International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-1 Issue-6, August 2012

An Extensive Literature Review on Lead Time Reduction in Inventory Control

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Abstract— This article provides a comprehensive introduction about the lead time reduction in inventory control research status in relevant fields from a different perspective. First, this paper proposes some key factors which should be considered in the lead time reduction studies; then, from the perspective of study scope, the current literatures are distinguished into four categories on the basis of years i.e. from year 1991 to 2000 is first part, second part is from year 2000 to 2004, third part is from year 2005 to 2008 and final part is from year 2008 to 2012. Literatures in each category are reviewed according to the key factors mentioned. The literature review framework in this paper provides a clear overview of the lead time reduction inventory study field, which can be used as a starting point for further research work.

Index Terms— crashing cost, Inventory control, Inventory Model, Lead time, Safety stock

I. INTRODUCTION

In today's competitive business world, companies require small lead times, low costs and high customer service levels to survive. Because of this, companies have become more customers focused. The result is that companies have been putting in significant effort to reduce their lead times. The main focus of companies in the 20th century was the customers. It has become more and more competitive to satisfy customers according to Gaither [5]. For instance, to perform in a global market, short lead times are essential to provide customer satisfaction. Organizations that have focused on cycle time as a productivity measure can reduce delivery time and improve quality, thereby creating more satisfied customer. Cycle time or lead time is from the time a customer release an order until the time they receive the finished product. Silver et al. [6] defined, lead time as the time that elapses between the placement of an order and the receipt of the order into inventory, lead time may influence customer service and impact inventory costs. As the Japanese example of just-in-time-production has shown, consequently reducing lead times may increase productivity and improve the competitive position of the company. According to Gaither [5] Inventory is a part and parcel of every facet of business life. Without it, no business activity can be performed, whether, it being a service organization like hospitals and banks etc. or manufacturing or trading organizations. Irrespective of the specific organizational setting, inventories are reflected by way of a conversion process of inputs to outputs. Inventory is simply a stock of physical assets having some economics value, which can be either in the form of material, money or labor. Inventory may be regarded as those goods which are procured, stored and used for day to day functioning of the organization. This can be in the form of physical resource such as raw materials, semi finished goods bought out products used in the production and assembling operations. Most managers don't like inventories because they are like money placed in a drawer, assets tied up in investments that are not producing any return and, in fact, incurring a borrowing cost. They also incur costs for the care of the stored material and are subject to spoilage and obsolescence. In the last two decades there have been a spate of programs developed by industry, all aimed at reducing inventory levels and increasing efficiency on the shop floor. Some of the most popular are conwip, kanban ,just-in-time manufacturing, lean manufacturing, and flexible manufacturing.In this paper our focus is not only on the criticality of effects of lead time on inventory, but also on the various techniques implemented so far to solve critical lead time reduction problems leading to inventory optimization and control through extensive literature review. Based on different outcomes revealed from open literature, the new possible methodologies are discussed in the later sections.

Manuscript published on 30 August 2012.
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II. LEAD TIME FUNDAMENTALS

The Japanese experience of using Just-In-Time (JIT) production shows that there are advantages and benefits associated with their efforts to control lead time. Japanese manufacturers are known for their strong and lasting partnership with their suppliers. This helps reduce lead time and is one of the sources of success of their JIT philosophy. Lead time has been a topic of interest for many authors like Das [1], Foote et al. [2], and Magson [3] Naddor [4]. Before 1980, customers tolerated long lead times which enabled producers to minimize product cost by using economical batch sizes. Later, when customers began to demand shorter lead times, they were able to get them from competitors. This is when the problem arose and companies started to look for changes to be more competitive. In an attempt to reduce lead time, businesses and organizations found that in reality 90% of the existing activities are non-essential and could be eliminated. As soon as manufacturers focused on processes, they found waste associated with changeovers, quality defects, process control, factory layout, and machine down time. So they tried to find ways to reduce or eliminate waste. Harrington [7] proposes by eliminating the non-value adding activities from the processes and streamlining the information flow significant optimization results can be realized.

