COST PERFORMANCE AND CUSTOMER SERVICE LEVEL UNDER SUPPLY QUANTITY, PROCESS QUANTITY,AND PROCESS TIMING UNCERTAINTIES IN A FLOW SHOP MANUFACTURING ENVIRONMENT

By

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CHAPTER I

THE PROBLEM AND ITS SETTING

Introduction

Uncertainty or variability is an attribute of change which can be planned or unplanned. It can be more or less certain. Even now, uncertainty is a real world manufacturing problem. It is a major problem that impedes manufacturing success. In manufacturing, almost nothing is perfectly predictable because of uncertain events such as machine breakdowns, material shortages, and variability in demand or supply volume. Uncertainty is one of the major problems for a firm seeking manufacturing flexibility to solve. Uncertainty directly affects the production system. It can create increasing production and inventory costs or unused capacity. For example, when uncertainty exists in manpower planning and purchasing decisions, it can create a costly instability (Ho, Law, and Rampal, 1995).

According to Vollmann, Berry, and Whybark (1992), there are two basic sources of uncertainty in manufacturing systems. The first one is demand uncertainty and the second one is supply uncertainty. Both demand and supply uncertainty are classified into two types: quantity uncertainty and timing uncertainty.

Another view of uncertainty is to categorize it in three basic sources: supply uncertainty, process uncertainty, and demand uncertainty. Each uncertainty is also categorized into two types: quantity uncertainty and timing uncertainty. This differs from the previous view in that it pertains to both process and supplier uncertainty. This view is adopted by Gupta and Brennan (1995). It is also the view adopted by this study. The framework of manufacturing uncertainty addressed in this study is shown in Figure 1.

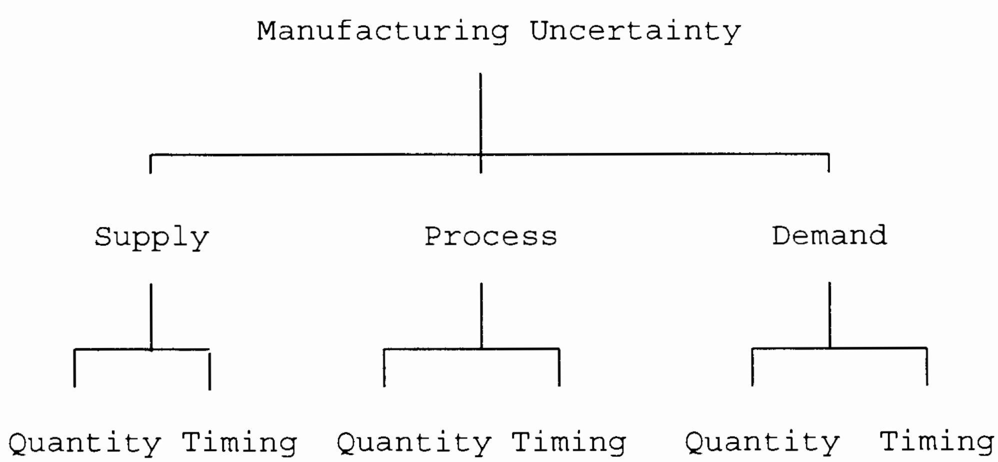


Figure 1. Uncertainty in A Manufacturing System.

Uncertainty in Flow Shop Manufacturing

Flow shop manufacturing is a type of production system within which all jobs visit each machine in the same sequence. A schematic of a four machine flow shop is shown in Figure 2. Uncertainty is often present in this type of system. As show in Figure 2, supply uncertainty occurs before processing, process uncertainty occurs while operating, and demand uncertainty occurs after finishing the manufacturing processes. In this study, only supply uncertainty and process uncertainty are considered.

The quantity actually processed in a period may be greater than or less than the expected plan due to supply or process uncertainty. During processing, a machine might create scrap which is one form of process uncertainty. Scrap or rework can create a high cost in terms of increased work in process and proportional increase in the processing time and increased variability in the number of visits to each machine (Bowman, 1994).

Normally, when process and supply uncertainty exist in a production system, production costs increase because increased uncertainty in process or supply increases the need for safety stock or safety lead time to provide a high service level in terms of meeting the demand quantity without any delay. Unfortunately, protecting against uncertainties by applying safety stock and safety lead time creates increased holding costs. Maintaining high service levels without increased holding cost thus becomes an important problem for firms and an important area for academic research.

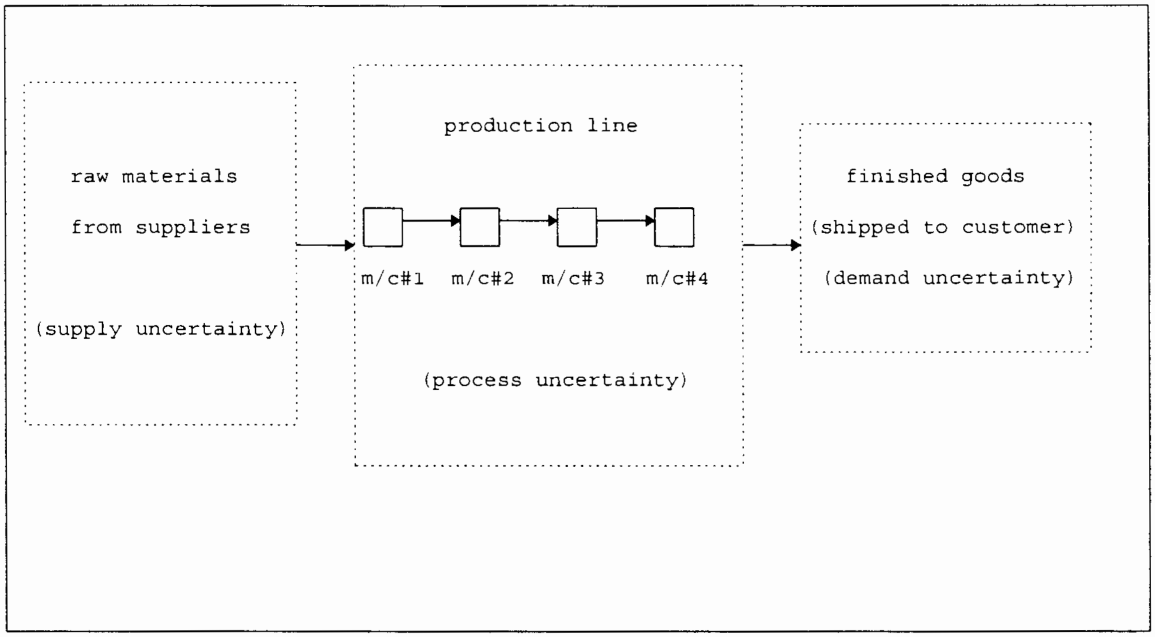


Figure 2. Schematic of Flow Shop Production Line.

Background

Types of Uncertainty

According to Vollmann, Berry, and Whybark (1992), the sources of uncertainty in MRP are classified in two categories;

1. Supply uncertainty that relates to the scheduled receipts for a part.
2. Demand uncertainty that involves changes in the gross requirements for a part.

They further classify uncertainty into two types: quantity uncertainty and timing uncertainty. Table 1 summarizes Vollmann, Berry, and Whybark's approach to the combinations of source and type with respect to uncertainty.

Demand quantity uncertainty

Demand quantity uncertainty in an MRP based system occurs when a Master Production Schedule (MPS) quantity is increased or decreased to reflect a change in the demand forecast or customer orders. It can also occur when there are changes which impact gross requirements of lower level items.

Demand timing uncertainty

Demand uncertainty occurs when timing changes in the projected requirements from period to period. This shift might result from a change in the promise date to a customer or from a change in a planned order for a higher level item.

TABLE I

THE SUMMARY OF SOURCE AND TYPE OF UNCERTAINTY

Type	Source	
	Supply	Demand
Timing	Orders are not received when they are due because of longer supplier lead-time or manufacturing lead-time.	Requirements shift from one period to the next.
Quantity	Orders are received with quantities more or less than planned or defect rates greater than planned.	Required quantity is more or less than order quantity.

Supply quantity uncertainty

Supply quantity uncertainty typically arises when the supplier delivers items less than or greater than the order quantity or when the inventory records overstate or understate the amount of physical inventory (Etienne, 1987).

Supply timing uncertainty

Supply timing uncertainty occurs when the supplier lead times are longer than planned. Therefore, when an order is released, the exact timing of its delivery is uncertain (Whybark and Williams, 1976).

Process quantity uncertainty

Process quantity uncertainty typically arises when scrap rate in a production process is greater than or less than planned (Etienne, 1987).

Process timing uncertainty

Process timing uncertainty occurs when manufacturing lead times are longer or shorter than planned. This means that there is an increase in either processing time or the number of visits to each machine (Bowman, 1994).

Customer Service Level

To assess the impact of uncertainty, measures of the service level and inventory cost are required. According to Greene (1974), customer service level can be defined by the following equation:

$$\text{service level} = \frac{(\text{units supplied without delay}) \times 100}{(\text{units required})}$$

$$= \frac{(\text{units required} - \text{units short}) \times 100}{(\text{units required})}$$

According to Waters (1992), "there are several ways in which customer service level can be measured:

- percentage of orders completely satisfied from stock.
- percentage of units demanded which are met from stock.
- percentage of time there is stock available.
- percentage of stock cycles without shortages.
- percentage of item-month there is available." (p. 151).

The percentage of units demanded which are met from stock is the most common method to measure customer service level (Waters, 1992). This method is considered in this study.

Holding and Stockout Cost

In a "push" production system, when raw materials from suppliers are available, the raw materials will be converted into finished goods by processing. The transformation of raw materials to finished goods is shown in Figure 3.

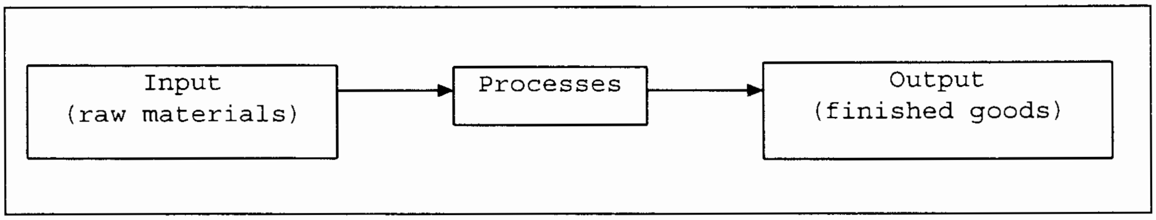


Figure 3: Transformation of Raw Materials to Finished Goods.

Inventory might occur anywhere through the process shown in Figure 3. Inventory may be categorized in three cases which are an accumulation of raw materials from suppliers, an in-process inventory to feed successive steps in production, or a finished goods inventory accumulated to meet customer requirements (Waters, 1992).

Consider the stock of finished goods at the end of a production line. If the rate of production is greater than actual demand, finished goods will accumulate while the line is operating. On the other hand, if the rate of production is less than actual demand, each unit of product is immediately moved to a customer and no stocks are held

(Waters, 1992). Figure 4 shows a manufacturing process producing for stock with finite replenishment rate (A) and finite demand (D). When manufacturing with rate A per unit time, the stock will build up with rate (A-D) per unit time to meet customer need with rate D per unit time. For periods when the amount of production quantity is greater than actual demand ($A_i > D_i$), there is a holding cost for unused units which is $(A_i - D_i)$*HC per unit of time where HC is holding cost per unit time. On the other hand, in periods when the amount of actual demand is greater than the produced quantity ($D_i > A_i$), there is a shortage cost for demand not met. The shortage cost that occurs is $(D_i - A_i)$*SC per unit time where SC is the shortage cost per unit. In the periods when actual demand exactly equals expected demand ($A_i = D_i$), there is neither a holding cost nor a stockout cost for units produced that period.

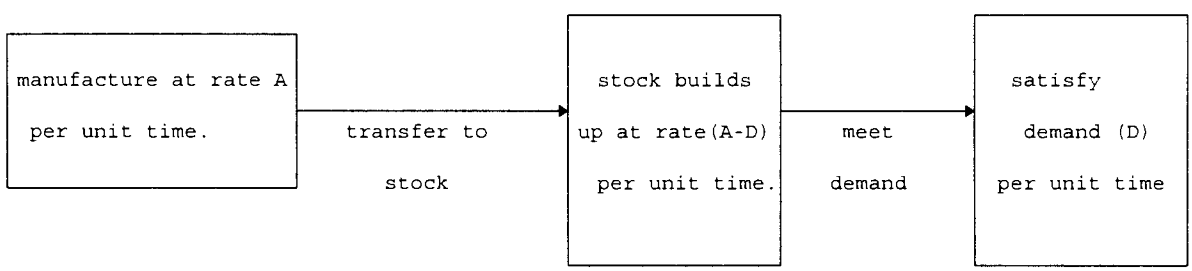


Figure 4. A Manufacturing Procedure for Stock with Finite Replenishment Rate (Waters, 1992).

According to Thomas (1980), there are four methods for determining stockout costs in production. The four cases are as follows:

1. Cost per stockout per incident.
2. Cost per unit time per stockout.
3. Cost per unit time multiplied by units out of stock per stockout.
4. Cost per unit out of stock per stockout.

Whichever is chosen, the stockout cost must be converted to an annual cost by allowing for the number of stockouts expected in a year in order to make it harmonious with the ordering and delivery cost and the inventory holding costs, assuming that all of them are based on annual periods. Cost per unit time multiplied by units out of stock per stockout is evaluated in this study.

The following example illustrates the calculation of stockout cost using each method.

Example: Assume that the stockout data collected in one year is as follows:

stockout no.	#of units out of stock (unit/stockout)	# of periods out of stock (periods/stockout)
1	10	1
2	30	2
3	10	5
4	40	3
5	15	4

stockout cost per incident ($) = 100

stockout cost per period per stockout ($) = 10

stockout cost per period ($) = 2

stockout cost per unit out of stock ($) = 3

Thus, the stockout cost of each method is as follows.

Method 1: By using cost per stockout incident

Cost of stockout = 5 periods/year x $100/period
= $500/year

Method 2: By using cost per period per stockout

Cost of stockout = (1x1x10)+(1x2x10)+(1x5x10)+(1x3x10)+(1x4x10)
= $150/year

Method 3: By using cost per unit time multiplied by units out of stock per stockout

Cost of stockout $= [(1x10)+(2x30)+(5x10)+(3x40)+(4x15)]x2$

$= \$600/year$

Method 4: By using cost per unit out of stock per stockout

Cost of stockout $= [10+30+10+40+15]x3$

$= \$315/year$

In conclusion, holding costs and stockout costs relate directly to manufacturing uncertainty and inventory control. The purpose of inventory control is to minimize the total cost of holding stock while maintaining customer service levels. Within this context, the following sections formally state the research considered within this thesis.

The Problem

Uncertainty is a problem in manufacturing systems which, even now, causes operations to be unsuccessful. It directly affects the production system since it creates increasing production and inventory costs. It also occurs either in flow shop manufacturing or in job shop manufacturing. When uncertainty exists in manufacturing systems, a firm must seek methods to effectively deal with it. At present, much research addresses this issue to reduce its negative impacts. Unfortunately, nearly all of the research focuses on uncertainty in job shop manufacturing. The research reported in this study is in the general area of uncertainty related to flow shop manufacturing. Only supply uncertainty and process uncertainty are considered while the demand is fixed. The purpose of this study is to conduct a sensitivity analysis of the cost performance in terms of inventory holding costs, stockout costs, and customer service level under the combination of process and supply uncertainty in a flow shop manufacturing environment.

Research Objectives

The specific research and objectives of this study are as follows:

1. To investigate how supply and process uncertainty affect cost performance and customer service level.
2. To conduct sensitivity analysis to evaluate cost performance and customer service level under different supply and process uncertainty levels.
3. Based on this study, recommendations on guidelines for manufacturers to help them understand and be able to analyze this issue when they are confronted with these uncertainties are established. For example, when manufacturers are confronted with supply quantity and process quantity uncertainty

that occur simultaneously, guidelines will provide the appropriate recommendations to deal with the priority uncertainty that has the most negative effect on flow shop performance.

The Delimitations

- Normally, process uncertainty is caused from variance in machines, variance in tooling, set up adjustment, operators, materials, and production yield. In this study, production yield is considered as the only cause of process uncertainty.
- In manufacturing systems, supply uncertainty affects flow shop manufacturing. It is separated into two types, quantity uncertainty and timing uncertainty. In this study, only quantity uncertainty is considered. Supply uncertainty is considered when receiving quantities either less than or greater than the expected order quantity.
- Demand for finished goods is constant.
- All operations in the production line have the same mean and variance for processing times. Thus, the result is a balanced line.
- Opportunity cost is not included in this study.

- No transportation times of parts from one machine to the next are considered.
- No blocking to stop the processing of parts is allowed.
- Backorders are not allowed.

The Definitions of Terms

Uncertainty or Variability. An attribute of change which can be planned or unplanned. The change can be more or less certain (or predictable) and more or less variable.

Manufacturing Lead Time. The total time required to manufacture an item from placement of an order to delivery to the customer. It is typically made up of four elements: run time, set up time, move time and queue time.

Production Plan. A plan to produce products. It links strategic goals to production and is coordinated with resource availability, sales objectives, and financial budgets for optimizing.

Master Plan Schedule (MPS): A disaggregated plan for end items or product options as offered to the customers. It provides the basis for making customer delivery promises, utilizing plant capacity effectively, and attaining the firm's strategic objectives as reflected in the production plan.

Flow Shop: A manufacturing environment in which every job must be processed on machines in the same sequence of work stations: operations, machines, and departments (Askin and Standridge, 1993).

Demand Uncertainty: A type of uncertainty wherein requirements vary randomly about some mean value. It can be categorized in two types. The first type is demand quantity uncertainty. This often occurs when forecasts are more or less than the actual demand volume. The second type is demand timing uncertainty. This often occurs when timing changes shift requirements from period to period.

