees et al. (1987) proposed a method of dynamically adjusting the number of kanbans at work centers in terms of estimated values of lead time for fixed quantity production-ordering kanban systems. Miyazaki et al. (1988) proposed an algorithm to obtain the optimal order interval that minimizes the total operation cost for the Kanban system. Karmarkar and Kekre (1989) showed that the number of kanbans and kanban sizes should be determined simultaneously, as the kanban size has a significant effect on the performance of kanban systems. Wang and Wang (1990) presented a continuous time Markovian approach for determining the number of kanbans between two adjacent workstations with the objective of minimizing work-in-process (WIP) inventory level. Askin et al. (1993) developed a stochastic model for determining the number of kanbans in a multi-item, just-in-time system. Mitwasi and Askin (1994) provide a nonlinear integer mathematical model for the multi-item, single stage, capacitated kanban system with dynamic demand. The kanban control system automatically reacts quickly to the random aspects of demand. Yanagawa et al., (1994) presented an algorithm to obtain the optimal order interval and the necessary number of kanbans to minimize the total operation cost with variable lead time. Ohno et al. (1995) derived the stability condition of a JIT production system for each of the two kinds of kanbans (production ordering and supplier kanbans) under the stochastic demand. Gupta and AlTurki (1997) introduced a systematic methodology to manipulate the number of kanbans in a JIT system for stochastic processing times and variable demand environment. Fujiwara et al., (1998) considered kanban-controlled, multi-stage production assembly system and evaluated system performance measures for a given set of design parameters: the raw-material batch order size, the reorder point, the number of kanbans circulating in each production stage. Erhun et al., (2003) proposed an analytical model to determine the design parameters of withdrawal cycle length, kanban sizes and number of kanbans simultaneously in a multi-item, multi-stage, multi-period, capacitated periodic review kanban system. Liberopoulos and Dallery (2003) proposed a unified modelling framework for comparing and contrasting classical multi-stage production-inventory control policies and introduce new control approaches as hybrids of simpler policies. A detailed literature review and classification techniques to determine both the design parameters and kanban sequences can be found in Akturk and Erhun (1999).

Lee et al., (1997) modeled the various proportions of defectives items produced in a multi-stage production system but did not consider the rework option of defective items. Mittal and Wang (1992) determined the number of kanbans in a production setting where breakdowns, reworks, setup times, variable processing times, and variable demand are modelled. Agnihothri and Kenett (1995) modeled the number of defects as a random variable and investigated the impact of defects on various system performance measures such as yield, production lead time, and work-in-process inventory for a production process with complete inspection followed by rework. Flapper and Jensen (2004) dealt with the rework of production rejects that deteriorate while waiting to be reworked. Hong et al., (1988) presented the method of finding the optimal screening procedures when the rejected items are reprocessed. Gunasekaran et al., (1993) determined economic production quantities to establish the relationship between quality, work-in-process inventory and lot size, so that there is a smooth flow of material in a multi-stage JIT production system. Ben-Daya (1999) developed a multi-stage lot sizing model for imperfect production processes that takes into effect of imperfect quality and inspection errors. Ben-Daya and Hariga (2000) and Moon et al., (2002) investigated the economic lot scheduling problem (ELSP) with imperfect production processes assuming exponential distribution of an elapsed time shift from an in-control state to an out-of-control state.

2.1.5 Lean manufacturing tools for supply chain

Although lean manufacturing is increasingly popular and a resolutely recognized approach to minimizing the cost in supply chain, the number of large scale methodical studies aimed at the implementation of lean tools in lean supply chain is still relatively insufficient. Manufacturing industries throughout the world are currently encountering a necessity to respond to rapidly changing global economic scenario. They are trying to balance economic and industrial performance through lean (Zhu and Sarkis 2004). By using fewer inventories, low setup costs, less cycle time, low lead times and optimal batch sizes to develop products at less cost to become highly responsive to customer demand with excellent quality products in the most efficient and economical manner is possible using lean manufacturing principles in the supply chain.

Ranky and Ranky (2000) have said that a flexible, lean and reconfigurable supply chain and production facilities are essential. Schonberger (1982), Barker (1994), Cusumano and Nobeoka (1998), Liker (1998) have mentioned that different lean tools and techniques have been developed over the years for elimination of waste and everyday new ones are proposed. There are nearly 100 powerful tools of lean manufacturing that are used to implement and support the waste eliminating operating strategy (George et al., 2005).

2.2 Research Propositions and Managerial Implications

The research propositions presented in this work are: (i) collaboration between manufacturer and retailer for setting a maximum-profit price, (ii) an integrated inventory optimal policy considering quality improvement, setup cost reduction and lead time reduction, (iii) determination of optimal cycle length and optimal number of inspections using time-varying lot sizes approach in an imperfect production processes considering quality improvement and setup cost reduction, (iv) determination of the optimal raw material ordering quantity, finished product batch size and number of kanbans (for a multi-stage production system) for production – delivery situations considering process inspection, restoration and rework, and (v) identification of lean tools that are essential for the lean supply chain performance.