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In the 1960s and 70s, manufacturers competed on the basis of cost efficiency. In the 1980s, quality was the rage and Zero Defects and Six Sigma came into vogue. Cost and quality are still crucial to world-class operations, but today, the focus is squarely on speed. Nearly all manufacturers today are under pressure from customers to cut lead times. And rapid-response manufacturing pays big dividends. Let's clarify what we mean by lead times. Customer lead time refers to the time span between customer ordering and customer receipt. Manufacturing lead time refers to the time span from material availability at the first processing operation to completion at the last operation. In many manufacturing plants, less than 10% of the total manufacturing lead time is spent actually manufacturing the product. And less than 5% of total customer lead time is spent in the production process. The cumulative cycle times of the processes in the value stream are the theoretical limit to how much we can reduce lead times, without investing in different equipment. Clearly, there is ample opportunity to reduce lead times in most organizations. Reducing lead times doesn't involve speeding up equipment to cut the cycle times or getting plant personnel to work faster. What is does involve is the rapid fulfillment of customer orders and the rapid transformation of raw materials into quality products in the shortest amount of time possible. In today’s competitive business world, companies require small lead times, low costs and high customer service levels to survive. Because of this, companies have become more customers focused. The result is that companies have been putting in significant effort to reduce their lead times. There are lot of factors affecting inventory, those are purchase price or production cost, selling price, procurement cost, holding costs, stock-out costs, demand, ordering cycle, lead time or delivery leg, number of supply echelons, etc. But the major factors affecting the inventory system are demand, cost factors, and lead time. All other factors can be treated as completely known for an inventory system. Although great improvements have been achieved in the means of transportation, communication and production, most procurement systems require some lead time in supply which is often uncertain. This uncertainty makes the solution to the inventory problem more complex and also increases the cost of inventory for the same level of performance. These effects of lead time are well known but are too general to be of much practical use. We need to know how and to what extent each of the many characteristics of lead time influence the cost of inventory in order to select the most economic of the various potential modes of supply. Lead time plays an important role in today’s logistics management.

III. KEY FACTORS IN LEAD TIME REDUCTION STUDY

Factors such as demand, order quantity, quality of product, reorder point, safety stock, and other factors like price discount, allow shortage or not, inflation, and the time-value of money are also important in the study and so on should be taken into consideration in the reduction of lead time in inventory study. By making different combinations of these factors stated above, we can get different inventory models. Demand acting as the driving force of the whole inventory system, demand is a key factor that should be taken into consideration in an inventory study. In their studies (Ben-Daya and Raouf [8]; Ouyang et al.[9]. Hariga, M. and Ben Daya, M.,[10]), they assumed that the lead-time demand follows the normal distribution. There are mainly two categories demands in the present studies, one is deterministic demand and the other is stochastic (probabilistic) demand. However, when the demands of the different customers are not identical in the lead time, then it was found that only a single distribution cannot use to describe the demand of the lead time. Moreover, it has seen that the reorder point r as a decision variable [11]. After that, many researchers have extensively studied this type of demand. Stochastic demand includes two types of demands: the first type characterized by a known demand distribution and on the contrary the second type characterized by arbitrary demand distribution. When the assumption of deterministic demand is relaxed and demand is assumed to be stochastic, lead time becomes an important issue and its control leads to many benefits.