Supply Uncertainty: A type of uncertainty which arises when orders are not received when due, or when the received quantity is more or less than expected. Supply uncertainty can be categorized in two types also. The first type is supply timing uncertainty. It arises from variations in shop flow time or vendor lead times. The second type is supply quantity uncertainty. This occurs when the actual quantity received is not equal to the planned receipt. It can also occur when there are shortages of lower-level materials or when production is overrun.

Safety Stock: A back-up supply of products which are held to use in emergency cases. It is used to satisfy the anticipated maximum demand requirements. Safety stock is often utilized in Material Requirements Planning (MRP) systems where the production is subject to quantity uncertainty problems. For example, safety stock can be applied when confronted with scrap quantities, spare parts demand, or other unplanned usage occurring frequently. According to Waters (1992), safety stock can be categorized in several ways such as raw materials, finished goods, spare parts, and work-in-process.

Safety Lead-time : A procedure in which shop orders or purchase orders are released to arrive one or more periods before requirements. Safety lead time is applied when the major uncertainty is about timing rather than quantity. For example, when the company buys material from vendors who often deliver late.

Holding cost : A cost which occurs when organizations carry materials or finished goods to ensure that the production will continue to function smoothly. Normally, this cost is a relatively high value, with typical costs amounting to 25% of unit cost per year (Waters, 1992).

Stockout cost : A cost which occurs when there is demand for a product whose stock has been exhausted and replenishment cannot be provided in time. In this study, stockout cost per unit is applied to stockouts.

Target customer service rate: The specified probability level that an item is supplied directly from inventory to the customer. For instance, when a company specifies a service level of 95%, it implies that there is a probability of 0.05 that a demand cannot be met from on-hand stock.

Assumptions

1. Uncertainty in a production system is a real world problem.

2. Solving this problem has value.

3. Uncertainty can occur at levels which are greater than or less than expected values.

4. Traditional MRP and MPS techniques are used to plan production.

The Importance of the Study

Uncertainty is one of the major problems which hinders the successful operation of a flow shop environment. It directly impacts the cost performance of the system by increasing inventory levels. In addition, uncertainty can cause an excessive rescheduling of open production orders.

In previous research, nearly all studies analyze the behavior of systems in terms of demand uncertainty, process uncertainty, or supply uncertainty in isolation in job shops. Especially for demand uncertainty, there are many studies involving MRP systems in job shop manufacturing environments. For example, there are many studies concerning lot sizing rules. Similarly, there are few studies about supply uncertainty and there is still a noted gap in the literature on MRP and other production systems which involve this type of uncertainty. Unfortunately, there are few research studies in flow shop manufacturing, especially, considering combinations of uncertainties. The research reported in this study is in the general area of uncertainty related to flow shop manufacturing. Only supply uncertainty and process uncertainty are considered while the demand is fixed.

This study will conduct a sensitivity analysis of the cost performance and its trend, and customer service rate under the combination of supply quantity uncertainty, process quantity uncertainty, and process timing uncertainty when varying the uncertainty intensity by using simulation in a flow shop manufacturing environment. It will provide guidelines for manufacturers to understand and to analyze this concern when they confront and deal with this problem in a production system.

CHAPTER II

THE REVIEW OF THE RELATED LITERATURE

Introduction

Uncertainty is defined as an attribute of change which can be planned or unplanned (Correa, 1994). As stated in the first chapter there are three sources of uncertainty in manufacturing: process, supply, and demand uncertainty. In addition, each source of uncertainty can be classified into two types: quantity uncertainty and timing uncertainty. This framework of uncertainty was illustrated in Figure 1 in the previous chapter.

Uncertainty affects manufacturing cost directly because firms must hold buffer stocks to ensure meeting customer requirements. In the past, most of the research attempted to minimize uncertainty's negative impacts on a job shop production system. They studied uncertainty either isolated by source and type or combined uncertainties focusing on both timing uncertainty and quantity uncertainty. Unfortunately, there are few research studies in flow shop manufacturing, especially, examining combinations of uncertainties.

In this study, process quantity uncertainty, process timing uncertainty, and supply quantity uncertainty are considered in a flow shop system. Sensitivity analysis is conducted to observe the cost performance in terms of holding cost, stockout cost, and customer service level under combinations of all three types of uncertainties. Simulation experiments are conducted to determine the impact of process and supply uncertainty on the cost performance and customer service level.

Buffering Mechanisms for Reducing Uncertainty in Manufacturing Systems

Some researchers attempt to reduce the system nervousness created by uncertainty. Several methods have been recommended to reduce nervousness in order to minimize its negative impacts on production systems. These methods include safety stock, safety lead-time, and safety capacity.

Safety Stock

Safety stock is often used in Material Requirements Planning (MRP) Systems where production is subjected to quantity uncertainty problems. For instance, safety stock can be applied when confronted with scrap quantities, spare parts demand, or other unplanned usage occurring frequently (Vollmann, Berry, and Whybark, 1992). Some researchers conclude that safety stock should be applied only to compensate for forecast errors at the end-item level (Ho, Law, and Rampal, 1995). Sridharan and LaForge (1989) suggest that an increase in safety stock does not necessarily lead to a reduction in schedule instability at the MPS level.

Safety Lead-time

Safety lead time is applied when the major uncertainty is about timing rather than quantity. An example would be when a company buys materials from vendors who often deliver late. Orders from vendors are subject to timing uncertainty due to variability in both transportation times and production (Vollmann, Berry, and Whybark, 1992). Grasso and Taylor (1984) also investigate the effectiveness of using safety stock and safety lead time to deal with timing uncertainty caused by variability in the lead time of purchased items which involve multi-level product structures. They conclude that the use safety lead time is more prudent to counteract supply timing uncertainty than safety stock.

Safety Capacity

Production slack is another buffering mechanism to deal with uncertainty in an MRP system. Production slack can be created by having additional machine capacity, labor, and time. Slack or safety capacity, is used to allow for increasing production in a shop. Unfortunately, it can cause an increased production cost because of the additional costs associated with slack manpower or materials (Vollmann, Berry, and Whybark, 1992; Ho, Law, and Rampal, 1995). It has been shown to be beneficial when dealing with bottleneck work centers (Ho, Law, and Rampal, 1995).

Schmitt (1984) examines the effectiveness of using net change MRP updates, safety capacity, and safety stock to deal with uncertainty in production systems. Schmitt concludes that the choice between safety capacity and safety stock represents a tradeoff between regular time employment costs and costs of material investment. This means that the cost of maintaining safety capacity and the cost of holding inventory must be carefully evaluated in order to select a suitable buffering method. He also concludes that safety capacity produces lower inventory levels than does net change MRP when large set-up or purchased lead times are employed.

Uncertainty and Its Effects in a Production System

Uncertainty and Cost Performance

Uncertainty impacts directly on cost performance. It creates an increasing cost and burden on throughput. When uncertainty exists in a production system, such as, when deliveries are late or demand is higher than expected, organizations will hold additional stocks to add a margin of safety. The larger the quantity of safety stock, the higher the probability of meeting demand and the lower the probability of shortage. This means that higher safety stocks give higher customer service levels. The more assurance of a high service level, the larger safety stock expenses become (Waters, 1992).

Sridharan and LaForge (1989) examined the effectiveness and the variability of using safety stock to reduce schedule instability at the MPS level in terms of cost and customer service levels. Sridharan and LaForge conclude that an increase in safety stock at the MPS level leads to higher customer service levels. Unfortunately, increases in safety stock always lead to higher cost penalties relative to optimal cost. Furthermore, Miller (1988) concluded that material management, inspection and stocking of incoming materials, and vendor control and assessment are more costly when the uncertainty increases. The investment required for both processes and finished goods inventories increase due to uncertainty.

Uncertainty and Customer Service Level

Customer service level is one measurement frequently used to evaluate manufacturing performance. Normally the choice of service level is made by management. They must assess all the information available and choose appropriate levels for all items. According to Waters (1992), higher safety stocks give higher service levels and lower the probability of shortages. However, it is difficult for a firm to have a high enough level of safety stock to ensure a service level of 100% because large stock quantities can become expensive. Customer service levels are typically measured in one of two ways: 1) A percentage of replenishment order cycles in which one or more units are backordered, 2) the average length of time required to satisfy backorders (Vollmann, Berry, and Whybark, 1992).

Bowman (1994) and Sridharan and LaForge (1989) also study customer service level by measuring manufacturing performance. Sridharan and LaForge (1989) conclude that an increase in safety stock at the MPS level leads to higher customer service levels.

Process Uncertainty

Most uncertainty research has been done on process uncertainty. Gupta and Brennan (1995), focusing on a multi-level product structure environment in job shop manufacturing, study the effects of supply and process uncertainty in an MRP system. Five factors, product structure, lot sizing rule, source of lead-time uncertainty, lead-time bias factor, and holding costs, are examined to study their effect on the behavior of this system in the presence of uncertain lead-times due to unpredictability in supply and process uncertainty. The study reveals that the costs increase when the lead-time bias factor is increased, the choice of lot sizing rule impacts the cost performance regardless of the presence of lead time uncertainty, and the cost structure is influence by the product structure in the presence of the uncertainty of lead time.

Quality problems are one of the difficulties in process uncertainty which effect the manufacturing cost directly because more capacity is needed for rework and extra production to replace scraps. Bowman (1994) states that there is a relationship between quality and manufacturing cost, the percent scraps, and inventory cost in a production line. When a process is faced with a high percent of scrap because of poor quality, the firm will be confronted with a high inventory cost.

One way to reduce inventory levels is to reduce process variability. Process variability can be reduced in two ways: reducing the length of the line by reducing the labor or machine content of the product through product redesign, or by reducing the process time variation (Crandall and Burwell, 1993). Machines are one of the important factors in production systems. If they have good efficiency for operating, production yield will increase. On the other hand, if they have low operating efficiency, they may not produce product in sufficient quantities or with sufficient quality. Klastorin, Matheson, and Moinzadeh (1993) stated that when machines are unreliable, producing quality products becomes a problem.

One way to address the problem when machines are unreliable is to buffer inventory at machines which immediately follow the unreliable machines. In this case, the buffer can help to minimize the effects of unreliable machines on the next stage of the production.

Supply Uncertainty

There are two uncertainty cases for supply uncertainty: timing uncertainty and quantity uncertainty. According to Whybark and Williams(1976), supply timing uncertainty is in vendor lead-time for outside purchases. It is a variability in both production and transportation time. Timing uncertainty can be handled by planning the material deliveries earlier than the normal need (safety lead times).

Safety stock is needed when supply does not match demand. If either supply or demand uncertainty is increased, the need for safety stock is also increased (Bowman, 1994). Etienne (1987) studied the optimal buffering strategies under uncertainties in an MRP environment. He reveals that there are three approaches to deal with the buffering problem in MRP and minimize the cost of dealing with uncertainty. The first approach is a safety lead-time. Safety lead time is preferable for the timing uncertainty case. The second approach is a service level model. High service levels favor safety stock, while low service levels favor safety lead time. The third approach deals with timing and quantity uncertainty which occur simultaneously. To deal with both quantity and timing uncertainty he suggests building safety stock for quantity uncertainty and then applying safety lead-time to the augmented order.

Summary

It can be seen that uncertainty acts on a real world manufacturing system, flow shop or job shop system. When uncertainty exists in the manufacturing system, firms have problems to address, especially, manufacturing costs and customer service. The behaviors of the combinations of all uncertainties on cost performance and customer service levels remain an important area for research. It is distinctive that this study will consider the cost performance and customer service level of a flow shop under the combination of supply and process uncertainty. This study will determine the relationship between cost performance and customer service level and uncertainties, supply and process uncertainties, when they exist within a flow shop.

CHAPTER III

THE RESEARCH METHODOLOGY

A Simple Model

In this study, three uncertainties are considered to determine cost performance by considering holding and stockout costs and customer service level. As shown in Figure 2 in Chapter 1, a schematic of a four machine flow shop, uncertainty is often present in this type of system and also can occur anywhere through the manufacturing system. The three uncertainties considered in this study are supply quantity uncertainty, process quantity uncertainty, and process timing uncertainty.

Process Quantity Uncertainty

Process uncertainty can be caused by the variances in machining time, variances in tooling, set up adjustments, operators, materials, and production yields (Crandall and

Burwell, 1993). In this study, production yield is the only cause considered for process quantity uncertainty.

Process Timing Uncertainty

Process timing uncertainty occurs when manufacturing cycle times are longer or shorter than planned. Process timing uncertainty based on uniformly distributed processing times is considered in this study. The same mean processing time and the same distribution is assumed for all machines. A uniform distribution is suitable for simple processes which have no special causes that could enlarge the period of the time (Crandall and Burwell, 1993).

Supply Quantity Uncertainty

Two cases related to receiving uncertain raw material quantities from suppliers will be evaluated in this study. These cases can be either less than or greater than expected order quantity.

1. When raw materials received are greater than actual order quantity, the production process will produce finished goods at a greater level than planned in the MPS assuming scrap losses occur at anticipated levels. The result is that the finished stock level is higher than expected. In

this case, the high stock levels cause unnecessary holding costs for unused units.

Thus, the holding cost = (A-D)*HC

Where

A = Actual of quantity finished goods from production (units)

D = Actual demand (units)

HC= Holding cost ($/unit/period)

2. When raw materials received are less than the order quantity, production will produce less finished goods than planned in the MPS assuming scrap losses occur at anticipated levels. The result is that the firm will experience shortage costs because it cannot meet customer demand.

Thus, the shortage cost = (D-A)*SC

Where SC = shortage cost ($/unit)

Performance Measures

In this study, three measures: customer service level, holding cost, and stockout cost, are used to evaluate manufacturing performance.

Customer Service Level

Customer service level is defined as the proportion of units supplied without delay to total units required. It can also be expressed as a percentage.

For example: Units supplied without delay = 90 units

Units demanded = 100 units

Thus,

Service level = (90/100)x100

= 90 %

Holding Cost

Inventory holding costs are those costs which are directly attributable to the amount of increase in on-hand inventory and the time for which inventoried parts are held (Reisman, et al., 1972).

For periods when the amount of production quantity is greater than actual demand, there is a holding cost for unused units which is $(A_i - D_i)*HC$ per unit time.

Where A_i = manufacturing rate in each period (units)

D_i = demand rate in each period (units)

HC = holding cost ($/unit/period)

Stockout Cost

In periods when the amount of actual demand is greater than the produced quantity, there is a shortage cost for demand not met. In this study, the shortage cost is lost sales because customers will withdraw their orders and go to another supplier.

Thus; the shortage cost that occurs is $(D_i - A_i)*SC$ per unit time.

Where SC = shortage cost per unit

Both holding cost and stockout cost must account for inventory available from previous periods. A detailed example which demonstrates this concept is provided in a later section of this chapter.

Description of the Model

The manufacturing system modeled is a flow shop. In a flow shop, a job is processed through a fixed sequence of operations.

For the flow shop considered in this study, the following assumptions are made.

- Set up time for all machines is zero.
- The demand for finished goods per period is constant.
- No machine breakdowns occur.

- All machines have the same processing distribution, the same mean processing time and the same processing time variance.
- Plant capacity is sufficient to produce demanded products in each period.
- Buffers between machines have unlimited capacity.
- No transportation times of parts from one machine to the next are considered.
- No blocking to stop the processing of parts is allowed.
- The jobs arriving to the process are sequenced based on the First In-First Out (FIFO) procedure.
- There are fifty-two working days per year, there are five working days per week, and there are eight working hours per day.

Experimental Design

The System Description

A simulation model is constructed using SLAM II (Pritsker, 1995). The simulated flow shop consists of four single-machine workcenters which produce a single finished product. The experimental factors and their levels are described below.

The demand input to the simulation flow shop model is the finished goods consumption rate based on customer demand. It is a constant in this study; 300 units per day.

In these experiments, uncertainty levels are varied to examine their effects on holding costs, stockout costs, and customer service levels. Only one product is considered in these experiments and its routing visits all machines in machine numeric order. Raw material arrives at the rate of one batch per day with a mean quantity of 300 units/batch and a deviation from the mean which is a sample from a normal distribution with parameters which vary according to intensity level of supply quantity uncertainty. The required individual processing time for each unit at each machine is determined by independently sampling from uniform distributions, each with the same mean and variance.

It is assumed that production will process all materials received from suppliers. Thus, the system can be classified as a "push" system. The suppliers deliver raw materials on time but not certain in quantity. As soon as raw materials are available, the production system starts to produce products. In the production line, there are four single-machine workcenters and the parts move individually from one machine to the next. It is assumed that each machine creates scrap independently. After processing at each machine, a part will be determined to be a scrap if the random number from simulation program (SLAM II) is less than the experimental percent scrap level.

After production is completed, at the end of each day, available finished goods are shipped immediately to meet customer demand. Costs in terms of inventory carrying costs and stockout costs and customer service rate are calculated. The diagram of the physical system of the flow shop in this study is shown in Figure 5.

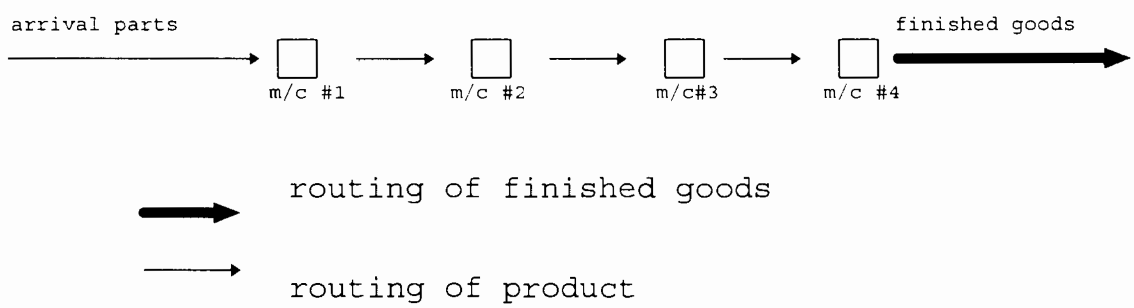


Figure 5. Physical Diagram of the System.