The managerial implications discussed in this work are related to (i) analysis of supply chain coordination for pricing, order quantity and investment decisions, (ii) analysis of integrated JIT inventory, (iii) analysis of economic production quantity model, (iv) analysis of rework and number of shipments in a production system, and (v) analysis of lean manufacturing tools for lean supply chain.

2.2.1 Pricing, investment and order quantity decisions in collaboration between a manufacturer and a retailer

Banerjee (2005) developed a concurrent pricing and lot sizing model with an objective to determine simultaneously the product's selling price and supplier's production lot size for a stated gross profit. Suppliers and customers collaborate on pricing in order to establish mutually beneficial relationships (Voeth and Herbst, 2006). Joglekar et al. (2006) presented a set of eight models of coordination in a supply chain consisting of one manufacturer and one retailer of a product with price sensitive demand. They recommended that the supply chain should coordinate its pricing decisions but should not indulge in coordination of its order quantity decisions. Ray (2005) explored the effect of price and attribute sensitivity of random demand and cost/investment to achieve an attribute level on the optimal price and stocking decisions. Using integrated operations – marketing model with price and order quantity as decision variables, Ray et al., (2005) determined relevant decision variables that maximize the firm's profit. Gurnani et al., (2007) analyzed the nature of both product pricing and timing of investment decisions. They studied three cases of supply contract between a supplier and buyer, and discussed the role of uncertainty, cost of building quality and cost of selling effort in decision making. Their analysis indicated that both firms can benefit from each other's investment in product quality and selling effort respectively, while the timing of price commitment decisions can influence the investment decisions. Table 2.1 provides a comparison of different features on some research works on supply chain coordination for pricing, ordering quantity and investment decisions.

The relation between the optimal configuration of investment, price and order quantity from the perspective of manufacturer and retailer is discussed (Parveen and Rao, 2008). Customer demand is sensitive towards both price as well as non price factors. The retailer influences product demand by investing in demand enhancing efforts and the manufacturer invests in quality improvement. The retailer incurs the cost of selling effort and the manufacturer incurs the cost of quality improvement. The benefit in the improved demand potential due to selling effort by the retailer and quality improvement by the manufacturer affects both retailer and manufacturer. Hence the proposition P1 is:

P1: Collaboration between manufacturer and retailer for setting a maximum-profit price.

Table 2.1 Comparison of different features on some research works on supply chain coordination for pricing, order quantity and investment decisions

Attributes	Banerjee (2005)	Voeth and Herbst (2006)	Joglekar et al., (2006)	Ray (2005)	Ray et al., (2005)	Gurnani et al., (2007)
Supply chain intra-organization coordination for price (xp) and order quantity (xo)	(xp)		(xp), (xo)		(xp), (xo)	
Supply chain inter-organization coordination for price (xp), order quantity (xo), selling effort (xs), product quality (xq) and attribute (xa)	(xo)	(xp)	(xp), (xo)	(xp), (xo), (xa)		(xp), (xs), (xq)
Production lot size (supplier's lot size is a function of buyer's ordering quantity) factor (x)	(x)		(x)			
Demand for the product as a function of time (xt), price (xp), selling effort (xs), quality (xq) and attribute(xa)		(xp)	(xp)	(xp), (xa)	(xp)	(xp), (xs), (xq) (xt)

The managerial implications in the analysis of supply chain coordination for pricing, order quantity and investment decisions are:

1. The concurrent inventory lot sizing and pricing model (Banerjee, 2005) is useful from the supplier's profit margin perspective. Also the model provides an appropriate economic production/ inventory policy, in response to customer's own individually derived optimal ordering pattern. Supplier can establish the pricing and inventory policies with a reasonably good estimate of the value of the buyer's ordering to holding cost ratio.
2. The ingredients for success in implementation of supply chain pricing (Voeth and Herbst, 2006) are: (a) identifying key relevant costs, (b) issues related to the distribution of profit made by the manufacturer, (c) information and communication infrastructures to ensure that the collaboration partners are in constant contact with one another, (d) clarity regarding tasks, competencies and responsibilities, (e) designated suppliers of a particular category of product, (f) absolute transparency and trust, which will form the basis for successful collaboration.