In the classical inventory model, it is implicitly assumed that the quality level is fixed at an optimal level, i.e., all items are assumed to have perfect quality. However, in the real production environment, it can often be observed that there are defective items being produced due to imperfect production processes. Juran was one of the first to think about the quality. This was illustrated by his "Juran trilogy", an approach to cross-functional management, which is composed of three managerial processes: quality planning, quality control and quality improvement. Without change, there will be a constant waste, during change there will be increased costs, but after the improvement, margins will be higher and the increased costs get recouped. The defective items must be rejected, repaired, reworked, or, if they have reached the customer, refunded. In all cases, substantial costs are incurred. Therefore, for the system with an imperfect production process, the manager may consider investing capital on quality improvement, so as to reduce the quality-related costs. In literature, Porteus[12] and Rosenblatt and Lee [13] are among the first who explicitly elaborated on a significant relationship between quality imperfection and lot size. Keller and Noori [14] extended Porteus’ [12] work to the situation where the demand during lead time is probabilistic and shortages are allowed. Hwang et al.[15] studied the multiproduct economic lot size models in which setup reduction and quality improvement can be achieved with a one-time initial investment. Hong and Hayya [16] presented a model including a budget constraint and other types of continuous functions for quality enhancement and setup cost reduction. Ouyang and Chang[17] investigated the impact of quality improvement on the modified lot size reorder point models involving variable lead time and partial backorders. Ouyang et al. [18] extended Ouyang and Chang’s [17] model by investing in process quality improvement and setup cost reduction simultaneously. Reducing lead times is especially important in situations where customer demand is uncertain, since long lead times put the company at a high risk of running out of stock before an order arrives. In this context, a variety of studies illustrate that reducing replenishment lead time may lower the safety stock, reduce the stock out loss, and improve the customer service level, which results in lower expected total costs. Safety stock also a very important factor in reduction of lead time analysis. A large number of researchers (Yu-Cheng Hsiao [19], Jack C. Hayya, Terry P. Harrison. X. James He [20], Christoph H. Glock [21]) have worked out the effect of lead time reduction on safety stock.

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Further, it has been shown that lead time is correlated with financial performance indicators, such as ROI (Return of Investment) or average profit (see Christensen et al.,[22]). This underscores the importance of managing lead time inversely related to the demand rate. In contrast to the general assumption that lead time crashing cost depends on the number of orders only (Ben-Daya and Abdul raouf [8], Ouyang et al.[18], Ouyang, and Chang [17]). Kim and Benton [23] established a linear relationship between lead time and lot size in the classical stochastic continuous review (Q; r) model, and demonstrated that significant savings could occur if firms considered the impact of lot size on the lead time and safety stock requirement. Hariga [24] modified Kim and Benton's model by rectifying the expression of the annual backorder cost and proposing another relation for the revised lot size to generate a smaller lot size than that of Kim and Benton [23]. Hariga [23] extended the study by considering the investment in setup time reduction and the relationship between lead time, lot size and setup time. Pan et al. [25] proposed that the transportation cost, the overtime wages and extra inventory holding costs for expedition were proportional to the item quantities rushed and hence the crashing cost could be represented as the sum of a fixed portion and a variable portion proportional to the quantities in the rushed order. Ouyang and Wu [11] consider both lead time and the order quantity as the decision variables of a mixture of backorders and lost sales inventory model in which the shortages are allowed and consider the demand of the lead time with normal distribution. Safety stocks are extra inventory kept on hand as a cushion against stock-outs due to random perturbations of nature or the environment. Lead time is an important element in any inventory management system. Ouyang and Wu [11] propose that by shortening the lead time, they can lower the safety stock, reduce the loss caused by stockout, improve customer service level, and increase the competition ability in business. Price (quantity) discount is an important strategy which the seller always uses to encourage the buyer to purchase in large quantities; many researchers have taken this factor into consideration in lead time reduction inventory modeling. Allowing shortage or not is another factor which researchers always focus on (Ouyang et al [11], LiangYuh Ouyang and Chuang [26], Ben-daya, Hariga [27], Jun-Yeon Lee, Leroy B. Schwarz [28], Hsiao [19]), some of their studies supposed that shortage is not allowed, the rest supposed that shortage is allowed and then corresponding inventory strategy can be made according to the two assumptions respectively. In fact, shortages usually happen in our daily life and what's more, in the circumstance of high deteriorating rate, the demand may need to be backlogged to reduce cost due to deterioration, so there are more studies that concentrate on the assumption that shortage is allowed. There are two cases when dealing with the shortage, one case supposes that the shortage items are totally backlogged and the other case supposes that the shortage items are partly backlogged, that is to say, the customers are only willing to accept part of the items that are out of stock this period and can only be supplied by the seller in the next period.