Consider the stock of finished goods at the end of a production line in each day. If finished goods available from production (current day plus previous day surpluses) are greater than actual demand, the firm must deal with a cost for holding products which are not used but are held to service demand in future days. On the other hand, if finished goods available from production plus any prior surplus production are less than actual demand, the firm must deal with a shortage cost for demand not met which is lost sales.

In addition, customer service rate which is defined as the proportion of units supplied without delay is calculated for each case in this study.

The Experimental Factors and Levels

To study the behavior of the system in terms of total cost and customer service level under the combination of process and supply uncertainties, the simulation model will be exercised to investigate the influence of the following experimental factors and levels.

1. Number of Machines

The number of machines represents a measure of the complexity of a flow shop environment. In this study, only one level is studied, four single-machine workcenters. A review of the literature shows that the number of machines used in nearly all research is less than ten single-machine workcenters. Several selected references related to the number of machine studied are shown in Table II. Four machines were selected for this study to maintain the focus on uncertainty levels rather than on shop size.

Additionally, the four machine shop is the least complex modeling effort.

TABLE II

REFERENCES RELATED TO THE NUMBER OF MACHINES STUDIED

Numbers of machine pattern (machines)	**Reference**
4 6 8	Crandall and Burwell (1993)
9	Yang and Sum (1994)

2. <u>Process uncertainty and pattern</u>

Processing time is one of the essential factors considered. In this study, process quantity uncertainty is caused by the production yield. The same mean processing time and the same process distribution is assumed for all machines. These experiments consider five processing time levels for a product in each machine. The first one is a constant processing time with zero variation which is used for a reference point. The constant is 1.00 minute per unit per machine. The other processing times are drawn by sampling from four different uniform distributions which are (0.75,1.25), (0.80,1.20), (0.85,1.15) and (0.90,1.10). These distributions were also utilized in the studies by Crandall and Burwell(1993), Benton(1993), and Bowman(1994).

Percent scrap represents a process quantity uncertainty. In this study, the scrap levels are varied to investigate their effects. It is assumed that scrap is detected after every machine and the scrap rate is assumed equal for all machines. Three levels of percent scrap, 0.0%, 0.5%, and 1.0% in each machine, are evaluated in this study. These levels were also considered by Bowman(1994), who studied six single-machine workcenters in series.

3. Supply Uncertainty

In this study, supply uncertainty occurs when the quantity delivered is either less than or greater than the order quantity. The mean of supply quantity is assumed to be equal to the actual order quantity but the standard deviation of the supply quantity is varied. Two levels of the standard deviation are evaluated in this study. Variations from the mean are generated from a Normal distribution with mean zero and standard deviations of $50^{1/2}$ and $100^{1/2}$ units. They can be presented as Normal(0,50) and Normal(0,100).

4. Cost Structure

- ***Holding Cost***

In this study, there is only one level of the holding costs. It is fixed at $ 0.50 per unit per day.

- ***Stockout cost per unit:***

There is only one level of stockout cost per unit. The stockout cost per unit is $0.50 per unit.

The following example illustrates how to calculate the holding costs and the stockout costs.

Example:

Day no.	Finished goods[1] (units)	Demand (units)	Holding costs ($)	Accumu-lated holding costs ($)	Stockout costs ($)	Accumu-lated stockout costs ($)
1	310	300	5	5	-	-
2	350	300	30	35	-	-
3	200	300	-	35	20	20
4	250	300	-	35	25	45

From this example, the holding costs and stockout costs at the end of the fourth day are $35 and $45, respectively.

Note: (1) The finished goods shown in this example are calculated based on random raw material quantities, processing times, and percent scraps.

(2) Holding cost for day no. 2 = [(350-300)*0.50]+10*0.50

= $30

(3) Stockout cost for day no. 3 = [(300-200)-60]*0.50

= $20

5. Summary

Table III summarizes the experimental factors and levels used in this study.

Simulation Model

A SLAM II simulation model is developed to generate the experimental data. In this study, the objective is to study the sensitivity of manufacturing performance in terms of holding costs, stockout costs, and customer service rate. To evaluate the sensitivity of the holding and stockout costs and customer service level, two models are built. The first will describe the system as it would operate in an ideal situation with no uncertainty in production: no scrap and exact supply quantity. This model will act as the

TABLE III

EXPERIMENTAL FACTOR ALTERNATIVES SELECTED

Factors	No. of levels	Pattern and Level Values
1. No. of machines (machines)	1	4
2. Supply (units)	3	300 300+normal(0,50) 300+normal(0,100)
3. Process (in terms of percent scraps in each machine)	3	0% 0.5% 1%
4. Processing Time in each machine (min./unit)	5	1 UNFRM(0.75,1.25), UNFRM(0.80,1.20), UNFRM(0.85,1.15), UNFRM(0.90,1.10)
5. Holding cost ($/unit/day)	1	0.50
6. Stockout cost per unit ($/unit)	1	0.50

reference model. The second model model (an extension of the first model) will examine the system under uncertainty. It permits a parametric revision to study the uncertainty cases.

Cost Performance

For each case studied, cost performance in terms of holding and stockout costs will be calculated based on all uncertainties. Total costs at the end of simulated period can be calculated as follows.

Total cost (TC) = Accumulated holding costs (\$) + Accumulated stockout costs (\$)

Thus;

$$TC = C_h + C_s$$

Total carrying costs (C_h) $= \sum^{n}_{i=1} I_i * HC$

$$= \sum^{n}_{i=1} \max\{I_{i-1} + (A_i - D), 0\} * HC$$

Where

I_i = Inventory quantity at the end of period i (units)

I_0 = Initial inventory = 0 unit

A_i = Actual quantity of finished goods from production in each period time (units)

D = Actual demand (units)

HC= Holding cost (\$/unit/day)

i = Period number in simulated time (day).

Total stockout costs (C_s) $= \sum^{n}_{i=1} STK_i * SC$

$= \sum^{n}_{i=1} \max\{D-A_i-I_{i-1},0\} * SC$

Where

STK_i = Stockout quantity at day i (units)

SC = Stockout cost ($/unit)

Thus;

Total costs = $C_h + C_s$

$= \sum^{n}_{i=1} \max\{I_{i-1} + (A_i-D),0\} * HC +$

$\sum^{n}_{i=1} \max\{D-A_i-I_{i-1},0\} * SC$

Customer Service Level

As described in the first chapter, the customer service level can be calculated in the following way.

$$\text{service level} = \frac{\text{(units supplied without delay) x 100}}{\text{(units required)}}$$

$$= \frac{\text{(units required - units short) x 100}}{\text{(units required)}}$$

Customer service level for each possible case can be calculated as shown in Table IV.

TABLE IV

SUMMARIZED CUSTOMER SERVICE LEVELS IN EACH EVENT

Cases	Events	Explanations	Customer service level (%)
1. Zero On hand inventory ($I_{n-1}=0$)	-Demand is met.	-Actual quantity of finished goods (A_n) is greater than or equal to demand rate (D).	100
	-Demand cannot be met.	-Actual quantity of finished goods (A_n) is less than demand rate (D).	$(A_n/D)*100$
2. Positive on hand inventory ($I_{n-1}>0$)	-Demand is met.	-Actual quantity of finished goods (A_n) is less than demand rate (D) but actual quantity of finished goods(A_n) plus on hand inventory (I_{n-1}) is greater than demand rate (D).	100

TABLE IV (continue)

Cases	Events	Explanations	Customer service level (%)
	-Demand is met.	-Actual quantity of finished goods (A_n) is greater than demand rate (D).	100
	-Demand cannot be met.	-Actual quantity of finished goods (A_n) plus on hand inventory (I_{n-1}) is still less than demand rate (D).	$[(A_n+ I_{n-1})*100]/D$

From Table IV, the formula to calculate customer service level is shown as follows.

$$CUST_i = \begin{cases} \min[(A_i+ I_{i-1})*100]/D,\ 100] & ,\ n \ni I_{n-1}>0] \\ \min[(A_i *100)/D,\ 100] & ,\ n \ni I_{n-1}=0] \end{cases}$$

Thus;

$$ACUST = \sum^{N}_{i=1} CUST_i/N$$

Where

$CUST_i$ = Customer service level for day i (%)

ACUST = Average customer service level at the end of N simulated days.

Five simulation replications will be made for each combination. A review of the literature shows that the number of replications used in nearly all research is five. Several selected references related to the number of replications of the simulation runs are shown in Table V. To ensure that the steady state performance of the system is being considered, it is necessary to eliminate the data from the initial part of the simulation run. In each run, the system simulation experiment is for 650 days (or 312,000 minutes). In order to ensure steady state conditions, the results presented are based on the last 500 days (or 240,000 minutes) of simulation output. The output generated from the first 150 days (or 72,000 minutes) simulation is eliminated.

This procedure generates a total of forty five averages for each performance measure, each based on five replications.

	3	levels of process uncertainty
x	3	levels of supply quantity uncertainty
x	5	levels of processing time
	45	experiment cells
x	5	replications per cell
	225	simulation runs

TABLE V

REFERENCES RELATED TO THE NUMBER OF REPLICATIONS OF THE SIMULATION RUNS

Number of Replications	Reference
5	Kropp, Carlson, and Juker (1983)
5	Sridharan and Berry (1990)
5	Grasso and Taylor (1984)
5	Sridharan and LaForge (1989)

CHAPTER IV

FINDINGS

Verification and Validation

The computer model results are tested to ensure that the model corresponds accurately to the intended system. Manual calculations are performed to trace the model and verify that the model performs as intended.

To verify that the simulation model performs as intended, four test cases are evaluated. There is a 25-day simulated time in each case. The results of these experiments are shown in Table VI and the data from running the simulation to test the verification is shown in Appendix C. Given that the performance measures for the computer model and manual calculations match each other, the model is considered to be verified.

Validation is not a significant issue in this study since there is no real system against which to validate the model.

TABLE VI

THE RESULTS OF VERIFICATION

CASE	Accumulated Total Stockout Cost ($)		Accumulated Total Holding Cost ($)		Accumulated Total Holding Cost ($)		Average Customer Service Level (%)	
	SLAM II	MANUAL CALCULATION	SLAM II	MANUAL CALCULATION	SLAM II	MANUAL CALCULATION	SLAM II	MANUAL CALCULATION
- Supply 300 units - Scrap 0 % - Processing Time UNFRM(0.75,1.25)	0.00	0.00	0.00	0.00	0.00	0.00	100.00	100.00
- Supply 310 units - Scrap 0 % - Processing Time UNFRM(0.75,1.25)	0.00	0.00	1,625.00	1,625.00	1,625.00	1,625.00	100.00	100.00
- Supply 300 units + NORM(0,10) - Scrap 0 % - Processing Time UNFRM(0.75,1.25)	114.00	114.00	10.50	10.50	124.50	124.50	97.00	97.00
- Supply 310 units - Scrap 1 % - Processing Time UNFRM(0.75,1.25)	22.00	22.00	9.50	9.50	31.50	31.50	99.40	99.40

The Base Experiment Results

Data was collected for the cost performance and customer service levels from 45 combinations. Each combination was formed from the following three factors:

1. Supply Quantity, 3 levels;
2. Percent Scrap, 3 levels;
3. Processing Time, 5 levels.

Statistical estimates of the treatment combination means of the performance measurements represent the measures of the impact of the various factors on the system performances. The two system performance measures used in this study are total cost (holding cost plus stockout cost) and customer service level.

Appendix D reflects the detailed experimental results which are summarized (in Tables VII through XI) and analyzed in the sections which follow. These tables contain 3 levels of percent scrap, 3 levels of supply quantity, and 5 levels of processing time. The details of the factors were presented earlier in Table III.

TABLE VII

SUMMARY OF THE AVERAGE TOTAL COST AND CUSTOMER SERVICE FOR PROCESSING TIME (MIN./UNIT): 1.00

Supply Condition	Percent Scrap (%)		
	0.0%	0.5%	1.0%
• **NO VARIATION :300+NO ERROR TERM**			
- **ACC.TOTAL STOCKOUT COST($)**	0.00	1,488.00	2,957.10
- **ACC.TOTAL HOLDING COST($)**	0.00	0.00	0.00
- **ACC.TOTAL COSTS($)**	0.00	1,488.00	2,957.10
- **CUSTOMER SERVICE RATE(%)**	100.000	98.011	96.049
• **MEDIUM VARIATION:300+norm(0,50)**			
- **ACC.TOTAL STOCKOUT COST($)**	8.00	1,370.90	2,843.20
- **ACC.TOTAL HOLDING COST($)**	39,604.30	447.00	68.30
- **ACC.TOTAL COSTS($)**	39,612.30	1,817.90	2,911.50
- **CUSTOMER SERVICE RATE(%)**	99.989	97.167	96.594
• **HIGH VARIATION :300+norm(0,100)**			
- **ACC.TOTAL STOCKOUT COST($)**	22.70	1,374.20	2,845.40
- **ACC.TOTAL HOLDING COST($)**	42,692.00	1,117.70	228.90
- **ACC.TOTAL COSTS($)**	42,714.70	2,491.90	3,074.30
- **CUSTOMER SERVICE RATE(%)**	99.970	98.162	96.195

TABLE VIII

SUMMARY OF THE AVERAGE TOTAL COST AND CUSTOMER SERVICE FOR PROCESSING TIME (MIN./UNIT): UNFRM(0.75,1.25)

Supply Condition	Percent Scrap (%)		
	0.0%	0.5%	1.0%
• **NO VARIATION: 300+NO ERROR TERM**			
- ACC.TOTAL STOCKOUT COST($)	0.00	1,474.71	2,957.10
- ACC.TOTAL HOLDING COST($)	0.00	0.00	0.00
- ACC.TOTAL COSTS($)	0.00	1,474.71	2,957.10
- CUSTOMER SERVICE RATE(%)	100.000	98.030	96.051
• **MEDIUM VARIATION: 300+norm(0,50)**			
- ACC.TOTAL STOCKOUT COST($)	8.00	1,369.00	2,856.40
- ACC.TOTAL HOLDING COST($)	36,604.30	445.60	58.30
- ACC.TOTAL COSTS($)	39,612.30	1,814.60	2,914.70
- CUSTOMER SERVICE RATE(%)	99.989	98.169	96.183
• **HIGH VARIATION: 300+norm(0,100)**			
- ACC.TOTAL STOCKOUT COST($)	22.70	1,374.00	2,845.70
- ACC.TOTAL HOLDING COST($)	4,2692.00	1,129.00	223.00
- ACC.TOTAL COSTS($)	4,2714.70	2,503.00	3,068.70
- CUSTOMER SERVICE RATE(%)	99.970	98.162	96.146

TABLE IX

SUMMARY OF THE AVERAGE THE TOTAL COST AND CUSTOMER SERVICE FOR PROCESSING TIME (MIN./UNIT): UNFRM(0.8,1.2)

Supply Condition	Percent Scrap (%)		
	0.0%	0.5%	1.0%
• **NO VARIATION: 300+NO ERROR TERM**			
- ACC.TOTAL STOCKOUT COST($)	0.00	1,484.00	2,958.50
- ACC.TOTAL HOLDING COST($)	0.00	0.00	0.00
- ACC.TOTAL COSTS($)	0.00	1,484.00	2,958.50
- CUSTOMER SERVICE RATE(%)	100.000	98.020	96.050
• **MEDIUM VARIATION: 300+norm(0,50)**			
- ACC.TOTAL STOCKOUT COST($)	8.00	1,354.60	2,831.70
- ACC.TOTAL HOLDING COST($)	39,604.30	459.30	61.500
- ACC.TOTAL COSTS($)	39,612.30	1,813.90	2,893.20
- CUSTOMER SERVICE RATE(%)	99.989	98.174	96.215
• **HIGH VARIATION: 300+norm(0,100)**			
- ACC.TOTAL STOCKOUT COST($)	22.70	1,368.90	2,853.50
- ACC.TOTAL HOLDING COST($)	42,692.00	1,152.90	226.70
- ACC.TOTAL COSTS($)	42,714.70	2,521.80	3,080.20
- CUSTOMER SERVICE RATE(%)	99.970	98.170	96.186

TABLE X

SUMMARY OF THE AVERAGE TOTAL COST AND CUSTOMER SERVICE FOR PROCESSING TIME (MIN./UNIT): UNFRM(0.85,1.15)

Supply Condition	Percent Scrap (%)		
	0.0%	0.5%	1.0%
• **NO VARIATION: 300+NO ERROR TERM**			
- **ACC.TOTAL STOCKOUT COST($)**	0.00	1,481.20	2,958.40
- **ACC.TOTAL HOLDING COST($)**	0.00	0.00	0.00
- **ACC.TOTAL COSTS($)**	0.00	1,481.20	2,958.40
- **CUSTOMER SERVICE RATE(%)**	100.000	98.061	96.049
• **MEDIUM VARIATION: 300+norm(0,50)**			
- **ACC.TOTAL STOCKOUT COST($)**	8.00	1,364.80	2,838.70
- **ACC.TOTAL HOLDING COST($)**	39,604.30	455.10	63.40
- **ACC.TOTAL COSTS($)**	39,612.30	1,819.90	2,902.10
- **CUSTOMER SERVICE RATE(%)**	99.989	98.175	96.207
• **HIGH VARIATION: 300+norm(0,100)**			
- **ACC.TOTAL STOCKOUT COST($)**	22.70	1,371.90	2,847.30
- **ACC.TOTAL HOLDING COST($)**	42,692.00	1,128.90	217.80
- **ACC.TOTAL COSTS($)**	42,714.70	2,500.80	3,065.10
- **CUSTOMER SERVICE RATE(%)**	99.970	98.164	96.193

TABLE XI

SUMMARY OF THE AVERAGE THE TOTAL COST AND CUSTOMER SERVICE FOR PROCESSING TIME (MIN./UNIT): UNFRM(0.9,1.1)

Supply Condition	Percent Scrap (%)		
	0.0%	0.5%	1.0%
• NO VARIATION: 300+NO ERROR TERM			
- ACC.TOTAL STOCKOUT COST($)	0.00	1,480.10	2,956.20
- ACC.TOTAL HOLDING COST($)	0.00	0.00	0.00
- ACC.TOTAL COSTS($)	0.00	1,480.10	2,956.20
- CUSTOMER SERVICE RATE(%)	100.00	98.023	96.05
• MEDIUM VARIATION: 300+norm(0,50)			
- ACC.TOTAL STOCKOUT COST($)	8.00	1,368.20	2,839.80
- ACC.TOTAL HOLDING COST($)	39,604.30	464.80	63.20
- ACC.TOTAL COSTS($)	39,612.30	1,833.00	2,903.00
- CUSTOMER SERVICE RATE(%)	99.989	98.210	96.204
• HIGH VARIATION: 300+norm(0,100)			
- ACC.TOTAL STOCKOUT COST($)	22.70	1,372.30	2,854.40
- ACC.TOTAL HOLDING COST($)	42,692.00	1,187.80	233.50
- ACC.TOTAL COSTS($)	42,714.70	2,560.10	3,087.90
- CUSTOMER SERVICE RATE(%)	99.970	98.184	96.184

<u>Total Cost Analysis Results</u>

From Tables D1-D5 (in appendix D), it can be observed that when percent scrap is 0% for both the medium variation and the high variation in supply quantity (300+NORM(0,50) and 300+NORM(0,100), respectively), the holding cost for <u>each run</u> varies widely. This is due to the amount of variation of supply and the point in simulated time at which the variation occurs. If raw materials are released in a high volume during the early days, the holding cost will be become and remain high due to high inventories. Table XII illustrates this wide variation of the holding costs of each run for five levels of process timing uncertainty (processing time). From table XII, the mean and standard deviation of the total cost are $39,612.30 and $15,603.47 for the medium variation in supply quantity case and $42,714.7 and $18,128.18 for the high variation in supply quantity case. The mean and standard deviation of customer service level for the medium variation in supply quantity are 99.990% and 0.017% and 99.970% and 0.037% for the high variation in supply quantity case. The 95% confidence interval of the total cost and customer service level for the medium variation in supply quantity case are from $22,697.30 to $57,127.29 and from 99.97% to 100%, respectively. The 95% confidence interval of the total cost and customer service level for the high variation in supply quantity case are from $21,871.17 to $63,558.23 and from 99.93% to 100%, respectively.

