Key-Part Based Lead Time Management for the Make-to-Order Production System in a Global Supply Chain Network

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ABSTRACT

Key-Part Based Lead Time Management

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The objective of the present thesis is to explore a satisfying lead time management for companies that implement a Make-to-Order production system in a global supply chain network. A huge lead time waste caused by early arrival of parts dominates total inventory losses and accounts for 54% in entire process according to some statistical data.

In the present thesis, a new theory named the Key-Part Based Lead Time Management (KPBLTM) was proposed to reduce non-value added waste. The contents of this thesis consist by constructing objective functions, proposing a practical methodology, comparing the satisfying solution with the optimal solution, proving the sufficient conditions of existence of the key part, demonstrating the robustness of the key part, applying to analyze the other production patterns, and building a connection between the Key-Part Based Lead Time Management and MRP system.

A managerial solution derived from the Key-Part Based Lead Time Management is depicted as: once receiving orders from customers, Make-to-Order companies schedule the arrival of the purchased parts based on the lead time of the key part.

Finally, the total inventory loss including the holding costs and the customer penalty will be dramatically reduced.

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I want to present this thesis to all my family. They are Xinxin, Dandan, France, Nanfang Xiao, Suibai Wang, Xuemei Xiao and her family. I want to express my gratitude for all of their love and support.

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Chapter 1

Introduction

In order to reduce inventory, more and more companies have decided to transfer their production from Make-to-Stock production system to Make-to-Order production system. However, Make-to-Order production faces unprecedented challenges to fill their customer orders quickly and to reduce their operating costs. Moreover, some kinds of companies such as: small and medium-sized companies which strongly rely on global supply chain network have to deal with considerable variations in lead time. In this present thesis, a new satisfying lead time management will be developed based on lead time management which proves as an important issue in gaining and maintaining a competitive edge in the current marketplace. In this chapter, two terminologies are introduced and a case study is presented to lay the basic foundations for the following chapters.

1.1 Global Supply Chain Network

The advantages of international purchasing in the USA have been investigated by Scully and Fawcett (1994). They showed that a global supply chain secures advantages in terms of the availability of specific items, higher levels of product quality, and/or lower product costs.

In the recent decade, more and more companies have been shifting their manufacturing operation to lower-cost facilities in Asia by building their production base there or by purchasing parts from there. The benefits from global supply chain can be concluded in the following: access to lower priced goods; enhance the competitive position; access to higher quality goods; access to worldwide technologies; improve the delivery performance and customer service; increase the number of suppliers; help to meet countertrade obligations.

1.2 Make-to-Order Production

Make-to-Order production system defines as follows: a product is made only when an order is received. For example, Toyota production is a typical Make-to-Order production.

Toyota Co. started to make automobiles in the 1950s. In its first 13 years, Toyota produced only less than 40% of Ford production in one day. After 50 years of growth, Toyota produced more automobiles than Ford did in 2006. Moreover, Toyota is now listed the second among automobile producers in the world. The most surprising fact is that Toyota's profits in 2006 were greater than the sum of that of GM, Ford, and Chrysler.

One of the important factors contributing to Toyota's success is the Toyota Production System (TPS), which was labeled as the Lean Production by Professor James P.Womack in his book (Womack, 1990). The system is also called Just-in-Time (JIT) in some professional books.

In the area of supply chain management, the traditional Make-to-Stock production system prepares the inventory before receiving the customer orders by relying on market forecasts. There are two unavoidable downsides to this system: one is the inventory where the forecast production is more than the market need, another is the sale losses where the forecast production is less than the actual market need. Toyota changes the production system from traditional Make-to-Stock to Make-to-Order, which prepares the inventory with right items with the right amount at the right time according to customer needs. As a result, the inventories are actually reduced or even eliminated. This system gives Toyota an advantage in the price competition.

1.3 The Situation of the Small and medium-sized companies

In order to succeed in Make-to-Order production under global supply chain network, some endeavors should be focused on how to introduce that type of production into diversified companies. For giant companies such as Toyota and Dell Company, suppliers have to move or rebuild their factories toward those giants to guarantee their services on a daily response. However, those dreams never arise for small and medium-sized companies. Their situations have features as follows:

- Less Research

In fact, the majority of findings in the literature concern the global purchasing behavior of multinational enterprises. Hardly any empirical research has been done on small and medium-sized firms (SMEs). A focus on SMEs may not only test the validity of earlier findings, but also bring new insights (Quintens et al, 2006).

- Longer lead time

As a result of globalization in the manufacturing industry, part suppliers have changed. The former suppliers who produced labor intensive parts have had to make a choice: to move their plants to developing countries or to quit their markets. However, some former suppliers who produce capital intensive or technology-intensive parts can still survive by retaining their advantages. Finally, the global supply chain is forced into existence by unseen hands.

A global supply chain network brings both sides to companies: the positive side is that companies can find products or parts of the best quality with lowest prices worldwide. Whereas, the negative side is that companies need to take a longer time to obtain those products and parts. The longer lead time not only increases risk to inventory loss but also adds risk to customer penalty.

The scope of the present thesis is to help companies to perform well in the Make-to-Order production system under the global supply chain network.

1.4 Case Study

H Company, a Montreal-based enterprise operating on a small and medium scale, has produced central vacuum cleaners using the Make-to-Order production by means of a global supply chain network. H Company is an ideal example to which all the necessary assumptions apply and to which future research can be applied.

By analyzing this case study in the following, a global supply chain will be formulated and some details behind certain phenomena will be explored.

1.4.1 Global Supply Chain Network

For Model HXX in H Company, a completed product is assembled from 73 individual parts from 49 part numbers. According to the location of the suppliers, the distances in the global supply chain network are divided into categories of Europe, China, USA, Ontario, Quebec, Montreal and company itself. See in Figure 1.

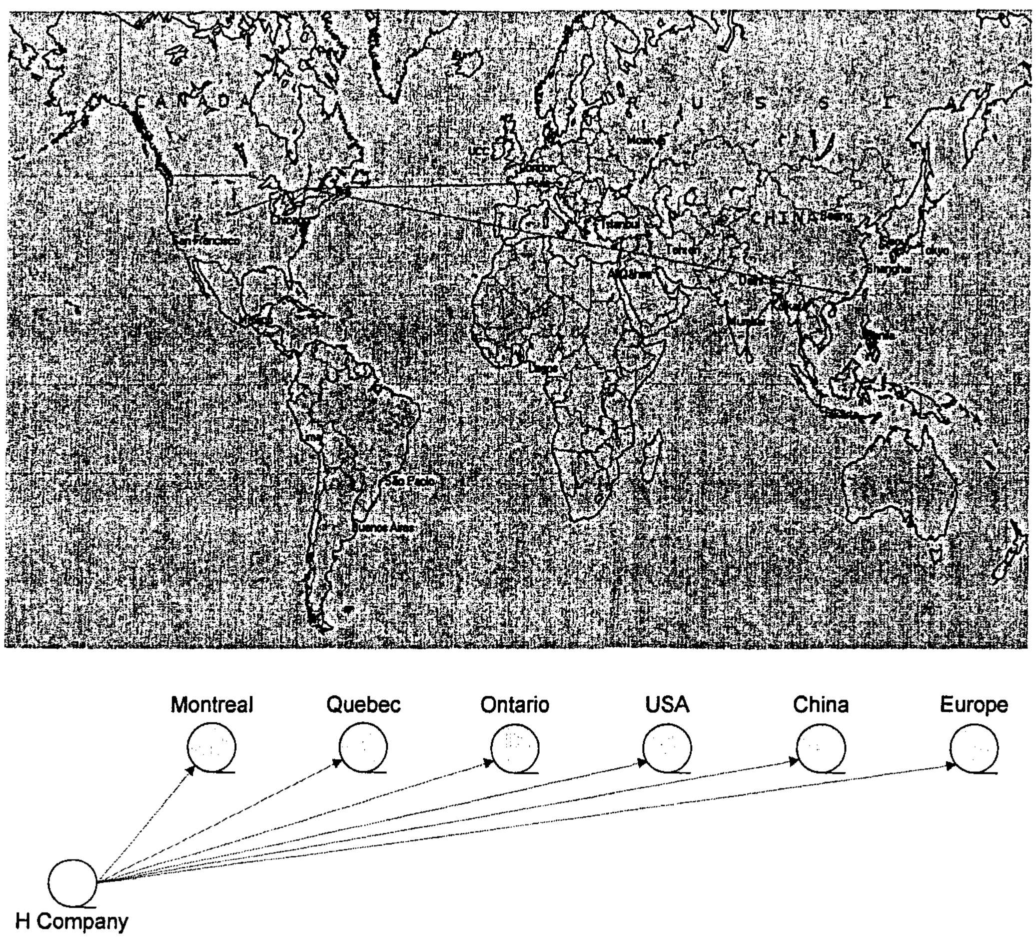


Figure 1: Global Supply Chain Network

1.4.2 Lead time Analysis

Lead time management proves as an important issue in gaining and maintaining a competitive edge in the current marketplace. Lead time management plays a cornerstone role not only in formulating global supply chain network, but also in establishing our future theory. In this present thesis, lead time is defined as the amount of time between the placing of an order and the receipt of the goods ordered. The major lead time includes the order delivery time, the supply preparation time, the transportation time and the unload time.

In the present thesis, the variation of lead time is classified into two groups: the variation of lead time for individual part and variation of lead time among all parts used to make the product. Moreover, the efficiency of the global supply chain is described by the ratio or range of maximum lead time to the minimum lead time. For example, in the point of view of the case study, the maximum length of the lead time of motor part is 90 days and the minimum length of the lead time of a shroud part is 1 day. The efficiency of global lead time is described by 90 in ratio and 89 days in range shown in Figure 2.

Compared with a local supply chain network, a global supply chain network has a larger variation in lead time generally. When variation of lead time is higher, the factor of lead time becomes critical to inventory costs. For instance, if all suppliers prepare their parts at same time, the early arrivals will wait for later arrivals in the warehouse. Finally, the total inventories are increased.

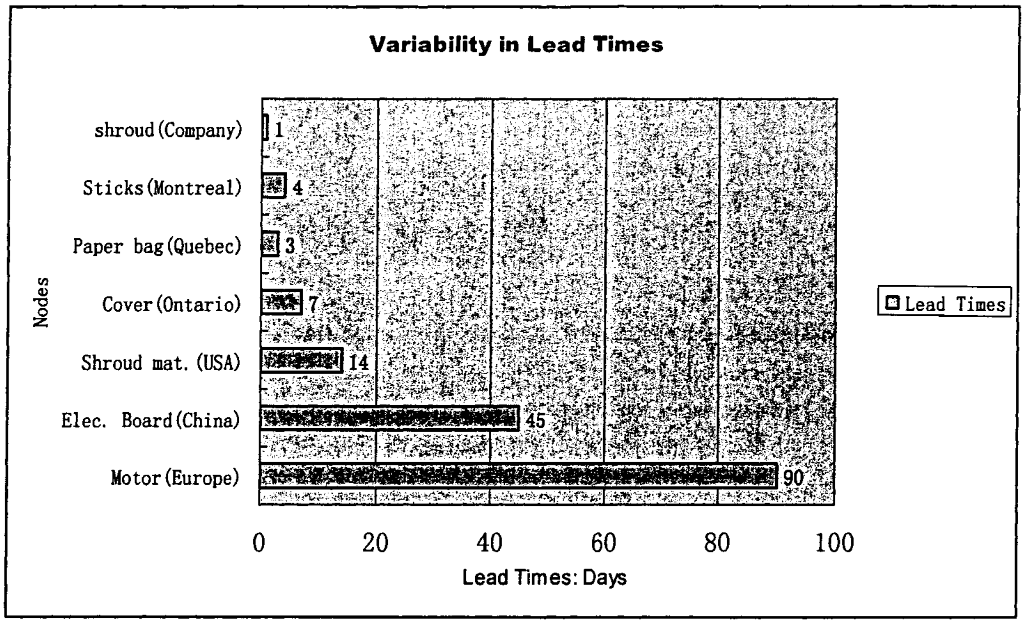


Figure 2: Comparison of Variation in Lead Time

1.4.3 On-Hand Inventory Analysis

On-Hand Inventory is defined as the physical quantity of current inventory. In the Make-to-Order production system, companies prepare the purchased part lists only when the customer orders are coming; if companies send all purchase orders to suppliers simultaneously without considering variation of lead time among global supply chain, the earlier arriving parts have to wait at warehouse. Finally, the on-hand inventory is created.

In our case study, Company H sends all purchase orders to suppliers immediately when it receives customer orders. The sequence of part arrivals is as follows: 53 parts from the Montreal and the Quebec nodes arrive firstly between the 1^{st} and the 7^{th} day; 8 parts from the Ontario node get to the warehouse between the 7^{th} and the 10^{th} day; 5 parts from the US node come to the warehouse between the 10^{th} and the 15^{th} day; 4 parts from the China node arrive at the warehouse between the 40^{th} and the 50^{th} day; 3

parts from the Europe node get to warehouse between the 70th and the 90th day. Once all the pre-ordered parts are gathered at the warehouse, they are transferred to the production department immediately and are assembled continuously.

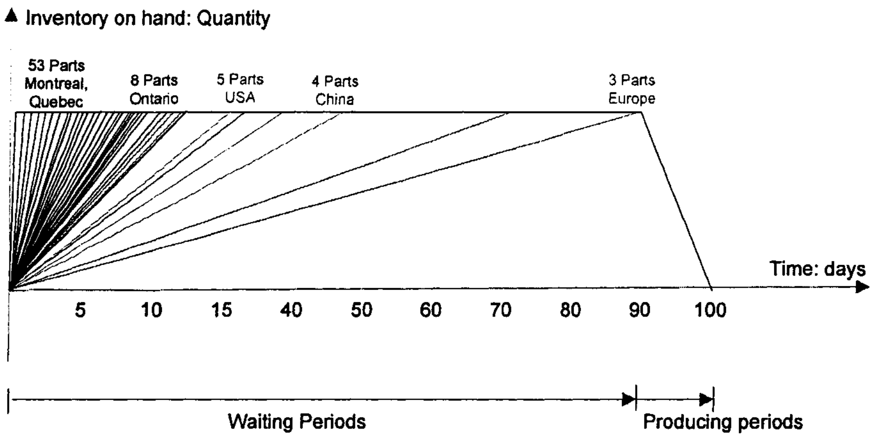


Figure 3: Sequence of the Part Arrivals

1.5 Objective

Global supply chain network is typically characterized by larger variation of lead time among network. In order to address the challenges, we propose the Key-Part based Lead Time Management. This methodology can reduce on-hand inventory by scheduling purchase orders for Make-to-Order production under global supply chain network.

The objective of the present thesis is to reduce lead time waste by means of scheduling purchase orders.

1.6 Proposals

In order to explore satisfying purchase policy for Make-to-Order in a global supply chain network, the proposals are as follows:

Based on my target to reduce lead time waste for small and medium-sized company which prepare to work in Make-to-Order production in global supply chain network, By reviewed the state-of-the-art academic literatures and practical literatures in the global purchase policy, the researched topics and useful methodologies are obtained. Collectively, the outline of the Key-Part Based Lead Time Management is proposed based on those reviews.

The Key-Part Based Lead Time Management is established by the application of a series of steps of logical reasoning. Those steps include concept definition, model formulation, mathematical formulas expression, satisfying solution comparison, practical methodology, existence proofs, and a case study demonstration. Moreover, to find the key part conveniently, a practical methodology based on matrix calculation is derived.

The application of the Key-Part Based Lead Time Management is explored. A satisfying purchase policy for Make-to-Order in a global supply chain network is developed. Moreover, through the integration the Key-Part Based Lead Time Management and MRP II system, we can automatically implement business planning, master scheduling, detailed material planning, plant and suppliers scheduling, and execution. In the mean time, the total inventory loss will be reduced to an approximate minimum.

Although the Key-Part Based Lead Time Management determines a satisfying solution rather than an optimal solution, the reasons why the satisfying solution from Key-Part Based purchase policy is the first choice are explained in this thesis.

1.7 Thesis Organization

Chapter 1, Introduction of present thesis, presents the motivation, significance, objective and a case study.

Chapter 2, Literature review, examines the previous research achievements dealing with the lead time management in the domains of global supply chain network, Make-to-Order production, and MRP II system.

Chapter 3, develop the Key-Part Based Lead Time Management from introducing the concept of key part into supply chain management; establish methodology with assumptions, algorithm, and case application.

Chapter 4, based on the case study, the Key-Part Based Lead Time Management is quantified by means of visual charts and is applied to analyze classified production such as push and Ford.

Chapter 5, reveals that even the Key-Part Based Lead Time Management develops the satisfying solution rather than the optimal solution, this methodology is essentially to the actual application.

Chapter 6, in order to apply the Key-Part Based Lead Time Management into the practical reality, a matrix calculation is introduced with the features of convenience, accuracy, and precision.

Chapter 7, the sufficient conditions of existence of the key part is proved and the robustness of the key part is demonstrated by six experiments.

Finally, Chapter 8, Conclusions and Future Work, summarizes the directions in the future research.

1.8 Contributions

The contributions of this thesis can be summarized as follows:

- The key part concept is proposed in the domain of lead time management.
- The Key-Part Based Lead Time Management has been proposed completely including concept introduction, problem formulation, model definition, formulas expression, satisfying solution comparison, practical methodology provision, mathematical proofs, and a case study demonstration.
- A relationship between the Key-Part Based Lead Time Management and general production systems such as: push production, JIT, and MRP are built.

Chapter 2

Literature Review

The objective of the present thesis is to explore a satisfying purchase policy for small and medium-sized companies that implement Make-to-Order production in a global supply chain network. The literature review for this thesis focuses on lead time management in Make-to-Order production and global supply chain network, at meantime, literature reviews include the purchase section of the MRP system.

The relationship among those review parts are as follows: starting from the updated paper reviews in the area of Make-to-Order production and global supply chain network, we can have a big picture of the state of the art research in lead time management; by focusing on the intersect parts of Make-to-Order production and global supply chain network, we can locate our target and align levels in the present thesis; by reviewing the purchase section of MRP system, we can apply our future lead time management into reality.

2.1 Lead Time Management in the Global Supply Chain Network

The Bullwhip Effect caused from supply chain is defined as the phenomenon in which the variance of buyer demand becomes increasingly amplified and distorted at each echelon upwards throughout the supply chain. That is, the actual variance and magnitude of the orders at each echelon is increasingly higher than the variance and magnitude of the sales, and this phenomenon propagates upstream within the chain. Lee et al. (1997) demonstrated that this "bullwhip effect" is positively related to lead time. The actual variance and magnitude of the lead time at the closer nodes are lower than the variance and magnitude of the lead time at the farther nodes. This phenomenon propagates upstream within the chain. Moreover, as supply chain extends to global supply chain, the Bullwhip Effect is more obviously.

Much of the supply chain literature on lead time reduction had been largely anecdotal and exploratory. Hopp and Spearman (1996) compiled a set of the mathematical principles determining lead time based on queuing theory called Factory Physics. Suri (1994, 1998) simultaneously developed a manufacturing strategy called Quick Response Manufacturing that addressed implementation of lead time reduction principles in manufacturing environments. Both Factory Physics and Quick Response Manufacturing formalized the relationships of bottleneck utilization, lot sizes, and variation to lead time. However, those mathematical principles are not emphasized in much of the operations management literature concerning lead time reduction and do not appear to have been widely disseminated to practitioners.

Frohlich and Westbrook (2002) suggested just-in-time (JIT) delivery (frequent, small lots with a reduction of buffer inventories), reduction of the supplier base, evaluating suppliers based on quality and delivery performance, establishing long-term contracts with suppliers, elimination of paperwork, coordinated planning, and improved logistics communication.

Treville et al (2004) proposed a framework for prioritizing lead time reduction in a demand chain improvement project, using a typology of demand chains to identify and recommend trajectories to achieve desirable levels of market mediation performance. Examples of full information transfer can be found from case study of automobile assembly and seat manufacturing at Toyota Motor Manufacturing's Georgetown plant, in which automobiles exiting the paint line transmit an electronic signal to the seat supplier so that the seat that has been customized for that particular automobile can be manufactured and delivered to the Toyota assembly line by the time the automobile reaches the point in the assembly process where the seat is installed (Mishina, 1993).

2.2 Lead Time Management in the Make-to-Order Production

For a Make-to-Order sector of industry, the time spent producing the order can be defined in terms of two "lead times". They are manufacturing lead time (MLT) and total delivery lead time (DLT). Tatsiopoulos developed a methodology specifically designed to control the MLT and the DLT for companies in the MTO sector. It is a two-tier system which addresses the customer enquiry stage and the stage at which orders are released to the shop floor so that processing can begin. It is based on the control of a hierarchical chain of aggregate backlog-where a backlog is the processing time required by a set of orders. The aim is to keep each backlog within limits which can be processed within an acceptable length of time. He suggested that this would make it possible to maintain delivery and manufacturing lead time at the desired level for all orders. However, he did not explore the detailed control mechanisms required to achieve this.

Hendry and Kingsman (1993) considered four main features. They are (1) integration between the marketing and production departments when determining order delivery dates; (2) input/output control so that input is controlled in terms of orders accepted or released whilst output is controlled in terms of the processing capacity to be available in future periods; (3) lead time management; and (4) hierarchical production planning. This paper looks in detail at how lead time can be managed and how input/output control is implemented.

In the book of "Competing against time: how time-based competition is reshaping global markets", Stalk and Hout (1990) claimed that the true value-added time is typically only 0.05-5% of entire time in the entire supply chain procedure. Among those non-value added times, 54% of time wastes by waiting activity and 24% of time lavishes by transportation shown in Figure 4. Stalk provided some managerial skills to reduce lead time and improve performance. A Japanese scholar, Luhtala (1994), asserts that time involved in manufacturing and assembly processes is typically only one-third of the total time in Make-to-Order production. A big portion of two-thirds of the time is spent in non-value added activities such as order processing, transportation, installation and parts waiting.

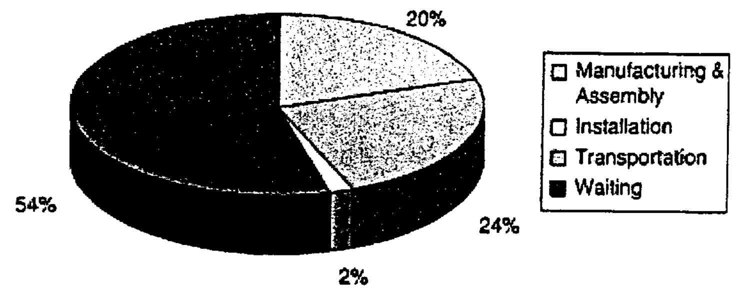


Figure 4: Non-Value Added Times in a Global Supply Chain Network

Jahnukainen et al (1999) explored ways of reducing the lead time from suppliers. Their solutions, which focus more on the management skills, are listed in Table 1 and Figure 5.

Problems	Prerequisites	Solutions
Poor component delivery punctuality	Separate supplier management and purchasing	Suppliers contolled as own manufacturing
Slow inventory turnover	Sourcing structure	Special arrangements for critical components
Critical components	Sourcing policy	Modern purchasing practices
Timing	Integration and cooperation	
Long delivery time		

Table 1: Problems, Prerequisites and Solutions of Efficient Purchasing

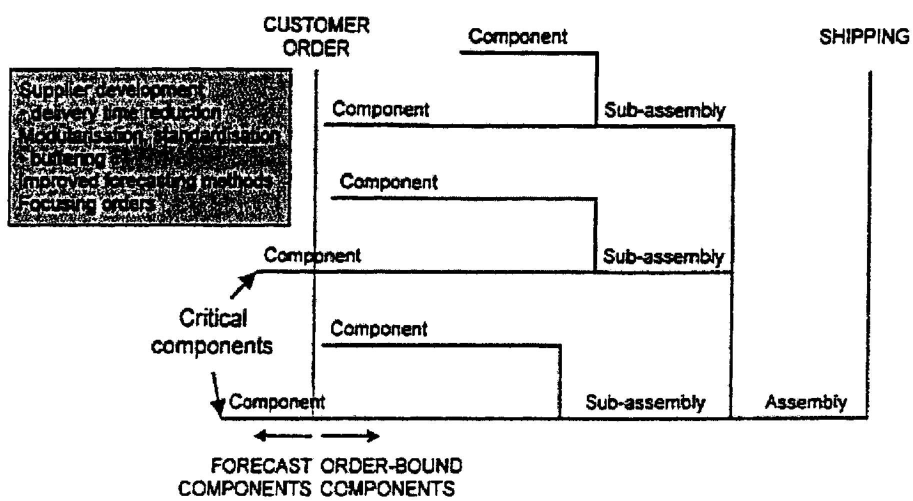


Figure 5: Improvement of the Purchase Policy

2.3 Material Purchasing Section in MRP II System

MRP has evolved through some phases in history. In the 1960s, MRP I was introduced by Orlicky, Plossl, and Wight in IBM (Orlicky 1975). It facilitated only the job of planning raw materials and parts. In the 1970s, a closed loop MRP was created as manufacturing and purchasing oriented for its new function from capacity planning (Adams, 1985). In 1978, MRP II was developed with new additions from the top management perspective, the customer perspective, and the financial perspective. In the late 1980s, ERP (Enterprise Resource Planning) was developed by adding logistics planning based on MRP II (Rondeau, 2001).