IV. LEAD TIME REDUCTION REVIEW IN INVENTORY STUDY

It is normally observed that after receiving an order, supplier needs some time to deliver the item, which is known as lead-time. Lead-time is normally fuzzy or stochastic in nature. A number of research papers have been already published in this direction (Das,[1], Foote et al.[2]). One of the first papers dealing with a variable lead time in an inventory model is due to Liao and Shyu, [29]. The authors assumed that lead time can be decomposed into several components, each having a different piecewise linear crashing cost function for lead time reduction, and that each component may be reduced to a given minimum duration. Under the assumption that the lot size is predetermined and that demand is normally distributed, they calculate an optimal lead time and show that reducing lead time may result in lower expected total costs. Ben-Daya and Raouf, [8] revisit Liao and Shyu [29] and proposed a model that treats both lead time and order quantity as decision variables. They develop two models, one that uses the lead time crashing cost-function proposed by Liao and Shyu and one that uses an exponential crashing cost function. Then they propose models which use different representations of the relationship between lead time crashing cost and lead time. And the Possible extensions of their work include considering stochastic lead time and introducing lead time as a decision variable in other inventory models. Ouyang et al. [11] introduced another extension and include shortages in the model. They assumed that the shortages are allowed and they extend the Ben-Daya and Raouf [8] model by adding the stock out cost. In addition, during the stock out period, the total amount of stock out is considered a mixture of backorders and lost sales. Finally they concluded that, when the distribution of the lead time demand is completely known, a mixture inventory model with backorders and lost sales can be solved. Possible extension of theirs work may be conducted by considering the inventory model with a mixture of backorders and lost sales using the minimax distribution free procedure. Moon and Choi, [30] considered a continuous review inventory model with a mixture of backorders and lost sales in which the order quantity, the reorder point and lead time are decision variables. That model improves the existing one, and results in both significant savings in the total expected annual cost and higher service level. The objective of that paper was to correct and improve the Ouyang, yen & Wu [11] model by simultaneously optimizing both the order quantity and the reorder point. A significant amount of savings over the model was achieved. Ouyang and Wu, 1998 present an inventory model with a mixture of backorders and lost sales for minimizing the sum of the ordering cost, holding cost, stock out cost and crashing cost, where both lead-time and the order quantity were considered as the decision variables. There authors relax the assumption about the form of probability distribution of lead-time demand and apply the minimax distribution free procedure to solve the problem. Authors find that the order quantity per cycle in the lost sales case is greater than in the backorders case. Besides, for fixed lead time (L), order quantity (Q) and safety factor (k) have negative relation. It implies increasing safety factor (i.e., increasing the safety stock) decrease the order quantity. In further research on that problem, it would be of interest to examine a non-linear relationship that exists between the crashing cost and the lead time. On the other hand, the minimax distribution free procedure could possibly be applied to other inventory models so as to extend the research further.