TABLE XII

THE HOLDING COSTS OF EACH RUN FOR ALL LEVELS OF PROCESSING TIME

Supply Condition	Percent Scrap 0%				
	1	2	3	4	5
MEDIUM VARIATION: 300+norm(0,50)					
- ACC.TOTAL STOCKOUT COST($)	30.50	0.00	9.50	0.00	0.00
- ACC.TOTAL HOLDING COST($)	*42,989.00*	*35,603.00*	*14,698.00*	*51,800.50*	*52,931.00*
- ACC.TOTAL COSTS($)	43,019.50	35,603.00	14,707.50	51,800.50	52,931.00
- CUSTOMER SERVICE RATE(%)	99.960	100.000	99.988	100.000	100.000
• HIGH VARIATION: 300+norm(0,100)					
- ACC.TOTAL STOCKOUT COST($)	62.00	0.00	42.50	0.00	9.00
- ACC.TOTAL HOLDING COST($)	*50,854.50*	*32,062.50*	*16,79*	*51,285.50*	*62,466.50*
- ACC.TOTAL COSTS($)	50,916.50	32,062.50	16,833.50	51285.50	62,475.50
- CUSTOMER SERVICE RATE(%)	99.917	100.000	99.944	100.000	99.988

The total cost performance ANOVA results are presented in Table XIII. The R-square, which is a measure of how well the model fits data, is 0.839. The R-square is a high value which means that the model fits the data quite well. The ANOVA results show that main effect supply quantity uncertainty, the main effect process quantity uncertainty (percent scrap), and the interaction between supply quantity uncertainty and process quantity uncertainty are significant at the 0.05 level. This is indicated because their probability of being greater than the F-test values is less than the 0.05 level (Pr>F=0.0001). This can be interpreted to mean that supply quantity uncertainty, process quantity uncertainty, and the interaction between these factors significantly change the total cost. Process quantity uncertainty is the most significant factor affecting the total cost performance because its F-test is the highest value (F value=245.75). This means that when process quantity uncertainty is applied, it will cause a larger expected change in the expected value of total costs than the other factors. The next most influential factor is supply quantity uncertainty which has an F value of 77.18.

The process timing uncertainty factor (processing time) is not significant at the 0.05 level. This is indicated by its probability of being greater than the F value being 1.00 or 100%.

The F-tests (ANOVA) presented so far test whether statistically significant differences exist among the means of total cost under different treatment combinations, but they do not indicate whether the average total cost of one group (or each combination) differs significantly from another average total cost group (or another combination). Least Significant Difference tests (LSD) and Bonferroni (Dunn) T tests are performed to test these multiple comparisons.

TABLE XIII

THE SAS SYSTEM : ANALYSIS OF VARIANCE PROCEDURE
DEPENDENT VARIABLE: TOTAL COST

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	44	9620047495.6399	1355001079.44636	21.32	0.0001
Error	180	11442520460.800	63569558.11556		
Corrected Total	224	71062567956.440			

R-Square	**C.V.**	**Root MSE**	**COST Mean**
0.838980	73.90709	7973.05199504	10787.94000000

Source	**DF**	**Anova SS**	**Mean Square**	**F Value**	**Pr > F**
SUPPLY	2	9813111691.760	4906555845.880	77.18	0.0001
SCRAP	2	31244890128.407	15622445064.203	245.75	0.0001
SUPPLY*SCRAP	4	18562021112.633	4640505278.158	73.00	0.0001
PROCTIME	4	3389.296	847.324	0.00	1.0000
SUPPLY*PROCTIME	8	4617.718	577.215	0.00	1.0000
SCRAP*PROCTIME	8	6969.138	871.142	0.00	1.0000

1. When considering the factors individually:

Comparing measurement performances among all levels at the 0.05 level, the results are shown as follows.

1.1 Supply quantity uncertainty

- Tables E-2, G-3, and H-3 (in Appendix E, G, and H respectively) show the multiple comparison procedures for total cost, holding cost, and stockout cost for the supply quantity uncertainty factor, respectively. Interpretation of these results is presented below.

1.1.1 Changing the level of supply quantity uncertainty changes the average of total cost, the holding cost, and the stockout cost. They range from $1,480 to $16,104, $0 to $14,687, and $1,405.033 to $1479.43 respectively.

1.1.2 The average total cost when the supply quantity uncertainty is set at the middle or the high variation in quantity (300+NORM(0,50) and 300+NORM(0,100), respectively) is not significantly different, but the average total cost of both of these cases is significantly higher than the average total cost when compared to the supply quantity uncertainty with no variation.

1.1.3 The average holding cost when the supply quantity uncertainty is set at the middle or the high variation in quantity (300+NORM(0,50) and 300+NORM(0,100), respectively) is not significantly different, but the average holding cost of both of these cases is significantly higher than the average holding costs when compared to the supply quantity uncertainty with no variation.

1.1.4 The average stockout cost when the supply quantity uncertainty is set at the middle or the high variation in quantity (300+NORM(0,50) and 300+NORM(0,100), respectively) is not significantly different, but the average stockout cost of both of these cases is significantly lower than the average stockout costs when compared to the supply quantity uncertainty with no variation. A summary of the discussion when considering just the supply quantity uncertainty is shown in Table XIV.

TABLE XIV

THE SUMMARY OF THE TOTAL COST DISCUSSION WHEN CHANGING THE SUPPLY QUANTITY UNCERTAINTY LEVELS

Factor	Summary of the effects
Supply quantity uncertainty (supply)	1. Changing the level of supply quantity uncertainty changes the average total cost, holding cost, and stockout cost. 2. Both of the average total cost and average holding cost when supply quantity uncertainty is set at the medium and high variation are not significantly different but each of them is significantly higher than the supply quantity uncertainty set at the no variation level. 3. The stockout cost when supply quantity uncertainty is set at the medium and high variation is not significantly different but each of them is significantly lower than the supply quantity uncertainty set at the no variation level.

1.2 Process quantity uncertainty (percent scrap)

- Tables E-3, G-4, and H-4 (in Appendix E, G, and H), show the multiple comparison procedures for total cost, holding cost, and stockout cost for the process quantity uncertainty factor (percent scrap):

1.2.1 When changing the level of percent scrap, the total cost, the holding cost, and the stockout cost change over a wide range. They vary from $1,939-$27,442, $96 to $27,433, and $10.233 to $2,882.743, respectively.

1.2.2 The average total cost and the holding cost when percent scrap is 0% is significantly higher than the total cost when percent scrap is either 0.5% or 1%. The total costs considered in this study are only the holding costs and stockout costs. Although the total cost is minimum when percent scrap is either 0.5% or 1.0%, there are some missing costs that are not considered in this study, for example, labor costs, material costs, and holding costs.

1.2.3 The average stockout cost when percent scrap is 1% is significantly higher than the stockout cost when percent scraps are either 0.5% or 0%. The summary of the discussion when considering just the process quantity uncertainty (percent scrap) is shown in Table XV.

TABLE XV

THE SUMMARY OF THE TOTAL COST DISCUSSION WHEN CHANGING THE PROCESS QUANTITY UNCERTAINTY LEVELS

Factor	Summary of the effects
Process quantity uncertainty (scrap)	1. Changing the level of process quantity uncertainty changes the average total cost, holding cost, and stockout cost. 2. When percent scrap is zero percent (0%), both of the average total cost and holding cost are the highest. However, this result is different from the study of Bowman (1994) in case that the inventory cost is very high when the percent scrap is high in order to meet the customer demand by giving a 95% fill rate. 3. When percent scrap is one percent (1%), the stockout cost is the highest.

1.3 Process timing uncertainty

- Tables E-4, G-5, and H-5 (in Appendix E, G, and H, respectively) show the multiple comparison procedures for the total cost, holding cost, and stockout cost for the process timing uncertainty factor (processing time).

1.3.1 The average of the total cost, the holding cost, and the stockout cost are not significantly different for all levels of processing time. The summary of the discussion when considering just the process timing uncertainty (processing time) is shown in Table XVI.

TABLE XVI

THE SUMMARY OF THE TOTAL COST DISCUSSION WHEN CHANGING THE PROCESS TIMING UNCERTAINTY LEVELS.

Factor	Summary of the effects
Process timing uncertainty (proctime)	1. Changing the level of process timing uncertainty does not change the average total cost, holding cost, and stockout cost.

2. When considering the interaction between factors.

Because processing time is not significant at the 0.05 level, the interaction between percent scrap and processing time (scrap*proctime) and the interaction between supply quantity uncertainty and processing time (supply*proctime) are not significant at the 0.05 level. The interaction between supply quantity uncertainty and process quantity uncertainty is considered for testing the multiple comparisons for interactions. From Table XVIII and Figure 6, it can be observed that the effect on one variable depends upon the levels of the other variables because when both supply and process quantity uncertainty change, the total costs change. For example, when supply quantity uncertainty is set at no variation and percent scarp is zero, the total cost is $1,481.60, but when supply quantity uncertainty is set at high variation and percent scrap is zero, the total cost is $39,612.30. This means that when the levels of supply quantity uncertainty and process quantity uncertainty change, the total costs change, in short, the effect of supply quantity uncertainty (for all three levels) on the total costs depends upon the levels of process quantity uncertainty (percent scrap), or the effect of percent scrap on the total costs depends upon the levels of supply quantity uncertainty.

The total cost is minimum when there is no variation in supply quantity (300 units/day) and there is no scrap (percent scrap is zero) and is maximum when percent scrap is zero with the high variation in supply quantity (300+NORM(0,100)). However, from the Least Significant Difference test (LSD) shown in Appendix F, the difference in means of the total cost of each pair (or combination) are less than the LSD values. The total cost between the no variation in supply quantity case with zero percent scrap

(300 units and 0% scrap) and all levels of supply quantity uncertainty with percent scrap 0.5% and 1% are not significantly different, and the total costs between zero percent scrap with the medium and high variation in supply quantity are not significantly different at the 0.05 level. The summary of the discussion when considering the interaction between supply quantity uncertainty and process quantity uncertainty (percent scrap) is shown in Table XVII.

TABLE XVII

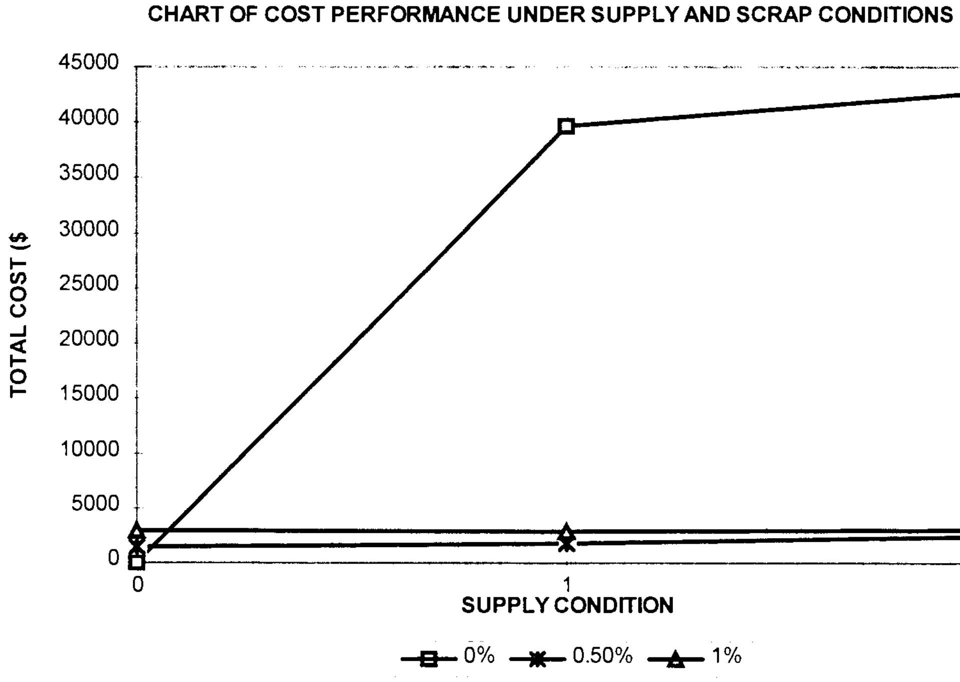
THE SUMMARY OF THE TOTAL COST DISCUSSION OF THE INTERACTION BETWEEN THE SUPPLY QUANTITY UNCERTAINTY AND PROCESS QUANTITY UNCERTAINTY.

Factor	Summary of the effects
The interaction between the supply quantity uncertainty and process quantity uncertainty (process*supply)	1. From LSD test at the 0.05 level, the difference in means of the total costs of each pair (or combination) are less than LSD values, - the total cost between the no variation in supply quantity case with zero percent scrap (300 units and 0% scrap) and all levels of supply quantity uncertainty with percent scrap 0.5% and 1% are not significantly different. - the total costs between zero percent scrap with the medium and high variation in supply quantity are not significantly different. In addition, this results in the highest total cost.

TABLE XVIII

THE COST PERFORMANCE OF THE INTERACTION BETWEEN SUPPLY QUANTITY UNCERTAINTY AND PROCESS QUANTITY UNCERTAINTY (PERCENT SCRAP)

Level of SUPPLY	Level of SCRAP	COST N	COST Mean	COST SD
0	0	25	0.0000	0.0000
0	1	25	2957.4200	22.3158
0	0.5	25	1481.6000	14.3425
1	0	25	39612.3000	14243.9501
1	1	25	2908.9000	43.9723
1	0.5	25	1819.8600	47.2195
2	0	25	42714.7000	16548.6859
2	1	25	3082.4000	67.4137
2	0.5	25	2514.2800	119.0660



Note: For supply level:

level 0= supply quantity = 300 units

level 1= supply quantity with middle variation in mean = 300+NORM(0,50) units

level 2= supply quantity with middle variation in mean = 300+NORM(0,100) units

Figure 6: Chart of The Total Costs under Supply Quantity Uncertainty and Process Quantity Uncertainty (percent scrap)

Customer Service Level Analysis Results

The customer service level (ANOVA) results are presented in Table XIX. The R-square of this model is 0.9974. This means that the model fits the data very well because the R-square is a high value. Based on the analysis of variance at the 0.05 level, the main effect supply quantity uncertainty, the main effect process quantity uncertainty (percent scrap), and the interaction between supply quantity uncertainty and process quantity uncertainty are significant. This can be seen since their probabilities of being greater than the F-test values are less than 0.05 (Pr>F=0.0001). When supply quantity uncertainty, process quantity uncertainty (percent scrap), and the interaction between supply quantity uncertainty and process quantity uncertainty are applied, the customer service level significantly changes. From Table XIX, process quantity uncertainty is the most significant factor affecting the customer service rate because its F-value is the highest value (F value=34,800.05). The next most significant is supply quantity uncertainty for which the F value is 19.29. The process timing uncertainty (processing time) factor is not significant because its probability of being greater than the F value is 1.00 or 100%.