3. Considering the tangible and intangible costs of a coordination mechanism, the supply chain's profit from inter-organizational coordination for pricing decisions alone is only marginally smaller than the profit from complete coordination. The inter-organizational coordination for only price determination gives lower cost due to incorrect estimate of demand elasticity compared to coordination for order quantity decisions (Joglekar et al., 2006).
4. By taking into account of attribute sensitivity of demand, the firms will be able to market better products, increase availability and extract a price premium from the customers. Considering the randomness of demand forces, firms must hold less stock and set attribute levels at low values (Ray, 2005).
5. From a profit perspective it is better for managers to be aggressive on price rather than reducing price too much, especially for highly price-sensitive and non-linear demand. Optimal order size is not necessarily monotone increasing in the setup cost for highly elastic demand and quite high setup cost (Ray et al., 2005).
6. Supplier prefers to make pricing and quality investments decisions when the demand uncertainty is low. If the cost of selling effort is low, buyer prefers the supplier to commit the wholesale price first. When the investment costs are low, supplier invests in product quality and sets the wholesale price for the product (Gurnani et al., 2007).

2.2.2 JIT integrated inventory model for a buyer and a vendor considering the impact of quality improvement, setup cost and lead time reductions

Banerjee and Kim (1995) developed a joint optimal integrated inventory policy that results in economic benefits to both vendor and buyer compared to independently derived policies. Zhu et al., (2007) investigated the interaction of quality improvement decisions with operational decisions (such as the buyer's order quantity and supplier's production lot size) and showed that buyer involvement can have significant impact on the profits of both parties and of the supply chain. The need to incorporate quality considerations into lot sizing decisions is a pre-requisite in just-in-time (JIT) inventory management (Khouja, M., 2003). Yang and Pan (2004) extended their earlier work (Pan and Yang, 2002) to investigate a JIT integrated inventory model that accounts for replenishment lead time reduction and quality improvement investment considerations. Ouyang et al. (2002) presented a model with imperfect production process based on lead time reduction and quality. Table 2.2 provides a comparison of different features on some research works on integrated JIT inventory.

Table 2.2 Comparison of different features on some research works on integrated JIT inventory

Attributes	Banerjee and Kim (1995)	Zhu et al., (2007)	Khouja (2003)	Yang and Pan (2004)	Ouyang et al., (2002)
Optimal lot size based on supplier's independently derived optimal policy (x) / joint optimal integrated inventory policy (xx)	(x), (xx)	(x), (xx)	(xx)	(xx)	(x)
Production lot size factor (x) and raw material lot size factor (xx)	(x), (xx)	(x)	(x)	(x)	
Setup cost (xc) reduction of single item					(xc)
Quality improvement of single (x) item		(x)		(x)	(x)
Lead time reduction (x)				(x)	(x)

A joint optimal policy standpoint to achieve the reduction in lot size transferred from vendor to buyer considering the impact of quality improvement is discussed (Parveen and Rao, 2009a). In a production system, the proportion of the defective products increases with increased production lot sizes. A joint integrated approach results in lower total cost as compared with decentralized approaches. Inclusion of quality improvement aspects can lead to a large reduction in production lot sizes and can cause the vendors to produce according to JIT. Buyer integration with high quality vendor is preferred due to lower total costs. Constraints on the quality improvement yield a higher total relevant cost for buyer and vendor coordination. In the production environment, lead time can be reduced by an additional crashing cost. In just-in-time production system, quality improvement, setup cost reduction and lead time reduction can be achieved through various efforts. Hence the proposition P2 is:

P2: An integrated inventory optimal policy considering quality improvement, setup cost reduction and lead time reduction.

The managerial implications in the analysis of integrated JIT inventory are:

1. Joint optimal integrated inventory replenishment policy will result in savings to both vendor and buyer, and reduction in the vendor's production batch size. However, the delivery lot size to the buyer increases with higher vendor setup cots (Banerjee and Kim,

1995). Integrated replenishment policy along with setup reduction will result in reduction in both vendor's batch size and input material procurement lot sizes.

2. Buyer's involvement in supplier's quality improvement can have a significant impact on the profits of both parties and of the supply chain as a whole (Zhu et al., 2007). The greater the know-how of the buyer relative to that of the supplier, the more aggressive the buyer should be in supplier's quality improvement. Furthermore, buyer should choose a high-quality supplier and invest in the supplier's quality improvement.
3. JIT Suppliers should not only deliver to retailers on just-in-time basis but also match the delivery with JIT production. Incorporating quality leads to an increase in the retailer order quantity, decrease in the production quantity of supplier, and decrease in the average inventory of the whole system (Khouja, 2003).
4. The philosophy of JIT purchasing is to establish a long-term relationship with vendors in order to minimize ordering cost and holding cost (Yang and Pan, 2004). As the ordering cost decreases, the number of deliveries increases, which in turn causes the order quantity to decrease and consequently the holding costs, are reduced.
5. Setup cost reduction, quality improvement and lead-time reduction are recognized as effective ways to achieve the JIT goal (Ouyang et al., 2002). For a given lead-time demand distribution, simultaneous consideration of quality improvement and setup cost reduction results in higher savings in expected annual total cost as compared to the quality improvement model.