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Hariga and Ben-Daya,[31] developed a continuous review inventory model where the reorder point; the ordering quantity and the lead time are decision variables. Models with full and partial information about the lead time demand distributions were developed. They also proposed an inventory control models with variable lead time for periodic review and base stock inventory policies. In the latter models they also consider situations of complete and partial knowledge about the lead time demand distribution. These stochastic inventory models relax the classical assumption of treating the lead time as an exogenous parameter. Ouyang and Chuang, [26] extend Ouyang et al.'s [11] model, and proposed more general model that allow the backorder rate as a control variable. Ouyang and Chuang there assumed that the backorder rate is dependent on the length of lead time through the amount of shortages. In the real market as unsatisfied demands occur, the longer the length of lead time is, the smaller the proportion of backorder would be. Considering the reason, they assumed that the backorder rate is dependent on the length of lead time through the amount of shortages. They first assumed that the lead time demand follows a normal distribution, and then relax the assumption about probability distributional form of the lead time demand and applied the minimax distribution free procedure to solve the problem. In future research on that problem, it would be of interest to treat the reorder point as a decision variable. Chen, Chang and Ouyang [32] study the effect of lead time reduction on continuous review inventory systems with partial backorders. Specifically, they modified Moon and Choi's [30] model to include the cases of the linear and logarithmic relationships between lead time and ordering cost reductions. The objective was to minimize the total related cost by simultaneously optimizing the order quantity, reorder point, and lead time. Under the assumptions that lead time demand follows a normal distribution, an algorithm to find the optimal solutions for both cases is developed. Finally author concluded that when the reduction of lead time accompanies a decrease of ordering cost, the smaller lot size and larger savings of total expected annual cost can be realized. It may be an interesting research topic to consider other types of relationship between lead time and ordering cost, or further extend the proposed problem to include the interactions between lead time, order quantity, and/or ordering cost. Pan and Yang [33] were presented, an integrated inventory model with controllable lead time. The proposed model was shown to provide a lower total cost and shorter lead time as compared with those of Banerjee [34] and Goyal[35]. Goyal [35] extended Banerjee’s model by relaxing the lot-for-lot production assumption. Pan and Yang [33] further extended Goyal’s [35] model by relaxing the production assumption and developed a integrated inventory model with controllable lead time was suggested and it was shown to provide a lower total cost and shorter lead time as compared with the models of Banerjee[34] and Goyal [35]. By adopting a jointly optimal ordering policy, one partner’s gain exceeds the other’s loss, and the net benefit can be shared by both parties in some equitable fashion. . Ben-Daya and Hariga [36] published a Papers dealing with lead-time crashing consider the lead-time crashing cost as a recurring cost, i.e. the cost is incurred at every cycle. That paper considers the crashing cost as one time investment and a stochastic continuous review inventory model involving lead-time as a decision variable. Summary of that paper was, Lead-time had been divided into its three main components: setup time, productive time and non-production time. These components reflect set-up cost reduction, lot size lead-time interaction and lead-time crashing, respectively. The finite investment approach for lead-time and set-up cost reduction and their joint optimization, in addition to the lot size lead-time interaction, introduce a realistic direction in lead-time management and control. The effect of learning in the production time component of the lead-time and the production cost is another contribution of that paper. Ben-Daya and Hariga [27] considered the single vendor single buyer integrated production inventory problem. They relax the assumption that demand is deterministic and assumed that it was stochastic and tackle the lead time issue. They assumed a linear relationship between lead time and lot size but take into consideration also nonproductive time in the lead time expression. Lee, Wu and Hou [37] extend and correct the model of Ouyang and Wu [17]. That paper considers that the number of defective units in an arrival order to be a binominal random variable. They derived a modified mixture inventory model with backorders and lost sales, in which the order quantity, lead time and reorder point are decision variables. In future research on that problem was, it would be interesting to deal with the inventory model with a service level constraint or defective units in inventory model with sub lot sampling inspection. Pan, Lo, and Hsiao [38] considers a continuous review inventory system in which shortage was allowed and the total amount of stock out was a combination of backorder and lost sale. Objective to simultaneously optimizing the order quantity, lead time, backordering and reorder point. It was assumed that the supplier may offer a backorder price discount to the patient customers with outstanding orders during the shortage period and the backorder ratio is proportion to the price discount. Furthermore, it was assumed that the inventory lead time is controllable and the crashing cost can be represented as a function of reduced lead time and the quantities in the orders. Since the shortage cost is explicitly included, the reorder point is also treated as a decision variable in that paper. Yang, Ronald and Chu [39] extend the inventory model of Ouyang et al. [11]. When the distribution of lead time demand is normal, they considered the time value of a continuous review inventory model with mixture of backorders and lost sales. In that article, they provide a mixed inventory model, in which the distribution of lead time demand was normal, to consider the time value. Firstly, the study tried to find the optimal reorder point and order quantity at all lengths of lead time with components crashed to their minimum duration. Secondly, they developed a method to insure the uniqueness of the reorder point to locate the optimal solution. By shortening lead time companies lower the safety stock, reduce the stock out loss and satisfy market demand to gain competitive advantages in business. Under this situation, the firm must pay higher crashing costs, especially in the impact of time value. Therefore, they wished to balance time and costs, and obtain an optimal replenishment policy to minimize the expected present value of costs. They treated the reorder point as a new decision variable to obtain the optimal expected present value of costs. Zequeira, Durán and Gutierrez [40] studied the determination of the optimal lead time, reorder point and order quantity considering that the back-order probability of a demand made during a stock-out period depends on the interval from the moment in which the order is placed until the next replenishment.