The core of material purchasing planning is the same for all those methods (Figure 6). They are the following: a company would input the forecasts or customer orders for its product, run those against a bill of material that defines how many of each part were used in the product, and calculate the total requirements for each raw material and part. Those requirements were then netted against the current inventory and calculated how many of each part the company has to purchase or build to support the production schedules. Lead time offsets were used to calculate when purchased parts need to be ordered (Schorr, 1998).

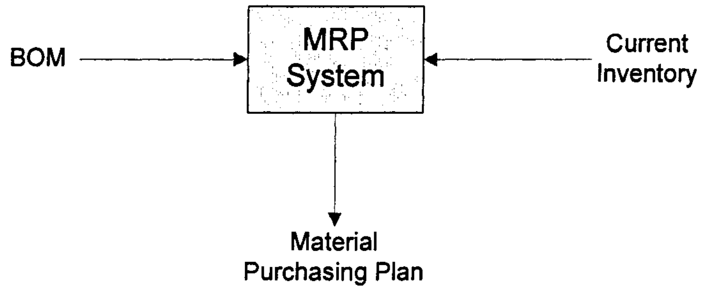


Figure 6: **Material Purchasing Section in MRP II System**

2.4 Replenishments for MRP II System

MRP II system succeeds in many diversified enterprises; however, there is still a lot of room for improvement. Some scholars endeavor to reinforce its weakness or expand its extensions continuously shown as follows:

In a global manufacturing network, Rupp and Ristic (2000) developed a distributed planning methodology to optimize both for the local manufacturing units and for the whole supply chain network.

In the areas of Engineered-to-Order, Jin and Thomson (2000) indicated that each contract brings a new requirement for materials and for the scheduling of tasks. Current MRP systems do not work well in an Engineered-to-Order system. A new framework for the design of a MRP system has been developed that addresses this problem. Those framework features include the following: integrated finite capacity scheduling, combined planning for engineering and manufacturing, and new scheduling algorithms for dynamic scheduling.

In the areas of Make-to-Order production, MRP II system can accurately solve problems like "what are we going to make?", "what does it take to make it?", "what do we have?", and "what do we have to get?" However, for the problem of "when should parts be purchased?", MRP II considers lead times offsets but hardly reflects the influences from customer penalty in the case of late delivery.

Chapter 3

Key-Part Based Lead Time Management

By transplanting concepts from tunnel engineering, a new concept named key part is formed in the supply chain management; by following the methodology of the modeling process step by step, the whole system of the Key-Part Based Lead Time Management is developed and demonstrated in a case study.

3.1 Key Block Concept in Tunnel Engineering

In civil engineering, Goodman and Shi (1981) proposed a key block theory that had already been used to analyze reinforcement processes in tunnel engineering. Once a tunnel section was excavated by the explosion method, the loosened stone layers would be formed around the opening to maintain stabilization. In this temporary structure, there is an important block called the key block, which is ensuring the safety of the whole structure. The satisfying re-enforcement process should start from the key block and then extend to the rest of the location. Finally, that process is the satisfying solution in the construction and produces safe, economical and rapid results.

3.2 Key Part Concept in Supply Chain Management

Due to my unique experience in both Civil Engineering and supply chain management, I find that there is a logical similarity between the reinforcement procedures in Tunnel

Engineering and the satisfying purchase schedules in supply chain management from the point of view of the operational research.

The key part in this thesis is defined as the special part if the purchase policy is based on the lead time of the key part, the total inventory cost will be reduced to the approximate minimum value. Based on the concept of key part, the contents of Key-Part Based Lead Time Management are the following: while receiving orders from customers, a Make-to-Order company purchases all parts from a global supply chain network. The total inventory loss is calculated by determining the sums of holding costs at the warehouse and from customer penalty caused by the overdue delivery. The inventory loss is minimized if parts are required to arrive at the warehouse at the same date as the key part.

3.3 Explanation of the Key-Part Based Lead Time Management

In order to illustrate the Key-Part Based Lead Time Management, the product structure and purchase schedules are useful.

- Product Structure Demonstration

As basic elements in product structures, parts are defined as designed objects that have no assembly operations until they arrive at the final assembly line (Poli, 2001). In the present thesis, all parts are considered to be purchased from a global supply chain network and then are assembled into final products by manufacturing systems.

An assembly is a series of parts put together in a product realization process. Furthermore, a product is formed as a functional designed object that is made to be sold and/or used as a unit.

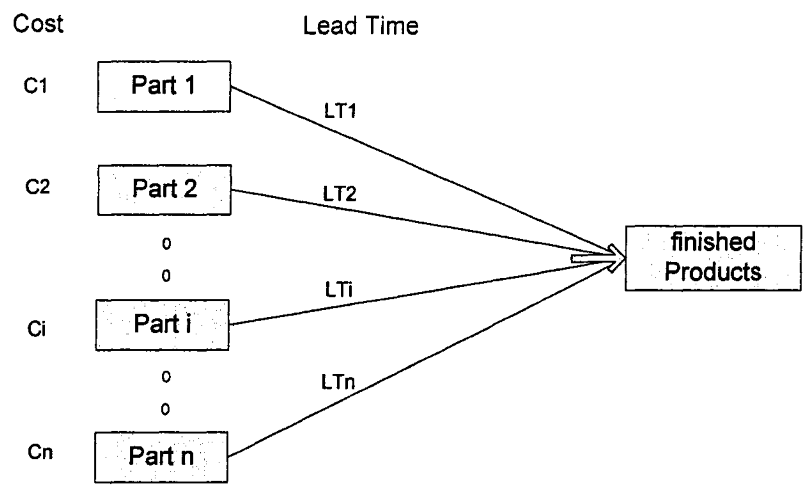


Figure 7: Multi-Parts Purchasing and Assembling System

A general product structure (Figure 7) is consists of parts, costs and lead times and is described as follows:

Parts $\{Part1, Part2,.., Parti,..Partn\}$

Costs $\{Cost1, Cost2,.., Costi,..Costn\}$

Lead time $\{LT1, LT2,.., LTi,..LTn\}$

- Purchase Policy

The purchase policy refers to the company's procedures including attitude, rules, and guidelines towards the approved suppliers. In the traditional Make-to-Stock purchasing procedures, a company may send purchase orders to suppliers simultaneously, after that all parts will arrive at the warehouse continuously (Figure 8). The physical inventory caused by over purchasing is primarily rather than the lead time waste created by diversified lead times. However, in the Make-to-Order purchasing procedures, the global supply chain network prolongs the part lead times and then lead time waste becomes the significant new dominator among total inventory losses.

- Key-Part Based Lead Time Management

In order to reduce those lead time wastes, the Key-Part Based lead time management is proposed for the first time in the present thesis with the contents as follows: suppose that we choose the lead time of part k to guide the arrivals of parts. Those parts whose lead time is less than that of part k are required to arrive simultaneously. At this moment, the value of the total inventory loss is in the name of Part k-based inventory loss.

As we know, by calculating part k-based inventory loss from part 1 to part n, we can obtain a set of the inventory loss and then determine the key part that has a minimum of inventory loss among the set. Based on that key part, a Key-Part Based lead time management is formulated and demonstrated in Figure 8.

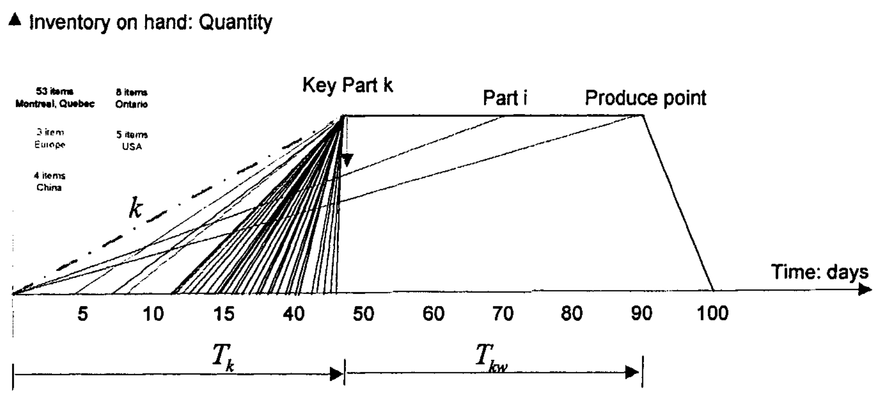


Figure 8: **Chart of Key Part Concept**

3.4 Restriction of the Research Area by Ishikawa Diagram

The Ishikawa diagram (Ishikawa, 1985), which is also called the Cause-and-Effect or Fishbone Diagram, is used to identify the key sources that contribute most significantly to the problem being examined. It also illustrates the relationships among the wide variety of possible contributors to the effect. Ishikawa proposed this tool in the 1960s (Benbow, 2004).

The Ishikawa Diagram can help to narrow research areas for a make-to-order system in a global supply chain network. In the point of view of the inventory control, a satisfying purchase policy aims to reduce the target of total inventory losses and increase customer satisfaction. Generally, those targets can be implemented by taking action on the suppliers, the transportation, the warehouse and the purchase policies.

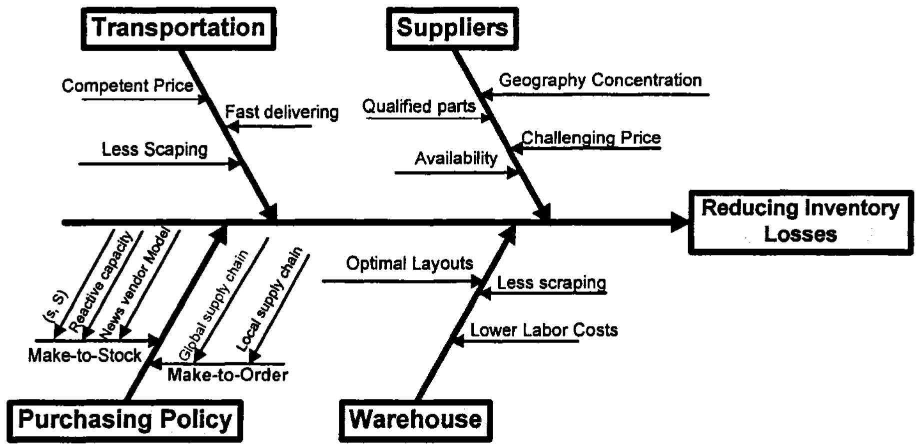


Figure 9: Ishikawa Diagram in Analysis of Inventory Reduction

In the present thesis, the supply chain system in the present thesis is assumed maturely, so sources of improvement such as the suppliers, the transportation and the warehouse are neglected. The research fields are only considered elements of the purchase policy (Figure 9).

In the field of purchase policy, our future research aims at small and medium-sized companies that have been practicing Make-to-Order systems in a global supply chain network to reduce their inventory loss (Lewis, 2002).

3.5 Model of Methodology

In the present thesis, the modeling methodology refers to a body of practices, procedures, and rules in constructing scientific models. In order to develop the Key-Part Based Lead Time Management, the modeling methodology can help us to organize the logical thinking and construct the expressions of mathematical models.

3.5.1 Introduction to Modeling Process

In order to construct Key-Part Based purchase policy, a modeling process is followed to transfer the actual model to our research model by means of sorting out the significant factors and following detailed logical procedures (Kocsondi 1976).

The main stages of the modeling process in general are included in the following:

- Recognizing the necessity of modeling
- Modeling the theoretical preparation
- Creating the model
- Analyzing the model
- Transmitting knowledge from the model to reality
- Verifying and checking the new knowledge
- Implementing the results in practice or inserting the new knowledge into a scientific theory

3.5.2 Model Evolution

In the course of constructing the satisfying purchase policy, the model has evolved through three forms by means of two transformations. The first transformation transfers the real system to the economic model, which is named the homomorphic transformation; the second transformation transfers the economic model to mathematical model, which is named the isomorphic transformation (Kocsondi 1976).

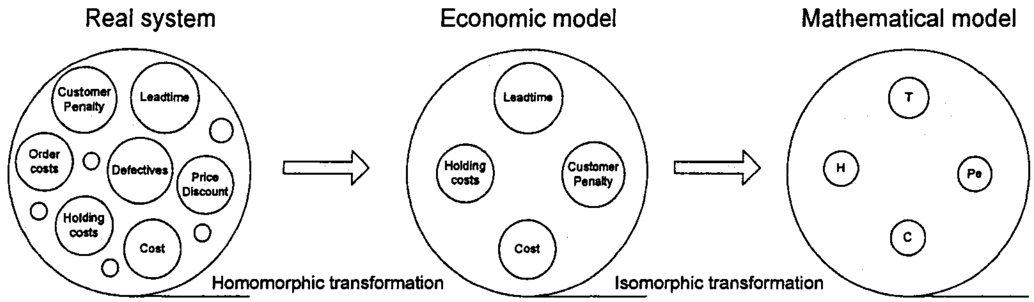


Figure 10 : Models Evolution

➢ Homomorphic Transformation

The concept of Homomorphism which comes from the mathematics of algebraic structures implies that one part is identical to a part of the other.

It would be impossible to consider more elements and parameters in our new purchase policy because those factors constitute a very large numerical set in a real system. We have to disregard some of the individual elements such as the price discount caused by the mass purchasing, the excessive purchases caused by defectives, and the purchasing order costs. Finally, the real system with numerous elements will be transferred into a new system named the economic model with a smaller number of elements such as the product structure, the part lead time and the part cost. The most significant property of this new system is that its variables respond to changes in the controlling or influencing parameters in the same way that the real system would react. The homeomorphic transformation is unambiguous in one direction only and helps us to select the significant elements in our new purchase policy.

➢ Isomorphic Transformation

Isomorphism implies that the systems are identical. The economic model of our new purchase policy must be translated into a mathematical language, which is named mathematical model. There is a mutual and unambiguous correspondence between the elements in the mathematical model and the elements in the economic model. In this present case study, the element set in the economic model is {Part lead time, Holding costs, Customer penalty, Part costs} and the corresponding set in the mathematical model is {T, H. Pe, C}. See Figure 10.

3.6 System of the Key-Part Based Lead Time Management

The elements of the Key-Part Based Lead Time Management are determined by using the results from the modeling methodology. Next, by interacting, those elements are interrelated or interdependent and then form an entire system of the Key-Part Based Lead Time Management. The system has inputs, outputs, objective functions, and feedbacks shown in Figure 11 (Rupp and Ristic, 2000).

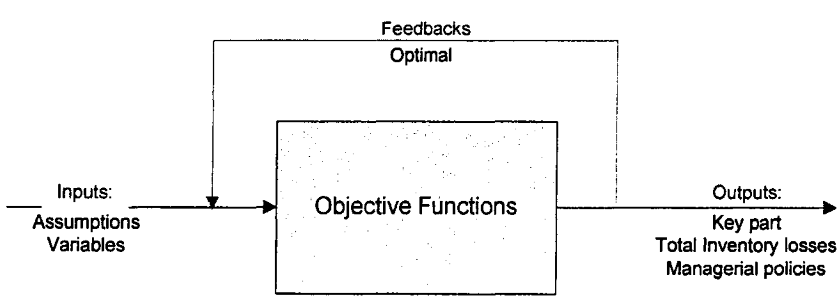


Figure 11: Element Interrelation in the Key-Part Based Lead Time Management

In the present thesis, the Key-Part Based Lead Time Management consists of inputs (general assumptions, product structures, part costs, part lead times, holding costs, customer penalty, and the global supply chain network), outputs (the key part, the minimum inventory loss, and a satisfying purchase policy), objective functions (the mathematical expressions), and feedbacks (returns of a portion of the output of a process to obtain ideal solutions).

The Key-Part Based Lead Time Management aims to obtain the satisfying solution. The eminent management scientist and Nobel Laureate in economics, Herbert Simon, points out that satisfying customers is much more prevalent than optimizing in actual practice (Hillier, 2004). He described the tendency of managers to seek a solution that is "good enough' for the problem at hand rather than to try to develop an overall measure of performance to optimally reconcile conflicts between various desirable objectives.

From the viewpoint of the system, the Key-Part Based Lead Time Management has elements of the assumptions, the definitions, algorithms, and the algorithm. The breakdowns of those contents are listed in the followings:

3.6.1 Assumption

To establish the system of the Key-Part Based Lead Time Management, the assumptions should be built firstly to simplify problems by neglecting some insignificant elements. In the present thesis, the detailed assumptions are as follows:

- FOB (Free On Board). The supplier pays the shipping costs and insurance costs from the point of manufacture to the port, at which point the company takes over the responsibility. So, it is assumed that the company incurs no costs in making a purchasing plan early.

- Parts might undergo a lengthy lead time waste at the warehouse. If the parts arrive at the warehouse at different times, the early arrivals suffer by remaining as inventory for a long time.

- The manufacturing process can start only if all the parts are ready at the warehouse.

- Customer penalties (P_e) are related to the sale price of the final product and the length of the delay in getting to the customers.

- Part costs (C_i) replace part prices (P_i). Part cost refers to the total spent for one kind of part and is calculated by $C_i = s \times P_i$, where s denotes the numbers of one kind of part i in a final product.

- The inventory loss is determined only by holding costs inside the warehouse and the customer penalty based on the overdue delivery.

Based on the assumptions given above, the Key-Part Based Lead Time Management is developed in the following:

3.6.2. Algorithm

The algorithm in the Key-Part Based Lead Time Management is defined as a set of ordered steps to obtain a satisfying solution for the Make-to-Order production in a global supply chain network. Specifically, the algorithm consists of a series of mathematical expressions also called the objective functions. The Algorithm is developed in the following steps:

- Planning

The insignificant factors, which are neglected in the planning phase, consist of the price discounts caused by mass purchasing in quantity, the excessive purchases caused by defectives, and the purchasing order costs neglected because of their insignificant effects. According to the reality of the small and medium-sized companies in the Make-to-Order system in the global supply chain network, the significant factors consist of the holding cost at the warehouse and the customer penalty.

- Formulating the Problems

Compared with the Make-to-Stock system, which has a large physical inventory caused by uncertain market estimations, the Make-to-Order system in a global supply chain network entails certain part demands with the considerable lead time waste. The Key-Part Based Lead Time Management might benefit from a satisfying purchase policy based on a rescheduling of part arrivals.

- Principle

According to the assumptions above, we know that the total inventory loss is composed of only two significant inventory losses. One is the holding cost caused by the different part arrivals at the warehouse; another is the customer penalty caused by the overdue delivery. In other words, a satisfying solution arises when the sum of the holding cost plus the customer penalty reaches approximate-minimum values. The equalization is expressed as follows:

Total Inventory Losses = Holding Cost + Customer Penalty

- Mathematical expression

Based on the statements from principles, the algorithm in the Key-Part Based Lead Time Management can be expressed in mathematical equation:

Loss $(n, h, P_e, T_i, C_i) =$

$$h \times [\sum_{i=1}^{k} C_i \times T_{kw} + \sum_{i=k+1}^{n} (C_i \times T_{iw})] + [\sum_{i=1}^{k} f(T^i{}_{kw}) + \sum_{i=k+1}^{n} f(T^i{}_{iw})] \times P_e \qquad (1)$$

Formula 1: General Objective Function

Where:

h: Holding cost. This refers to money spent to keep and maintain a stock of goods in storage. The unit of the holding cost designates as per day per dollar.

C_i: Part i cost. This can be calculated by $C_i = s \times P_i$, where P_i is the part price, s denotes the numbers of part i in the final product.

T_i: Lead time of Part i

T_k: Lead time of dummy key part k

$T_{\max}$: The greatest lead time among all parts

T_{iw}: The waiting time of part i at the warehouse. $T_{iw} = T_{\max} - T_i$

T_{kw}: The waiting time of dummy key part at the warehouse. $T_{kw} = T_{\max} - T_k$

k: The position of dummy key part. It is located at k^{th} in the part data of the increased sequence.

$f(T^i{}_{kw})$: The function of the probability of delay time for final products. Values of $f(T^i{}_{kw})$ indicates the potential delay time for final products caused by delay of part i. In addition, the policy demands that if the lead time of part i is smaller than the lead time of dummy key part k, then part i must be changed its arrival date at the warehouse to the same time as dummy key part k.

$f(T^i{}_{iw})$: The function of the Probability of the delay time for final products. However, in this expression, because the lead time of part i is equal to or greater than the lead time of the dummy key part i, the policy requires that those parts arrive at the warehouse on their own schedules.

P_e : Customer penalty for each delay day.

In order to illustrate the meaning of those parameters, Figure 12 is based on the present case study. The purchase policy is described in the following: supposing that the dummy key part k has a lead time of 50 days. All parts with smaller lead times than part k will change their arrival dates to match the arrival date of the part k; but for parts with greater lead times than the part k, their arrival dates will remain unchanged.

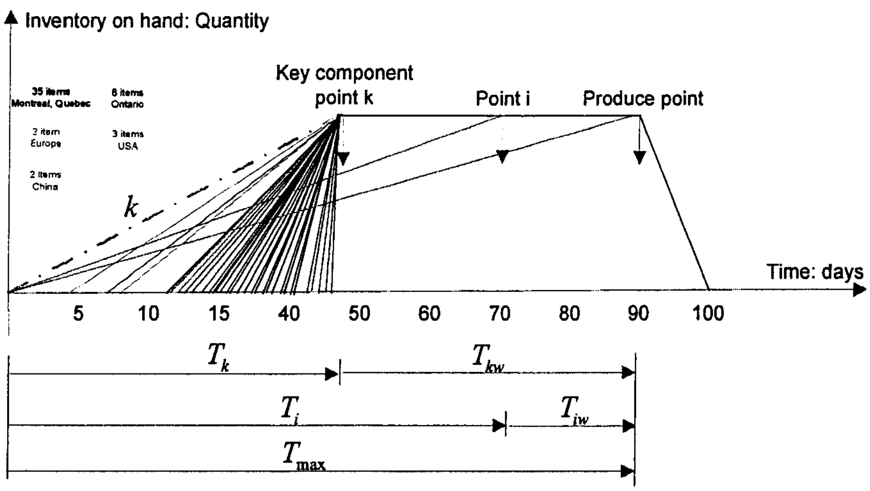


Figure 12: Sketch Map to Construct a Loss Function

Additionally, the dummy key part is a fictitious key part to be used to determine the true key part. The basic idea is that all parts act as dummy key parts individually and then their results are collected into one set of total inventory loss. Moreover, there is a minimum value in the set that corresponds to the true key part.

3.6.3 Identification of the Key Part

The location of the key part can also be observed from a chart of the total inventory loss vs. the individual dummy key part. Suppose that we have already obtained a set of total inventory loss by using Formula 1. In the course of constructing the chart, a horizontal coordinate represents the location of the dummy key part, and a vertical coordinate denotes the total inventory loss of that dummy key part. Any point (x, y) in the chart shows that when the dummy key part is located at part x, the total inventory loss can be evaluated as y. One example in Figure 13 shows the location of the true key part by a solid point.

In addition, if there is more than one candidate key part based on the value from the total inventory loss, the principle for choosing the favorite key part is depicted in Chapter 7.1.2 (Page 83).

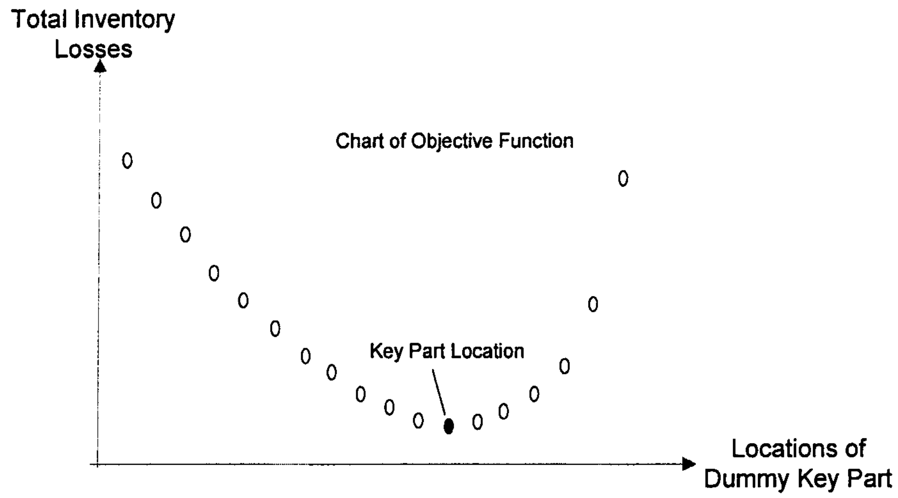


Figure 13: Indication to the Location of the Key Part

3.7 Key-Part Based Lead Time Management in a Case Study

Based on the present case study, the Key-Part Based Lead Time Management consists of the customer penalty function, the probable delay time function, the holding cost function, and the objective function. Moreover, in the present thesis, all functions are visualized by using the Matlab.