2.2.3 Optimal cycle length and number of inspections in a deteriorating production processes with investment on setup cost reduction and quality improvement

Kim et al., (2001) assumed the production process is subject to a random deterioration from the in-control state to the out-of-control state and derived the exact optimal production run length and inspection schedule. Freimer et al., (2005) analyzed options of investing in reducing setup cost and derived expressions for marginal value of setup cost reduction. Hou (2007) investigated the effects of an imperfect production process on the optimal production cycle time when setup cost and process quality are functions of capital investment. Bicheno et al., (2001) developed a batch sizing procedure from a lean perspective which provides significant inventory savings under the constraint of limited available changeover time using common cycle approach.

Banerjee et al., (1996) investigated the impact of setup cost and time reduction on production batch sizes and the schedule in a batch manufacturing system by using the common cycle approach under budgetary and capacity constraints. Moon et al., (2002) developed mathematical models for economic lot scheduling problem using both the common cycle approach and the time-varying lot sizes approach, taking into account the effects of imperfect quality and process restoration. Table 2.3 provides a comparison of different features on some research works on economic production quantity model.

Table 2.3 Comparison of different features on some research works on economic production quantity model

Attributes	Kim et al., (2001)	Freimer et al., (2005)	Hou (2007)	Bicheno et al., (2001)	Banerjee et al., (1996)	Moon et al, (2002)
Defects produced at a constant rate (x) / as a time varying function (xx)	(x)	(xx)	(x)			(x)
Optimal production run time for single (xs) / multiple (xm) items, and production quantity (xxs) for single / multiple (xxm) items	(xs)	(xxs)	(xs)	(xxm)	(xm)	(xm)
Optimal inspection schedules for single (x) / multiple (xx) items	(x)					(xx)
Setup cost reduction of single (xc) / multiple items (xxc) and setup time reduction of single (xt) / multiple items (xxt)		(xc)	(xc)		(xxc)	
Quality improvement of single item (x)		(x)	(x)			
Common cycle (x) / time varying (xx) approach for multiple items				(xx)	(x)	(x), (xx)

Derivation of optimal production run length and inspection schedule of a production process subject to a random deterioration from the in-control state to the out-of-control state considering the investment on (i) setup cost reduction, (ii) quality improvement and (iii) both setup cost reduction and quality improvement is discussed (Parveen and Rao, 2009b). The investment in setup cost reduction will result in reduction in primarily the optimal production run length means small lot size, while the investment in quality improvement results in number of inspections undertaken to be unity during each production run. The investments in setup cost reduction and process quality improvements of a production process achieve some of the characteristics of JIT system such as small lot sizes and high quality. The number of inspections with investment in setup cost reduction and quality improvement is reduced. Time-varying lot sizes approach yields lower expected total cost compared to common cycle approach. Hence the proposition P3 is:

> P3: Determination of optimal cycle length and optimal number of inspections using time-varying lot sizes approach in an imperfect production processes considering quality improvement and setup cost reduction.

The managerial implications in the analysis of economic production quantity model are:

1. When the inspection cost and restoration cost are relatively low, it may be more economical to reduce the average holding cost by shortening the production run length rather than to reduce the average inspection cost and restoration cost in a production cycle by extending the production run length (Kim et al., 2001).
2. Investment in setup cost reduction will result in a reduction in the number of defects produced. The faster the process deteriorates the shorter the optimal run length. The number of defects at the optimal run length is unaffected by the holding cost and the setup cost. The total number of defects can increase or decrease with an investment in quality improvement (Freimer et al., 2005).
3. Investment in setup reduction leads to a reduction in optimal production run length and to a reduced lot size, whereas investment in process quality improvement leads to an increase in optimal production run length and to an increase in lot size. An investment in setup cost reduction is ideal for low interest rates, small initial lot sizes, and high demand rate. An investment in the process quality improvement is ideal for high demand rate and high initial production run length (Hou, 2007).
4. A general reduction in changeover times is promoted by companies as shorter changeovers can be scheduled more frequently within a constrained overall available changeover time. A batch sizing policy with an objective to minimize inventory by determining product-individual batch sizes and replenishment cycles combined with changeover time reduction could provide savings in inventory (Bicheno et al., 2001).

5. Reduction in setup times for the different products will increase the available capacity, also allow more frequent setups, thereby reducing the manufacturing batch sizes and inventory levels of the products. Investment in setup reduction results in significant cost savings in addition to lot size reduction (Banerjee et al., 1996).
6. The problem of feasibility arises with setup time. The lot sizes must be sequenced so that the intervals of production do not overlap and the sum of the setup times does not exceed the time available for setups. The time-varying lot sizes approach provides savings in comparison to common cycle approach (Moon et al, 2002).