TABLE XIX

ANALYSIS OF VARIANCE PROCEDURE
DEPENDENT VARIABLE: CUSTOMER SERVICE LEVEL

Sum of Source	Mean DF	Squares	Square	F Value	Pr > F
Model	44	553.6330432	12.5825692	1583.90	0.0001
Error	180	1.4299299	0.0079441		
Corrected Total	224	555.0629732			

R-Square	C.V.	Root MSE	CUST Mean
0.997424	0.090865	0.089129	98.08984

Source	DF	Anova SS	Mean Square	F Value	Pr > F
SUPPLY	2	0.3064373	0.1532187	19.29	0.0001
SCRAP	2	552.9070638	276.4535319	34800.05	0.0001
SUPPLY*SCRAP	4	0.2493120	0.0623280	7.85	0.0001
PROCTIME	4	0.0246193	0.0061548	0.77	0.5429
SUPPLY*PROCTIME	8	0.0323415	0.0040427	0.51	0.8487
SCRAP*PROCTIME	8	0.0526304	0.0065788	0.83	0.5788

Similar to the total cost analysis, the F-tests (ANOVA) presented thus far determines whether differences exist among several means of the customer service levels of difference combinations, but they do not tell whether the average customer service level of one group (or each combination) differs significantly from another average customer service level group (or another combination).

Least Significant Difference test (LSD) and Bonferroni (Dunn) T tests are performed to test multiple comparisons.

1. When considering the factors individually:

Comparing the measurement performances among all levels at the 0.05 level, the results are discussed below.

1.1 Supply quantity uncertainty

- From Table E-6 (in Appendix E), changing the level of supply quantity uncertainty changes the average customer service level. It ranges from 98.0394% to 98.123%. The average of the customer service rates between supply quantity uncertainty with the middle and the high variation in supply quantity (300+NORM(0,50) and 300+NORM(0,100), respectively) are not statistically significantly different. In addition, the customer service rates of both of these cases are statistically significantly higher than the customer service rates when supply quantity uncertainty has no variation from the mean. This is due to the fact that, in this later case, there are enough finished goods to meet customer demands. The summary discussion of the customer service level when considering only supply quantity uncertainty is shown in Table XX.

TABLE XX

THE SUMMARY OF THE CUSTOMER SERVICE LEVEL DISCUSSION WHEN CHANGING THE SUPPLY QUANTITY UNCERTAINTY LEVELS.

Factor	Summary of the effects
Supply Quantity uncertainty (supply)	1. Changing the level of supply quantity uncertainty changes the average customer service levels. 2. Customer service levels for supply quantity uncertainty with the medium and high variation are not significantly different but they are significantly higher than the supply quantity uncertainty with no variation.

1.2 Process quantity uncertainty (percent scrap)

- From Table E-7 (in Appendix E), changing the level of percent scrap causes a statistically significant change in the average customer service level. It ranges from 96.1474% to 98.9864%. The average customer service rates from all levels of percent scrap are statistically significantly different. It is the highest when percent scrap is 0% and the next highest when percent scrap is 0.5%. The summary of the discussion when considering just the process quantity uncertainty (percent scrap) is shown in Table XXI.

TABLE XXI

THE SUMMARY OF THE CUSTOMER SERVICE LEVEL DISCUSSION WHEN CHANGING THE PROCESS QUANTITY UNCERTAINTY LEVELS

Factor	Summary of the effects
Process quantity uncertainty (scrap)	1. Changing the level of process quantity uncertainty causes a change of the average customer service level. 2. When percent scrap is zero percent (0%), the average customer service level is the highest. 3. When percent scrap is one percent (1%), the average customer service level is the lowest.

1.3 Process timing uncertainty.

- From Table E-8 (in Appendix E), the average of the customer service rates are not significant different for all levels of processing time uncertainty. The summary of the discussion when considering just the process timing uncertainty (processing time) on the customer service level is shown in Table XXII.

TABLE XXII

THE SUMMARY OF THE CUSTOMER SERVICE LEVEL DISCUSSION WHEN CHANGING THE PROCESS TIMING UNCERTAINTY LEVELS

Factor	Summary of the effects
Process timing uncertainty (proctime)	1. Changing the level of process timing uncertainty does not change the average customer service level.

2. When considering the interaction between factors.

Because processing time uncertainty is not significant at the 0.05 level, the interaction between percent scrap and processing time (scrap*proctime) and the interaction between supply quantity uncertainty and processing time (supply*proctime) are not significant at the 0.05 level. The interaction between supply quantity uncertainty and process quantity uncertainty is used to test the multiple comparisons. From Table XXIV and Figure 7, it can be observed that the effect of one variable depends upon the levels of the other variables because when both supply and process quantity uncertainty change, the customer service levels change. For example, when supply quantity uncertainty is set at no variation and percent scrap is zero, the customer service level is 100%, but when supply quantity uncertainty is set at high variation and percent scrap is 0.5%, the average customer service level is 98.164%. This means that when the levels of supply quantity uncertainty and process quantity uncertainty change, the customer service level changes, in short, the effect of supply quantity uncertainty (for all three levels) on the customer service level depends upon the levels of process quantity uncertainty (percent scrap). In the same way, the effect of percent scrap on the customer service level depends upon the level of supply quantity uncertainty. The average customer service is maximum when there is no variation in supply quantity with 0% percent scrap (300 units/day and 0% scrap) and is minimum when there is no variation in supply quantity with 1% of scrap (300 units and 1% scrap).

However, from the Least Significant Difference Test (LSD) at the 0.05 level, shown in Appendix F, the difference in means of the customer service level of each pair (or combination) are less than the LSD values,

- the mean of the customer service levels are equal and the highest for all levels of supply quantity uncertainty when percent scrap is zero percent (0%) because the firm has finished goods to meet most of the customer requirements.

- for the 0.5% and 1% scrap levels, at the middle and high variation in supply quantity (300+NORM(0,50) and

300+NORM(0,100)), the customer service levels are not significantly different but they are significantly higher than the customer service level when there is no variation in supply quantity. The summary of the discussion when considering the interaction between supply and process quantity uncertainty (percent scrap) is shown in Table XXIII.

TABLE XXIII

THE SUMMARY OF THE RESULT DISCUSSION OF THE INTERACTION BETWEEN THE SUPPLY QUANTITY UNCERTAINTY AND PROCESS QUANTITY UNCERTAINTY ON THE CUSTOMER SERVICE LEVEL.

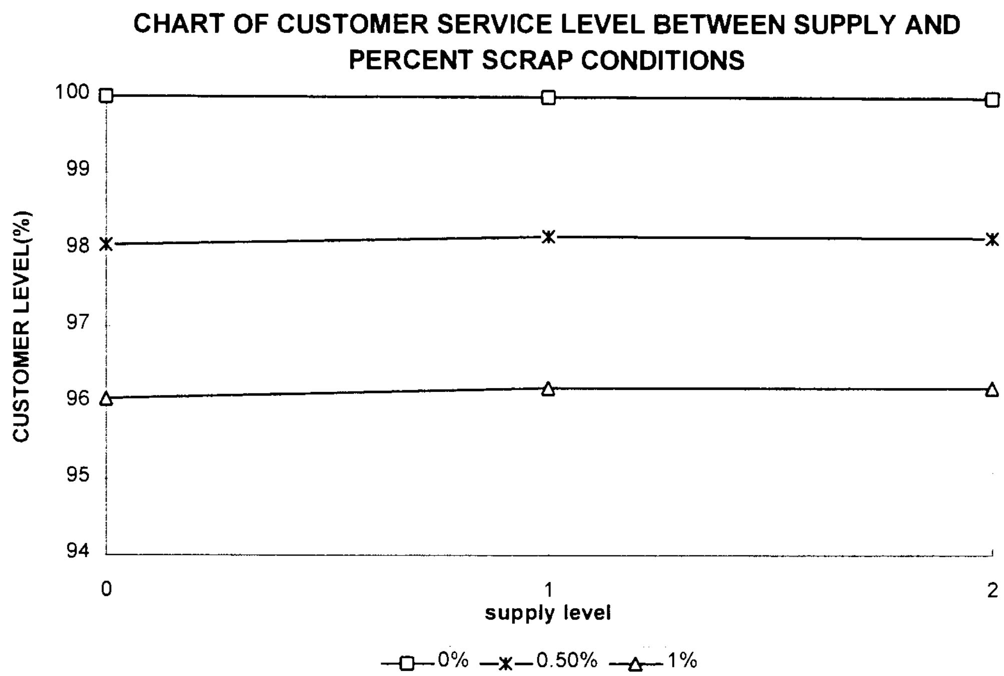
Factor	Summary of the effects
The interaction between process quantity uncertainty (process*supply)	1. From the LSD test at the 0.05 level, because the difference in means of the customer service level of each pair (or each combination) are less than LSD values, - the mean of the customer service levels are equal and the highest for all levels of supply quantity uncertainty when percent scrap is zero percent (0%). - for the 0.5% and 1% scrap levels, at the middle and high variation in supply quantity (300+NORM(0,50) and 300+NORM(0,100)), the customer service levels are not significantly different but they are significantly higher than the customer service level when there is no variation in supply quantity. - the average customer service level is the highest when percent scrap is zero (0%) for all levels of supply quantity uncertainty. - the average customer service level is the lowest when percent scrap is one (1%) with no variation in supply quantity uncertainty.

TABLE XXIV

THE CUSTOMER SERVICE LEVELS OF THE INTERACTION BETWEEN SUPPLY QUANTITY UNCERTAINTY AND PROCESS QUANTITY UNCERTAINTY (PERCENT SCRAP)

Analysis of Variance Procedure

Level of SUPPLY	Level of SCRAP	N	CUST Mean	CUST SD
0	0	25	100.0000000	0.00000000
0	1	25	96.0513520	0.03061956
0	0.5	25	98.0638280	0.19333566
1	0	25	99.9894400	0.01599708
1	1	25	96.2013520	0.06383936
1	0.5	25	98.1786720	0.06981929
2	0	25	99.9698000	0.03411842
2	1	25	96.1895520	0.09139776
2	0.5	25	98.1646000	0.09814977



Note: For supply level:

level 0= supply quantity = 300 units

level 1= supply quantity with middle variation in mean = 300+NORM(0,50) units

level 2= supply quantity with middle variation in mean = 300+NORM(0,100) units

Figure 7: Chart of Customer Service Level under Supply Quantity Uncertainty and Process Quantity Uncertainty (Percent Scrap).

CHAPTER V

SUMMARY AND CONCLUSIONS

Discussion of Research Findings

The results of this study provide evidence of where the existing wisdom (the combined effects of uncertainties occurring simultaneously in a production line) may not be valid. This study has focused on creating a model of a manufacturing system which, although subject to uncertainties, has the advantage of the latest information.

A simulation, written using SLAM II, was used to generate the data. The data was analyzed using a multi-factor analysis of variance model using the SAS programming language to assess the impact of three factors on the average total costs and customer service levels of the system. This study assesses the impact of various factors on performance measures (total costs and customer service levels) in a flow shop manufacturing environment. The three factors analyzed were supply quantity uncertainty, process quantity uncertainty, and process timing uncertainty. There are three levels for both supply quantity uncertainty and process quantity uncertainty and five levels for process timing uncertainty. The three levels for supply quantity uncertainty are 300 units+no error term, 300+NORM(0,50), and 300+NORM(0,100). The three levels of process quantity are 0.0% scrap, 0.5% scrap, and 1.0% scrap for each machine. The five levels of process timing uncertainty are 1, UNFRM(0.75,1.25), UNFRM(0.8,1.2), UNFRM(0.85,1.15), and UNFRM(0.9,1.1) minutes per part, respectively.

The experiment has provided the following answers to the question stated in the goals and objectives of this research.

1. Both supply quantity uncertainty and process quantity uncertainty (percent scrap) significantly affect the total cost and customer service level. Process timing uncertainty (processing time) is not significant because of the excess plant capacity in this study. Process quantity uncertainty causes a high stockout cost and a low customer service level. Supply quantity uncertainty results in a high inventory cost and high customer service level.

2. Process quantity uncertainty (percent scrap) is the most significant on both total cost and customer service level. The next most significant factor is supply quantity uncertainty.

3. When comparing among all factors individually.

process quantity uncertainty with zero percent scrap causes both of the highest average total costs and the highest customer service level as well. It cause a high total cost because of high inventories. When the firm has enough finished goods to meet customer demand, the customer service level is high.

4. When considering the interaction between supply quantity uncertainty and process quantity uncertainty,

- the total costs between zero percent scrap with the medium and high variation in supply quantity are not significantly different. In addition, they are the highest total costs.

- the customer service levels are not significantly different between the medium and high variation in supply quantity even when the firm has scrap in the production line but they are significantly higher than in the no variation in supply quantity case. However, the customer service levels are the highest when there is no scrap in the production line for all levels of supply quantity uncertainty.

Practical Guidelines

A summary of practical guidelines suggested by the research are:

1. When there is no variation in supply quantity, to reduce the cost and increase the customer service level, the firm should focus on process quantity uncertainty (percent scrap) by reducing percent scrap. From this study, if the percent scrap increases, the average stockout costs will also increase.

2. Because the zero percent scrap level with the variation in supply quantity causes a high total cost, changing the level of supply uncertainty causes changes in total cost performance. To reduce the total cost, the firm should control how to release the raw material quantities. This means that when there is no scrap in the production line (percent scrap=0%), the firm should control the raw materials to be as close as possible to the customer need to avoid excess inventories. By controlling the excess inventories, the firm can also avoid high holding costs. Another way to reduce the total costs is by having a good relationship and communications with suppliers, so that they will deliver the exact quantity of needed raw materials.

3. When the firm confronts both supply quantity uncertainty and process quantity uncertainty simultaneously, the recommendation from this study is:

- When percent scrap increases, the stockout cost increases but the change in stockout cost is relatively small. As for the holding cost, there is a sharp reduction when the percent scrap changes from 0% scrap to either 0.5% or 1% scrap. This means that most costs which occur when there is scrap in the production line are stockout costs. To reduce the stockout cost and increase the customer service level, the firm should try to reduce percent scrap in the production line and then have a good relationship and communications with suppliers to get the exact quantity of needed raw materials.

4. Process timing uncertainty is not significant on either total costs or customer service levels in this study. This is likely due to excess plant capacity. The total costs and customer service levels are equal for all levels of processing times at the same supply quantity levels. This means that if the maximum plant capacity is enough to process the arriving raw materials, both the measures of performances are unaffected. The customer service level remains the same because the firm still has enough finished goods to meet customer requirements.

5. This study is appropriate for a firm that has the same or similar circumstances as this study. It concerns supply quantity uncertainty, process quantity uncertainty, and process timing uncertainty in a flow shop manufacturing environment that has only four machines in the production lines, percent scrap for each machine is less than or equal 1%, and plant capacity is enough to produce products even

though it is effected by the variation in supply quantity. This study is a simple case that shows the affects and the results of three uncertainties on total cost and customer service level.

This study provides a better understanding of the impacts of supply quantity uncertainty, process quantity uncertainty, and process timing uncertainty on the performance measures of total cost and customer service level. However, several important issues need to be studied further. Uncertainty in demand quantity and uncertainty in processing time which have an effect on the plant capacity is an important area for future study. Further research addressing these issue should be encouraged.

BIBLIOGRAPHY

Askin, R.C. and Standridge, C.R. (1993). Modeling and Analysis of Manufacturing Systems., New York: John Wiley & Sons.

Benton, W.C. (1993). Time and cost-based priorities for job shop scheduling. International Journal of Production Research, 31(7), 1509-1513.

Bowman, R.A. (1994). Inventory: The opportunity cost of quality. IIE Transactions, 26(3),40-47.

Correa, H.L., (1994). Linking Flexibility, Uncertainty and Variability in Manufacturing Systems, Brookfield, Vermont: Avegury.

Crandall, R.E. and Burwell, T.H. (1993). The effect of work-in-process inventory levels on the throughput and lead times. Production and Inventory Management Journal, 34(4), 6-11.

Etienne, E.C. (1987). Choosing optimal buffering strategies for dealing with uncertainty in MRP. Journal of Operations Management, 7(1&2), 102-120.

Grasso, E.T. and Taylor, B.W. (1984). A simulation-based experimental investigation of supply/timing uncertainty in MRP systems. International Journal of Production Research, 22(3), 485-497.

Greene, J.H. (1974). Production and Inventory Control. Homewood, Illinois: Richard D. Irwin, INC.

Gupta, S.M. and Brennan L. (1995). MRP systems under supply and process uncertainty in an integrated shop floor control environment. International Journal of Production Research, 33(1), 205-220.

Ho, C-J., Law, W-K., and Rampal, R.(1995). Uncertainty - dampening methods for reducing MRP system nervousness. International Journal of Production Research, 33(2), 483-496.

Klastorin, T.D., Matheson, L., and Moinzadeh, K. (1993). On the use of buffer inventories to minimize costs with an unreliable machine. IIE Transactions, 25(5), 50-62.

Kropp, D.H., Carlson, R.C., and Juker, J.V.(1983). Concepts, theories, and techniques: Heuristic lot-sizing approaches for dealing with MRP system nervousness. Decision Sciences, 14(2), 156-168.

Miller, S.S. (1988). Competitive Manufacturing-Using Production as a Management Tool, New York: Van Nostrand Reinhol Company.

Pritsker, A.A.B. (1995). Introduction to Simulation and SLAM II, West Lafayette, Indiana: New York.

Reisman, A., Dean, B.V., Salvador, M.S., and Oral, M. (1972). Industrial Inventory Control. New York: Science Publishers, Inc.

Schmitt, T.G. (1984). Resolving uncertainty in manufacturing systems. Journal of Operations Management, 4(4), 331-345.

Sridharan, V. and Berry, W.L. (1990). Freezing the Master Production Schedule under demand uncertainty. Decision Sciences, 21(1), 97-120.

Sridharan,V. and LaForge,R.A. (1989). The impact of safety stock on schedule instability, cost and service. Journal of Operations Management, 8(4), 327-347.

Thomas, A.B. (1980). Stock Control in Manufacturing Industries. Guildford, London: Billing & Sons Limited.

Vollmann, T.E., Berry, W.L., and Whybark, D.C. (1992). Manufacturing Planning and Control Systems. Boston, Massachusetts: Richard D. Irwin, INC.

Waters, C.D.J. (1992). Inventory Control and Management. Chichester, New York: John Wiley & Sons.