3.7.1 Customer Penalty Function

Customers impose charges on companies that fail to comply with on time delivery. The value of the customer penalty depends on the sale price of the final products and the deferred times to customers. According to the guild regulations of the manufacturing industry, the value of the customer penalty is charged x-thousandths of the sale price for each delay day as shown in Formula 2.

$$P_e = \frac{P_{sale} \times x}{1000} \times T_{delay} \quad (2)$$

Formula 2: **Customer Penalty Function in Guild Regulations**

In the present case study, the sale price of the central vacuum cleaner is \$500. So, the function of the customer penalty can be specified as follows:

$$P_e = \frac{500}{1000} \times T_{delay} = 0.5 \times f(T^i{}_{iw}) \quad (3)$$

Formula 3 : **Customer Penalty Function in the Case Study**

Where: $f(T^i{}_{iw})$ denotes the probability of the time delay for the final product and is detailed in the following.

3.7.2 Delay Time Function $f(T^i{}_{iw})$

In the function of delay time, the elements of $f(T^i{}_{iw})$ consist of:

- T^i : The lead time of part i. If a process has a fixed delay probability, the final product delay will be increased when the lead time of part i is added.
- T_{iw} : The waiting time of part i. This refers to how long part i waits at the warehouse. If a part arrives at the warehouse early, there is a lesser probability that the final products will be delivered late to the customers.
- $T_{iw}{}^i$: This refers to a situation where, when the lead time of part i is greater than the lead time of the dummy key part, part i arrives at the warehouse and impacts on the delay time for the final products.

- In a Make-to-Order production, if any part arrives at the warehouse earlier or later than its schedule date based on its lead time, it can be regarded as variations of lead time. Moreover, if a part arrives at the warehouse later than the scheduled date based on its lead time, this status is called the major variation.

The specific delay time function in this case study is established in the following: suppose that each of parts arriving at the warehouse has exactly the same exponential distribution. According to the principles of the mixture distribution, the finished products also will have that distribution. Moreover, assume that the delay of any part will cause delay of the finished products. Next, it is assumed that the delay time of the finished products is the multiplication of the individual delay time of the parts. Nextly, with the help from Matlab, a function expression is to be explored to best fit the history records in this case study. Finally, the delay time function of the final products causing from the individual part delay is expressed as follows:

$$f(T^{i}{}_{iw}) = \frac{T_i}{8} \times (e^{-\frac{T_w}{1.6}}) \tag{4}$$

Formula 4 : Delay Time Function of the Final Products in the Case Study

Where: $T_{iw} = T_{\max} - T_i$

In conclusion, the longer the lead time of part i, the longer the entire supply chain network $T_{\max}$, and the longer the delay time for final products in probability.

3.7.3 Simulation of the Delay Time Function of the Final Product in Matlab

The delay time function of the final product is caused by the individual part. For example, if a kind of control board part is chosen, the delay time function of the final product can be visualized by means of Matlab. Description of the control board in the present case study is listed as follows:

$T_{\max}$: The maximum lead time from motor part equals 90 days

T_i : The lead time of the electrical board equals 45 days

Delay time function is specified in Formula 5.

$$f(T_w) = \frac{T_{\max} - T_w}{8} \times (e^{-\frac{T_w}{1.6}}) = \frac{45}{8} \times (e^{-\frac{T_w}{1.6}}) \tag{5}$$

Formula 5 : Delay Time Function of the Control Board Part in the Case Study

Based on Formula 5, the delay time function for control board part is given in Figure 14 by running Program 1. Some comments about the chart are listed as follows:

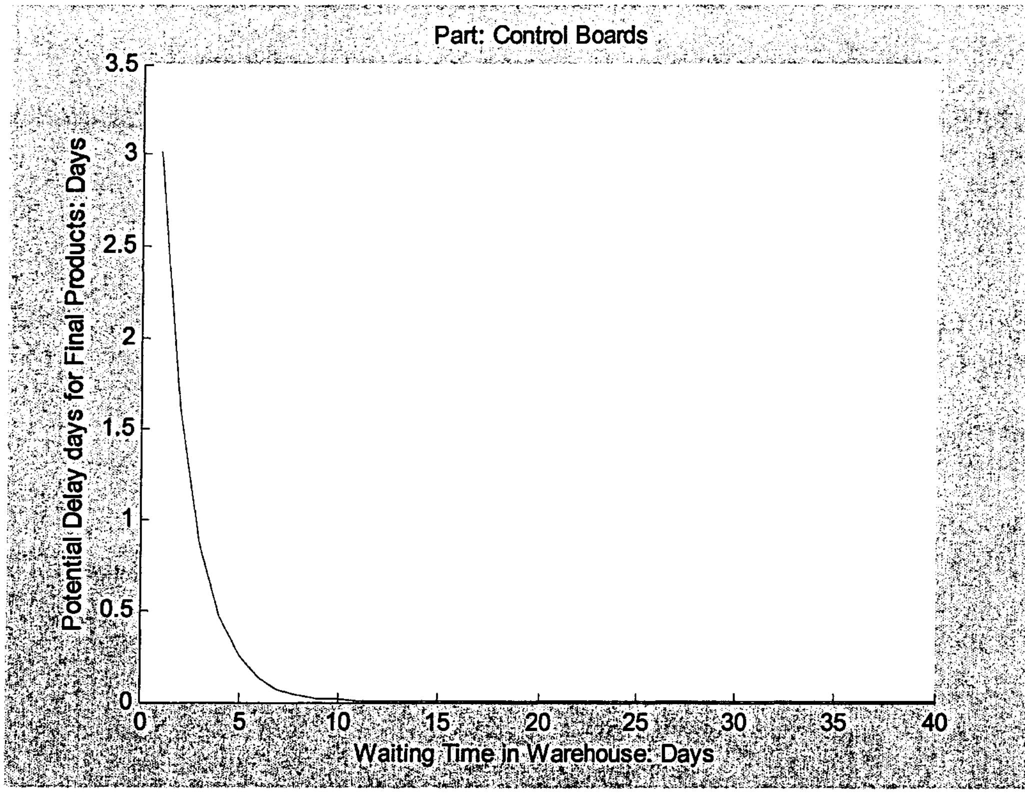


Figure 14: Chart for Probable Delay Time vs. Part Waiting Time in Warehouse

- The lead time of the control board part equals 45 days.

- If the control board part arrives exactly on the 45th day (the part waiting time T_w in the warehouse equals 0 day), the delay time of the final products to the customers will be estimated as 5.6 days; if the control board arrives exactly on the 44th day (the waiting time T_w in the warehouse equals 1 day), the delay time of the final products to the customers will be estimated as 2.9 days; if the part arrives exactly on the 38th day (the waiting time T_w in the warehouse equals 7 days), the delay time of the final products to customers will be estimated as 1.9 days.

In summary, those comments agree with rules of thumb. The detailed delay time can be changed according to the different cases.

3.7.4 Simulation of the Customer Penalty Function in Matlab

The customer penalty function relates to the delay time function and then is obtained in the following way. See Formula 6.

$$P_e = 0.5 \times f(T^j{}_{iw}) = \frac{45}{16} \times (e^{-\frac{T_w}{1.6}}) \qquad (6)$$

Formula 6 : Customer Penalty Function in the Case Study

Based on Formula 6, the customer penalty function of the control board part is given in Figure 15 by running Program 2. Some comments about the chart are as follows:

- The lead time of the control board part equals 45 days.

- If the control board parts arrive exactly on the 45th day (the waiting time T_w in the warehouse equals 0 days), because of 5.6 delay days to customers, the company is charged \$2.8 for each final product; if the part arrives exactly on the 44th day (the waiting time T_w in the warehouse equals 1 day), because of 2.9 delay days, the company is charged \$1.5 for each final product;; if the part arrives exactly on the 38th day (the waiting time T_w in the warehouse equals 7 days), because of 1.9 delay days, the company is charged \$0.02 for each final product.

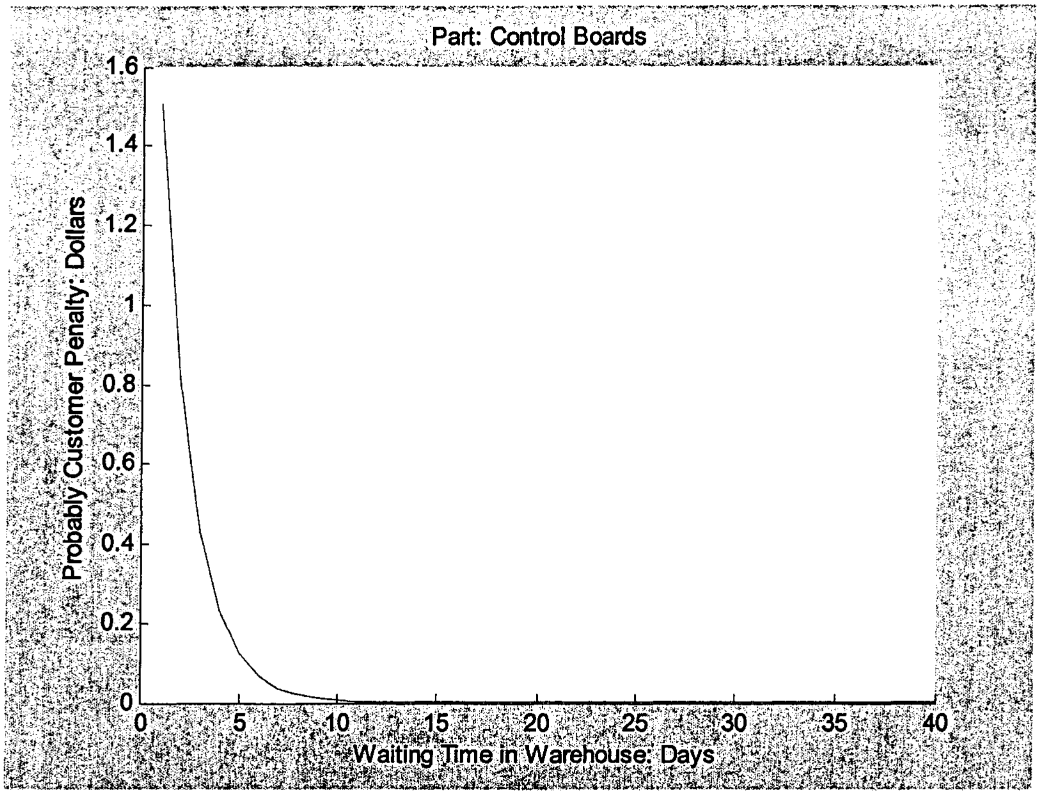


Figure 15: Chart of Customer Penalty vs. Part Waiting Time for Control Board Part in Case Study

In summary, these comments agree to rules of thumb. The changes in the detailed delay times and charge fees are based on different cases.

3.7.5 Analysis of Holding Costs

In general, holding costs include the opportunity costs of inventory investment and other related costs such as storage, insurance, taxes and allowance for deterioration. In the make-to-order system under global supply chain network, because some parts arrive at the warehouse early and have to wait for other parts before they are assembled into final products, companies have to pay for this lead time waste. In the present case study, the holding costs are simplified to the capital loss that is calculated by using bank interest. Suppose that bank interest is 10% per year, so

$h = (10\% \div 365) = \$\,2.74 \times 10^{-4}$ /Day

3.7.6 Objective Function

The parameters and subfunctions such as customer penalty P_e, holding costs h, and delay time function $f(T^{j}{}_{iw})$ are detailed in the early paragraphs. So, the general objective function is specified in Formula 7.

$$\text{Loss}\,(n,\ h,\ P_e,\ T_i,\ C_i) =$$

$$2.74 \times 10^{-4} \times [\sum_{i=1}^{k} C_i \times (T_{\max} - T_{k)} \ + \sum_{i=k+1}^{n} (C_i \times (T_{\max} - T_i))]$$

$$+ [\sum_{i=1}^{k} \frac{T_i}{8} \times e^{-\frac{1}{1.6} \times (T_{\max} - T_k)} + \sum_{i=k+1}^{n} \frac{T_i}{8} \times e^{-\frac{1}{1.6} \times (T_{\max} - T_i)}] \times 0.5 \qquad (7)$$

Formula 7 : Objective Function in the Case Study

In conclusion, the Key-Part Based Lead Time Management is established basically by far. The new theory consists of a series of assumptions, two parameters (customer penalty P_e, holding costs h), and two subfunctions (delay time function, customer penalty function). In Chapter 4, which follows, the Key-Part Based Lead Time Management is explored by using quantitative analysis to obtain a satisfying purchase policy.

Chapter 4

Quantitative Analysis to the Key-Part Based Lead Time Management

In the present chapter, quantitative analysis is used to explore the Key-Part Based Lead Time Management. First, based on the present case study, the chart of total inventory loss vs. dummy key parts is depicted and then the true key part is determined; secondly, the Key-Part Based Lead Time Management is applied to an analysis of the inventory in two specific areas: one is in the traditional push production in which customer penalty is always neglected; another is in giant companies such as Ford and Toyota in which holding cost is normally neglected.

Finally, based on the data analysis, a satisfying purchase policy is evolved from the Key-Part Based Lead Time Management to reduce lead time waste.

4.1 Review of Simulation Methodology

Computer simulation methods in inventory control have been in use since the 1950s (Greene, 1997), and they are based on the idea that experimental or gaming approaches can be a useful support to decision making. The idea is to try out a policy before it is implemented. Clearly, there are several ways in which this can be done:

- The policy can be tried in the real world, but in a controlled way so that its effects can be understood and analyzed. There are obvious problems with this approach, especially in systems that are dangerous or expensive to operate. Experimenting with the real system can turn out to be experimenting with disaster. Nevertheless, this type of direct experimentation does have its place, especially when training people.

- A second option is to develop a mathematical model of the system being studied. This is the specialty of operations research. This approach works well for some types of applications (for example, in simple queuing systems) but not so well in others. While mathematical models are used to represent a complex dynamic system, such a system may be impossible to solve or virtually impossible to formulate without excessive approximations.

- Hence, the third option is to simulate the system of interest in a computer-based model and then carry out experiments on that model to see what would be the best policy to adopt in practice.

In the present thesis, the quantitative analysis is based on the methodology of computer simulations. The detailed steps consists of building an exclusive objective function, developing programs in Matlab, revealing the nature of the Key-Part Based Lead Time Management, determining a satisfying solution in the inventory control, and finally exploring some applications.

4.2 Simulation Process of the Key-Part Based Lead Time Management

In the present thesis, computer simulation can be used not only to obtain a satisfying lead time management but also to explore its application.

In general, the necessary elements in the simulation include parameters, objective functions and subfunctions, flowcharts, and simulating programs.

4.2.1 Parameters

In the present case study, the parameters in the objective function are calculated in Chapter 3 and are summarized as follows:

$h = \$2.74 \times 10^{-4}$: The holding cost is the time value of money per day for each \$1 inventory.

$P_{enalty} = \$0.5$: The customer penalty is the time value of money for each delay day.

$n = 49$: The total part numbers in a final product.

$C_i \& T_i$: the data of costs and lead times of all the parts are ordered in increased sequence in Table 5.

4.2.2 Simulation Flowchart

As we know, a flowchart can help us to organize our activities in define phases. By using a graphic representation in the flowchart, developers can track actions, simplify the work, and optimize the entire system. However, in the present thesis, the purpose of the simulation procedure is to locate the key part and to obtain a satisfying purchase policy.

In order to construct the flowchart, the first step is to depict the logical processes in the natural language as follows:

- First, establish that the dummy key part i is located in Part 1.
- Calculate the corresponding total inventory loss and collect it in vector L (1).
- Circulate i from 1 to n by increasing space in 1.
- Sort out the true key part from vector L where the minimum value exists.

The second step is to transfer the natural languages into the flowchart language. In the flowchart, there are sets of symbols such as rectangles, diamonds, and connecting lines that show the step-by-step progression through a procedure. Block diagrams are the simplest and most prevalent type of flowchart. Such diagrams provide a quick, uncomplicated view of a process. Functional flowcharts picture movement between different work units. Finally, the finished simulation flowchart for the Key-Part Based Lead Time Management is shown in Figure 16.

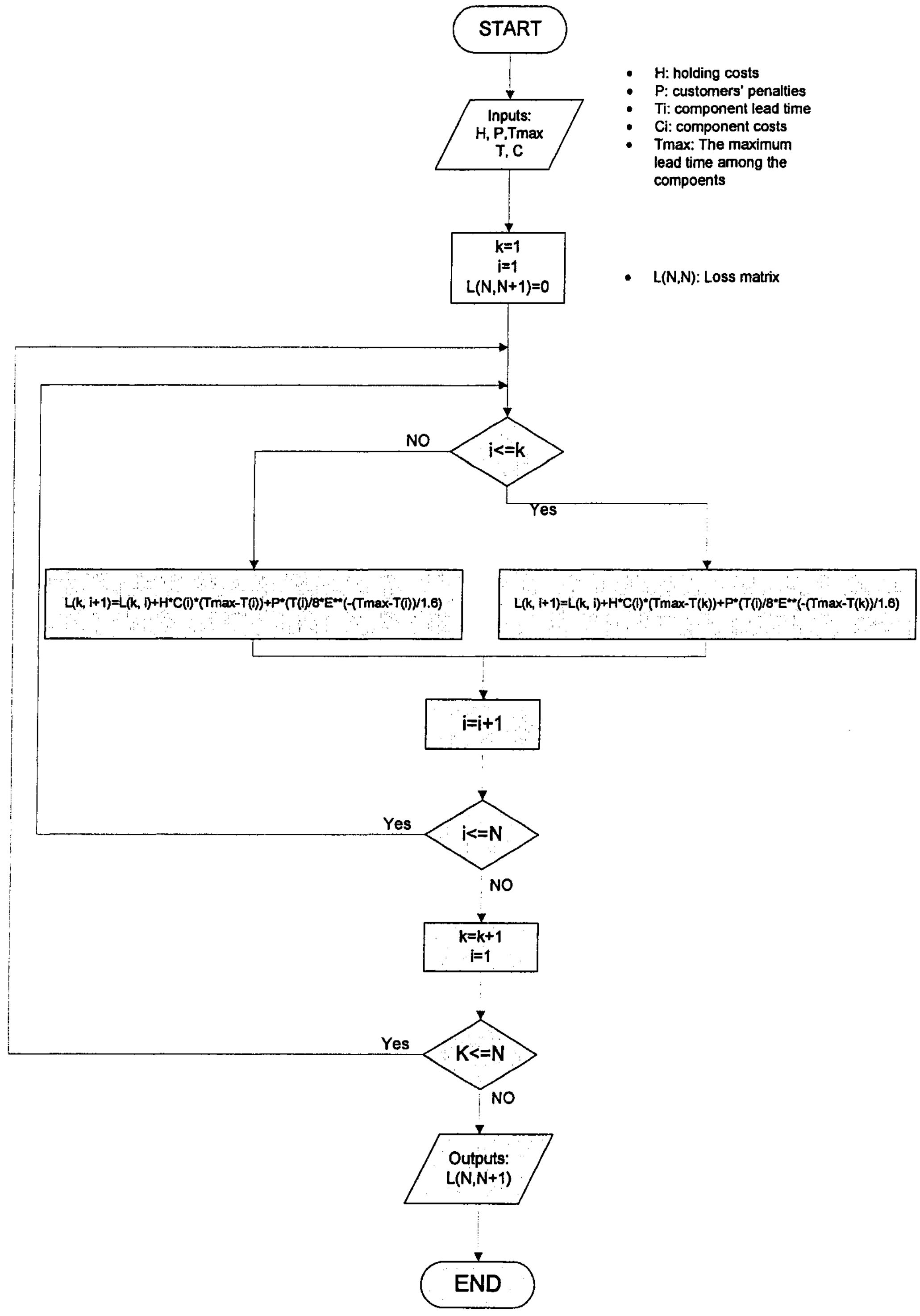


Figure 16: **Simulation Flowchart for the Key-Part Based Lead Time Management**

4.2.3 Programs

Matlab, known as the language of technical computing, is a high-level language and interactive environment that enables us to perform computationally intensive tasks faster than with traditional programming languages. Mostly, all the graphic features that are required to visualize engineering and scientific data are available in Matlab. The stronger functions combining high speed calculation with the flexible graphic outputs are very useful for our research.

Based on the flowchart in Figure 16, Program 3 is developed in Matlab and Figure 17 is achieved after running that program.

4.3 Simulation Results

The simulation results consist of a series of the total inventory losses corresponding to the dummy key parts. By using the graphic functions of Matlab, those results are brought together and plotted in Figure 17. In the coordinates of (X_i, Y_i), X_i represents the location of the dummy key part, and Y_i represents the total inventory loss in dollars corresponding to X_i.

The simulation results consist of three phases in the present case study. They are the flat phase, the downward phase, and the abrupt upward phase. A detailed analysis is as follows:

- Flat Phase

Inside the first 40 points, the curve of total inventory loss looks flat. Their values are approximately equal to \$8.93. This phenomenon is explained by recognizing that if the selected dummy key part has smaller lead times, the parts will arrive at the warehouse in advance and lead to less possibility of customer penalty. Finally, the value of the total inventory loss is about one digit number.

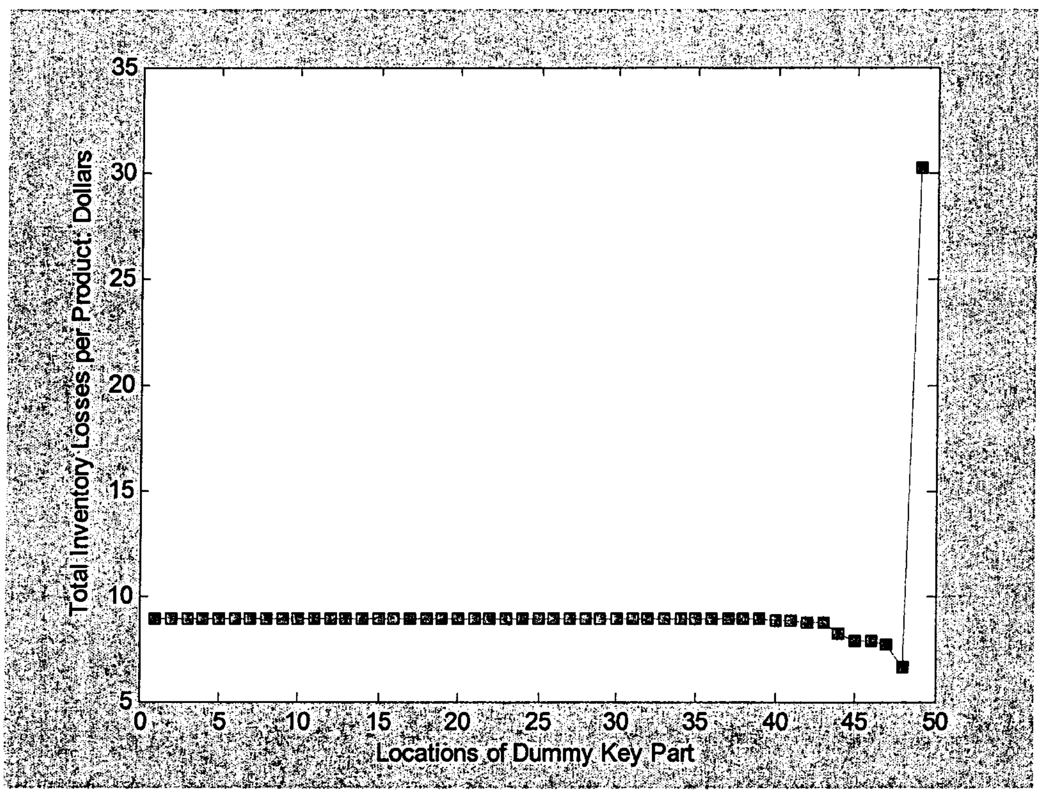


Figure 17: Chart of Total Inventory Loss vs. Dummy Key Parts

- Downward Phase

Inside points of the 40th to 49th, the curve goes downward and the value of the minimum loss equals \$6.58. This phenomenon is explained by recognizing that because the dummy key part has greater lead times, the holding cost is reduced dramatically as well as the possibility of the customer penalty still remains at lower level. Moreover, the true key part arises in this phase.

- Abrupt Upward Phase

The curve goes upward sharply in this phase. This phenomenon is explained by recognizing that as the dummy key part is close to deadline to customers, the holding cost remains at the bottom line, but the probability of the delay time and the customer penalty is considerable. Finally, the total inventory loss reaches $30.25 for each final product.

4.4 Analysis of the Key Part Location

Based on an analysis of Figure 17, we know that value of the minimum total inventory loss is located at the 49^{th} point. So, the 49^{th} part is the true key part in the present case study. The minimum inventory loss arises if all parts except the motor part are required to arrive at the warehouse at the same date as the 49^{th} part. The description of the key part in the present case study is as follows:

- The carbon brush is the true key part.
- In the rated BOM (Bill of Material) lists, the key part is numbered in the 16^{th} place.
- The key part is produced in Europe and its lead time (T_k) equals 70 days.

➢ The cost of the key part (C_k) equals 6 dollars.

➢ In a final product, two pieces of carbon brush is required.