2.2.4 Optimal batch size in a single-stage imperfect production system with inspection errors and optimal number of kanbans in a multi-stage JIT production-delivery system with rework consideration

Ojha et al., (2007) determined the optimal raw material ordering quantity and finished product batch size for three production-delivery situations namely lot-for-lot (LFL), single purchase single delivery (SPSD), and single purchase multiple delivery (SPMD). Ben-Daya and Rahim (2003) showed that when inspection and restoration are introduced, lower costs are incurred, and larger lot sizes are produced because of reduction in quality control costs. Sarker and Parija (1996) analyzed a JIT production-delivery system, where a manufacturer is expected both to synchronize its production with the buyer's lumpy demand and to coordinate the ordering of raw materials with production schedules so that both raw materials and finished goods inventory are reduced. Wang and Sarker (2006) studied a multi-stage supply chain system linked by kanban mechanism that operates under a just-in-time delivery policy to determine the number of kanbans, the batch size, the number of batches and the total quantity over one period. Their results show that the improvements in reduction of inventory and customer service in a supply chain are accomplished through the kanban mechanism. Sarker et al., (2008) developed economic batch quantity models related to reworking of defective items in a multi-stage production system and dealt with policies of (1) instantaneous rework in the same cycle with no shortage, and (2) rework done after N cycles incurring shortages in each cycle of a single-stage extended to multi-stage system. Table 2.4 provides a comparison of different features on some research works on rework and number of shipments in a production system.

Table 2.4 Comparison of different features on some research works on rework and number of shipments in a production system

Attributes	Ojha et al, (2007)	Ben-Daya and Rahim (2003)	Sarker and Parija (1996)	Wang and Sarker (2006)	Sarker et al., (2008)
Defects produced at a constant rate in the imperfect production system (x)	(x)	(x)			(x)
Inspection of all items in single stage (x) / multistage (xx) production system	(x)	(xx)			
Inspection errors while screening of defective items in a single stage (x) / multi-stage production system (xx) and restoration of the process to the in-control state (xxx)	(x)	(xx), (xxx)			
Quality costs due to non-conforming items and inspection errors in a multistage (x) production system		(x)			
Reworking of all items in the same cycle (x) / optimum number of cycles for rework (xx)	(x)				(x), (xx)
Optimal raw material ordering quantity (xr), optimal production quantity (xp), production lot size factor (xl), optimal number of kanbans (xk)	(xr), (xp), (xl)	(xp)	(xr), (xp), (xl)	(xr), (xp), (xk)	(xp)

Inspection and restoration in the imperfect production process results in larger batch sizes and lower total costs. In a production system, rework process plays an important role in eliminating waste and effectively controlling the cost of manufacturing. When defective items are reworked within the same cycle, the optimal quantity and total cost increase with defects to compensate for the loss of planned products. Hence the proposition P4 is:

> P4: Determination of the optimal raw material ordering quantity, finished product batch size and number of kanbans (for a multi-stage production system) for production – delivery situations considering process inspection, restoration and rework.

The managerial implications in the analysis of rework and number of shipments in a production system are:

1. Lot-for-lot policy is recommended when the inventory carrying cost is high. Single purchase single delivery policy is recommended when the ordering cost is low, or price discount is offered for lump sum purchase. Single purchase multiple delivery is

recommended when inventory is supplied in small batches. As the proportion of defectives increases, the optimal lot size decreases, while the optimal total cost increases for all the models. As the inspection errors increase, the optimal batch size decreases, while the optimal total cost increases. As the ordering and setup costs increase, the optimal batch size as well as the total cost increase. Batch sizes generally increase with increase in the ratio of setup cost for production to ordering cost of raw material (Ojha et al., 2007).

2. Inspection and restoration of the processes are the means of improving quality and results in reductions in quality control costs. When inspection and restoration are carried out, lower costs are incurred and larger lot sizes are produced (Ben-Daya and Rahim, 2003).
3. In a JIT environment, a manufacturer is expected to reduce the setup and ordering costs as much as possible, so as to minimize inventory and the total cost. However, it is important to estimate the sensitivity of total cost to the changes in ordering cost and setup cost (Sarker and Parija, 1996).
4. As the kanbans are circulated smoothly in a supply chain system, the productivity increases and the wasted materials, time and labor in the production are reduced. Organizations can economically benefit from savings from improvements in reduction of inventory in a supply chain accomplished through the kanban mechanism (Wang and Sarker, 2006).
5. In the rework done within the same cycle with no shortage, the optimal quantity increases with defects to compensate for the loss of planned products. In the rework done after a number of cycles, incurring shortages in each cycle, the optimal quantity also increases with the defects (Sarker et al., 2008).