Whybark, D.C. and Williams, J.G. (1976). Material requirements planning under uncertainty. Decision Sciences, 7(3), 595-606.

Yang, K.K. and Sum, C.C. (1994). A comparison of job shop dispatching rules using a total cost criterion. International Journal of Production Research, 32(4), 807-820.

APPENDICES

APPENDIX A

THE NETWORK DIAGRAM

APPENDIX A

THE NETWORK DIAGRAM

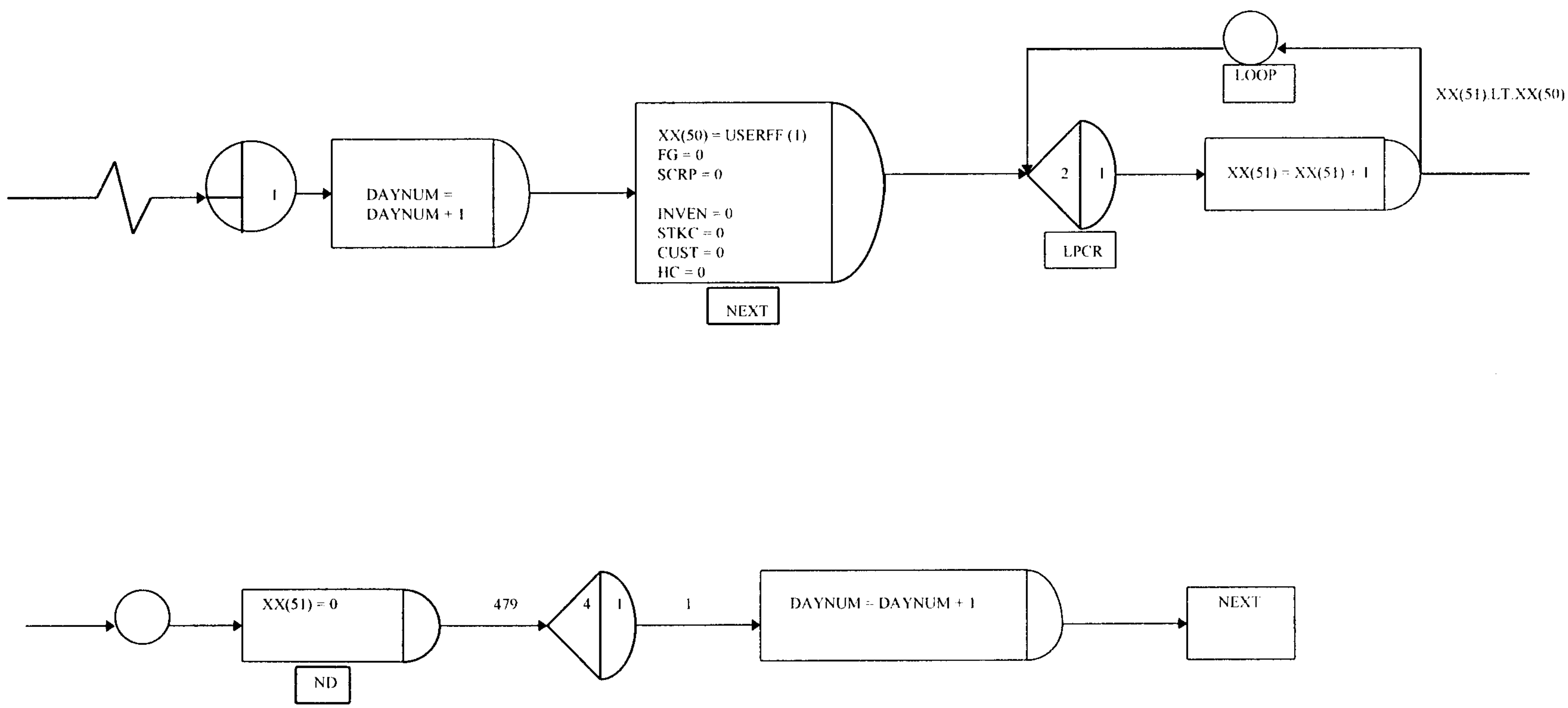


Figure A-1: The Net Work Diagram of Raw material Arrival

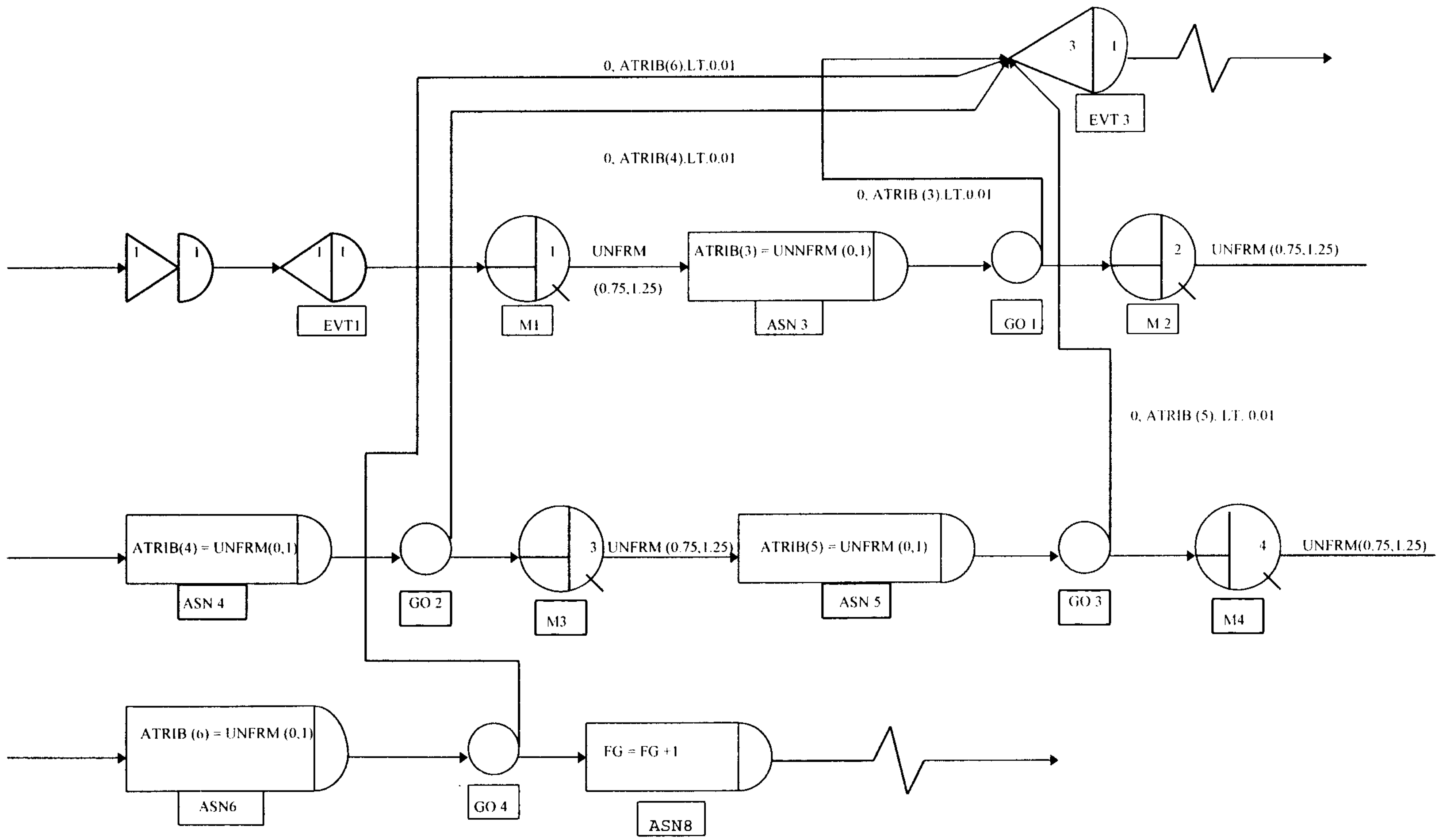


Figure A-2: The Main Network Diagram

APPENDIX B

THE NETWORK STATEMENT MODEL

APPENDIX B

THE NETWORK STATEMENT MODEL

This program illustrates the case as follows:
- Supply Quantity Uncertainty: 300+NORM(0,100)
- Process Quantity Uncertainty: 0.5%
- Process Timing Uncertainty: UNFRM(0.75,1.25)

```
GEN,KANCHANA,THESIS,05/15/96,5, ,NO, ,NO,YES/1;
LIMITS,4,6,1500;
EQUIVALENCE/XX(1),FG/
            XX(2),SCRP/
            XX(3),INVEN/
            XX(4),CUST/
            XX(5),NXTD/
            XX(20),DAYNUM/
            XX(72),STKC/
            XX(73),HC/
            XX(99),TSTKC/
            XX(71),THC/
            XX(100),TINVEN;
;
;*************************************************************************
;*                           GLOBAL VARIABLES                             *
;*                                                                        *
;*ATRIB(1)  : ARRIVAL TIME OF RAW MATERIALS                               *
;*ATRIB(3)  : SCRAP RANDOM NUMBER SAMPLING FROM UNIFORM DISTRIBUTION FOR MACHINE 1  *
;*ATRIB(4)  : SCRAP RANDOM NUMBER SAMPLING FROM UNIFORM DISTRIBUTION FOR MACHINE 2  *
;*ATRIB(5)  : SCRAP RANDOM NUMBER SAMPLING FROM UNIFORM DISTRIBUTION FOR MACHINE 3  *
;*ATRIB(6)  : SCRAP RANDOM NUMBER SAMPLING FROM UNIFORM DISTRIBUTION FOR MACHINE 4  *
;*XX(1),FG                   :FINISHED GOODS                              *
;*XX(2),SCRP                 :SCRAPS                                      *
;*XX(3),INVEN                :INVENTORY QUANTITIES IN EACH DAY            *
;*XX(4),CUST                 :CUSTOMER SERVICE LEVEL INEACH DAY           *
;*XX(20),DAYNUM              :DAY NO.                                     *
;*XX(71),THC                 :ACCUMULATED HOLDING COSTS                   *
;*XX(72),STKC                :STOCKOUT COSTS IN EACH DAY                  *
;*XX(73),HC                  :HOLDING COSTS IN EACH DAY                   *
;*XX(99),TSTKC               :ACCUMULATED TOTAL STOCKOUT COSTS            *
;*XX(100),TINVEN             :ACCUMULATED TOTAL INVENTORIES               *
;*************************************************************************
;
INTLC,XX(1)=0,
      XX(2)=0,
      XX(3)=0,
```

```
XX(4)=0,
      XX(51)=0;
NETWORK;
      CREATE;
      ASSIGN,DAYNUM=1;
NEXT  ASSIGN,XX(50)=USERF(1),
             FG=0,
             SCRP=0,
             INVEN=0,
             STKC=0,
             CUST=0,
             STKC=0,
             HC=0;                  INITIALIZED VARIABLES AT THE BEGINNING OF EACH DAY
LPCR  EVENT,2;
      ASSIGN,XX(51)=XX(51)+1,1;
      ACT,0,XX(51).LT.XX(50),LOOP;
      ACT,0,XX(51).GE.XX(50),ND;
LOOP  GOON,1;
      ACT, , ,LPCR;
ND    GOON,1;
      ASSIGN,XX(51)=0;
      ACT,479, , ;
      EVENT,4;
      ACT,1, , ;
      ASSIGN,DAYNUM=DAYNUM+1;
      ACT, , ,NEXT;
;
;*************************************************************************
;*                                                                       *
;*                          MAIN NETWORK BODY                            *
;*************************************************************************
;
ARVL  ENTER,1,1;
        ACT, , ,EVT1;
EVT1  EVENT,1;
      ACT, , ,M1;
M1    QUEUE(1);                           MACHINE 1
      ACT,UNFRM(0.75,1.25), ,ASN3;
ASN3  ASSIGN,ATRIB(3)=UNFRM(0,1);         SAMPLING RANDOM NO. FROM UNFRM DIST.
      ACT, , ,GO1;
GO1   GOON,1;
      ACT,0,ATRIB(3).LT.0.005,EVT3;       WHEN RANDOM NO. < % SCRAP => SCRAP
      ACT;
M2    QUEUE(2);                           MACHINE 2
      ACT,UNFRM(0.75,1.25), ,ASN4;
ASN4  ASSIGN,ATRIB(4)=UNFRM(0,1);         SAMPLING RANDOM NO. FROM UNFRM DIST.
      ACT, , ,GO2;
GO2   GOON,1;
      ACT,0,ATRIB(4).LT.0.005,EVT3;       WHEN RANDOM NO. < % SCRAP => SCRAP
      ACT;
M3    QUEUE(3);                           MACHINE 3
      ACT,UNFRM(0.75,1.25), ,ASN5;
ASN5  ASSIGN,ATRIB(5)=UNFRM(0,1);         SAMPLING RANDOM NO. FROM UNFRM DIST
      ACT, , ,GO3;
```

```
GO3    GOON,1;
       ACT,0,ATRIB(5).LT.0.005,EVT3;          WHEN RANDOM NO. < % SCRAP => SCRAP
       ACT;
M4     QUEUE(4);                              MACHINE 4
       ACT,UNFRM(0.75,1.25), ,ASN6;
ASN6   ASSIGN,ATRIB(6)=UNFRM(0,1);            SAMPLING RANDOM NO. FROM UNFRM DIST
       ACT, , ,GO4;
GO4    GOON,1;
       ACT,0,ATRIB(6).LT.0.005,EVT3;          WHEN RANDOM NO. < % SCRAP => SCRAP
       ACT,0,ATRIB(6).GE.0,ASN8;
GO5    GOON;
       ACT, , ,EVT3;
EVT3   EVENT,3;
       TERM;
ASN8   ASSIGN,FG=FG+1;
       TERM;
       END;
INIT,0,312000;                                SIMULATED TIME
MONTR,CLEAR,72000;                            CLEAR STATISTICS FOR WARM UP PERIOD
SIMULATE;
MONTR,CLEAR,72000;
SIMULATE;
MONTR,CLEAR,72000;
SIMULATE;
MONTR,CLEAR,72000;
SIMULATE;
MONTR,CLEAR,72000;
FIN;
```

```
C***********************************************************************
C*                                                                     *
C*                         SUBROUTINE EVENT                            *
C***********************************************************************
C*
      SUBROUTINE EVENT(I)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR,
     +NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      EQUIVALENCE(XX(100),TINVEN),(XX(99),TSTKC),(XX(98),TCUST),
     +(XX(97),TSCRP),(XX(1),FG),(XX(2),SCRP),(XX(4),CUST),(XX(70),TC),
     +(XX(71),THC),(XX(72),STKC),(XX(73),HC),(XX(20),DAYNUM),
     +(XX(21),INVEN),(XX(23),ACUST),(XX(24),OUT),(XX(25),A1)
C*
C*
      GO TO (1,2,3,4), I
C***********************************************************************
C*                             EVENT(1)                                *
C*    INITIALIZED VARIABLES TO BE ZERO AT THE BEGINNING OF EACH DAY    *
C***********************************************************************
    1 IF (TNOW.EQ.0.0) THEN
         TINVEN=0.0
         TSTKC=0.0
         TCUST=0.0
         TSCRP=0.0
         THC=0.0
         A1=0.0
      END IF
      RETURN
C***********************************************************************
C*                             EVENT(2)                                *
C*          CREATE RAW MATERIALS BASED ON PROBABILITY DISTRIBUTION     *
C***********************************************************************
    2 CALL ENTER(1,ATRIB)
      RETURN
C*
C***********************************************************************
C*                             EVENT(3)                                *
C*                          SCRAP COUNTING                             *
C***********************************************************************
C*
    3 SCRP=SCRP+1.0
      RETURN
C*
C***********************************************************************
C*                             EVENT 4                                 *
C*            THE CALCULATION OF PERFORMANCE MEASUREMENTS              *
C***********************************************************************
C*
    4 IF (FG .LT. 300.0 .AND. TINVEN .EQ. 0.0) THEN
         OUT=FG
         CUST=(OUT/300.0)
         STKC=((300.0-OUT) * 0.50)
         HC=0.0
         A1=1.0
```

```
      END IF
      IF (FG.LT.300.0 .AND. TINVEN.GE.1.0) THEN
         IF (FG+TINVEN .GE. 300.0) THEN
            OUT=300.0
            CUST=1.00
            HC=((FG+TINVEN-300.0) * 0.50)
            A1=2.0
            INVEN=300.0-FG
            TINVEN=TINVEN-INVEN
         ELSE IF (FG+TINVEN .LT. 300.0) THEN
               OUT=(FG+TINVEN)
               CUST=(OUT/300.0)
               STKC=((300.0-OUT) * 0.50)
               A1=3.0
               HC=0.0
               INVEN=0.0
               TINVEN=0.0
         END IF
      END IF
      IF (FG.GE.300.0) THEN
         A1=6
         IF (TINVEN.GE.1.0) THEN
            OUT=300.0
            CUST=1.00
            HC=((FG-300.0+TINVEN) * 0.50)
            A1=4.0
            INVEN=FG-300.0
            TINVEN=TINVEN+INVEN
         ELSE IF (TINVEN.EQ.0.0) THEN
              OUT=300.0
              CUST=1.00
              HC=((FG-300.0) * 0.50)
              A1=5.0
              INVEN=FG-300.0
              TINVEN=TINVEN+INVEN
         END IF
      END IF
      TSTKC=TSTKC+STKC
      THC=THC+HC
      TC=TSTKC+THC
      TCUST=TCUST+CUST
      ACUST=(TCUST/DAYNUM)
      IF (DAYNUM.EQ.1.0) THEN
      PRINT*,'DAY ',' FG ',' SCRP',' TINVEN ',
     +'     ACTSTKC  ','   ACTHC ','        ACTC', '    CUST ','ACUST',
     +' COND '
      END IF
      PRINT 10,DAYNUM,FG,SCRP,TINVEN,TSTKC,THC,TC,CUST,ACUST,A1
   10 FORMAT (1X,F4.0,1X,F4.0,1X,F3.0,1X,F5.0,1X,F11.2,
     +1X,F11.2,1X,F11.2,2X,F5.3,2X,F5.3,1X,F3.0)
      RETURN
      END
C***********************************************************************
```

```
C*************************************************************************
C*                                                                       *
C*                           FUNCTION SUBUF                              *
C*************************************************************************
C*
FUNCTION USERF(IFN)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR,
     +NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      GO TO (1), IFN
C*
C*************************************************************************
C*                            USERF(1)                                   *
C*************************************************************************
    1 USERF=300.0+RNORM(0.0,10.0,3)
      RETURN
      END
C*
C*************************************************************************
```