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They presented two models for the specification of the backorder probability: piecewise constant functions and exponential functions. Their approach would be useful when there is prior information on the loyalty of a customer to a product, and this information can be expressed in terms of piecewise constant probability or exponential functions. Pan and Hsiao [41] focuses on the reduction of overall system response time and inventory lead time reduction has been one of the favorite topics for both researchers and practitioners. Under probabilistic demand, inventory shortage is unavoidable. In order to make up for the inconvenience and even the losses of royal and patient customers, the supplier may offer a backorder price discount to secure orders during the shortage period. That paper extends the work of Ouyang et al.[11] by proposing that both the lead time and the backorder price discount to be negotiable and the lead time crashing cost to be represented as a function of both the order quantity and the reduced lead time. Chang et al. [42] investigated how lead time and ordering cost reduction affect the integrated inventory model. Lead time crash cost was assumed to depend on ordered lot size and the amount of lead time to be shortened. Moreover, ordering cost was included among the decision variables. Two models were proposed in that study. The first model employed a logarithmic investment cost function for ordering cost reduction, in which the ordering cost and lead time reductions were performed independently. The second model assumed that the ordering cost and lead time reductions interacted with each other linearly. An iterative algorithm was devised to determine the optimal solution for lot size, reorder point, ordering cost, lead time, and number of shipments between the vendor and buyer. Hoque and Goyal,[43] demonstrated that the model of an integrated inventory problem under controllable lead-time between a vendor and a buyer and its heuristic solution procedure, proposed by Pan and Yang [33] based on equal-sized batch transfer, may lead to an erroneous solution due to the lack of appropriate constraints on a batch size. To overcome the shortcoming, an alternative generalized model was developed in that paper. It was developed based on equal or unequal sized batch transfer of the lot from the vendor to the buyer. Constant safety stock over time to meet the demand by a lot is assumed and the lead-time is reduced with an additional crashing cost. It was shown theoretically that if the ratio of the production rate to demand is higher than the ratio of the highest lead-time to the least lead-time, then problem's parameter values do not warrant the use of unequal-sized batches. Otherwise, lot transfer by unequal sized batches may be effective. A number of properties that lead to the optimal solution of the model were established, and following these properties, an algorithm to obtain the optimal solution was presented. The technique in that paper provides the optimal lot and batch quantities, number of equal and unequal sized batches, lead-time and safety stock per lot by minimizing the total cost of setups or ordering, inventory holding, safety stock and lead-time crashing. Lee and Schwarz [28] examined a continuous-review, single-item, (Q, r) inventory system from an agency perspective, in which the hidden effort of an agent influences the item's replenishment lead time. They had demonstrated that the possible influence of the agent on the replenishment lead time can be large, but that a simple linear contract is capable of recapturing most of the cost penalty of ignoring agency. Finally, they made a few comments about the applicability of their results to the lost-sales or partial-backordering scenario. In their analysis they assumed that unmet demand is fully backordered, and used an exact cost function to measure the cost impact of lead time reduction. Although their analytical results on the payment schemes remain applicable to scenarios in which unmet demand is partially or fully lost, no exact expression for the average cost per unit time of a (Q; r) policy exists for the lost-sales scenario, much less the partial backordering scenario. Ouyang et al. [44] extend Yang and Pan [39] model by adding the shortage cost and considering the reorder point as a decision variable. These results reveal that taking the reorder point as a decision variable will improve the system performance and annual joint total expected cost. Also, it shows when there is an investing option of improving the process quality, it is advisable to invest. Using the model obtained in that paper, managers can quickly respond to customer's demand by efficiently determining the appropriate ordering policy. As for future research, it is assumed that the capital investment in quality improvement is a logarithmic function of the quality level. They note that the logarithmic function is one of the possible investment functions, and it would be of interest to consider other investment functions for that problem. Another possible research topic is to evaluate the impact of various types of imperfect production systems and inspection policies on integrated inventory models. Chen and Chang [45] were proposed two new methods for solving a seasonal demand problem with variable lead-time and resource constraints. First, in order to solve the variable lead time, a linear programming relaxation using piecewise linearization techniques was derived. Then, a mixed integer program with linearization techniques was constructed for the seasonal demand problem. Hsiao [19] given a note on Ben-Daya and Hariga [27] that the lead time is proportional to the lot size produced by the vendor in addition to a fixed delay due to the transportation, setup and nonproductive time. The end-customers accept backorders when the shortage occurs at the buyer side. An order to the vendor is placed each time the inventory level reaches the reorder point. In that note, a modified model was proposed under a different assumption that there are two different reorder points and service levels.