2.2.5 Analysis of lean tools for supply chain performance

Pavnaskar et al., (2003) have listed 101 tools of lean. Many of the lean tools are interrelated as the success or failure in one has direct or indirect impact on the others. The effects and advantages of lean in a practical production environment and ways of implementing them needs a thorough and careful study because a headlong rush to become lean can result in many misapplications of lean tools (Pavnaskar et al., 2003). White et al., (1999) provided a good empirical work focusing only on Just-In-Time (JIT) manufacturing. Samson and Terziovski

(1999) concentrated on the Total Quality Management (TQM). McKone et al., (2001) focused on Total Productive Maintenance (TPM). Cua et al., (2001) related the implementation of JIT, TQM and TPM on manufacturing performance. Shah and Ward (2003) examined three organizational context characteristics-unionization, plant age and plant size and their influence on the implementation of manufacturing practices.

Table 2.5 Comparison of different features on some research works on analysis of lean manufacturing (LM) tools

Attributes	Pavnaskar et al., (2003)	Shah & ward (2003)	White et al., (1999)	McKone et al., (2001)	Samson et al., (1999)	Cua et al., (2002)
Classification of LM tools (x)	(x)					
Examining LM tools on unionization, plant age, plant characteristics (xx)		(xx)				
Empirical work on LM tools for JIT manufacturing (xm)			(xm)			
Study of the TQM lean tool in manufacturing performance (xq)					(xq)	
Study of the TPM lean tool in manufacturing performance (xp)				(xp)		
Study of TQM, TPM, JIT lean tools in manufacturing performance (xs)						(xs)

In the perspective of the lean supply chain, there is an absolute need for shorter lead times, smaller batch sizes, lesser cycle length and highest quality with pressures on reducing the manufacturing costs (Bonney et al., 2003). There is a need to identify and analyze the lean tools that are linked to the performance of the lean supply chain. Hence the proposition P5 is:

P5: Identification and analysis of lean tools which are essential for the lean supply chain.

The managerial implications in the analysis of lean manufacturing tools for supply chain performance are:

1. Through lean manufacturing principles, industries are attempting to reduce the wastes in their supply chain operations to produce goods at a lower cost.
2. In order to achieve the goals of a lean supply chain system, proper identification and application of the lean tools used in lean supply chain is absolutely necessary.

2.3 Research Objectives

This research attempts to provide a framework for an integrated approach to the design and analysis of lean manufacturing system with a perspective of lean supply chain. The present work provides research propositions and managerial implications regarding the integration of lean manufacturing principles with a focus in the following areas: (i) Pricing, investment and order quantity decisions in a supply chain between a manufacturer and a retailer, (ii) JIT inventory analysis for a buyer and vendor considering the quality improvement, setup cost and lead time reductions, (iii) Optimal cycle length and number of inspections considering the setup cost reduction and quality improvement, (iv) Optimal batch size with inspection errors and optimal number of kanbans with rework consideration, and (v) analysis of lean manufacturing tools in supply chain.

The objectives of the present research are as follows:

(i) To obtain a model of intra and inter coordination between manufacturer and retailer that results in highest profit for the supply chain, under the assumption that customer demand is sensitive to both price as well as non price factors.

(ii) To investigate the effect of quality improvement using the integrated vendor – buyer inventory model under the conditions of quality improvement efforts by both buyer and vendor. To investigate the result of investments in setup cost reduction, quality improvement and lead time reduction on the JIT integrated inventory model.

(iii) To determine simultaneously optimal production run length and inspection schedules in a deteriorating production process under the investment in both setup cost reduction and quality improvement. Also to determine optimal cycle length using both time-varying lot sizes and common cycle approach, and the number of inspections considering process inspection and restoration under the investment in both setup cost reduction and quality improvement.

(iv) To determine the optimal batch size in a single-stage production system with rework consideration under different options of raw material ordering and finished goods delivery situations. Also to determine the optimal number of kanbans in a multi-stage JIT production-delivery system with rework consideration.

(v) To substantiate evidence that implementing lean supply chain using the lean manufacturing tools helps to increase productivity.

2.4 Research Methodology

The research methodology in this research has been development of models for realizing each of the research objectives of this research work.

2.4.1 Comprehensive Research Methodology

The research methodology used for obtaining the research objectives are show in figure 2.2. From the research propositions, problem identification and formulation was done. Based on the problem formulation, the design of models was done as follows: (i) notations and assumptions to be used in the models were defined, (ii) algebraic expressions of the models were formulated, (iii) detailed solution algorithms were developed and (iv) solution procedure for the algorithms was described. The models thus designed were analysed with the help of numerical case studies. The data for the numerical case studies were taken from the literature, to identify the betterment of the solution of the models from the existing literature. From the numerical case studies, results were tabulated. 2D and 3D graphs were also plotted to discuss the results and provide the appropriate research contributions. Finally the scope for future work was also spelt out separately for all the models in the conclusion.