APPENDIX C

THE VALIDATION DATA

APPENDIX C

THE VALIDATION DATA

CASE 1 : SUPPLY QUANTITY = 300 UNITS

PERCENT SCRAP = 0.0%

PROCESSING TIME= UNFRM(0.75,1.25)

DAY	FG	SCRP	TINVEN	ACTSTKC	ACTHC	ACTC	CUST	ACUST	COND
1.	300.	0.	0.	0.00	0.00	0.00	1.000	1.000	5.
2.	300.	0.	0.	0.00	0.00	0.00	1.000	1.000	5.
3.	300.	0.	0.	0.00	0.00	0.00	1.000	1.000	5.
4.	300.	0.	0.	0.00	0.00	0.00	1.000	1.000	5.
5.	300.	0.	0.	0.00	0.00	0.00	1.000	1.000	5.
6.	300.	0.	0.	0.00	0.00	0.00	1.000	1.000	5.
7.	300.	0.	0.	0.00	0.00	0.00	1.000	1.000	5.
8.	300.	0.	0.	0.00	0.00	0.00	1.000	1.000	5.
9.	300.	0.	0.	0.00	0.00	0.00	1.000	1.000	5.
10.	300.	0.	0.	0.00	0.00	0.00	1.000	1.000	5.
11.	300.	0.	0.	0.00	0.00	0.00	1.000	1.000	5.
12.	300.	0.	0.	0.00	0.00	0.00	1.000	1.000	5.
13.	300.	0.	0.	0.00	0.00	0.00	1.000	1.000	5.
14.	300.	0.	0.	0.00	0.00	0.00	1.000	1.000	5.
15.	300.	0.	0.	0.00	0.00	0.00	1.000	1.000	5.
16.	300.	0.	0.	0.00	0.00	0.00	1.000	1.000	5.
17.	300.	0.	0.	0.00	0.00	0.00	1.000	1.000	5.
18.	300.	0.	0.	0.00	0.00	0.00	1.000	1.000	5.
19.	300.	0.	0.	0.00	0.00	0.00	1.000	1.000	5.
20.	300.	0.	0.	0.00	0.00	0.00	1.000	1.000	5.
21.	300.	0.	0.	0.00	0.00	0.00	1.000	1.000	5.
22.	300.	0.	0.	0.00	0.00	0.00	1.000	1.000	5.
23.	300.	0.	0.	0.00	0.00	0.00	1.000	1.000	5.
24.	300.	0.	0.	0.00	0.00	0.00	1.000	1.000	5.
25.	300.	0.	0.	0.00	0.00	0.00	1.000	1.000	5.

S L A M   I I   S U M M A R Y   R E P O R T

SIMULATION PROJECT THESIS   BY KANCHANA

DATE 5/15/1996   RUN NUMBER 1 OF 1

CURRENT TIME 0.1200E+05
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

FILE STATISTICS

FILE NUMBER	LABEL/TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	M1 QUEUE	93.5966	99.6362	299	299	143.9948
2	M2 QUEUE	0.8777	1.4542	10	0	1.4043
3	M3 QUEUE	0.6904	1.0173	5	0	1.1047
4	M4 QUEUE	0.5826	0.9573	7	0	0.9321
5	CALENDAR	3.4961	1.8918	301	2	0.2438

SERVICE ACTIVITY STATISTICS

ACTIVITY INDEX	START NODE OR ACTIVITY LABEL	SERVER CAPACITY	AVERAGE UTILIZATION	STANDARD DEVIATION	CURRENT UTILIZATION	AVERAGE BLOCKAGE	MAXIMUM IDLE TIME/SERVERS	MAXIMUM BUSY TIME/SERVERS	ENTITY COUNT
0	M1 QUEUE	1	0.6255	0.4840	1	0.0000	185.2266	306.3711	
0	M2 QUEUE	1	0.6233	0.4846	0	0.0000	180.3213	301.3125	
0	M3 QUEUE	1	0.6241	0.4844	0	0.0000	178.3286	274.0679	
0	M4 QUEUE	1	0.6233	0.4846	0	0.0000	177.1904	225.3369	

FORTRAN STOP

CASE 2: SUPPLY QUANTITY = 310 UNITS

PERCENT SCRAP = 0.0%

PROCESSING TIME = UNFRM (0.75,1.25)

DAY	FG	SCRP	TINVEN	ACTSTKC	ACTHC	ACTC	CUST	ACUST	COND
1.	310.	0.	10.	0.00	5.00	5.00	1.000	1.000	5.
2.	310.	0.	20.	0.00	15.00	15.00	1.000	1.000	4.
3.	310.	0.	30.	0.00	30.00	30.00	1.000	1.000	4.
4.	310.	0.	40.	0.00	50.00	50.00	1.000	1.000	4.
5.	310.	0.	50.	0.00	75.00	75.00	1.000	1.000	4.
6.	310.	0.	60.	0.00	105.00	105.00	1.000	1.000	4.
7.	310.	0.	70.	0.00	140.00	140.00	1.000	1.000	4.
8.	310.	0.	80.	0.00	180.00	180.00	1.000	1.000	4.
9.	310.	0.	90.	0.00	225.00	225.00	1.000	1.000	4.
10.	310.	0.	100.	0.00	275.00	275.00	1.000	1.000	4.
11.	310.	0.	110.	0.00	330.00	330.00	1.000	1.000	4.
12.	310.	0.	120.	0.00	390.00	390.00	1.000	1.000	4.
13.	310.	0.	130.	0.00	455.00	455.00	1.000	1.000	4.
14.	310.	0.	140.	0.00	525.00	525.00	1.000	1.000	4.
15.	310.	0.	150.	0.00	600.00	600.00	1.000	1.000	4.
16.	310.	0.	160.	0.00	680.00	680.00	1.000	1.000	4.
17.	310.	0.	170.	0.00	765.00	765.00	1.000	1.000	4.
18.	310.	0.	180.	0.00	855.00	855.00	1.000	1.000	4.
19.	310.	0.	190.	0.00	950.00	950.00	1.000	1.000	4.
20.	310.	0.	200.	0.00	1050.00	1050.00	1.000	1.000	4.
21.	310.	0.	210.	0.00	1155.00	1155.00	1.000	1.000	4.
22.	310.	0.	220.	0.00	1265.00	1265.00	1.000	1.000	4.
23.	310.	0.	230.	0.00	1380.00	1380.00	1.000	1.000	4.
24.	310.	0.	240.	0.00	1500.00	1500.00	1.000	1.000	4.
25.	310.	0.	250.	0.00	1625.00	1625.00	1.000	1.000	4.

S L A M   I I   S U M M A R Y   R E P O R T

SIMULATION PROJECT THESIS — BY KANCHANA

DATE 5/15/1996 — RUN RUMBER 1 OF 1

CURRENT TIME 0.1200E+05
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

FILE STATISTICS

FILE NUMBER	LABEL/TYPE		AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	M1	QUEUE	99.8476	103.1527	309	309	148.6564
2	M2	QUEUE	1.1177	1.5308	8	0	1.7307
3	M3	QUEUE	0.6952	1.0352	6	0	1.0764
4	M4	QUEUE	0.6146	0.9188	6	0	0.9516
5		CALENDAR	3.5830	1.8690	311	2	0.2413

SERVICE ACTIVITY STATISTICS

ACTIVITY INDEX	START NODE OR ACTIVITY LABEL		SERVER CAPACITY	AVERAGE UTILIZATION	STANDARD DEVIATION	CURRENT UTILIZATION	AVERAGE BLOCKAGE	MAXIMUM IDLE TIME/SERVERS	MAXIMUM BUSY TIME/SERVERS	ENTITY COUNT
0	M1	QUEUE	1	0.6461	0.4782	1	0.0000	176.1475	313.7490	
0	M2	QUEUE	1	0.6458	0.4783	0	0.0000	171.4800	312.5891	
0	M3	QUEUE	1	0.6452	0.4785	0	0.0000	168.3881	298.4111	
0	M4	QUEUE	1	0.6460	0.4782	0	0.0000	166.6798	286.2085	

FORTRAN STOP

CASE 3 : SUPPLY QUANTITY = 310 UNITS

PERCENT SCRAP = 1.0%

PROCESSINT TIME = UNFRM (0.75,1.25)

DAY	FG	SCRP	TINVEN	ACTSTKC	ACTHC	ACTC	CUST	ACUST	COND
1.	300.	10.	0.	0.00	0.00	0.00	1.000	1.000	5.
2.	297.	13.	0.	1.50	0.00	1.50	0.990	0.995	1.
3.	302.	8.	2.	1.50	1.00	2.50	1.000	0.997	5.
4.	298.	12.	0.	1.50	1.00	2.50	1.000	0.998	2.
5.	296.	14.	0.	3.50	1.00	4.50	0.987	0.995	1.
6.	300.	10.	0.	3.50	1.00	4.50	1.000	0.996	5.
7.	293.	17.	0.	7.00	1.00	8.00	0.977	0.993	1.
8.	301.	9.	1.	7.00	1.50	8.50	1.000	0.994	5.
9.	301.	9.	2.	7.00	2.50	9.50	1.000	0.995	4.
10.	295.	15.	0.	8.50	2.50	11.00	0.990	0.994	3.
11.	297.	13.	0.	10.00	2.50	12.50	0.990	0.994	1.
12.	302.	8.	2.	10.00	3.50	13.50	1.000	0.994	5.
13.	301.	9.	3.	10.00	5.00	15.00	1.000	0.995	4.
14.	299.	11.	2.	10.00	6.00	16.00	1.000	0.995	2.
15.	296.	14.	0.	11.00	6.00	17.00	0.993	0.995	3.
16.	299.	11.	0.	11.50	6.00	17.50	0.997	0.995	1.
17.	290.	20.	0.	16.50	6.00	22.50	0.967	0.994	1.
18.	298.	12.	0.	17.50	6.00	23.50	0.993	0.994	1.
19.	297.	13.	0.	19.00	6.00	25.00	0.990	0.993	1.
20.	299.	11.	0.	19.50	6.00	25.50	0.997	0.994	1.
21.	298.	12.	0.	20.50	6.00	26.50	0.993	0.993	1.
22.	297.	13.	0.	22.00	6.00	28.00	0.990	0.993	1.
23.	304.	6.	4.	22.00	8.00	30.00	1.000	0.994	5.
24.	296.	14.	0.	22.00	8.00	30.00	1.000	0.994	2.
25.	303.	7.	3.	22.00	9.50	31.50	1.000	0.994	5.

S L A M   I I   S U M M A R Y   R E P O R T

SIMULATION PROJECT THESIS   BY KANCHANA

DATE 5/15/1996   RUN NUMBER 1 OF 1

CURRENT TIME 0.1200E+05
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

FILE STATISTICS

FILE NUMBER	LABEL/TYPE		AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	M1	QUEUE	99.7885	103.0900	309	309	148.5685
2	M2	QUEUE	0.8308	1.2296	7	0	1.2981
3	M3	QUEUE	0.4822	0.8132	6	0	0.7599
4	M4	QUEUE	0.3095	0.5766	4	0	0.4923
5		CALENDAR	3.5469	1.8659	311	2	0.2423

SERVICE ACTIVITY STATISTICS

ACTIVITY INDEX	START NODE OR ACTIVITY LABEL		SERVER CAPACITY	AVERAGE UTILIZATION	STANDARD DEVIATION	CURRENT UTILIZATION	AVERAGE BLOCKAGE	MAXIMUM IDLE TIME/SERVERS	MAXIMUM BUSY TIME/SERVERS	ENTITY COUNT
0	M1	QUEUE	1	0.6459	0.4782	1	0.0000	176.3335	313.0425	
0	M2	QUEUE	1	0.6407	0.4798	0	0.0000	172.2856	294.7688	
0	M3	QUEUE	1	0.6339	0.4817	0	0.0000	171.1215	308.3428	
0	M4	QUEUE	1	0.6264	0.4838	0	0.0000	171.2097	122.7607	

FORTRAN

CASE 4: SUPPLY QUANTITY = 300+NORM(0,10)

PERCENT SCRAP = 1.0%

PROCESSING TIME = UNFRM(0.75,1.25)

DAY	FG	SCRP	TINVEN	ACTSTKC	ACTHC	ACTC	CUST	ACUST	COND
1.	289.	9.	0.	5.50	0.00	5.50	0.963	0.963	1.
2.	295.	12.	0.	8.00	0.00	8.00	0.983	0.973	1.
3.	291.	14.	0.	12.50	0.00	12.50	0.970	0.972	1.
4.	285.	11.	0.	20.00	0.00	20.00	0.950	0.967	1.
5.	303.	13.	3.	20.00	1.50	21.50	1.000	0.973	5.
6.	297.	11.	0.	20.00	1.50	21.50	1.000	0.978	2.
7.	295.	16.	0.	22.50	1.50	24.00	0.983	0.979	1.
8.	286.	11.	0.	29.50	1.50	31.00	0.953	0.975	1.
9.	295.	13.	0.	32.00	1.50	33.50	0.983	0.976	1.
10.	305.	14.	5.	32.00	4.00	36.00	1.000	0.979	5.
11.	290.	14.	0.	34.50	4.00	38.50	0.983	0.979	3.
12.	282.	9.	0.	43.50	4.00	47.50	0.940	0.976	1.
13.	300.	9.	0.	43.50	4.00	47.50	1.000	0.978	5.
14.	309.	12.	9.	43.50	8.50	52.00	1.000	0.979	5.
15.	292.	15.	1.	43.50	9.00	52.50	1.000	0.981	2.
16.	285.	15.	0.	50.50	9.00	59.50	0.953	0.979	3.
17.	295.	14.	0.	53.00	9.00	62.00	0.983	0.979	1.
18.	281.	14.	0.	62.50	9.00	71.50	0.937	0.977	1.
19.	275.	9.	0.	75.00	9.00	84.00	0.917	0.974	1.
20.	277.	15.	0.	86.50	9.00	95.50	0.923	0.971	1.
21.	303.	14.	3.	86.50	10.50	97.00	1.000	0.973	5.
22.	282.	13.	0.	94.00	10.50	104.50	0.950	0.972	3.
23.	288.	11.	0.	100.00	10.50	110.50	0.960	0.971	1.
24.	286.	11.	0.	107.00	10.50	117.50	0.953	0.970	1.
25.	286.	14.	0.	114.00	10.50	124.50	0.953	0.970	1.

S L A M   I I   S U M M A R Y   R E P O R T

SIMULATION PROJECT THESIS   BY KANCHANA

DATE 5/15/1996   RUN NUMBER 1 OF 1

CURRENT TIME 0.1200E+05
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

FILE STATISTICS

FILE NUMBER	LABEL/TYPE		AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	M1	QUEUE	95.6728	100.8876	320	300	145.5838
2	M2	QUEUE	0.8448	1.3507	7	0	1.3518
3	M3	QUEUE	0.4143	0.7704	6	0	0.6704
4	M4	QUEUE	0.2825	0.5647	4	0	0.4611
5		CALENDAR	3.4849	1.8771	322	2	0.2444

SERVICE ACTIVITY STATISTICS

ACTIVITY INDEX	START NODE OR ACTIVITY LABEL		SERVER CAPACITY	AVERAGE UTILIZATION	STANDARD DEVIATION	CURRENT UTILIZATION	AVERAGE BLOCKAGE	MAXIMUM IDLE TIME/SERVERS	MAXIMUM BUSY TIME/SERVERS	ENTITY COUNT
0	M1	QUEUE	1	0.6333	0.4819	1	0.0000	197.5156	323.0791	
0	M2	QUEUE	1	0.6249	0.4842	0	0.0000	196.3438	310.0364	
0	M3	QUEUE	1	0.6166	0.4862	0	0.0000	195.8467	199.8271	
0	M4	QUEUE	1	0.6101	0.4877	0	0.0000	195.9814	148.0234	