Chandra and Grabis [46] developed a model with lead time-dependent procurement costs and assumed that shortening lead time results in increased procurement costs. The relationship between lead time and procurement costs is established with the help of a linear and a nonlinear procurement cost function. The objective of their paper was to find the lead-time value representing the trade-off between benefits of lead-time reduction and increase in the procurement cost. The lead-time reduction is expected to reduce the inventory cost because of more accurate demand information and lower safety stock requirements. Yet, it increases the procurement cost because the supplier sets a higher price for short lead-time orders, limited supplies force to seek more costly alternative products or a more expensive shipping mode was used to ensure the shorter lead-time. Lee and Schwarz [47] examined a single-item, periodic-review inventory system with stochastic lead times, in which a replenishment order was delivered immediately or one period later, depending probabilistically on costly effort. The objective was to determine a joint inventory policy and effort-choice strategy that minimizes the expected total costs.

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Their analytical and computational analysis suggests that (i) a state-dependent base-stock policy is optimal; (ii) the optimal effort strategy is such that the marginal cost of effort is equal to the value of immediate delivery, and (iii) the cost impact of lead time reduction can be very large. First, their analytical and computational results suggest that, from either a centralized or agency perspective, a state-dependent base-stock policy may be optimal in the business scenarios examined. In their policy the effort for lead-time reduction (e.g., expediting, use of better equipment) and the target inventory are chosen in each replenishment cycle based on the level of current inventory. Although caution suggests the consideration of other types of policies (e.g., base-stock policies, (s, S) policies) in developing decision-support software, their results indicate that state dependent base-stock policies may be cost-effective ones to use. Chang and Lo [48] proposed an approach to overcome the drawback of traditional methods of L.Y. Ouyang, N.C. Yeh, K.S. Wu [11] for improving the continuous and discrete lead time with mixture of backorders and lost sales, by which only a local optimal solution can be obtained. In addition, the proposed model allows decision-makers to add suitable constraints to their model in accordance with their actual business environments. The integral optimization approach is employed to consider the mixture of backorders and lost sales. To solve the proposed model, only one step is needed and the DM is allowed to add constraints to the model to suit real-world situations. In addition, the extended model was more user-friendly and effective as it can be simply operated through an ordinary commercial program, and it can solve the specific problems in the related field. Jha and Shanker, [49] modified the model of Ouyang et al. [44] by introducing a service level constraint, instead of considering the shortage cost in the objective function. In that paper, they presented the SLC approach to the vendor–buyer integrated inventory model involving variable lead time, i.e. the lead time is controllable and reducible by adding additional crash costs. Consequently, that study considers an integrated inventory model involving variable lead time in which the objective was to minimize the joint total expected cost of the vendor–buyer integrated system and subject to a service level constraint on the buyer by simultaneously optimizing the order quantity, lead time and the number of shipments between the vendor and buyer in a production cycle. It has been shown that if service level is a binding constraint, then the joint total expected cost decreases nonlinearly with safety factor otherwise increases linearly. Chaharsooghi and Heydari, [50] suggested that Lead time is one of the inseparable parameters of each supply chain. Moreover, lead time varies because of environmental uncertainties and it is one of the serious factors that challenge suppliers and buyers in a supply chain. Two statistical characteristics of LT are (1) LT mean and (2) LT variance. The former concerns supply performance, while the latter concerns environ- mental uncertainties. Reduction of both LT mean and LT variances investment strategies has been considered in previous studies, Ryu and Lee,[51]. They have taken, a four-echelon supply chain and has been simulated in which orders are placed based on a simple rule that considers LT, on-hand inventory, and scheduled receipts. In their paper, they answer this critical question: ‘‘which one is preferable in supply chain management: LT variance or mean reduction?’’ Using a simulation model, the effects of intervening variables are removed as much as possible. Using canonical correlation, they show that the effect of LT variance on SC performance is much greater than effect of the LT mean. Hayya, Harrison and He,[20] studied the reduction of stochastic lead time by using the exponential distribution to characterize lead time. In reducing the lead time they took advantage of order crossover. With order crossover, the lead times are transformed to effective lead times whose mean is the same as that of the original lead time, but whose variance is smaller than that of the original variance. Now when they introduce the resulting variance (due to order crossover) in the optimization, it would naturally lead to a lower cost, because of lower safety stocks. So they could do a trade-off analysis and evaluate whether reducing the mean would recover the lead time reduction cost. The two-stage model they presented was in a simple form in that the demand rate is constant, the lead time reduction cost can be calculated, and the shortages are negligible. The model itself requires numerical search (or Mathematical) to yield an optimal solution, because it does not directly yield closed-forms. So they used a first stage to obtain closed-form estimates that they then used as initial values for the second stage. Christoph H. Glock,[21] studied alternative methods for reducing lead time and their impact on the safety stock and the expected total costs of a (Q, s) continuous review inventory control system. Glock focused on a single- vendor–single-buyer integrated inventory model with stochastic demand and variable, lot size-dependent lead time and assumed that lead time consists of production and setup and transportation time. As a consequence, lead time may be reduced by crashing setup and transportation time, by increasing the production rate, or by reducing the lot size. They illustrate that the lead time reduction is especially beneficial in case of high demand uncertainty .Further, his studies indicate that a mixture of setup time and production time reduction is appropriate to lower expected total costs.

V. CONCLUSION

The lead time reduction on inventory system has attracted more and more attention and many researchers have conducted extensive studies in this area. In this paper, from a different perspective, we have tried to make a review on lead time reduction literatures. In many practical situations, lead time can be reduced at an added crashing cost; in other words, it is controllable. By shortening the lead time, it was found that safety stock can be lowered, reduce the loss caused by stock out, improve the service level to the customer, and increase the competitive ability in business. Time and cost are the most important competitive factors in business. Under cost considerations, a firm can apply a variety of means to reduce the lead time to satisfy customer’s demands. Decomposing the lead time into several crashing periods is a controllable way to achieve balance between the two factors of time and costs. Crashing costs are divided into operation costs, transportation costs, and production costs for increasing the production rate of suppliers. These costs include overtime pay for employees, extra costs for choosing speedy transportation, and renewal equipment costs and so on. The impacts of economic cycles such as inflation or deflation cause variation of the purchasing power of money. One major drawback was identified when studying the literature on lead time reduction in inventory models is that the vast majority of authors assumed that.

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lead time is independent of the lot size quantity and that a piecewise linear function is appropriate to describe the relationship between lead time reduction and lead time crashing costs.. Investigating Lead time reduction investment strategies can be considered as a future research topic. Also, studies on simultaneous reduction of "Lead time" and "Lead time uncertainty" can show some other aspects of profitability and reveal the limitations of Lead time uncertainty reduction.. It is recommended that more and more researchers begin to study reduction of lead time in inventory problems in supply chain with fuzzy, stochastic and dynamic research methods, only in this way, can the researches be applied to practice. It is hoped that this paper can provide an overview of the reduction of lead time in inventory study in the recent years and so act as a cornerstone for future study in this field.

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