➢ If companies use the Key-Part Based Lead Time Management to plan the purchase policy, the total inventory loss should be reduced to \$6.60 per final product.

➢ A satisfying purchase policy is obtained shown in Figure 18.

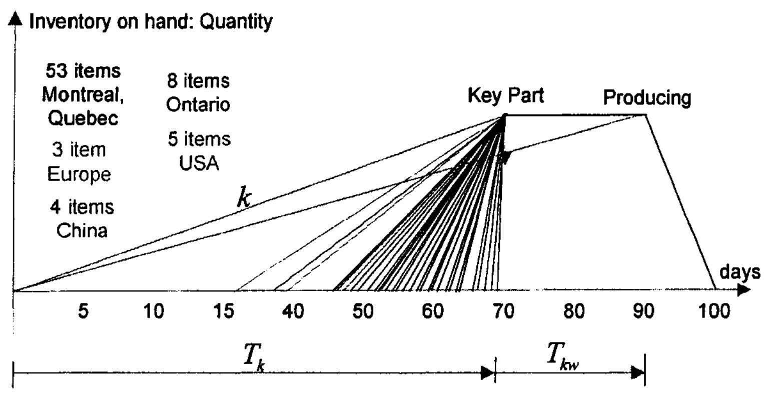


Figure 18: New Purchasing Schedules from Key-Part Based Lead Time Management

A satisfying purchase policy is described as follows: once orders are received from the customers, the first step is to determine the location of the key part based on our lead time management; the second step is to determine the individual part purchase order that designate the arrival date. In the present case study, the motor parts arrive at the warehouse on the 90th day and all of the other parts arrive at the warehouse exactly on the 70th day.

4.5 *Relationship between the Key-Part Based Lead Time Management and MRP II*

4.5.1 Analysis of MRP II

Material Requirements Planning (MRP II) is designed to assist manufacturers in inventory and production management. MRP II helps to ensure that materials will be available in sufficient quantities and at the proper time for production. Moreover, MRP II assists in generating and (as needed) revising production plans to meet the expected demands and replenishment plans to assure the timely availability of raw materials and all levels of product parts (Higgins, 2006).

MRP II performs according to the following steps: compiling a Bill of Materials (BOM) for the final products, requiring information on the lead time associated with each part in production, generating a master production schedule, deriving a schedule of part requirements. Some MRP software such as Mannex, MISys, and SysPro ERP can integrate all those procedures into one friendly interface.

In the traditional MRP system, all purchasing orders could be released to suppliers automatically. From the point of view of the Key-Part Based Lead Time Management, the procedure of MRP II in purchasing is considered as one case in which the dummy key part is located at the first point. In Figure 19, we know that the total inventory loss based on the purchasing schedules of MRP II equals $8.90 for each final item.

It is obvious that the MRP II can not seek out a satisfying solution or an optimal solution for Make-to-Order in the global supply chain network.

4.5.2 Relationship between the Key-Part Based Lead Time Management and MRP II

From the viewpoint of management, the Key-Part Based Lead Time Management focus on reducing the inventory wastes, but the MRP II excels in the production management. Moreover, thanks to the integration of the Key-Part Based Lead Time Management and the MRP system, the new combination will not only obtain a satisfying solution of the problem of the lead time waste but will also manipulate production efficiently.

The new combination system performs according to the following steps:

- Derive the part requirements based on the BOM lists of the MRP system.
- Extract all the part lead times and the part costs from the MRP system.
- Obtain the key part by means of the Key-Part Based Lead Time Management.
- Formulate a satisfying purchase policy and release the part purchasing orders.
- Once all of the parts are in the warehouse, the MRP II makes a production schedule.

In conclusion, the new combination system reduces the total inventory loss from $8.90 to $6.60 per product item. Inside of the combination system, the Key-Part Based Lead Time Management contributes to the inventory reduction. Meanwhile, the MRP system provides an excellent production management.

4.6 Application of the Key-Part Based Lead Time Management to Analyze the Management of Push Production

The management of push production is described as follows: In the traditional push or Make-to-Stock production, one company makes a production plan based on the estimation from the market places. The push production is driven by the management. Because companies make production plans to replenish the safety stock. So, the customer penalty (P_e) is neglected in push production.

The objective function in push production is concreted from Formula 7 by assigning the customer penalty (P_e) as zero and expressed in Formula 8.

$$\text{Loss}\,(n,\ h,\ T_i,\ C_i) = h \times [\sum_{i=1}^{k} C_i \times (T_{\max} - T_{k)} + \sum_{i=k+1}^{n} (C_i \times (T_{\max} - T_i))] \qquad (8)$$

Formula 8 : Objective Function in the Push Production

According to Formula 8, the simulation is developed in Program 4 in Matlab. After running that program, the results are shown in Figure 19.

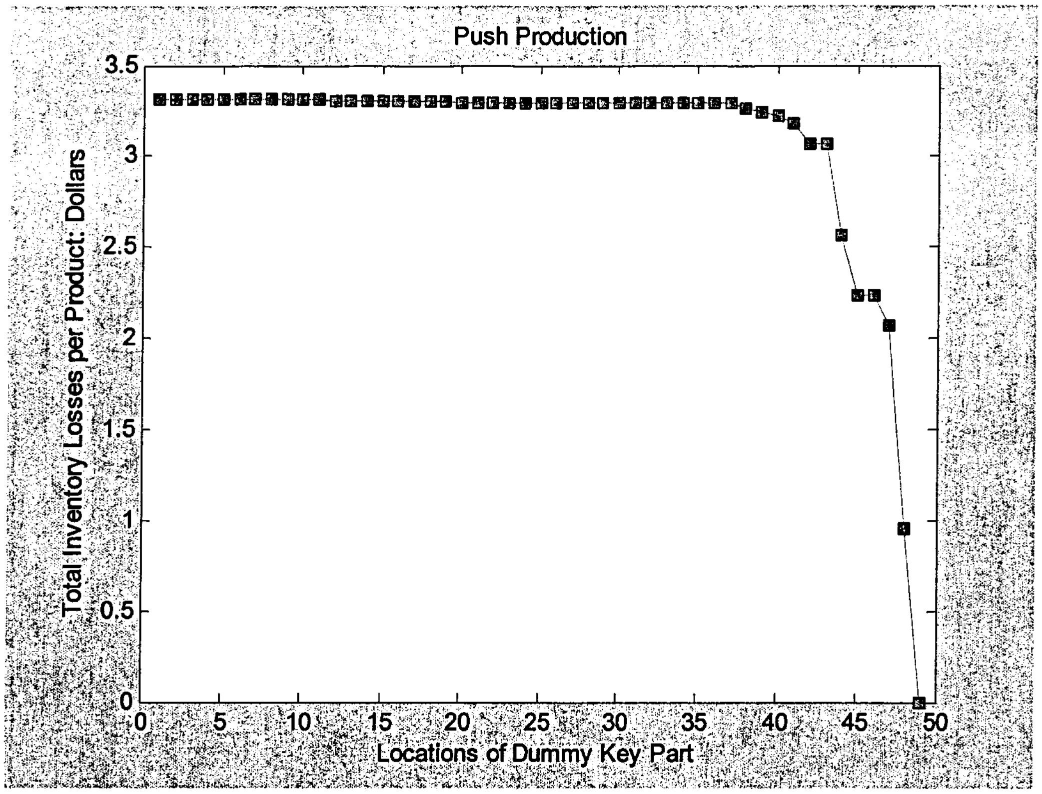


Figure 19: Chart of the Total Inventory Losses vs. Dummy Key Parts in the Push Production.

Observations based on the push production are summarized as follows:

- Entire levels of the total inventory losses in push production are decreased dramatically. In the case of the first forty dummy key parts, the total inventory loss is reduced from $8.90 to $3.30 per final product item.

- The key part of push production is located at the last point and its value of the total inventory loss equals zero.

- In the present case study, the satisfying purchase policy in push production is that as a production plan is received from the management; a purchasing schedule is formulated based on the motor part. All parts are designated to arrive at the warehouse on the 90th day (Figure 20).

➢ It appears as though push production eliminates the total inventory loss. However, in fact, push production only transfers inventory from part inventory to final product inventory.

In the reality, there are several reasons why many companies still keep the traditional push production and hesitate to transfer into the new pull production. One of these reasons is probably because the management in those companies fears the impact of the customer penalty.

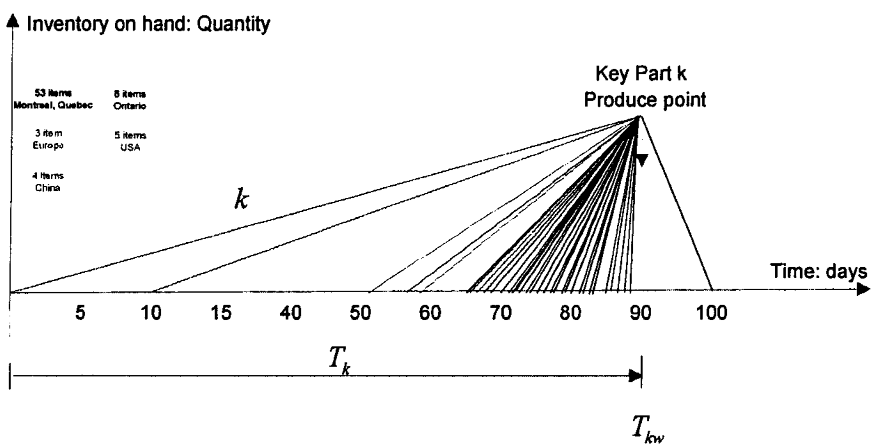


Figure 20: Plot of Key Part Schedule in the Push Production

4.7 Application of the Key-Part Based Lead Time Management to Analyze Management of the Ford Production

The management of the Ford Production is described as follows: In order to reduce considerable part inventory, Ford Company changed its payment procedures (Soderborg, 2004) from the pre-pay to the just-pay. Suppliers can be allowed to store their parts in the Ford warehouse early. However, Ford Company pays suppliers only when the parts of those suppliers are assembled in line. The Key-Part Based Lead Time Management can be used to analyze the management of Ford production by assigning the holding costs to zero.

In the Ford Production, the new objective function is concreted from Formula 7 by removing the holding cost part and expressed as follows:

$$\text{Loss}(n,\ h,\ P_e,\ T_i,\ C_i) = [\sum_{i=1}^{k} \frac{T_i}{8} \times e^{-\frac{1}{1.6}\times(T_{\max}-T_k)} + \sum_{i=k+1}^{n} \frac{T_i}{8} \times e^{-\frac{1}{1.6}\times(T_{\max}-T_i)}] \times P_{enalty} \quad (9)$$

Formula 9 : Objective Function in Ford Production

Basing on Formula 9, program 4 is developed in Matlab. After running that program, a chart of the total inventory loss vs. the dummy key parts is shown in Figure 21. Moreover, some observations are obtained as follows:

- The key part can be located at any part except the last part.
- The minimum total inventory loss equals $5.60.
- The value of total inventory losses equals $30 at the last point.
- It appears as though the Ford production eliminates the holding costs. However, in fact, Ford Company transfers only its part holding costs to suppliers.

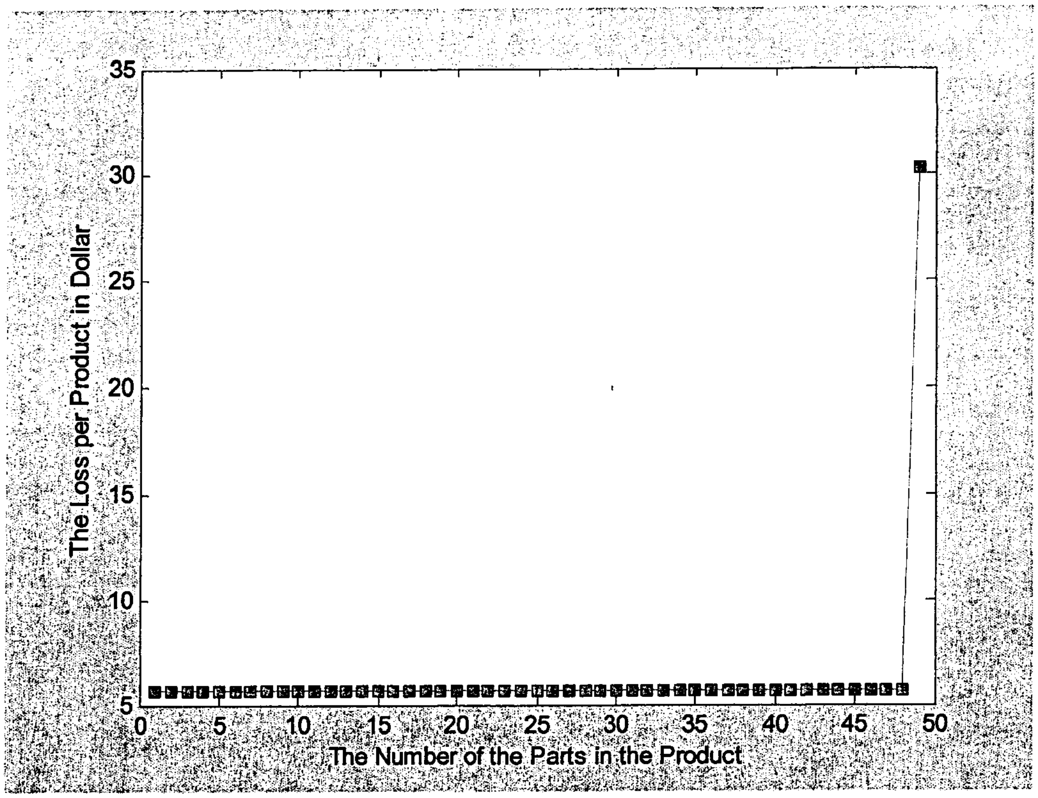


Figure 21: Chart of the Total Inventory Losses vs. Dummy Key Parts in Ford Production

With the same goal of removing the holding costs, Toyota Company implements its Just-In-Time production by sending the part purchasing orders daily to local suppliers (Mishina, 1995). Toyota could pay immediately when suppliers deliver parts to its warehouse. However, it is possible that suppliers reduce or eliminate their inventory by enhancing management. In industrial engineering, that process is called Toyota's Just-In-Time or lean production.

Finally, we conclude that the Key-Part Based Lead Time Management can not only reduce lead time waste, but can also help to analyze current popular inventory theories.

Chapter 5

Comparison between the Optimal Solution and the Satisfying solution

In the present thesis, an optimal solution refers to what a minimum total inventory loss does from the point of view of mathematical operations. However, the satisfying solution that is shown in the earlier chapters refers to what a company really wants in managerial operations. Of course, a satisfying solution is not necessarily equal to an optimal solution.

5.1 Objective Functions for the Optimal Solution

Loss $(n, h, P_e, T_i, C_i) =$

$$h \times [\sum_{i=1}^{k} C_i \times T_{kw} + \sum_{i=k+1}^{T_{\max}} (C_i \times T_{iw})] + [\sum_{i=1}^{k} f(T^i{}_{kw}) + \sum_{i=k+1}^{T_{\max}} f(T^i{}_{iw})] \times P_e \qquad (10)$$

Formula 10 : General Objective Function for the Optimal Solution

As we have seen in the earlier chapters, a satisfying solution is based on the Key-Part Based Lead Time Management. By determining the key part, a corresponding total inventory loss is the satisfying solution of the inventory control. Finally, the purchasing schedules based on the key part are the satisfying solution of a purchase policy.

However, an optimal solution is based on the time-based lead time management. By determining a specific date when the corresponding total inventory loss equals the minimum value, the optimal purchasing schedules are obtained.

The objective function of the optimal solution is constructed in Formula 10. Logical reasoning leads to the following: assuming that the length of the lead time in a global supply chain network equals T_{max} day; calculating a set of values for the total inventory loss according to the individual days inside of T_{max}; determining a specific date that has a minimum in that set; finally, the assumption that the optimal solution is the purchase policy based on that date. The process is demonstrated in Figure 22.

The objective function of the satisfying solution in Formula 1 is similar to that of the satisfying solution in Formula 10. However, the only difference is in the pattern of cyclic variable, which ranges from 1 to n inside of the part numbers in the satisfying solution and which ranges from 1 to T_{max} inside of the lengths of the lead time in the optimal solution.

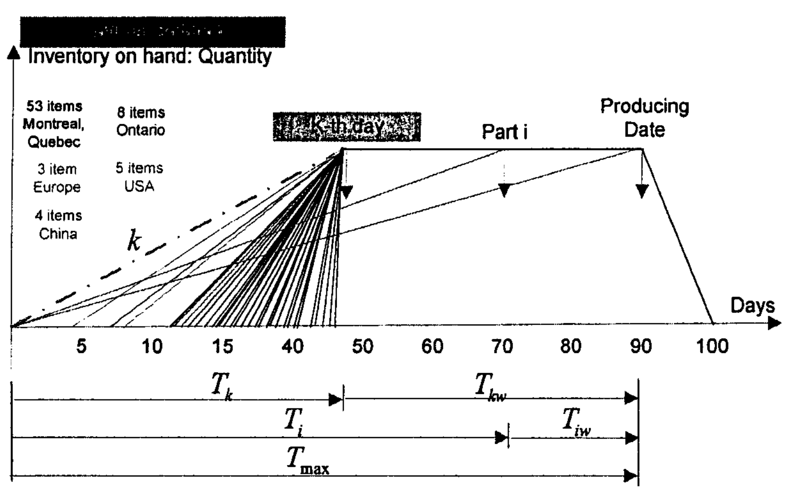


Figure 22: Arrival Schedules for the Optimal Solution

5.2 Flowchart of Simulation for the Optimal Solution

In order to compare the optimal solution with the satisfying solution, simulation in Matlab helps to explore the relationship visually based on the present case study.

To construct the flowchart of simulation for the optimal solution, the first step is to depict the logical process in the natural language as follows:

- First, let the cyclic variable i equal 1.
- Calculate corresponding values of the total inventory loss and then store them in the set.
- Circulate i from 1 to T_{max} by the increasing space in 1.
- Sort out the specific day in the set that has the minimum value.

The second step is to transfer the natural language into the flowchart language. The shortcut for building the flowchart of the optimal solution is to revise the flowchart of the satisfying solution in Figure 16. Finally, the new flowchart of the optimal solution is obtained in Figure 23. Its revision is marked with underscore sign.

Optimal solution

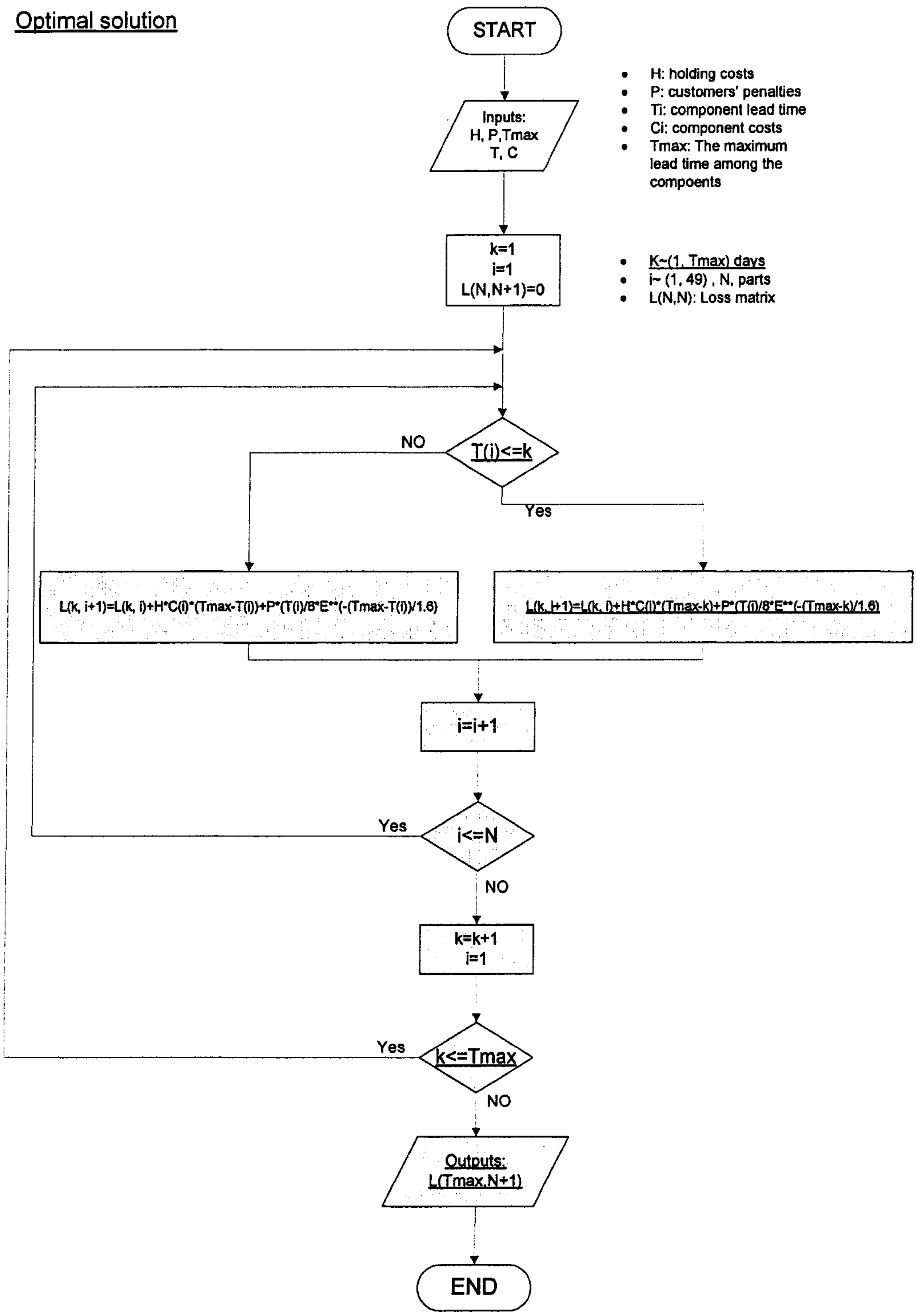


Figure 23: Flowchart of Simulation for the Optimal Solution

5.3 Comparison in the Case Study

Based on the flowcharts of both the satisfying solution in Figure 16 and the optimal solution in Figure 23, a simulation program, Program 5, is developed in Matlab. After running that program in the present case study, a chart comparing the optimal solution and the satisfying solution is depicted in Figure 24.

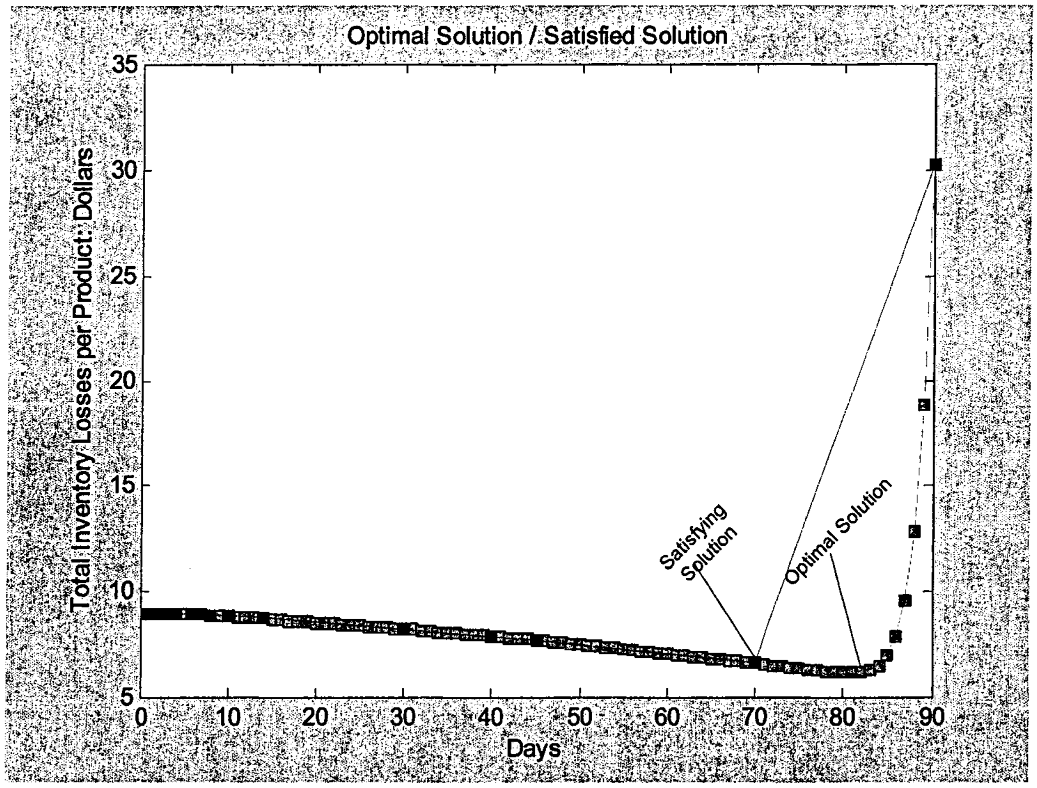


Figure 24: Comparison between the Optimal Solution and the Satisfying Solution in Case Study

Referring to Figure 24, some comments are provided in the following:

- When Figure 17 is compared with Figure 24, it becomes apparent that the chart shapes of the total inventory loss for the Key-Part Based Lead Time Management look differently. The reason is that the horizontal axis of Figure 17 is in parts and that of Figure 24 is in days.