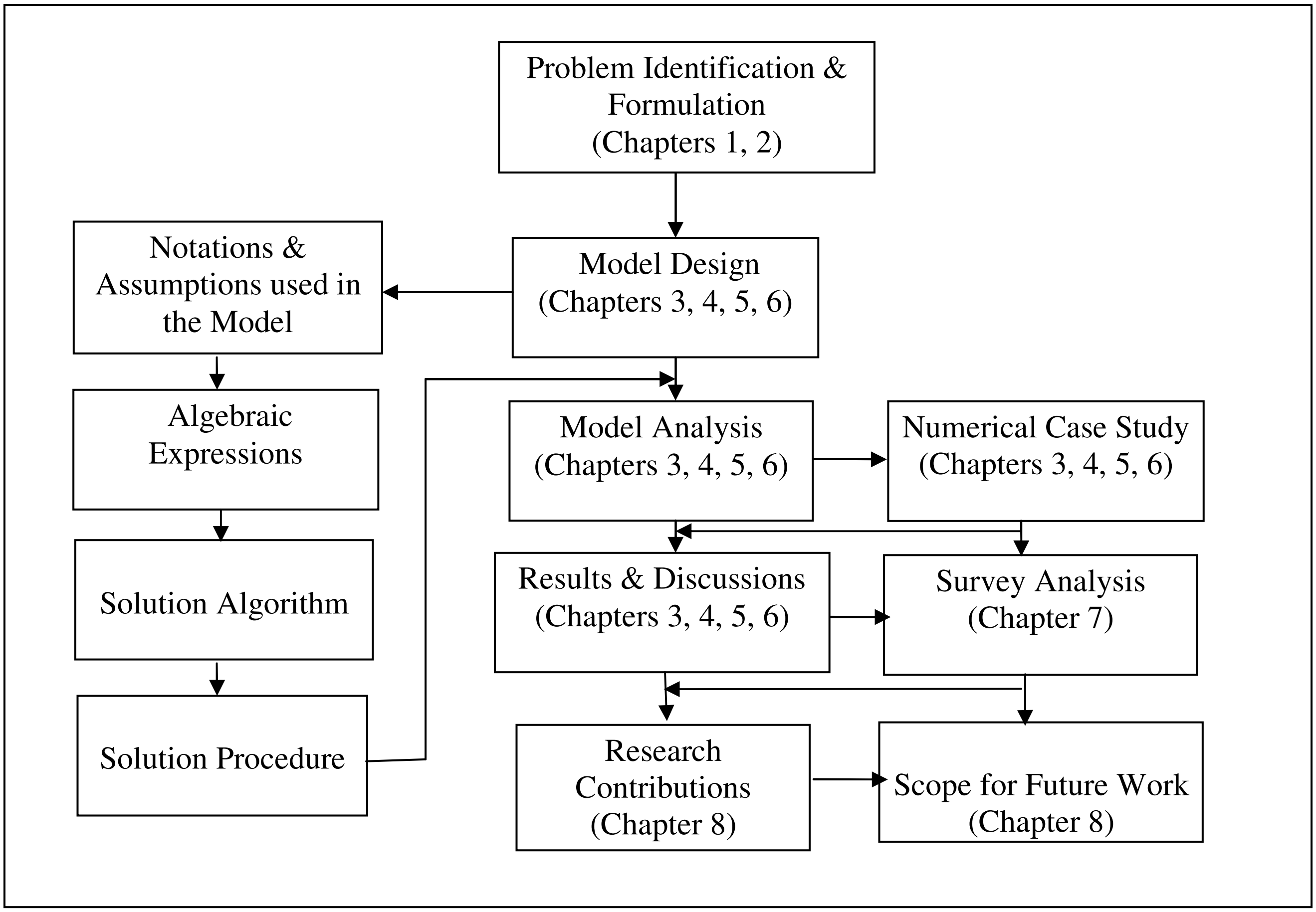

Figure 2.2. Flow Chart for the research methodology

The model thus designed was analysed with the help of a numerical case study. The data for the numerical case study were taken from the literature, to identify the betterment of the solution of the model from the existing literature. From the numerical case study, results were tabulated. 2D and 3D graphs were also plotted to discuss the results and provide the appropriate research contributions. Finally the scope for future work is also spelt out separately for all the models in the conclusion.

2.4.2 Generalized solution algorithm and procedure

A generalized solution algorithm and procedure are shown in figure 2.3. Since the research work was extension of the available literature, existing literature models were taken and new improvised models were formulated keeping in line with the research objectives. New equations were developed and initial values were set for the variables. Conditions for maximization of profit (chapter 3) and minimization of cost (chapters 4, 5 and 6) were set and the optimal values were found by iterative procedure. Numerical case studies were done based on these optimal values obtained.