- In Figure 24, the chart of the satisfying solution caused by the Key-Part Based Lead Time Management is a portion chart of the optimal solution chart.

- The satisfying solution caused by the Key-Part Based Lead Time Management is located at the 49^{th} part with the lead time of 70 days. Its total inventory loss equals \$6.5811; the optimal solution is located at the 81^{st} day and its total inventory loss equals \$6.1440. However, there is a 6.6% difference between the optimal solution and the satisfying solution.

In addition, the satisfying solution is not unnecessarily equal to the optimal solution. If part lead times are continuous, the satisfying solution must definitely coincide with the optimal solution; if part lead times are discontinuous, it is not necessary that two solutions are coinciding but very closely.

5.4 Advantages of the Satisfying Solution

Although the Key-Part Based Lead Time Management determines only the satisfying solution, companies still prefer the satisfying solution to the optimal solution. The advantages of the satisfying solution are listed as follows:

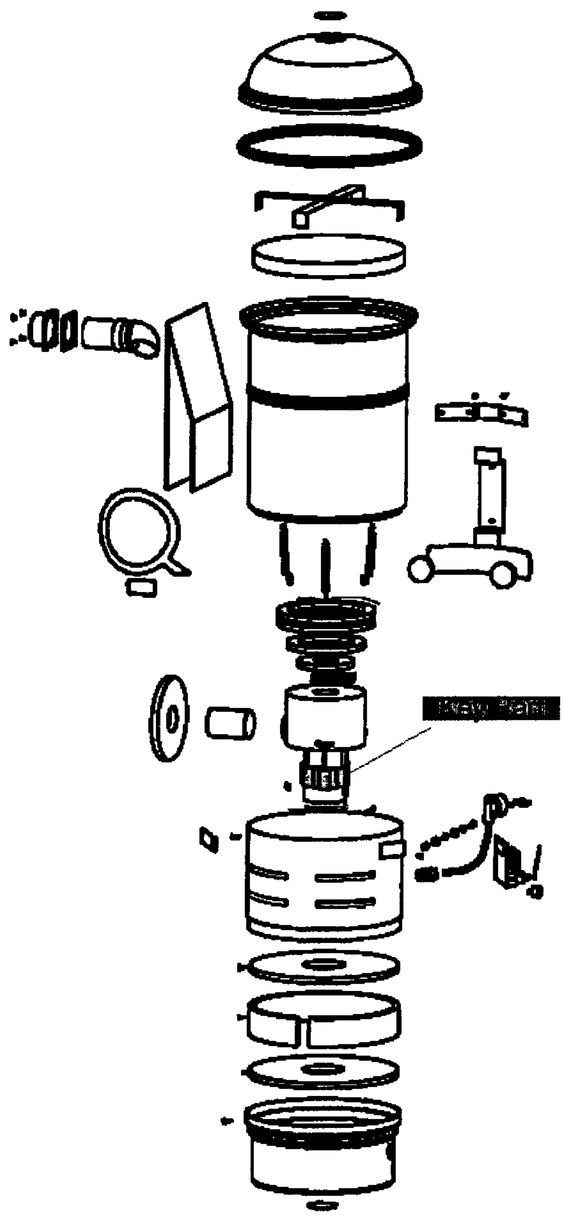
- Visual Thinking

The Key-Part Based Lead Time Management harmonizes well with human thinking. Visual thinking helps us to see the big picture, capture complex ideas quickly and easily, and identify relationships between ideas and processes (Arnheim, 2004). In the fields of the part purchase policy, the visual elements consist of the part cost, the part weight, the part dimensions, the part lead time, and the network in the global supply chain.

The Key-Part Based Lead Time Management is grounded on visual thinking. All purchasing schedules are established using the key part with a specific lead time. For managers and engineers, the satisfying solution based on the key part concept is much more impressive than the optimal solution with an accurate purchasing date (Figure 25).

➢ Robust to Variation

According to Formula 10, the optimal solution is too sensitive to variation. So, if any factor is changed, the optimal solution needs to be recalculated. However, the key part method is robust to variation whether the variation comes from the customer penalty, the holding cost, the part cost, or the part lead time. The detailed demonstrations in the robustness are shown in Chapter 7.



Key Part:
Name: Carbon Brush
Lead time: 70 Days
Costs: $6
Pieces: 2/Product
Producer: Europe

Purchase Policies:
All parts should arrive at warehouse by following part lead time of Carbon Brush.

Figure 25: Visualization of the Key Part in the Routine Operation

Chapter 6

A Matrix Calculation to Find the Key Part

In order to conveniently apply the Key-Part Based Lead Time Management in the real world, a practical methodology based on the matrix calculation to determine the key part is necessary. The constructing procedures involve in simplifying elements and reconstructing expressions. Moreover, the accuracy of the practical methodology is validated by comparing the results of the original Key-Part Based Lead Time Management with results of the practical methodology based on the same present case study.

6.1 Concepts of the Practical Methodology

Up to now, we know that the Key-Part Based Lead Time Management helps companies to reduce lead time waste definitely by formulating a satisfying purchase schedule based on the key part. However, there are still some difficulties in using it in the real world.

To determine the key part, companies prefer to use basic mathematical calculations rather than to develop programs. A practical methodology having advantages of simplification, rapidity, and accuracy is necessary for the application of the Key-Part Based Lead Time Management in practice.

To construct the practical methodology, the Key-Part Based Lead Time Management is considered as a whole system with elements of inputs, weights, outputs, and their inner relationship.

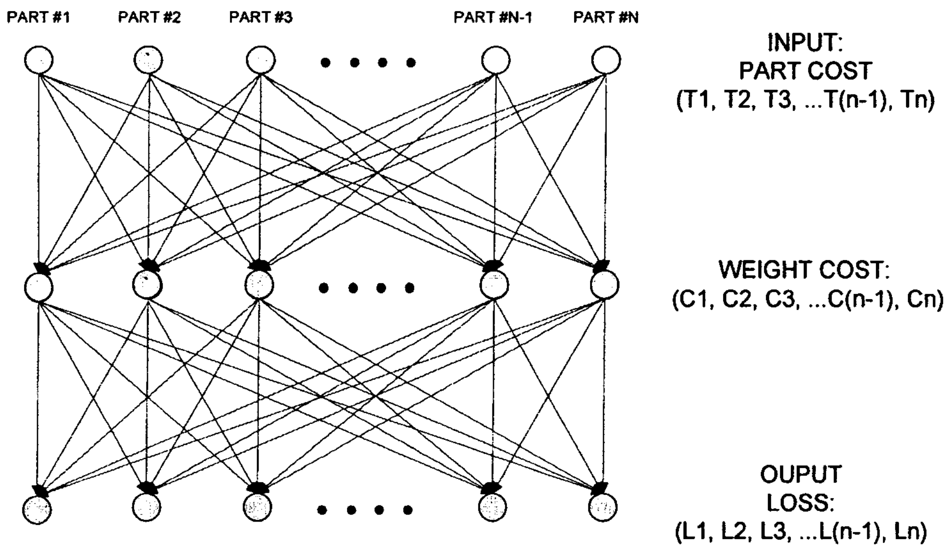


Figure 26: Structures of Key-Part Based Lead Time Management

- Input Vectors

$T = \{T_1, T_2, \ldots\ldots, T_{n-1}, T_n\}$: The vector of part lead time

$C = \{C_1, C_2, \ldots\ldots, C_{n-1}, C_n\}$: The vector of part cost

- Transfer Matrices:

$$Z=\begin{pmatrix} Z_{11} & Z_{12} & \cdots & Z_{1(n-1)} & Z_{1n} \\ Z_{21} & Z_{22} & \cdots & Z_{2n} & Z_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ Z_{(n-1)1} & Z_{(n-1)2} & \cdots & Z_{(n-1)(n-1)} & Z_{(n-1)n} \\ Z_{n1} & Z_{n2} & \cdots & Z_{n(n-1)} & Z_{nn} \end{pmatrix}$$

- Output Vector:

$LOSS = \{LOSS_1, LOSS_2, ...LOSS_i ..., LOSS_{n-1}, LOSS_n\}$: The vector of the total inventory loss

$LOSS_i$: The total inventory loss while $Part_i$ is the dummy key part

➢ Location of the key part

By analyzing the output vector $LOSS$, the key part is located at the place where the smallest value exists.

6.2 Expression of the Objective Function in the Practical Methodology

In the course of constructing the practical methodology, the objective function in Formula 1 is rewritten in Formula 11 as follows:

$\mathrm{Loss}(k)$ =

$$h \times [\sum_{i=1}^{k} C_i \times T_{kw} + \sum_{i=k+1}^{n} (C_i \times T_{iw})] + [\sum_{i=1}^{k} f(T^i{}_{kw}) + \sum_{i=k+1}^{n} f(T^i{}_{iw})] \times P_e$$

$$= \sum_{i=1}^{k} [h \times C_i \times T_{kw} + f(T^i{}_{kw}) \times P_e] + \sum_{i=k+1}^{n} [h \times C_i \times T_{iw} + f(T^i{}_{iw}) \times P_e] \quad (11)$$

Formula 11 : A Rewritten Objective Function

Moreover, Formula 11 is expanded into a matrix expression in Formula 12 as follows:

$$\begin{pmatrix} Loss(1) \\ Loss(2) \\ \ldots\ldots \\ Loss(n-1) \\ Loss(n) \end{pmatrix} = h \times \begin{pmatrix} T_{1w} & 0 & \ldots. & 0 & 0 \\ T_{2w} & T_{2w} & \ldots. & 0 & 0 \\ \ldots. & \ldots. & \ldots. & \ldots. & \ldots. \\ T_{(n-1)w} & T_{(n-1)w} & \ldots. & T_{(n-1)w} & 0 \\ T_{nw} & T_{nw} & \ldots. & T_{nw} & T_{nw} \end{pmatrix} \times \begin{pmatrix} C_1 \\ C_2 \\ \ldots\ldots \\ C_{n-1} \\ C_n \end{pmatrix}$$

$$+ \ P_e \times \begin{pmatrix} f(t^1{}_{1w}) & f(t^2{}_{2w}) & \ldots. & f(t^{n-1}{}_{(n-1)w}) & f(t^n{}_{nw}) \\ f(t^1{}_{2w}) & f(t^2{}_{2w}) & \ldots. & f(t^{n-1}{}_{(n-1)w}) & f(t^n{}_{nw}) \\ \ldots & \ldots. & \ldots. & \ldots. & \ldots. \\ f(t^1{}_{(n-1)w}) & f(t^2{}_{(n-1)w}) & \ldots. & f(t^{n-1}{}_{(n-1)w}) & f(t^n{}_{nw}) \\ f(t^1{}_{nw}) & f(t^2{}_{nw}) & \ldots. & f(t^{n-1}{}_{nw}) & f(t^n{}_{nw}) \end{pmatrix} \times \begin{pmatrix} 1 \\ 1 \\ \ldots. \\ 1 \\ 1 \end{pmatrix}$$

$$+ \ h \times \begin{pmatrix} 0 & T_{2w} & \ldots. & T_{(n-1)w} & T_{nw} \\ 0 & 0 & \ldots. & T_{(n-1)w} & T_{nw} \\ \ldots. & \ldots. & \ldots. & \ldots. & \ldots. \\ 0 & 0 & \ldots. & 0 & T_{nw} \\ 0 & 0 & \ldots. & 0 & 0 \end{pmatrix} \times \begin{pmatrix} C_1 \\ C_2 \\ \ldots\ldots \\ C_{n-1} \\ C_n \end{pmatrix}$$

$$= h \times \begin{pmatrix} T_{1w} & T_{2w} & \ldots. & T_{(n-1)w} & T_{nw} \\ T_{2w} & T_{2w} & \ldots. & T_{(n-1)w} & T_{nw} \\ \ldots. & \ldots. & \ldots. & \ldots. & \ldots. \\ T_{(n-1)w} & T_{(n-1)w} & \ldots. & T_{(n-1)w} & T_{nw} \\ T_{nw} & T_{nw} & \ldots. & T_{nw} & T_{nw} \end{pmatrix} \times \begin{pmatrix} C_1 \\ C_2 \\ \ldots\ldots \\ C_{n-1} \\ C_n \end{pmatrix}$$

$$+ P_e \times \begin{pmatrix} f(t^1{}_{1w}) & f(t^2{}_{2w}) & \ldots. & f(t^{n-1}{}_{(n-1)w}) & f(t^n{}_{nw}) \\ f(t^1{}_{2w}) & f(t^2{}_{2w}) & \ldots. & f(t^{n-1}{}_{(n-1)w}) & f(t^n{}_{nw}) \\ \ldots & \ldots. & \ldots. & \ldots. & \ldots. \\ f(t^1{}_{(n-1)w}) & f(t^2{}_{(n-1)w}) & \ldots. & f(t^{n-1}{}_{(n-1)w}) & f(t^n{}_{nw}) \\ f(t^1{}_{nw}) & f(t^2{}_{nw}) & \ldots. & f(t^{n-1}{}_{nw}) & f(t^n{}_{nw}) \end{pmatrix} \times \begin{pmatrix} T_1 \\ T_2 \\ \ldots\ldots \\ T_{n-1} \\ T_n \end{pmatrix}$$

$$= h \times Z_1 \times C + p_e \times Z_2 \times T \qquad (12)$$

Formula 12 : Expression of the Objective Function in the Practical Methodology

Where:

h, p_e : Constant parameters

$$Z_1 = \begin{pmatrix} T_{1w} & T_{2w} & \cdots & T_{(n-1)w} & T_{nw} \\ T_{2w} & T_{2w} & \cdots & T_{(n-1)w} & T_{nw} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ T_{(n-1)w} & T_{(n-1)w} & \cdots & T_{(n-1)w} & T_{nw} \\ T_{nw} & T_{nw} & \cdots & T_{nw} & T_{nw} \end{pmatrix}$$

$$Z_2 = \begin{pmatrix} f(t^1{}_{1w}) & f(t^2{}_{2w}) & \cdots & f(t^{n-1}{}_{(n-1)w}) & f(t^n{}_{nw}) \\ f(t^1{}_{2w}) & f(t^2{}_{2w}) & \cdots & f(t^{n-1}{}_{(n-1)w}) & f(t^n{}_{nw}) \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ f(t^1{}_{(n-1)w}) & f(t^2{}_{(n-1)w}) & \cdots & f(t^{n-1}{}_{(n-1)w}) & f(t^n{}_{nw}) \\ f(t^1{}_{nw}) & f(t^2{}_{nw}) & \cdots & f(t^{n-1}{}_{nw}) & f(t^n{}_{nw}) \end{pmatrix}$$

$$C = \begin{pmatrix} C_1 \\ C_2 \\ \cdots \\ C_{n-1} \\ C_n \end{pmatrix} \qquad T = \begin{pmatrix} T_1 \\ T_2 \\ \cdots \\ T_{n-1} \\ T_n \end{pmatrix}$$

6.3 Application of the Practical Methodology in the Case Study

The practical methodology has been established in the earlier paragraphs. In order to show how the practical methodology works, the present case study is analyzed. Furthermore, the accuracy of the practical methodology is explored afterward.

6.3.1 Data Summarization in the Case Study

Prior to applying the practical methodology to the present case study, all the necessary data from previous chapters are summarized and listed as follows:

- N: there are total of 49 part types in a final product.
- h : Parameter of holding costs means that \$0.000274 is charged by banks per day for each \$1 inventory.

➢ p_e: Parameter of customer penalty means that \$0.5 is charged by customers for each delay day.

➢ Probability delay time function for the final products: $f(t_{iw}) = \frac{1}{8} e^{-\frac{T_{iw}}{1.6}}$

➢ Part cost vector:

C=[0.2;0.3;1.1;0.3;0.45;0.15;0.15;0.1;2;0.5;9;1;5;5;3;2;1.5;2.5;3;2;3;1.5;2.5;1;2.2;1.2;0.5;1;
0.5;0.5;0.5;1;0.5;1;5;1;1;2.5;12;3.3;20;10;2.5;6;3;2;38;12;80;]

➢ Part lead time vector:

T=[1;1;1;1;1;1;1;2;2;2;3;3;3;3;3;3;3;3;4;4;4;4;4;4;4;4;4;4;4;4;4;4;4;4;4;6;7;8;10;14;14;30;
40;40;45;70;90;]

Transfer matrices: Z1=

89	89	89	89	89	89	89	89	88	88	88	87	87	87	87	87	87	87	87	86	86	86	86	86	86	86	86	86	86	86	86	86	86	86	86	86	86	84	83	82	80	76	76	60	50	50	45	20	0
89	89	89	89	89	89	89	89	88	88	88	87	87	87	87	87	87	87	87	86	86	86	86	86	86	86	86	86	86	86	86	86	86	86	86	86	86	84	83	82	80	76	76	60	50	50	45	20	0
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The transfer matrice Z1 can also be expressed in Figure 27 by Matlab.

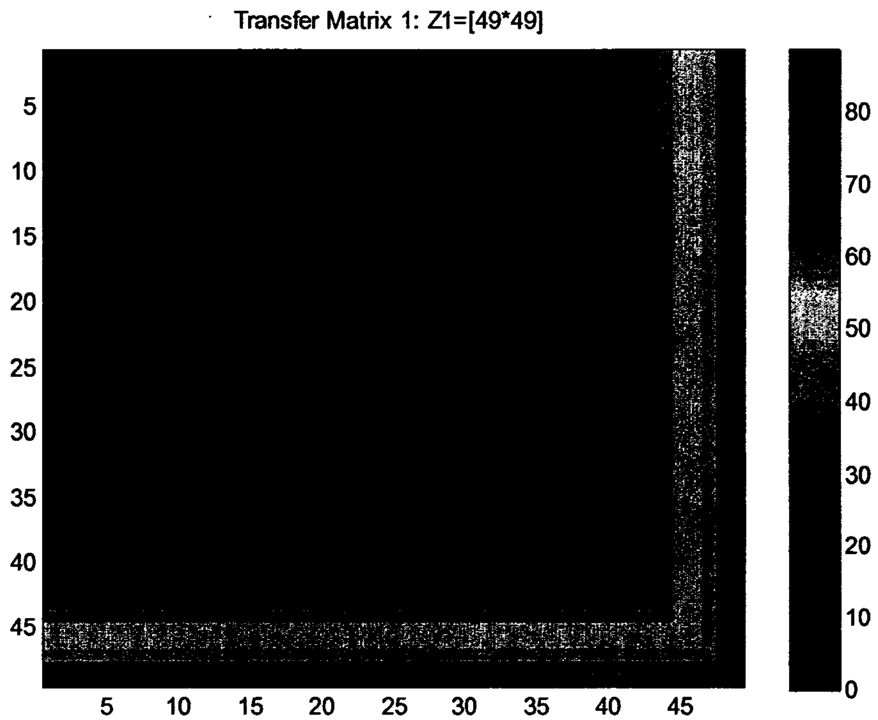

Figure 27: The Figure of the Transfer Matrice 1

➢ Transfer matrice: Z2=

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\end{pmatrix}
$$

Remark: "A" represent 0.125 in Matrix

Transfer matrice 2 can also be expressed in Figure 28.

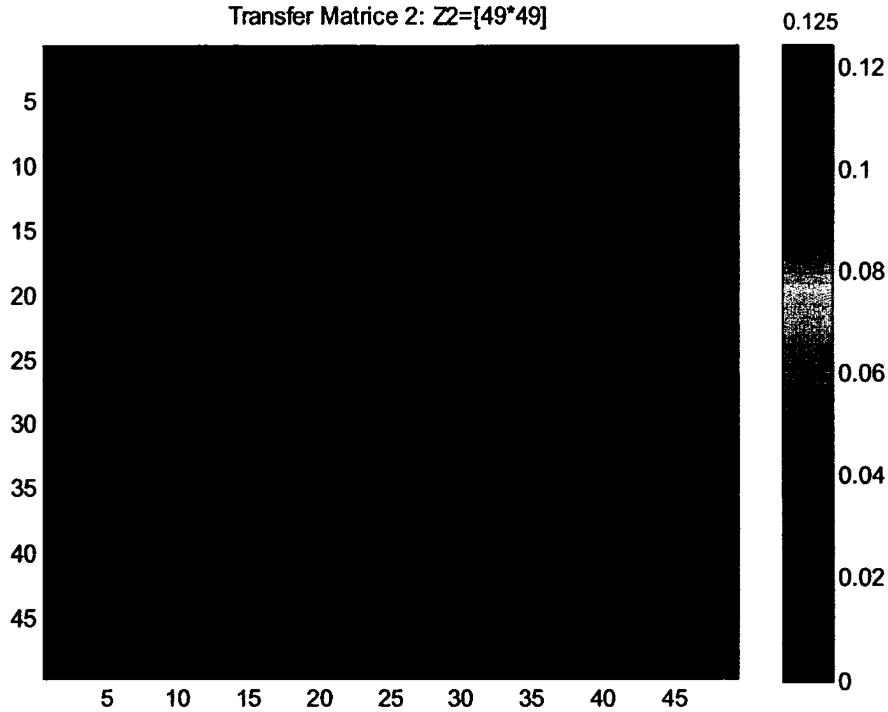

Figure 28: **The Figure of the Transfer Matrice 2**

6.3.2 Calculation Process

Based on the preconditioning data above, a small program (Program 6) is developed in Matlab to implement Formula 12. This program is easily accessed because it needs only a matrice calculation as following:

$$LOSS = h \times Z_1 \times C + p_e \times Z_2 \times T$$

6.3.3 Analysis of Results

After running Program 6, the results are automatically obtained as follows:

LOSS =[

8.9327, 8.9327, 8.9327, 8.9327, 8.9327, 8.9327, 8.9327, 8.9327,
8.9319, 8.9319, 8.9319, 8.9280, 8.9280, 8.9280, 8.9280, 8.9280,
8.9280, 8.9280, 8.9280, 8.9178, 8.9178, 8.9178, 8.9178, 8.9178,
8.9178, 8.9178, 8.9178, 8.9178, 8.9178, 8.9178, 8.9178, 8.9178,
8.9178, 8.9178, 8.9178, 8.9178, 8.9178, 8.8832, 8.8652, 8.8439,
8.7996, 8.6889, 8.6889, 8.1916, 7.8643, 7.8643, 7.6938, **6.5810**,
30.2500}

According to the output vector of LOSS, some observations are provided as follows:

- High Accurate Solution

The results of the practical methodology maintain the same accuracy as the results of the original Key-Part Based Lead Time Management. It is an identity transformation from Formula 1 that is the objective function of the original Key-Part Based Lead Time Management into Formula 12 that is the objective function of the practical methodology.

- Calculation quickly

From results in the output vector, the key part is easily obtained by determining where the minimum value is. In the present case study, the key part is located at the 49th part (in bold type) with the total inventory loss of $6.581.

- Highly Integrated Process

All of the desired results, namely both the key part location and the minimum total loss, are collected in the output vector.

In conclusion, we realize that the practical methodology of the Key-Part Based Lead Time Management is a concise, accurate and integrated methodology. So, the practical methodology of the Key-Part Based purchase methodology helps companies to reduce the considerable lead time waste and then to obtain the satisfying purchase policy in reality.

Chapter 7

Proof of the Sufficient Conditions of Existence of the Key Part and Demonstration of the Robustness of the Key Part

In order to lay foundation for the Key-Part Based Lead Time Management in theory, it is useful to prove sufficient conditions of existence of the key part and demonstrate the robust conditions of the key part.

In proving the sufficient conditions of existence of the key part, an exclusive method is built to obtain the key part. Therefore, it concludes that the sufficient conditions of key part exists; in demonstrating the robust conditions of the key part, six experiments based on the DOE (Design of Experiment) are designed to show that the key part is robust to variation of the part cost, the part lead time, the holding cost, the customer penalty, the key part cost, and the key part lead time.

The detailed procedures are described in the following.

7.1 Proof of the Sufficient Conditions of Existence of the Key Part

In principle, the method for proving is that if we reveal how to obtain the key part, we can say that the sufficient conditions of the key part exist. In the present thesis, the whole proving consists of the definition of parameters and vectors, the procedures, and the conclusions.

7.1.1 Definition

Prior to proving the sufficient conditions of the key part, the definition of the parameters and vectors is provided from earlier chapters. They are summarized as follows:

h : The part holding cost in the warehouse

p_e : The customer penalty

$\{T_1, ...T_i......T_n\}$: The vector of the part lead time

$\{C_1, ...C_i......C_n\}$: The vector of the part cost

7.1.2 Procedures

In the present thesis, there are seven established steps to obtain the key part. Each step is listed as follows:

1) Define the transfer matrix: $Z_1 = \begin{pmatrix} T_{1w} & T_{2w} & .... & T_{(n-1)w} & T_{nw} \\ T_{2w} & T_{2w} & .... & T_{(n-1)w} & T_{nw} \\ .... & .... & .... & .... & .... \\ T_{(n-1)w} & T_{(n-1)w} & .... & T_{(n-1)w} & T_{nw} \\ T_{nw} & T_{nw} & .... & T_{nw} & T_{nw} \end{pmatrix}_{n \times n}$

Where:

T_{iw}: The waiting time for part i in the warehouse. This can be calculated from the maximum lead time in the network minus the lead time of the part i. $T_{iw} = \max\{T_j\} - T_i$.