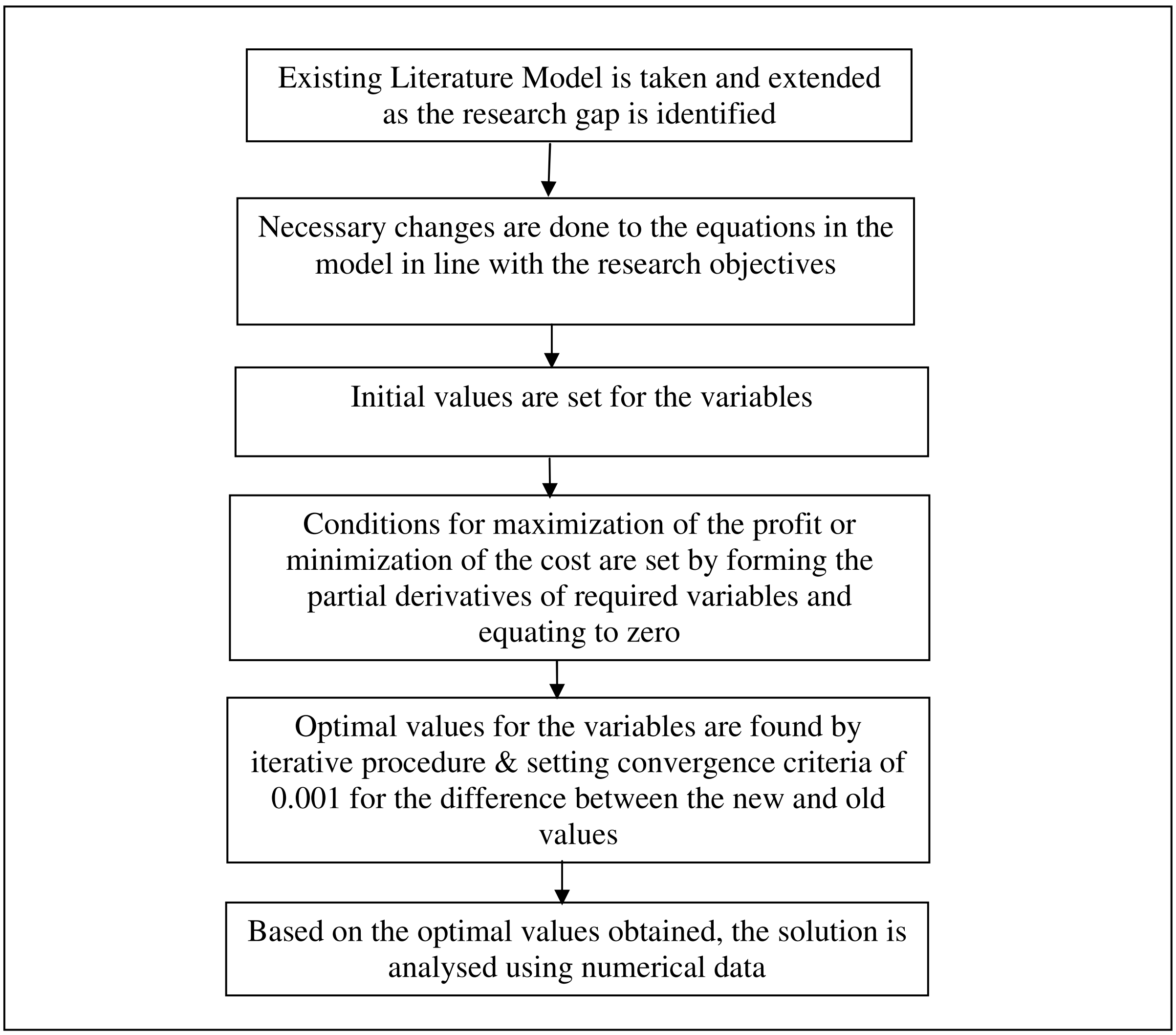

Figure 2.3. Generalized flow diagram for solution algorithm and procedure

2.4.3 Optimization method

In the models constructed as a part of this research work, interactions between the parameter(s) of algebraic function are solved using the algorithms developed. Newton-Raphson iterative method was used to find the optimal values of the variables.

Newton-Raphson method is used in the determination of root(s) of a function in single (or multiple) dimension(s) by iteration procedure starting from an approximate trial solution until some predetermined convergence criterion is satisfied. Newton-Raphson method is distinguished from the bisection and secant methods by the fact that it requires the evaluation of both function and its derivative at arbitrary points. Newton-Raphson method is used as the

(i) convergence is quadratic,

(ii) function's derivative is computed using a numerical difference to approximate the true local derivative, and

(iii) generalization to multiple dimensions can be easily extended (Press et al, 1994). Program code for the solution algorithm is developed and executed in MATLAB.