2) Define the transfer matrix Z_2:

$$Z_2 = \begin{pmatrix} f(t^1{}_{1w}) & f(t^2{}_{2w}) & \cdots & f(t^{n-1}{}_{(n-1)w}) & f(t^n{}_{nw}) \\ f(t^1{}_{2w}) & f(t^2{}_{2w}) & \cdots & f(t^{n-1}{}_{(n-1)w}) & f(t^n{}_{nw}) \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ f(t^1{}_{(n-1)w}) & f(t^2{}_{(n-1)w}) & \cdots & f(t^{n-1}{}_{(n-1)w}) & f(t^n{}_{nw}) \\ f(t^1{}_{nw}) & f(t^2{}_{nw}) & \cdots & f(t^{n-1}{}_{nw}) & f(t^n{}_{nw}) \end{pmatrix}_{n \times n}$$

Where:

$t^j{}_{iw}$: The status that the waiting time of the part i while part j as the dummy key part.

$f(t^j{}_{iw})$: The function of the probable delay time to final products based on the status of $t^j{}_{iw}$.

3) Define the vector of the part cost $C = \begin{pmatrix} C_1 \\ C_2 \\ \cdots \\ C_{n-1} \\ C_n \end{pmatrix}$

Where:

C_i: The cost of the part i.

4) Define the vector of the part lead time: $T = \begin{pmatrix} T_1 \\ T_2 \\ ..... \\ T_{n-1} \\ T_n \end{pmatrix}$

Where:

T_i: The lead time of the part i.

5) Define the constant parameters of h, p_e based on the history records.

6) Calculate

$$\begin{pmatrix} Loss(1) \\ Loss(2) \\ ..... \\ Loss(n-1) \\ Loss(n) \end{pmatrix} = h \times Z_1 \times C + p_e \times Z_2 \times T$$

Where:

$Loss(i)$: The total inventory loss while the dummy key part is located at the part i.

7) k is obtained if

$Loss(k) = \min\{Loss(i)\}$

In addition, if there is more than one key part in the output vector, the favorable key part is selected in terms of the specific situation of companies. In labor intensive companies for mass production, because the value of the final products is relatively lower, the companies are more concerned about the customer penalty caused by the part lead time than about the loss caused by the part holding cost. So, the favorable key part is chosen in terms of the part with the shortest lead time. However, in capital intensive or technical intensive companies, because parts are relatively expensive, companies are more concern about the holding cost. So, the choice of the favorable key part is based on the part with the most expensive price.

7.1.3 Conclusion

In conclusion, by following a series of specific steps, the key part is determined in terms of the lowest value in the output vector. Finally, it suffices that the key part exists in the satisfying purchase schedules.

7.2 Demonstration of the Robustness of the Key Part

The robustness of the key part position is important. From the viewpoint of companies, if the position of the key part is too sensitive to variation, companies need to update the key part frequently whenever the variation occurs. If the position of the key part is robust to variation, companies can make a relatively stable purchasing handbook that includes a detailed purchase policy based on the fixed key part. However, if a global supply chain network changes dramatically, a new updated key part must be determined based on the changed status.

In the present thesis, the variation is defined as the act of changing or altering something slightly but noticeably from the norm or standard. The robustness is defined on how insensitive the position of the key part is to the presence of input variation. Incomplete induction is used to demonstrate that the key part is robust to input variation.

7.2.1 DOE Table

Design of Experiment (DOE) is a structured, organized method for determining the relationship between the input variation and the position of the key part.

The general DOE consists of the following seven steps: setting objectives, selecting process variables, selecting an experimental design, executing the design, checking that the data are consistent with the experimental assumptions, analyzing and interpreting the results, and presenting the results.

In the present thesis, the variation of the key part is caused by the variables. Those variables are classified into external variables, internal variables, and shadow of the key part. The external variables consist of the holding cost (h) and the customer penalty (P_e); the internal variables consist of the part lead time T_i and the part costs C_i; the variables of the key part consist of the shadow price and shadow lead time (Benbow, 2002). All those variables are designed into DOE experiments and listed in Table 2.

DOE: Key Part Robust to Variation		
Run	Variable	Levels
1	Part costs	4
2	Part lead time	4
3	Customer penalty	4
4	Holding cost	4
5	Shadow cost of the Key Part	4
6	Shadow lead time of the Key Part	4

Table 2: DOE Designs

7.2.2 Variation from the Part Costs

In the first experiment, variation from the part cost is considered. The whole experiment process is presented as follows:

1) Assuming variation:

Suppose that the cost of all parts in a product fluctuates by α times concurrently caused by for example the worldwide energy shortage.

2) Designing the experiment:

Four levels are devised on the basis of : $\alpha = 0.9$, $\alpha = 1, \alpha = 1.1, \alpha = 1.2$

3) Executing: (Program 7)

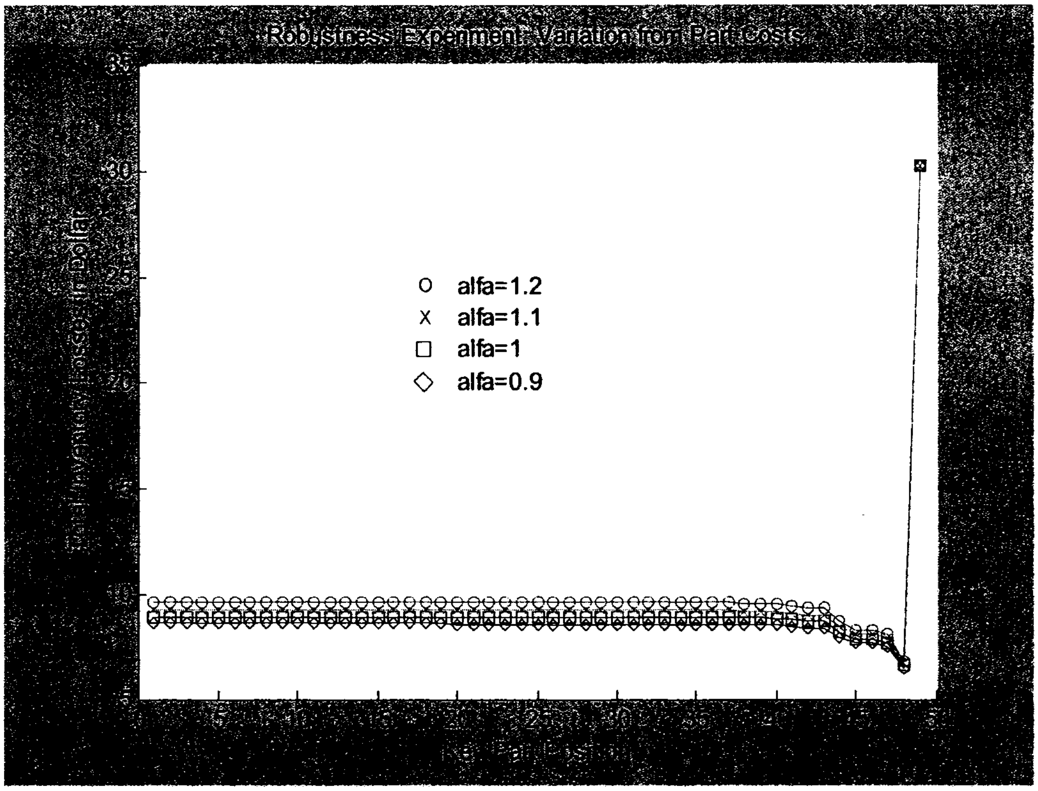

Figure 29: Robustness Experiment: Variation from the Part Cost

4) Results:

In Figure 29, each key part in the four groups is consistently located at the last 2nd part. So, it concludes that the position of the key part is robust to variation from the part cost.

7.2.2 Variation from the Part Lead Time

In the second experiment, the variation from the part lead time is considered. The whole experiment process is presented as follows:

1) Assuming variation:

Suppose that the lead time of all parts in a product is influenced α times concurrently.

2) Designing the experiment:

Four levels are devised on the basis of: $\alpha = 0.9, \alpha = 1, \alpha = 1.1, \alpha = 1.2$

3) Executing: (Program 8)

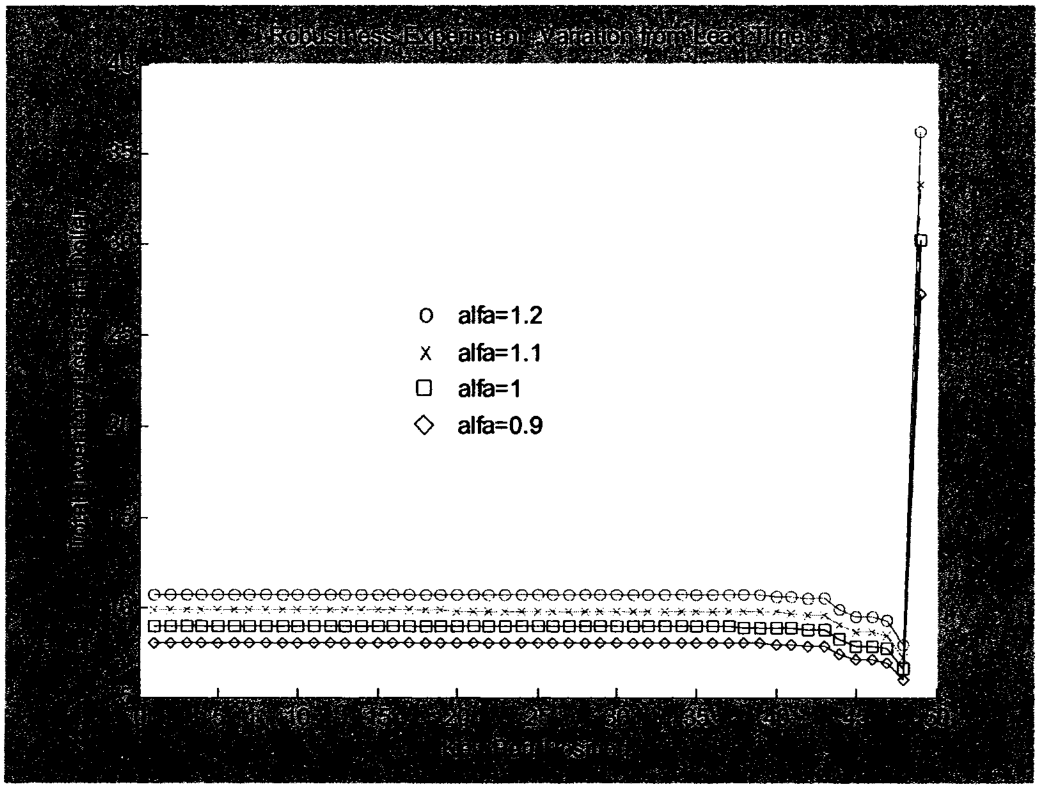

Figure 30: Robustness Experiment: Variation from the Part Lead Time

4) Results

In Figure 30, each key part in the four groups is consistently located at the last 2nd part. So, it is concluded that the position of the key part is robust to variation from the part lead time.

7.2.3 Variation from the Customer Penalty

In the third experiment, variation from the customer penalty is considered. The whole experiment process is presented as follows:

1) Assuming variation:

Suppose that the customer penalty (p_e) caused by markets is affected α times.

2) Designing the experiment:

Four levels are devised on the basis of: $\alpha = 1$, $\alpha = 1.4$, $\alpha = 1.8$, $\alpha = 2.2$

3) Executing: (Program 9)

4) Results:

In Figure 31, each key part in the four groups is consistently located at the last 2^{nd} part. So, it is concluded that the position of the key part is robust to variation from the customer penalty.

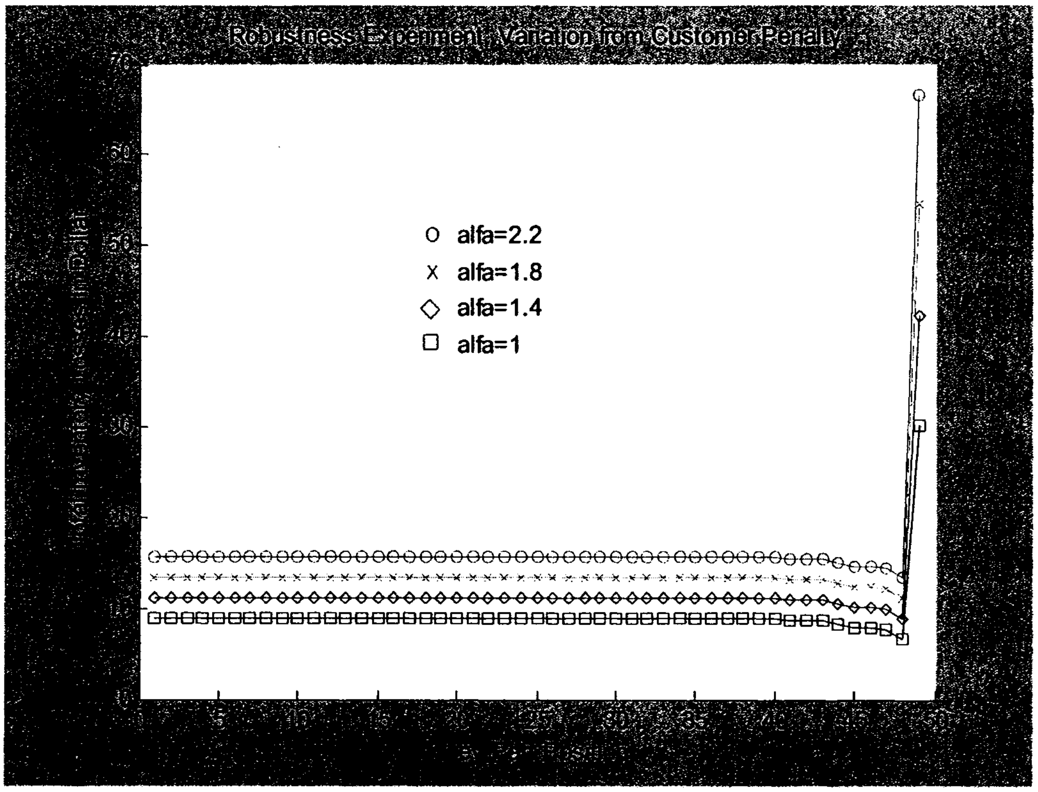

Figure 31: Robustness Experiment: Variation from the Customer Penalty

7.2.4 Variation from the Holding Cost

In the fourth experiment, variation from the holding cost is considered. The whole experiment process is presented as follows:

1) Assuming variation:

Suppose that holding cost (h) at the warehouse is affected α times.

2) Designing the experiment:

Four levels are devised on the basis of: $\alpha = 1$, $\alpha = 2, \alpha = 3, \alpha = 4$.

3) Executing: (Program 10)

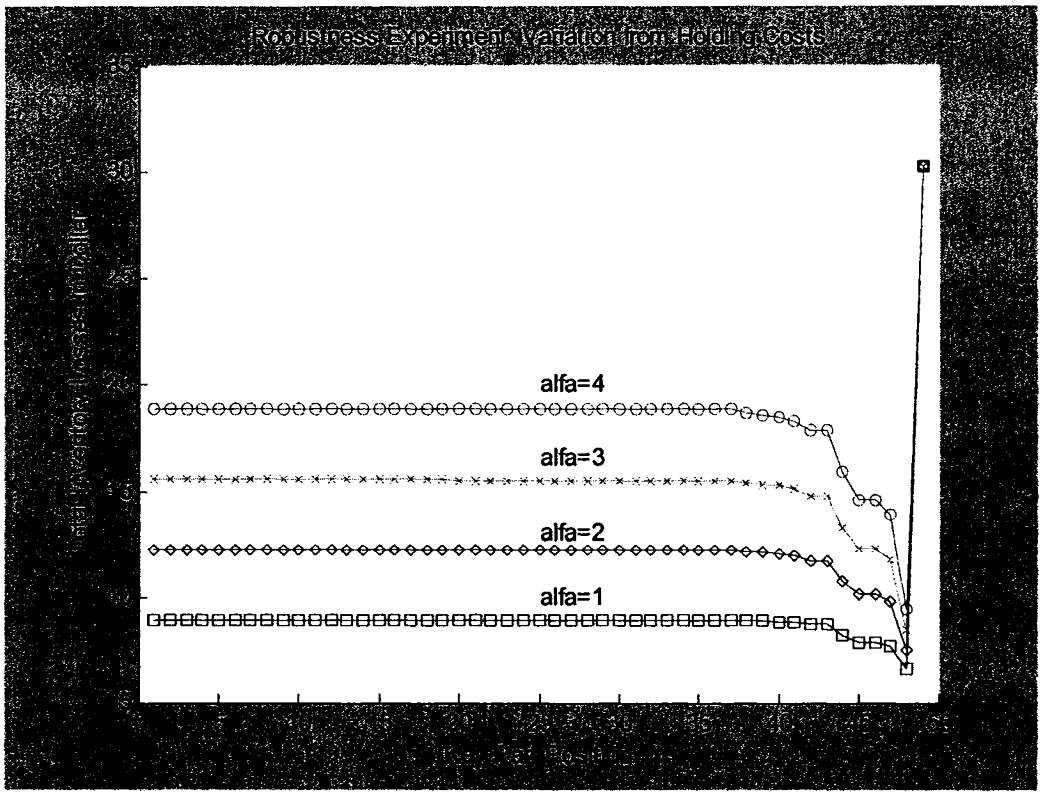

Figure 32: Robustness Experiment: Variation from the Holding Cost

4) Results

In Figure 32, each key part in the four groups is consistently located at the last 2nd part. So, it is concluded that the position of the key part is robust to variation from the holding cost.

7.2.5 Variation from the Shadow Cost of the Key Part

In the fifth experiment, variation from the shadow cost of the key part is considered. The whole experiment process is presented as follows:

1) Assuming variation:

Suppose that the cost from the key part is changed α times.

2) Designing the experiment:

Four levels are devised on the basis of: $\alpha = 1$, $\alpha = 2, \alpha = 3, \alpha = 4$.

3) Executing: (Program 11)

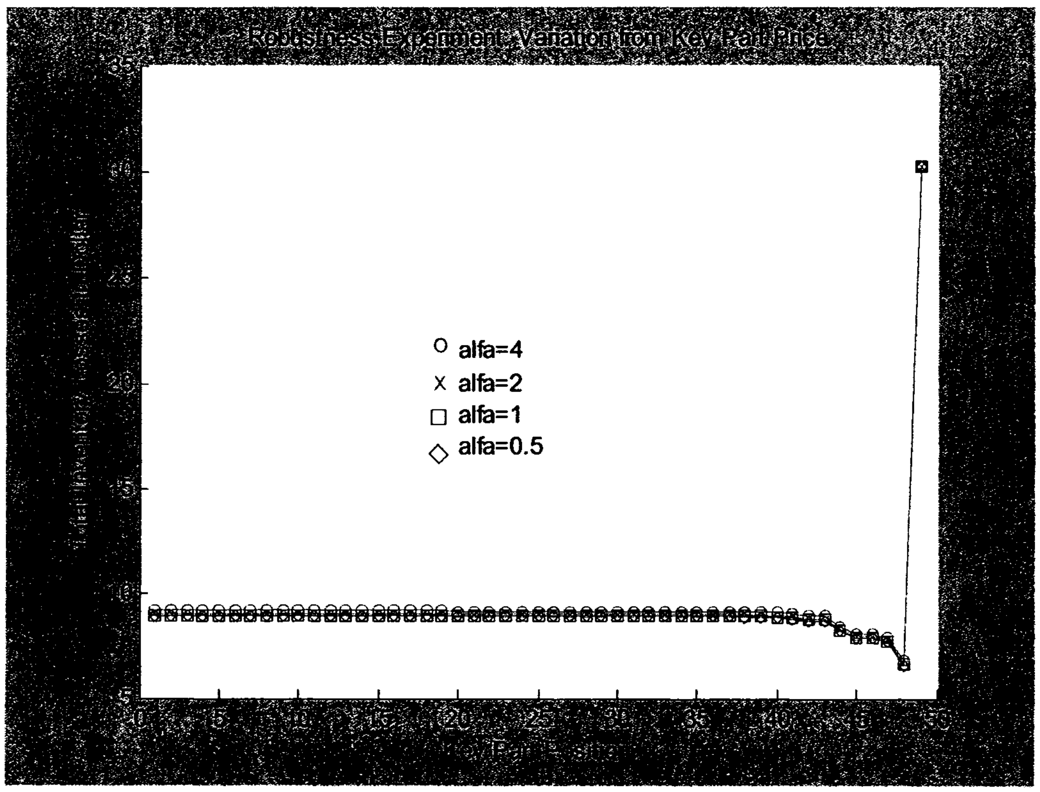

Figure 33: **Robustness Experiment: Variation from the Cost of the Key Part**

4) Results

In Figure 33, each key part in the four groups is consistently located at the last 2nd part. So, it is concluded that the position of the key part is robust to variation from the shadow cost of the key part.

7.2.6 Variation from the Shadow Lead Time of the Key Part

In the sixth experiment, variation from the shadow lead time of the key part is considered. The whole experiment process is presented as follows:

1) Assuming variation:

Suppose that the lead time of the key part is changed α times.

2) Designing experiment:

Four levels are devised as follows:

Lead time= 41^{days} $(\alpha = 0.59)$, lead time= 63^{days} $(\alpha = 0.90)$,

Lead time= 70^{days} $(\alpha = 1.00)$, lead time= 84^{days} $(\alpha = 1.20)$

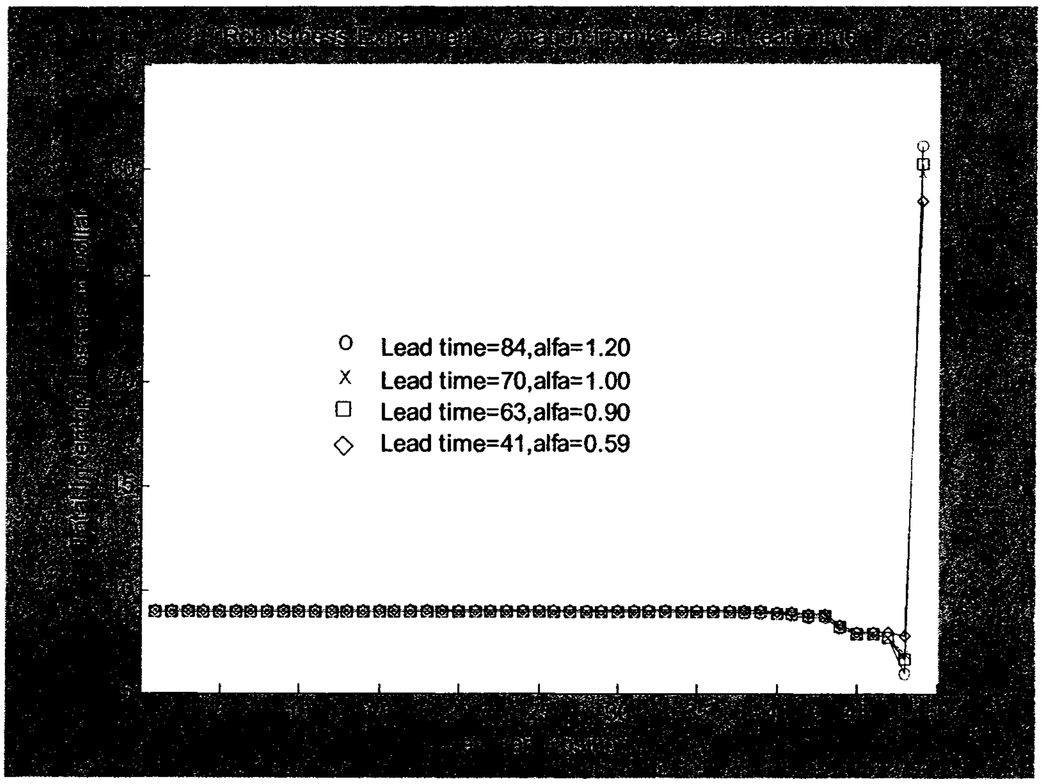

Figure 34: Robustness Experiment: Variation from the Lead Time of the Key Part

3) Executing: (Program 12)

4) Remarks:

In the group of the lead time= 41^{days} ($\alpha = 0.59$), the changed lead time of the key part is so huge that the arriving order of the parts is altered. However, we can still observe that the position of the key part is stable.

5) Results

In Figure 34, each key part in the four groups is consistently located at the last 2^{th} part. So, it is concluded that the position of the key part is robust to variation from the shadow lead time of the key part.

Chapter 8

Conclusion and Future Research

The Key-Part Based Lead Time Management has been established in the present thesis to provide a satisfying purchase policy for companies that have been practicing a Make-to-Order production in a global supply chain network. Some achievements presented in the present thesis are the following:

- A complete system of the Key-Part Based Lead Time Management has been established. This includes the elements of concepts, definitions, parameters, formulas, simulation programs, the practical methodology, proofs in the existences, and demonstration in robustness.

- A bridge between the Key-Part Based Lead Time Management and the MRP system has been constructed. The new combination system is in the following: starting from the MRP system to obtain the required part lists for a final product, the Key-Part Based Lead Time Management establishes a satisfying part purchase policy. Therefore, the total inventory loss in finance is reduced dramatically.

However, development of the Key-Part Based Lead Time Management is just in the starting phase. It still needs to be developed in both directions. In the one direction, more factors in objective functions can be considered to promote the accuracy in the real world; in another direction, the classic mathematic theory should be introduced to prove the sufficient and necessary conditions of existence and robustness of the key part.

8.1 Consideration of More Kinds of Losses in the Objective Function

The scope of two basic losses in objective functions needs to be expanded. In the present thesis, only two kinds of loss are dealt with. One is the holding cost, and another is the customer penalty. The holding cost can be replenished by losses from other kinds of loss such as the warehouse rent, the overhead cost, the deteriorative loss, and the scrap rates (Harhalakis and Yang, 1988); the customer penalty can be replenished by other kinds of loss such as the effects of the loss of reputation and indirect loss of customers.

In addition, the new kinds of financial loss need to be reflected in objective functions such as shortage loss, and order cost, etc.

8.2 Proof of the Sufficient and Necessary Conditions of Existence and Robustness of the Key Part

In Chapter 7, we have proved that the key part exists in sufficient conditions that are not necessary. In order to establish our theory completely, the necessity conditions need to be proved in the future research. Some mathematical tools such as Graph

Theory, Neural Network Design or Queue Theory (Foulds, 1994) are expected to prove the necessity of the existence of the key part.

In the field of robustness, the position of the key part is robust to variation as demonstrated by incomplete induction. In such illustrations, six sources of variation including the holding cost (H), the customer penalty (P_e), the part lead time (T_i), the part costs C_i, the key part price, and the lead time of the key part are grouped into four levels. According to logical thinking, incomplete induction is imperfect; therefore, a stricter more complete mathematical reasoning should be applied in future research.

8.3 Consideration of the Random Process

Parts with random lead time need to be reflected in the Key-Part Based Lead Time Management. Generally, the lead time of parts is fixed in a mature global supply chain network; however, in some cases, the lead time of parts is uncertain because of the supply and demand for fairly generic parts, or because of the insufficient capacity at the manufacturers (Song, 2000).

Parts with random purchasing quantity need to be considered in the Key-Part Based Lead Time Management. In some cases, the customers may be allowed to adjust the order quantity between placement of the order and the due date. So, the demand quantity is stochastic.

In future, the Key-Part Based Lead Time Management will be more perfect. By proving the sufficient and necessary conditions, the key part definitely exists in the satisfying purchase schedules; by replenishing more factors in objective functions, the Key-Part Based Lead Time Management will be precise; by considering the uncertain process including random part lead times and random part purchasing quantity, the Key-Part Based Lead Time Management will be applied to more wide areas.

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Appendix 1

Introduction to Case Study

A Canadian Company, H Company, designs and manufactures central vacuum cleaners in Montreal and distributes its products in North American and European markets. Since establishing the company in 1967, H Company has purchased parts from a local supply chain network and executed a Make-to-Stock production; in the 1990s, the company had to transform its production to the Make-to-Order system and purchase parts in a global supply chain network caused by fierce international competitions; in the 2000s, the company has been operating very well with the new status and has proposed some projects to reduce the lead time waste.

Among a series of product lines, the HXX model was selected to be a sample. The reasons are as follows: the standard model, HXX, has such an outstanding quality with an excellent price and a mass production that it is called the "ultimate in central vacuum systems" as can be seen in Figure 33, any improvement of this model in the area of inventory control will bring considerable financial benefits for H Company. The HXX model of the H Company is the ideal case in the present thesis because of its mature global supply chain network and its Make-to-Order production.

In the present thesis, the present case study plays an essential role not only to establish the Key-Part Based Lead Time Management but also to demonstrate robustness of the key part.

A1.1 Product Description

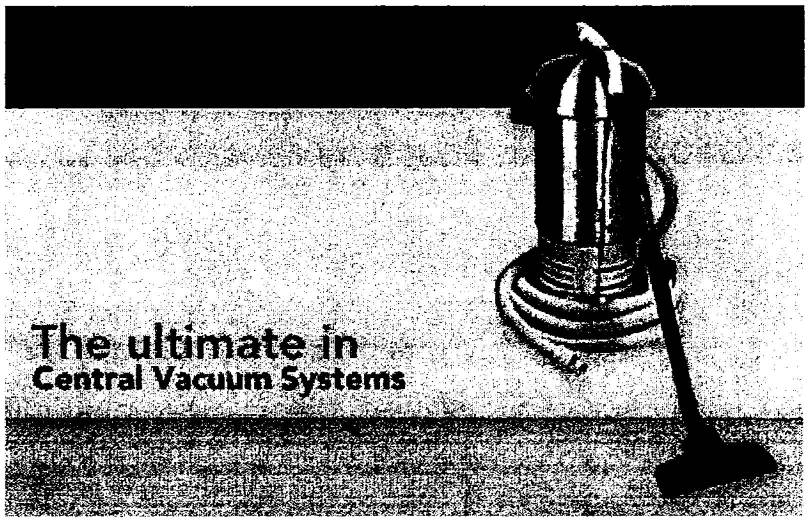

Figure 35: Photo of the Model HXX

Products of the centre vacuum cleaner are not the new faces for Canadian. In the early 1960's, the wonderful invention of PVC (PolyvinylChloride) pipe brought back the concept of the central vacuum system. However, with the advent of a wide range of new technologies in the 1990's, the industry of the central vacuum cleaners began to boom dramatically.

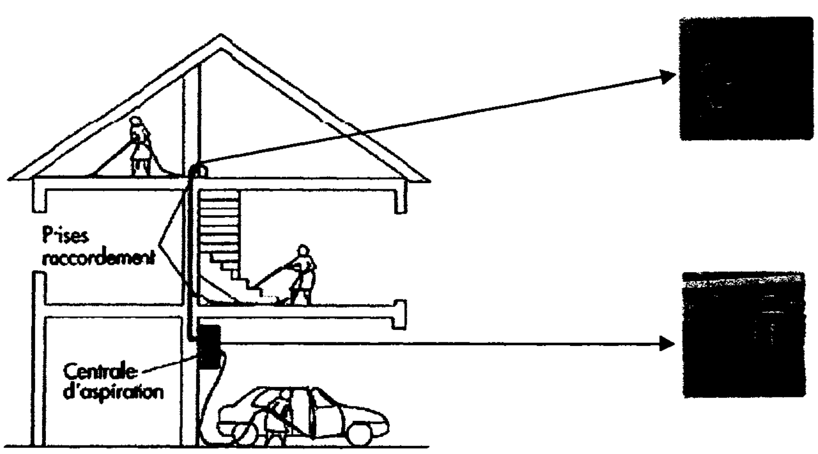

Figure 36: Product Installation: Model HXX

Normally, it is better to plan your central vacuum system while designing your new house because the PVC channels can be placed inside the wall without influencing any beauty of your house (Xiao & Delgado, 2004).

Based on the system installations in Figure 36, a description is provided in the followings:

- A power station in the garage connects to each inlet valve by a network of PVC.
- When any vacuum hose is inserted into one of the inlets, an on & off switch installed on the handle of the hose starts the system automatically.
- Dust is carefully captured and evacuated in a sealed tank far away from the living areas.

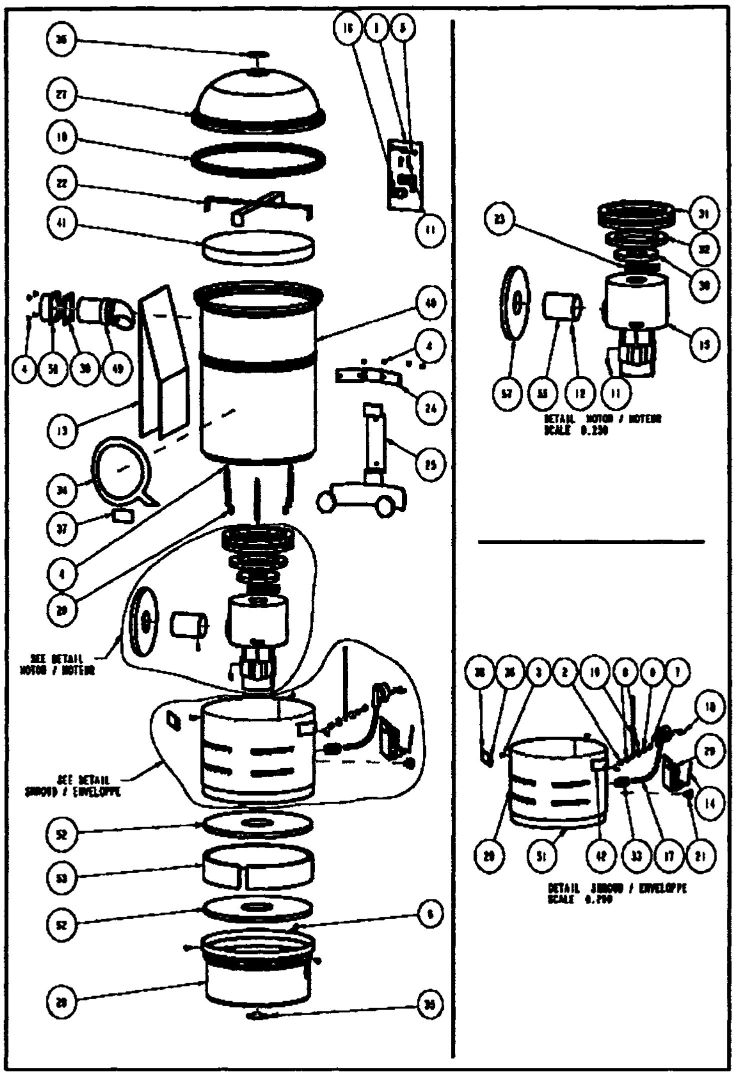

Figure 37: **Explosion of Model HXX**

A1.2 Explosion for Model HXX

In order to acquire clear concepts for the product, the explosion of a machine could greatly help to uncover the assembly procedures and to reveal the part levels.

There are two steps in the realization of the explosion (Figure 37). First, a machine is broken into three blocks, they are the general block on the left side, the motor block on the upper-right side, and the shroud block on the down-right side; secondly, the blocks are broken down into parts with exclusive numbers. All the parts are purchased from a global supply chain network, except the shroud part, which is produced by the H Company itself.

A1.3 BOM (Bill of Materials) of Model HXX

BOM (Bill of materials) is a list in which are specified the parts used to build a complete product. BOM can be used to keep track of the materials and parts used in the product design, purchasing, manufacturing, and customer service.

There is a total 49 part numbers representing 73 individual parts in each product. According to the physical features, all 49 part numbers are divided into groups of the electronic parts, the electrical parts, the hardware parts, the plastic parts, the printing parts, and the packing parts.

The elements of the BOM are as follows: the index number (corresponding to Figure 35), the part number (company own index), the quantities (of the pieces of each product), and the descriptions (technical terms) in Table 3.

Index	Part # Pièce	Qty / Qté	Description
1	1018	1	Plastic bag
2	2212	1	Nylon locknut
3	2219	3	Aluminium rivet 1/2"
4	2223-2	11	Aluminium rivet
5	2227	2	Gyproc screw
6	2230	3	Screw #8 1/2"
7	2232-1	1	Screw 10-24 5/8"
8	2254	2	10-24 hex nut
9	2259	1	Tooth washer
10	2286	1	Cover gasket
11	2287	3	Push-on connector
12	2295	1	Screw #8 1/2"
13	4464	1	Paper bag (PT8510 / SE)
	4464-1	1	Paper bag (Q AIR / PT8610EC* / NAE* / SA* / SAF* / SE)
14	5001	1	Cable tie
15	5108-1	1	Motor (PT8610EC* / NAE* / SA* / SAF*)
	6170	1	Motor (PT8510)
	6172	1	Motor (PT8610SE)
	6174	1	Motor (Q AIR)
	14020	1	Motor (PT8510SE)
16	5114	2	Carbon brush (PT8610EC* / NAE* / SA* / SAF*)
	5114-2	2	Carbon brush (Q AIR)
	---	---	N/A on PT8510 / SE / PT8610SE models
17	6109	1	Power cord (PT8510 / SE / PT8610SE)
	6109-2	1	Power cord (Q AIR / PT8610NAE* / SA* / SAF*)
	6109-7	1	Power cord (PT8610EC*)
18	6109-4	1	Plug protector (PT8510 / SE / PT8610SE)
	6109-5	1	Plug protector (Q AIR / PT8610NAE* / SA* / SAF*)
	---	---	N/A on PT8610EC* model
19	6111	1	Electric wire
20	6114	1	Electric board (PT8510 / SE / PT8610SE)
	6114-10	1	Electric board (Q AIR / PT8610EC* / NAE* / SA* / SAF*)
21	6115	1	Low voltage socket
22	6122	1	Bag protector
23	6124	1	Screen 3" x 3"
24	6124-1N	1	Machine fixing bracket
25	6125-3	1	Wall fixing bracket
26	6156-3	1	Motor shroud (PT8510SE)
	6156-7	1	Motor shroud (PT8510)
	6156-11	1	Motor shroud (PT8610EC* / SA* / SAF* / SE)
	6156-12	1	Motor shroud (Q AIR)
27	6201-1A	1	Cover
28	6201-2A	1	Anti-noise dome
29	6206	3	Retaining spring (PT8510SE / PT8610SE / Q AIR)
	6206-1	3	Retaining spring (PT8610EC* / NAE* / SA* / SAF*)
	2214, 9366, 2260 2254,2212-1 2263	3 3 6	Kit of screws, spacers, washers and nuts (PT8510)
30	7137	1	Motor gasket
31	7138	2	Motor gasket
32	7139	1	Motor gasket
33	7143-1	1	Strain relief
34	9180-1	1	Husky sticker (PT8610SA*)
	9180-2	1	Husky sticker (PT8510 / SE / PT8610EC* / NAE* / SAF* / SE)
	9180-9	1	Husky sticker (Q AIR)
35	9180-4	2	Logo for dome
36	9184	1	Canadien sticker
37	9187-1	1	Caution label (PT8510 / SE / PT8610EC* / NAE* / SAF* / SE, Q AIR)
	9187-1N	1	Caution label (PT8610SA*)
38	9191	1	Motor cut off sticker
	---	--	N/A on PT8510 / SE / PT8610SE models
39	9358-1	1	Intake gasket
40	6104A	1	Aluminium motor support
41	8BA111	1	Protection filter
42	9185B	1	Serial number label
43-48	N/I		
49	BI835N	1	Air intake and deflector
50	N/I		
51	GAB37	1	Foam for shroud
52	GAB39	2	Foam for dome
53	GAB43	1	Foam for dome
54	N/I		
55	VC93A	1	Aluminium exhaust
56	VCF815-1N	1	Air intake
57	WAL2	1	Exhaust gasket

Table 3: BOM of the Model HXX

A1.4 Part Purchase Distribution in Network

It is easy to understand that companies prefer to choose close suppliers because of the lower transportation fares and shorter lead times if other factors are the same. Figure 36 shows that as purchase distance increases in the global supply chain from Montreal, Quebec, Ontario, U.S.A, and China to Europe, the purchased part quantity in each node decreases from 36, 17, 8, 5, 4 to 3 pieces.

There is an exception in the global supply chain network in the present case study. Although the lengths of purchasing route to Chinese companies are further than to European companies. Fierce competition in local Chinese markets leads Chinese companies have shorter manufacturing lead time (MLT) than European companies do. Actually, from the point of view of Montreal-based Companies, the Chinese node is closer than the European node.

Another point to make is the node of the company itself. H Company sub-assembles a certain part, stainless shrouds, before storing them in the warehouse. So, in the global supply chain, the company node can be regarded as the closest node in that network.

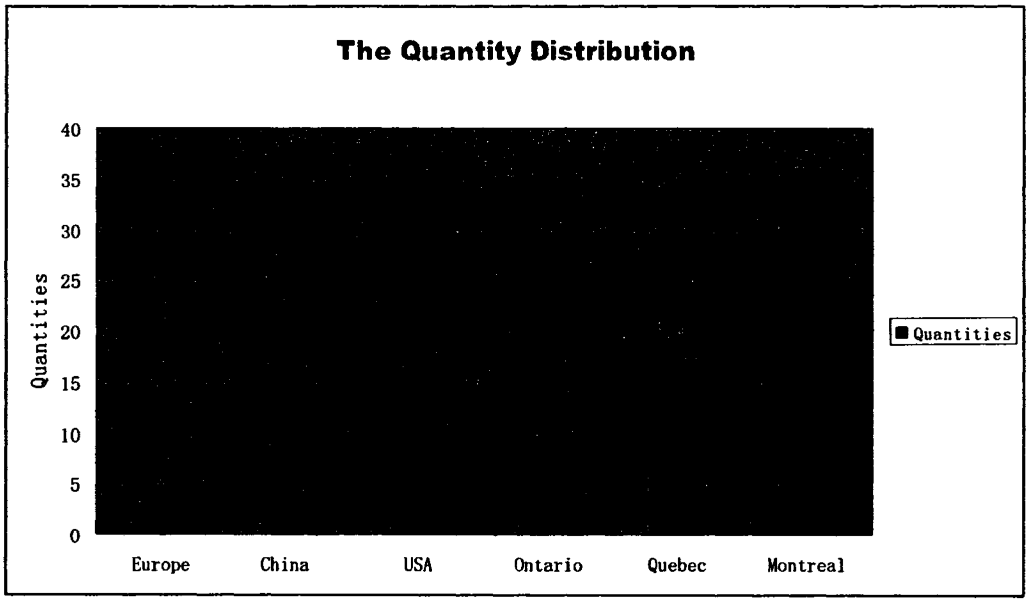

Figure 38: Histogram of the Part Quantity in Network

Finally, a global supply chain network is constructed based on the length of the part lead time, which is the sum of the part manufacturing lead time (MLT) and the part deliver lead time (DLT). In general, the quantity of purchased part is depicted that the larger distance in global supply chain, the fewer part quantity is purchased in that node. This phenomenon is shown in Figure 38.

A1.5 Comparison of Quantities vs. Prices in the Network

There is a co-relationship between part quantities and part prices in a global supply chain network. Smith (1999) presented a model to identify those items which can be beneficially procured from abroad and those that are best obtained locally. In the present case study, the quality of the motors is very important; some European companies are trusted; the cost reduction is expected from the control boards, Chinese products are selected; however, larger numbers of the small parts are purchased locally in Montreal because of convenience. See Figure 39. In general, the reason why company purchases specific parts from more distant nodes is that those parts can not be satisfied requirements of intensive technology or the price advantage from the local supply chain.

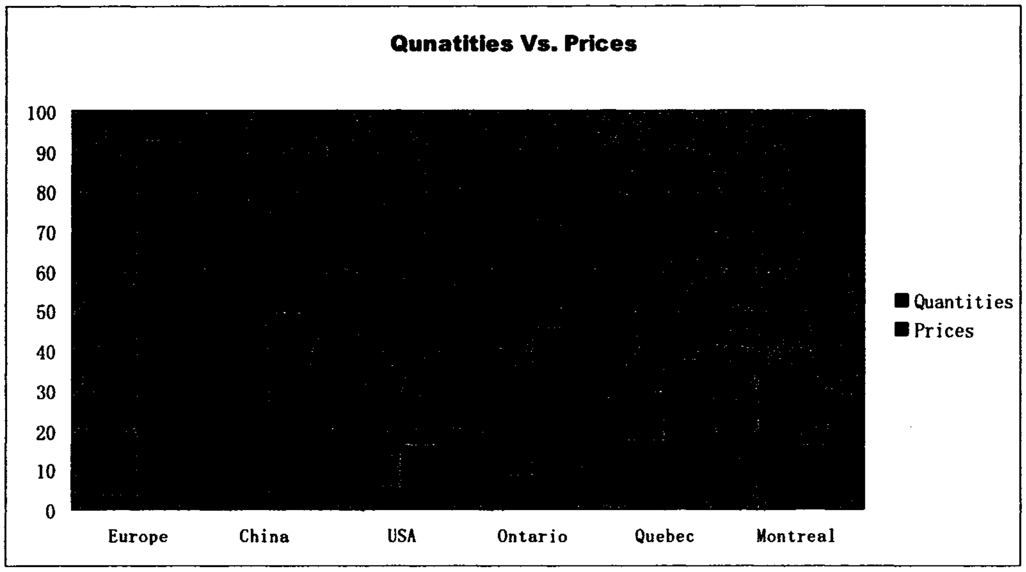

Figure 39: **Histogram for Part Quantities vs. Part Costs in Network**

Overall, a reasonable global supply chain network helps Company H to pursue the best quality assurance from qualified motors, an obvious cost reduction from the Chinese parts, and convenience for trivial many parts from local market.

A1.6 Part Representatives

Part representatives help to formulate a simplified and efficient global supply chain network. As we know, there is at least one part in each node. In order to simplify a global supply chain network, one part representative is chosen based on some certain principles. In the present case study, by considering factors such as part values, part volumes and part availability, the part representatives are selected and listed in Table 4. Finally, a simplified global supply chain network is formulated in which each node represents by only one part.

The part representatives in each node						
China	Europe	USA	Ontario	Quebec	Montreal	Company
Electrical Board	Motor	Shroud mat.	Cover	Paper bag	Sticks	Motor shroud

Table 4: **Part Representative in Each Node**

Appendix 2

Program Collections in Matlab

```
function probabledelaytime=probabledelaytime()
N=40;                          %waiting time in warehouse: days
y=zeros(N,1);                  %probable deferred days for final product
hold on;
T=45
for i=1:40;
    y(i)=T/8*exp(-i/1.6);
end;
i=1:1:40;
plot(i,y(i))
Title('Part: Control Boards')
xlabel('Waiting Time in Warehouse: Days');
ylabel('Potential Delay days for Final Products: Days');
```

Program 1: Programs of Probable Delay Time in Case Study

```
function customerpenalty=customerpenalty()
N=40;                          %the waiting days of the part: days
y=zeros(N,1);                  %the delay days of the final product
hold on;
T=45
for i=1:40;
    y(i)=T/16*exp(-i/1.6)
end;
i=1:1:40;
plot(i,y(i))
Title('Part: Control Boards');
xlabel('Waiting Time in the Warehouse: Days');
ylabel('Probable Customer Penalty: Dollars');
```

Program 2: Programs of Customer Penalty in Case Study

```
function objectivefunction=lossfunction()
N=49;                          %the total types of components
L=zeros(N,N+1);                %loss function
H=0.000274;                    %holding costs
```

```
PE=0.5;                              %customer penalty
T=xlsread('D:\masterthesis\excelthesis.xls','sheet12','b2:b50');        %Data input in lead time
C=xlsread('D:\masterthesis\excelthesis.xls','sheet12','C2:C50');        %Data input in costs
TMAX=T(49);
for k=1:N;
      for i=1:N;
      if i<=k;
           L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(k))+PE*T(i)/8*exp(-(TMAX-T(k))/1.6);
      else;
           L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(i))+PE*T(i)/8*exp(-(TMAX-T(i))/1.6);
      end;
  end;
end;
k=1:1:49;
plot(k,L(k,N+1),'-rs','linewidth' ,1,...
    'MarkerEdgeColor','k',...
    'MarkerFaceColor','g',...
    'MarkerSize',5);
xlabel('Locations of Dummy Key Part');
ylabel('Total Inventory Losses per Product: Dollars');
```

Program 3: Basic Programs for Objective Function

```
function objectivefunction=lossfunction()
%program4: Push production
N=49;                               %the total types of components
%T=zeros(N,1);                      %lead time of components
%C=zeros(N,1);                      %cost of components
L=zeros(N,N+1);                     %   loss function
H=0.000274;                         %holding costs
PE=0;                               %customer penalty
T=xlsread('D:\masterthesis\excelthesis.xls','sheet12','a2:a50');
C=xlsread('D:\masterthesis\excelthesis.xls','sheet12','C2:C50');
TMAX=T(49);
%hold on;
for k=1:N;
      for i=1:N;
      if i<=k;
           L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(k))+PE*T(i)/8*exp(-(TMAX-T(k))/1.6);
      else;
           L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(i))+PE*T(i)/8*exp(-(TMAX-T(i))/1.6);
      end;
  end;
end;
```

```
k=1:1:49;
Loss=L(k,N+1)
plot(k,L(k,N+1),'-rs','linewidth' ,1,...
    'MarkerEdgeColor','k',...
    'MarkerFaceColor','g',...
    'MarkerSize',5);
xlabel('Locations of Dummy Key Part');
ylabel('Total Inventory Losses per Product: Dollars');
title('Push Production');
```

Program 4: Programs of Objective Function in Push Production

```
function objectivefunction=lossfunction()
%comparison of satisfying solution and satisfying solution
N=49;                            %the total types of components
%T=zeros(N,1);                   %lead time of components
%C=zeros(N,1);                   %cost of components
L=zeros(90,N+1);                   %   loss function
H=0.000274;                     %holding costs
PE=0.5;                         %customer penalty
T=xlsread('D:\masterthesis\excelthesis.xls','sheet12','a2:a50');
C=xlsread('D:\masterthesis\excelthesis.xls','sheet12','C2:C50');
TMAX=T(49);
for k=1:90;              % 90 days
      for i=1:49;        % elements N=49
      if T(i)<=k;
          L(k,i+1)=L(k,i)+H*C(i)*(TMAX-k)+PE*T(i)/8*exp(-(TMAX-k)/1.6);
      else;
          L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(i))+PE*T(i)/8*exp(-(TMAX-T(i))/1.6);
      end;
   end;
end;
k=1:1:90;
Loss=L(k,N+1)
plot(k,L(k,N+1),'-gs','linewidth' ,1,...
    'MarkerEdgeColor','k',...
    'MarkerFaceColor','g',...
    'MarkerSize',5);
xlabel('Days');
ylabel('Total Inventory Losses per Product: Dollars');
hold on;
L=zeros(49,49+1);
TMAX=T(49);
```

```
%hold on;
for k=1:49;
        for i=1:49;
        if i<=k;
            L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(k))+PE*T(i)/8*exp(-(TMAX-T(k))/1.6);
        else;
            L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(i))+PE*T(i)/8*exp(-(TMAX-T(i))/1.6);
        end;
    end;
end;
k=1:1:49;
Loss=L(k,N+1)
plot(T(k),L(k,N+1),'-rs','linewidth',1,...
    'MarkerEdgeColor','k',...
    'MarkerFaceColor','r',...
    'MarkerSize',5);
title('Optimal Solution / Satisfying solution');
```

Program 5: Programs of Comparison between Optimal Solution and Satisfying solution

```
% the Practical methodology to Key-Part Based Lead Time Management and its case application
function objectivefunction=lossfunction()
N=49;                    %the total types of components
Z1=zeros(N,N);           %waiting time transfer matric
Z2=zeros(N,N);           %penalty transfer matric
C=zeros(N,1);            %Cost vector
T=zeros(N,1);            %Delay days function
PE=0.5;                  %customer penalty
H=0.000274;              %holding costs
LOSS=zeros(N,1);         %loss matrix
LOSS=H*(Z1*C)+PE*(Z2*T)
End
```

Program 6: Programs of Pratical Way for Key-Part Based Lead Time Management

```
% changing the part costs
function objectivefunction=lossfunction()
%lossfunction.m
N=49;                    %the total types of components
%T=zeros(N,1);           %lead time of components
%C=zeros(N,1);           %cost of components
```

```
L=zeros(N,N+1);                    %   loss function
H=0.000274;                        %holding costs
PE=0.5;                            %customer penalty
hold on;
% the first line at the alfa=1;
T=xlsread('D:\masterthesis\excelthesis.xls','sheet12','a2:a50');
C=xlsread('D:\masterthesis\excelthesis.xls','sheet12','C2:C50');
TMAX=T(49);
for k=1:N;
     for i=1:N;
     if i<=k;
          L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(k))+PE*T(i)/8*exp(-T(i)*(TMAX-T(k))/1.6);
     else;
          L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(i))+PE*T(i)/8*exp(-T(i)*(TMAX-T(i))/1.6);
     end;
  end;
end;
k=1:1:49;
plot(k,L(k,N+1),'-ks','linewidth' ,1,...
     'MarkerSize',5);
text(20,21.5,'alfa=1');
% the second line at the alfa=0.9
T=xlsread('D:\masterthesis\excelthesis.xls','sheet12','a2:a50');
C=xlsread('D:\masterthesis\excelthesis.xls','sheet12','C2:C50');
TMAX=T(49);
for k=1:N;
     for i=1:N;
     if i<=k;
          L(k,i+1)=L(k,i)+H*C(i)*0.9*(TMAX-T(k))+PE*T(i)/8*exp(-T(i)*(TMAX-T(k))/1.6);
     else;
          L(k,i+1)=L(k,i)+H*C(i)*0.9*(TMAX-T(i))+PE*T(i)/8*exp(-T(i)*(TMAX-T(i))/1.6);
     end;
  end;
end;
k=1:1:49;
plot(k,L(k,N+1),'-bd','linewidth' ,1,...
     'MarkerSize',5);
text(20,20,'alfa=0.9');
% the third line at the alfa=1.1
T=xlsread('D:\masterthesis\excelthesis.xls','sheet12','a2:a50');
C=xlsread('D:\masterthesis\excelthesis.xls','sheet12','C2:C50');
TMAX=T(49);
for k=1:N;
     for i=1:N;
```

```
        if i<=k;
            L(k,i+1)=L(k,i)+H*C(i)*1.1*(TMAX-T(k))+PE*T(i)/8*exp(-T(i)*(TMAX-T(k))/1.6);
        else;
            L(k,i+1)=L(k,i)+H*C(i)*1.1*(TMAX-T(i))+PE*T(i)/8*exp(-T(i)*(TMAX-T(i))/1.6);
        end;
    end;
end;
k=1:1:49;
plot(k,L(k,N+1),'-gx','linewidth',1,...
        'MarkerSize',5);
text(20,23,'alfa=1.1');
hold on;
% the fourth line at the alfa=1.2
T=xlsread('D:\masterthesis\excelthesis.xls','sheet12','a2:a50');
C=xlsread('D:\masterthesis\excelthesis.xls','sheet12','C2:C50');
TMAX=T(49);
for k=1:N;
        for i=1:N;
        if i<=k;
            L(k,i+1)=L(k,i)+H*C(i)*1.2*(TMAX-T(k))+PE*T(i)/8*exp(-T(i)*(TMAX-T(k))/1.6);
        else;
            L(k,i+1)=L(k,i)+H*C(i)*1.2*(TMAX-T(i))+PE*T(i)/8*exp(-T(i)*(TMAX-T(i))/1.6);
        end;
    end;
end;
k=1:1:49;
plot(k,L(k,N+1),'-ro','linewidth',1,...
        'MarkerSize',5);
text(20,24.5,'alfa=1.2');
xlabel('Key Part Position');
ylabel('Total Inventory Losses in Dollar');
title('Robustness Experiment: Variation from Part Costs')
```

Program 7: Robustness Experiment with Variation from Part Costs

```
% changing the lead times
function objectivefunction=lossfunction()
%lossfunction.m
N=49;                   %the total types of components
%T=zeros(N,1);          %lead time of components
%C=zeros(N,1);          %cost of components
L=zeros(N,N+1);         %  loss function
H=0.000274;             %holding costs
PE=0.5;                 %customer penalty
hold on;
```

```
% the first line at the belta=1;
T=xlsread('D:\masterthesis\excelthesis.xls','sheet12','a2:a50');
C=xlsread('D:\masterthesis\excelthesis.xls','sheet12','C2:C50');
TMAX=T(49);
for k=1:N;
        for i=1:N;
        if i<=k;
             L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(k))+PE*T(i)/8*exp(-T(i)*(TMAX-T(k))/1.6);
        else;
             L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(i))+PE*T(i)/8*exp(-T(i)*(TMAX-T(i))/1.6);
        end;
   end;
end;
k=1:1:49;
plot(k,L(k,N+1),'-ks','linewidth' ,1,...
        'MarkerSize',5);
text(20,22,'alfa=1');
% the second line at the belta=0.9
T=xlsread('D:\masterthesis\excelthesis.xls','sheet12','a2:a50');
C=xlsread('D:\masterthesis\excelthesis.xls','sheet12','C2:C50');
TMAX=T(49);
for k=1:N;
        for i=1:N;
        if i<=k;

L(k,i+1)=L(k,i)+H*C(i)*0.9*(TMAX-T(k))+PE*T(i)*0.9/8*exp(-T(i)*0.9*0.9*(TMAX-T(k))/1.6);
        else;

L(k,i+1)=L(k,i)+H*C(i)*0.9*(TMAX-T(i))+PE*T(i)*0.9/8*exp(-T(i)*0.9*0.9*(TMAX-T(i))/1.6);
        end;
   end;
end;
k=1:1:49;
plot(k,L(k,N+1),'-bd','linewidth' ,1,...
        'MarkerSize',5);
text(20,20,'alfa=0.9');
% the third line at the belta=1.1
T=xlsread('D:\masterthesis\excelthesis.xls','sheet12','a2:a50');
C=xlsread('D:\masterthesis\excelthesis.xls','sheet12','C2:C50');
TMAX=T(49);
for k=1:N;
        for i=1:N;
        if i<=k;
```

```
L(k,i+1)=L(k,i)+H*C(i)*1.1*(TMAX-T(k))+PE*T(i)*1.1/8*exp(-T(i)*1.1*1.1*(TMAX-T(k))/1.6);
        else;

L(k,i+1)=L(k,i)+H*C(i)*1.1*(TMAX-T(i))+PE*T(i)*1.1/8*exp(-T(i)*1.1*1.1*(TMAX-T(i))/1.6);
        end;
    end;
end;
k=1:1:49;
plot(k,L(k,N+1),'-gx','linewidth' ,1,...
         'MarkerSize',5);
text(20,24,'alfa=1.1');
hold on;
% the fourth line at the belta=1.2
T=xlsread('D:\masterthesis\excelthesis.xls','sheet12','a2:a50');
C=xlsread('D:\masterthesis\excelthesis.xls','sheet12','C2:C50');
TMAX=T(49);
for k=1:N;
        for i=1:N;
        if i<=k;

L(k,i+1)=L(k,i)+H*C(i)*1.2*(TMAX-T(k))+PE*T(i)*1.2/8*exp(-T(i)*1.2*1.2*(TMAX-T(k))/1.6);
        else;

L(k,i+1)=L(k,i)+H*C(i)*1.2*(TMAX-T(i))+PE*T(i)*1.2/8*exp(-T(i)*1.2*1.2*(TMAX-T(i))/1.6);
        end;
    end;
end;
k=1:1:49;
plot(k,L(k,N+1),'-ro','linewidth' ,1,...
         'MarkerSize',5);
text(20,26,'alfa=1.2');
xlabel('Key Part Position');
ylabel('Total Inventory Losses in Dollar');
Title('Robustness Experiment: Variation from Lead Time');
```

Program 8: Robustness Experiment with Variation from Part Lead Time

```
% changing the customer penalty
function objectivefunction=lossfunction()
%lossfunction.m
N=49;                          %the total types of components
%T=zeros(N,1);                 %lead time of components
%C=zeros(N,1);                 %cost of components
L=zeros(N,N+1);                 %   loss function
H=0.000274;                    %holding costs
```

```
hold on;
% the first line at the PE=0.5;
PE=0.5;                          %customer penalty
T=xlsread('D:\masterthesis\excelthesis.xls','sheet12','a2:a50');
C=xlsread('D:\masterthesis\excelthesis.xls','sheet12','C2:C50');
TMAX=T(49);
for k=1:N;
    for i=1:N;
    if i<=k;
        L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(k))+PE*T(i)/8*exp(-T(i)*(TMAX-T(k))/1.6);
    else;
        L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(i))+PE*T(i)/8*exp(-T(i)*(TMAX-T(i))/1.6);
    end;
  end;
end;
k=1:1:49;
plot(k,L(k,N+1),'-ks','linewidth' ,1,...
    'MarkerSize',5);
text(20,39,'alfa=1');
% the second line at the PE=0.7
PE=0.7;                          %customer penalty
T=xlsread('D:\masterthesis\excelthesis.xls','sheet12','a2:a50');
C=xlsread('D:\masterthesis\excelthesis.xls','sheet12','C2:C50');
TMAX=T(49);
for k=1:N;
    for i=1:N;
    if i<=k;
        L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(k))+PE*T(i)/8*exp(-T(i)*(TMAX-T(k))/1.6);
    else;
        L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(i))+PE*T(i)/8*exp(-T(i)*(TMAX-T(i))/1.6);
    end;
  end;
end;
k=1:1:49;
plot(k,L(k,N+1),'-bd','linewidth' ,1,...
    'MarkerSize',5);
text(20,43,'alfa=1.4');
% the third line at the PE=0.9
PE=0.9;                          %customer penalty
T=xlsread('D:\masterthesis\excelthesis.xls','sheet12','a2:a50');
C=xlsread('D:\masterthesis\excelthesis.xls','sheet12','C2:C50');
TMAX=T(49);
for k=1:N;
    for i=1:N;
```

```
        if i<=k;
            L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(k))+PE*T(i)/8*exp(-T(i)*(TMAX-T(k))/1.6);
        else;
            L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(i))+PE*T(i)/8*exp(-T(i)*(TMAX-T(i))/1.6);
        end;
    end;
end;
k=1:1:49;
plot(k,L(k,N+1),'-gx','linewidth' ,1,...
        'MarkerSize',5);
text(20,47,'alfa=1.8');
hold on;
% the fourth line at the PE=1.1
PE=1.1;                           %customer penalty
T=xlsread('D:\masterthesis\excelthesis.xls','sheet12','a2:a50');
C=xlsread('D:\masterthesis\excelthesis.xls','sheet12','C2:C50');
TMAX=T(49);
for k=1:N;
        for i=1:N;
        if i<=k;
            L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(k))+PE*T(i)/8*exp(-T(i)*(TMAX-T(k))/1.6);
        else;
            L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(i))+PE*T(i)/8*exp(-T(i)*(TMAX-T(i))/1.6);
        end;
    end;
end;
k=1:1:49;
plot(k,L(k,N+1),'-ro','linewidth' ,1,...
        'MarkerSize',5);
text(20,51,'alfa=2.2');
xlabel('Key Part Position');
ylabel('Total Inventory Losses in Dollar');
title('Robustness Experiment: Variation from Customer Penalty')
```

Program 9: Robustness Experiment with Variation from Customer Penalty

```
% changing the holding cost
function objectivefunction=lossfunction()
%lossfunction.m
N=49;                          %the total types of components
%T=zeros(N,1);                 %lead time of components
%C=zeros(N,1);                 %cost of components
L=zeros(N,N+1);                %   loss function
PE=0.5                         %customer penalty
hold on;
```

```
% the first line at the H=0.000274
H=0.000274;                    %holding costs
T=xlsread('D:\masterthesis\excelthesis.xls','sheet12','a2:a50');
C=xlsread('D:\masterthesis\excelthesis.xls','sheet12','C2:C50');
TMAX=T(49);
for k=1:N;
     for i=1:N;
     if i<=k;
         L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(k))+PE*T(i)/8*exp(-T(i)*(TMAX-T(k))/1.6);
     else;
         L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(i))+PE*T(i)/8*exp(-T(i)*(TMAX-T(i))/1.6);
     end;
  end;
end;
k=1:1:49;
plot(k,L(k,N+1),'-ks','linewidth' ,1,...
     'MarkerSize',5);
text(25,10,'alfa=1');
% the first line at the H=0.000274*2
H=0.000274*2;                  %holding costs
T=xlsread('D:\masterthesis\excelthesis.xls','sheet12','a2:a50');
C=xlsread('D:\masterthesis\excelthesis.xls','sheet12','C2:C50');
TMAX=T(49);
for k=1:N;
     for i=1:N;
     if i<=k;
         L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(k))+PE*T(i)/8*exp(-T(i)*(TMAX-T(k))/1.6);
     else;
         L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(i))+PE*T(i)/8*exp(-T(i)*(TMAX-T(i))/1.6);
     end;
  end;
end;
k=1:1:49;
plot(k,L(k,N+1),'-bd','linewidth' ,1,...
     'MarkerSize',5);
text(25,13,'alfa=2');
% the third line at the H=0.000274*3
H=0.000274*3;                  %holding costs
T=xlsread('D:\masterthesis\excelthesis.xls','sheet12','a2:a50');
C=xlsread('D:\masterthesis\excelthesis.xls','sheet12','C2:C50');
TMAX=T(49);
for k=1:N;
     for i=1:N;
     if i<=k;
```

```
            L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(k))+PE*T(i)/8*exp(-T(i)*(TMAX-T(k))/1.6);
        else;
            L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(i))+PE*T(i)/8*exp(-T(i)*(TMAX-T(i))/1.6);
        end;
    end;
end;
k=1:1:49;
plot(k,L(k,N+1),'-gx','linewidth',1,...
         'MarkerSize',5);
text(25,16.5,'alfa=3');
hold on;
% the fourth line at the H=0.000274*4
H=0.000274*4;                    %holding costs
T=xlsread('D:\masterthesis\excelthesis.xls','sheet12','a2:a50');
C=xlsread('D:\masterthesis\excelthesis.xls','sheet12','C2:C50');
TMAX=T(49);
for k=1:N;
        for i=1:N;
        if i<=k;
            L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(k))+PE*T(i)/8*exp(-T(i)*(TMAX-T(k))/1.6);
        else;
            L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(i))+PE*T(i)/8*exp(-T(i)*(TMAX-T(i))/1.6);
        end;
    end;
end;
k=1:1:49;
plot(k,L(k,N+1),'-ro','linewidth',1,...
         'MarkerSize',5);
text(25,20,'alfa=4');
xlabel('Key Part Position');
ylabel('Total Inventory Losses in Dollar');
title('Robustness Experiment: Variation from Holding Costs')
```

Program 10: Robustness Experiment with Variation from Holding Costs

```
% changing the price of the key part
function objectivefunction=lossfunction()
%lossfunction.m
N=49;                      %the total types of components
%T=zeros(N,1);             %lead time of components
%C=zeros(N,1);             %cost of components
L=zeros(N,N+1);            %   loss function
PE=0.5                      %customer penalty
H=0.000274;                %holding costs
hold on;
```

```
% the first line at the alfa=1
T=xlsread('D:\masterthesis\excelthesis.xls','sheet11','a2:a50');
C=xlsread('D:\masterthesis\excelthesis.xls','sheet11','C2:C50');
TMAX=T(49);
for k=1:N;
    for i=1:N;
    if i<=k;
        L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(k))+PE*T(i)/8*exp(-T(i)*(TMAX-T(k))/1.6);
    else;
        L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(i))+PE*T(i)/8*exp(-T(i)*(TMAX-T(i))/1.6);
    end;
  end;
end;
k=1:1:49;
plot(k,L(k,N+1),'-ks','linewidth',1,...
    'MarkerSize',5);
hold on;
% the second line at the alfa=0.9
T=xlsread('D:\masterthesis\excelthesis.xls','sheet11','a2:a50');
C=xlsread('D:\masterthesis\excelthesis.xls','sheet11','D2:D50');
TMAX=T(49);
for k=1:N;
    for i=1:N;
    if i<=k;
        L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(k))+PE*T(i)/8*exp(-T(i)*(TMAX-T(k))/1.6);
    else;
        L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(i))+PE*T(i)/8*exp(-T(i)*(TMAX-T(i))/1.6);
    end;
  end;
end;
k=1:1:49;
plot(k,L(k,N+1),'-bd','linewidth',1,...
    'MarkerSize',5);
hold on;
% the third line at the alfa=1.1
T=xlsread('D:\masterthesis\excelthesis.xls','sheet11','a2:a50');
C=xlsread('D:\masterthesis\excelthesis.xls','sheet11','E2:E50');
TMAX=T(49);
for k=1:N;
    for i=1:N;
    if i<=k;
        L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(k))+PE*T(i)/8*exp(-T(i)*(TMAX-T(k))/1.6);
    else;
        L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(i))+PE*T(i)/8*exp(-T(i)*(TMAX-T(i))/1.6);
```

```
        end;
    end;
end;
k=1:1:49;
plot(k,L(k,N+1),'-gx','linewidth' ,1,...
        'MarkerSize',5);
hold on;
% the fourth line at the alfa=1.2
T=xlsread('D:\masterthesis\excelthesis.xls','sheet11','a2:a50');
C=xlsread('D:\masterthesis\excelthesis.xls','sheet11','F2:F50');
TMAX=T(49);
for k=1:N;
        for i=1:N;
        if i<=k;
            L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(k))+PE*T(i)/8*exp(-T(i)*(TMAX-T(k))/1.6);
        else;
            L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(i))+PE*T(i)/8*exp(-T(i)*(TMAX-T(i))/1.6);
        end;
    end;
end;
k=1:1:49;
plot(k,L(k,N+1),'-ro','linewidth' ,1,...
        'MarkerSize',5);
xlabel('Key Part Position');
ylabel('Total Inventory Losses in Dollar');
title('Robustness Experiment: Variation from Key Part Price')
text(20,17,'alfa=0.5');
text(20,18.5,'alfa=1');
text(20,20,'alfa=2');
text(20,21.5,'alfa=4');
```

Program 11: Robustness Experiment with Variation from Key Part Costs

```
% changing the key part lead time
function objectivefunction=lossfunction()
%lossfunction.m
N=49;                      %the total types of components
%T=zeros(N,1);              %lead time of components
%C=zeros(N,1);              %cost of components
L=zeros(N,N+1);            %   loss function
PE=0.5                     %customer penalty
H=0.000274;                %holding costs
hold on;
% the first line at the alfa=1
T=xlsread('D:\masterthesis\excelthesis.xls','sheet15','A2:A50');
```

```
C=xlsread('D:\masterthesis\excelthesis.xls','sheet15','B2:B50');
TMAX=T(49);
for k=1:N;
        for i=1:N;
        if i<=k;
            L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(k))+PE*T(i)/8*exp(-T(i)*(TMAX-T(k))/1.6);
        else;
            L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(i))+PE*T(i)/8*exp(-T(i)*(TMAX-T(i))/1.6);
        end;
  end;
end;
k=1:1:49;
plot(k,L(k,N+1),'-ks','linewidth',1,...
        'MarkerSize',5);
hold on;
% the second line at the alfa=0.9
T=xlsread('D:\masterthesis\excelthesis.xls','sheet15','D2:D50');
C=xlsread('D:\masterthesis\excelthesis.xls','sheet15','E2:E50');
TMAX=T(49);
for k=1:N;
        for i=1:N;
        if i<=k;
            L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(k))+PE*T(i)/8*exp(-T(i)*(TMAX-T(k))/1.6);
        else;
            L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(i))+PE*T(i)/8*exp(-T(i)*(TMAX-T(i))/1.6);
        end;
  end;
end;
k=1:1:49;
plot(k,L(k,N+1),'-bd','linewidth',1,...
        'MarkerSize',5);
hold on;
% the third line at the alfa=1.1
T=xlsread('D:\masterthesis\excelthesis.xls','sheet15','G2:G50');
C=xlsread('D:\masterthesis\excelthesis.xls','sheet15','H2:H50');
TMAX=T(49);
for k=1:N;
        for i=1:N;
        if i<=k;
            L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(k))+PE*T(i)/8*exp(-T(i)*(TMAX-T(k))/1.6);
        else;
            L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(i))+PE*T(i)/8*exp(-T(i)*(TMAX-T(i))/1.6);
        end;
  end;
```

```
end;
k=1:1:49;
plot(k,L(k,N+1),'-gx','linewidth' ,1,...
        'MarkerSize',5);
hold on;
% the fourth line at the alfa=1.2
T=xlsread('D:\masterthesis\excelthesis.xls','sheet15','J2:J50');
C=xlsread('D:\masterthesis\excelthesis.xls','sheet15','K2:K50');
TMAX=T(49);
for k=1:N;
      for i=1:N;
      if i<=k;
           L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(k))+PE*T(i)/8*exp(-T(i)*(TMAX-T(k))/1.6);
      else;
           L(k,i+1)=L(k,i)+H*C(i)*(TMAX-T(i))+PE*T(i)/8*exp(-T(i)*(TMAX-T(i))/1.6);
      end;
   end;
end;
k=1:1:49;
plot(k,L(k,N+1),'-ro','linewidth' ,1,...
        'MarkerSize',5);
xlabel('Key Part Position');
ylabel('Total Inventory Losses in Dollar');
title('Robustness Experiment: Variation from Key Part Lead Time')
text(15,17,    'Lead time=41,alfa=0.59');
text(15,18.5,'Lead time=63,alfa=0.90');
text(15,20,    'Lead time=70,alfa=1.00');
text(15,21.5,'Lead time=84,alfa=1.20');
```

Program 12: Robustness Experiment with Variation from Key Part Lead Time

Appendix 3

Data Collections

[redacted]	No.	C: Cost	[redacted]	No.	C: Cost
	1	0.2		31	2.2
	3	0.3		32	1.2
	4	1.1		34	0.5
	5	0.3		35	1
	6	0.45		36	0.5
	7	0.15		37	0.5
	12	0.15		38	0.5
	14	0.1		39	1
	8	2		42	0.5
	9	0.5		51	1
	11	9		52	5
	2	1		53	1
	10	5		57	1
	13	5		55	2.5
	18	3		27	12
	21	2		29	3.3
	23	1.5		40	20
	28	2.5		26	10
	41	3		33	2.5
	19	2		17	6
	22	3		49	3
	24	1.5		56	2
	25	2.5		20	38
	30	1		16	12
				15	80

Table 5: Data of Part Lead Times and Part Costs in Case Study