FORTRAN STOP

APPENDIX D

THE RESULTS FROM SIMULATION

APPENDIX D
THE RESULTS FROM SIMULATION
TABLE D-1
RESULTS FROM SIMULATION: PROCESSING TIME (MIN./UNIT):1

supply conditions	Percent Scrap(%)														
	0.0%					0.5%					1.0%				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
* NO VARIATION: 300+ no error term															
- ACC.TOTAL STOCKOUT COST($)	0.0	0.0	0.0	0.0	0.0	1480.5	1497.0	1486.5	1502.0	1474.0	2948.5	2951.5	2942.5	2994.0	2948.5
- ACC.TOTAL HOLDING COST($)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
- ACC.TOTAL COSTS($)	0.0	0.0	0.0	0.0	0.0	1480.5	1497.0	1486.5	1502	1474	2948.5	2951.5	2942.5	2994.0	2948.5
- CUSTOMER SERVICE RATE(%)	100.0	100.0	100.0	100.0	100.0	98.025	97.998	98.012	97.991	98.029	96.061	96.057	96.068	95.999	96.058
* MEDIUM VARIATION: 300+norm(0,50)															
- ACC.TOTAL STOCKOUT COST($)	30.5	0	9.5	0.0	0.0	1342.0	1425.0	1428.5	1392.0	1267.0	2812.5	2882.0	2887.0	2886.5	2748.0
- ACC.TOTAL HOLDING COST($)	42989.0	35603.0	14698.0	51800.5	52931.0	537.0	340.5	384.5	491.5	481.5	59.0	78.0	64.0	77.0	63.5
- ACC.TOTAL COSTS($)	43019.5	35603.0	14707.5	51800.5	52931.0	1879.0	1765.5	1813.0	1883.5	1748.5	2871.5	2960.0	2951.0	2963.5	2811.5
- CUSTOMER SERVICE RATE(%)	99.96	100.0	99.988	100.0	100.0	98.209	98.094	98.087	98.142	98.305	96.239	96.143	96.1396	96.144	96.329
* HIGH VARIATION: 300+norm(0,100)															
- ACC.TOTAL STOCKOUT COST($)	62.0	0.0	42.5	0.0	9.0	1342.5	1448.5	1449.5	1398.0	1232.5	2812.0	2904.0	2906.0	2892.0	2713.0
- ACC.TOTAL HOLDING COST($)	50854.5	32062.5	16791.0	51285.5	62466.5	1350.5	855.5	926.0	1155.5	1301	217.0	238.5	198.5	264.5	226.0
- ACC.TOTAL COSTS($)	50916.5	32062.5	16833.5	51285.5	62475.5	2693.0	2304.0	2375.5	2553.5	2533.5	3029.0	3142.5	3104.0	3156.5	2939.0
- CUSTOMER SERVICE RATE(%)	99.917	100.0	99.944	100.0	99.988	98.204	98.062	98.059	98.134	98.349	96.239	96.116	96.115	96.137	96.368

TABLE D-2

FROM SIMULATION: PROCESSING TIME (MIN./UNIT): UNFRM(0.75,1.25)

supply conditions	Percent Scrap(%)														
	0.0%					0.5%					1.0%				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
* NO VARIATION: 300+ no error term															
- ACC.TOTAL STOCKOUT COST($)	0.0	0.0	0.0	0.0	0.0	1502.5	1453.0	1471.5	1465.5	1481.0	2934.5	2958.5	2942.5	2955.5	2994.5
- ACC.TOTAL HOLDING COST($)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
- ACC.TOTAL COSTS($)	0.0	0.0	0.0	0.0	0.0	1502.5	1453.0	1471.5	1465.5	1481.0	2934.5	2958.5	2942.5	2955.5	2994.5
- CUSTOMER SERVICE RATE(%)	100.0	100.0	100.0	100.0	100.0	97.990	98.061	98.033	98.045	98.02	96.084	96.048	96.075	96.05	96.00
* MEDIUM VARIATION: 300+norm(0,50)															
- ACC.TOTAL STOCKOUT COST($)	30.5	0.0	9.5	0.0	0.0	1339.5	1404.0	1415.5	1354.5	1331.5	2792.5	2851.0	2905.0	2918.0	2815.5
- ACC.TOTAL HOLDING COST($)	42989.0	35603.0	14698.0	51800.5	52931.0	449.5	461.5	368.0	502.0	447.0	78.0	58.0	44.0	59.0	52.5
- ACC.TOTAL COSTS($)	43019.5	35603.0	14707.5	51800.5	52931.0	1789.0	1865.5	1783.5	1856.5	1778.5	2870.5	2909.0	2949.0	2977.0	2868
- CUSTOMER SERVICE RATE(%)	99.96	100.0	99.988	100.0	100.0	98.207	98.122	98.108	98.191	98.217	96.272	96.186	96.117	96.101	96.238
* HIGH VARIATION: 300+norm(0,100)															
- ACC.TOTAL STOCKOUT COST($)	62.0	0.0	42.5	0.0	9.0	1358.0	1418.5	1469.0	1370.0	1254.5	2810.0	2922.0	2922.0	2840.5	2734.0
- ACC.TOTAL HOLDING COST($)	50854.5	32062.5	16791.0	51285.5	62466.5	1243.5	948.0	1054.0	1193.0	1206.5	221.0	214.0	219.5	223.5	237.0
- ACC.TOTAL COSTS($)	50916.5	32062.5	16833.5	51285.5	62475.5	2601.5	2366.5	2523.0	2563.0	2461.0	3031.0	3136.0	3141.5	3064.0	2971.0
- CUSTOMER SERVICE RATE(%)	99.917	100.0	99.944	100.0	99.988	98.182	98.099	98.032	98.171	98.324	96.242	96.094	96.097	96.204	96.347

TABLE D-3

RESULTS FROM SIMULATION: PROCESSING TIME (MIN./UNIT): UNFRM(0.8,1.2)

supply conditions	Percent Scrap(%)														
	0.0%					0.5%					1.0%				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
* NO VARIATION: 300+ no error term															
- ACC.TOTAL STOCKOUT COST($)	0	0	0	0	0	1483.5	1477.0	1489.5	1469.0	1501.0	2990.0	2921.0	2978.5	2933.5	2969.5
- ACC.TOTAL HOLDING COST($)	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
- ACC.TOTAL COSTS($)	0	0	0	0	0	1483.5	1477.0	1489.5	1469.0	1501.0	2990.0	2921.0	2978.5	2933.5	2969.5
- CUSTOMER SERVICE RATE(%)	100	100	100	100	100	98.021	98.03	98.018	98.038	97.994	96.008	96.10	96.024	96.081	96.035
* MEDIUM VARIATION: 300+norm(0,50)															
- ACC.TOTAL STOCKOUT COST($)	30.5	0.0	9.5	0.0	0.0	1301.0	1429.0	1400.0	1342.0	1301.0	2821.5	2858.5	2881.0	2836.5	2761.0
- ACC.TOTAL HOLDING COST($)	42989.0	35603.0	14698.0	51800.5	52931.0	479.5	412.0	433.0	538.0	434.0	53.0	69.0	43.5	75.0	67.0
- ACC.TOTAL COSTS($)	43019.5	35603.0	14707.5	51800.5	52931.0	1780.5	1841.0	1833.0	1880.0	1735.0	2874.5	2927.5	2924.5	2911.5	2828.0
- CUSTOMER SERVICE RATE(%)	99.96	100.0	99.988	100.0	100.0	98.187	98.087	98.127	98.207	98.260	96.230	96.177	96.145	96.208	96.314
* HIGH VARIATION: 300+norm(0,100)															
- ACC.TOTAL STOCKOUT COST($)	62.0	0.0	42.5	0.0	9.0	1359.0	1437.0	1441.0	1362.0	1245.5	2846.0	2866.0	2896.5	2875.0	2784.0
- ACC.TOTAL HOLDING COST($)	50854.5	32062.5	16791	51285.5	62466.5	1191.0	913.0	1045.0	1315.5	1299.5	227.5	239.0	214.5	198.5	254.0
- ACC.TOTAL COSTS($)	50916.5	32062.5	16833.5	51285.5	62475.5	2550.0	2350.5	2486.0	2677.5	2545.0	3073.5	3105.0	3111.0	3073.5	3038.0
- CUSTOMER SERVICE RATE(%)	99.917	100	99.944	100.0	99.988	98.179	98.077	98.068	98.182	98.341	96.192	96.170	96.128	96.159	96.279

ABLE D-4

RESULTS FROM SIMULATION: PROCESSING TIME (MIN./UNIT): UNFRM(0.85,1.15)

supply conditions	Percent Scrap(%)														
	0.0%					0.5%					1%				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
* NO VARIATION: 300+ no error term															
- ACC.TOTAL STOCKOUT COST($)	0.0	0.0	0.0	0.0	0.0	1494.0	1476.0	1493.0	1467.0	1476.0	2941.5	2943.5	2946.5	2983.5	2977.0
- ACC.TOTAL HOLDING COST($)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
- ACC.TOTAL COSTS($)	0.0	0.0	0.0	0.0	0.0	1494.0	1476.0	1493.0	1467.0	1476.0	2941.5	2943.5	2946.5	2983.5	2977.0
- CUSTOMER SERVICE RATE(%)	100.0	100.0	100.0	100.0	100.0	98.197	98.032	98.002	98.04	98.032	96.072	96.067	96.064	96.017	96.024
* MEDIUM VARIATION: 300+norm(0,50)															
- ACC.TOTAL STOCKOUT COST($)	30.5	0.0	9.5	0.0	0.0	1346.5	1407.0	1349.0	1293.0	1428.5	2834.5	2880.5	2855.0	2844.0	2779.5
- ACC.TOTAL HOLDING COST($)	42989.0	35603.0	14698.0	51800.5	52931.0	472.0	395.5	543.0	470.5	394.5	61.5	66.0	56.0	73.0	60.5
- ACC.TOTAL COSTS($)	43019.5	35603.0	14707.5	51800.5	52931.0	1818.5	1802.5	1892.0	1763.5	1823.0	2896.0	2946.5	2911.0	2917.0	2840.0
- CUSTOMER SERVICE RATE(%)	99.96	100	99.988	100.0	100.0	98.197	98.117	98.198	98.273	98.09	96.214	96.152	96.184	96.197	96.286
* HIGH VARIATION: 300+norm(0,100)															
- ACC.TOTAL STOCKOUT COST($)	62.0	0.0	42.5	0.0	9.0	1380.5	1418.0	1438.0	1367.5	1255.5	2820.0	2895.0	2915.5	2880.5	2725.5
- ACC.TOTAL HOLDING COST($)	50854.5	32062.5	16791	51285.5	62466.5	1153.5	907.0	1106.0	1275.5	1202.5	205.5	236.5	205.5	208.0	233.5
- ACC.TOTAL COSTS($)	50916.5	32062.5	16833.5	51285.5	62475.5	2534.0	2325.0	2544.0	2643.0	2458.0	3025.5	3131.5	3121.0	3088.5	2959.0
- CUSTOMER SERVICE RATE(%)	99.917	100.0	99.9436	100.0	99.988	98.15	98.103	98.073	98.175	98.317	96.229	96.131	96.104	96.148	96.353

TABLE D-5

RESULTS FROM SIMULATION: PROCESSING TIME (MIN./UNIT): UNFRM(0.9,1.1)

supply conditions	Percent Scrap(%)														
	0.0%					0.5%					1.0%				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
* NO VARIATION: 300 +no error term															
- ACC.TOTAL STOCKOUT COST($)	0.0	0.0	0.0	0.0	0.0	1507.0	1485.0	1483.5	1465.0	1460.0	2940.5	2944.0	2932.5	2965.0	2999.0
- ACC.TOTAL HOLDING COST($)	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
- ACC.TOTAL COSTS($)	0.0	0.0	0.0	0.0	0.0	1507.0	1485.0	1483.5	1465.0	1460.0	2940.5	2944.0	2932.5	2965.0	2999.0
- CUSTOMER SERVICE RATE(%)	100.0	100.0	100.0	100.0	100.0	97.986	98.016	98.018	98.045	98.050	96.071	96.065	96.086	96.037	95.995
* MEDIUM VARIATION: 300+norm(0,50)															
- ACC.TOTAL STOCKOUT COST($)	30.5	0.0	9.5	0.0	0.0	1354.5	1426.0	1429.5	1350.5	1280.5	2815.5	2886.5	2886.0	2844.0	2767.0
- ACC.TOTAL HOLDING COST($)	42989.0	35603.0	14698.0	51800.5	52931.0	457.5	401.5	447.0	526.0	492.0	61.5	66.5	50.5	75.5	62.0
- ACC.TOTAL COSTS($)	43019.5	35603.0	14707.5	51800.5	52931.0	1812.0	1827.5	1876.5	1876.5	1772.5	2877.0	2953.0	2936.5	2919.5	2829.0
- CUSTOMER SERVICE RATE(%)	99.96	100.0	99.988	100.0	100.0	98.188	98.291	98.09	98.195	98.289	96.237	96.142	96.141	96.198	96.302
* HIGH VARIATION: 300+norm(0,100)															
- ACC.TOTAL STOCKOUT COST($)	62.0	0.0	42.5	0.0	9.0	1373.5	1434.5	1437.5	1358.0	1258.0	2826.0	2921.5	2923.5	2880.5	2720.5
- ACC.TOTAL HOLDING COST($)	50854.5	32062.5	16791.0	51285.5	62466.5	1272.5	923.5	1165.0	1343.0	1235.0	219.5	228.5	220.5	211.5	287.5
- ACC.TOTAL COSTS($)	50916.5	32062.5	16833.5	51285.5	62475.5	2646.0	2358.0	2602.5	2701.0	2493.0	3045.5	3150.0	3144.0	3092.0	3008.0
- CUSTOMER SERVICE RATE(%)	99.917	100.0	99.944	100.0	99.988	98.159	98.082	98.073	98.189	98.321	96.220	96.100	96.093	96.151	96.357

APPENDIX E

THE STATISTICS FROM SAS PROGRAM FOR THE TOTAL COSTS AND CUSTOMER SERVICE LEVELS

APPENDIX E

THE STSTISTICS RESULTS FROM SAS PROGRAM FOR THE TOTAL COSTS AND CUSTOMER SERVICE LEVELS

TABLE E-1

THE SAS SYSTEM :ANALYSIS OF VARIANCE PROCEDURE
CLASS LEVEL INFORMATION FOR THE TOTAL COST

Class	Levels	Values
SUPPLY	3	0 1 2
SCRAP	3	0 1 0.5
PROCTIME	5	1 2 3 4 5

Number of observations in data set = 225

The SAS System

Analysis of Variance Procedure

Dependent Variable: COST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	44	9620047495.6399	1355001079.44636	21.32	0.0001
Error	180	11442520460.800	63569558.1155556		
Corrected Total	224	71062567956.440			

R-Square	C.V.	Root MSE	COST Mean
0.838980	73.90709	7973.05199504	10787.94000000

Source	DF	Anova SS	Mean Square	F Value	Pr > F
SUPPLY	2	9813111691.760	4906555845.880	77.18	0.0001
SCRAP	2	31244890128.407	15622445064.203	245.75	0.0001
SUPPLY*SCRAP	4	18562021112.633	4640505278.158	73.00	0.0001
PROCTIME	4	3389.296	847.324	0.00	1.0000
SUPPLY*PROCTIME	8	4617.718	577.215	0.00	1.0000
SCRAP*PROCTIME	8	6969.138	871.142	0.00	1.0000

TABLE E-2

THE SAS SYSTEM: THE MULTIPLE COMPARISON PROCEDURE
FOR THE TOTAL COST
FACTOR: SUPPLY QUANTITY UNCERTAINTY

T TESTS (LSD) FOR VARIABLE: COST
NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 180 MSE= 63569558
Critical Value of T= 1.97
Least Significant Difference= 2569.1

Means with the same letter are not significantly different.

T Grouping	Mean	N	SUPPLY
A	16104	75	2
A	14780	75	1
B	1480	75	0

The SAS System
Analysis of Variance Procedure

Bonferroni (Dunn) T tests for variable: COST

NOTE: This test controls the type I experimentwise error rate, but generally has a higher type II error rate than REGWQ.

Alpha= 0.05 df= 180 MSE= 63569558
Critical Value of T= 2.42
Minimum Significant Difference= 3146.3

Means with the same letter are not significantly different.

Bon Grouping	Mean	N	SUPPLY
A	16104	75	2
A	14780	75	1
B	1480	75	0

TABLE E-3

THE SAS SYSTEM:THE MULTIPLE COMPARISON PROCEDURE
FOR THE TOTAL COST
FACTOR: PROCESS QUANTITY UNCERTAITY

T TESTS (LSD) FOR VARIABLE: COST
NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 180 MSE= 63569558
Critical Value of T= 1.97
Least Significant Difference= 2569.1

Means with the same letter are not significantly different.

T Grouping	Mean	N	SCRAP
A	27442	75	0
B	2983	75	1
B	1939	75	0.5

The SAS System

Analysis of Variance Procedure

Bonferroni (Dunn) T tests for variable: COST

NOTE: This test controls the type I experimentwise error rate, but generally has a higher type II error rate than REGWQ.

Alpha= 0.05 df= 180 MSE= 63569558
Critical Value of T= 2.42
Minimum Significant Difference= 3146.3

Means with the same letter are not significantly different.

Bon Grouping	Mean	N	SCRAP
A	27442	75	0
B	2983	75	1
B	1939	75	0.5

TABLE E-4

THE SAS SYSTEM: THE MULTIPLE COMPARISON PROCEDURE FOR THE TOTAL COST FACTOR : PROCESS TIMING UNCERTAINTY

T tests (LSD) for variable: COST
NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 180 MSE= 63569558
Critical Value of T= 1.97
Least Significant Difference= 3316.7

Means with the same letter are not significantly different.

T Grouping	Mean	N	PROCTIME
A	10794	45	5
A	10789	45	1
A	10789	45	3
A	10784	45	4
A	10784	45	2

The SAS System

Analysis of Variance Procedure

Bonferroni (Dunn) T tests for variable: COST
NOTE: This test controls the type I experimentwise error rate, but generally has a higher type II error rate than REGWQ.

Alpha= 0.05 df= 180 MSE= 63569558
Critical Value of T= 2.84
Minimum Significant Difference= 4777.1

Means with the same letter are not significantly different.

Bon Grouping	Mean	N	PROCTIME
A	10794	45	5
A	10789	45	1
A	10789	45	3
A	10784	45	4
A	10784	45	2

TABLE E-5

THE SAS SYSTEM :ANALYSIS OF VARIANCE PROCEDURE CLASS LEVEL INFORMATION FOR THE CUSTOMER SERVICE LEVEL

Analysis of Variance Procedure

Class Level Information

Class	Levels	Values
SUPPLY	3	0 1 2
SCRAP	3	0 1 0.5
PROCTIME	5	1 2 3 4 5

Number of observations in data set = 225

ANALYSIS OF VARIANCE PROCEDURE
DEPENDENT VARIABLE: CUST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	44	553.6330432	12.5825692	1583.90	0.0001
Error	180	1.4299299	0.0079441		
Corrected Total	224	555.0629732			

R-Square	C.V.	Root MSE	CUST Mean
0.997424	0.090865	0.089129	98.08984

Source	DF	Anova SS	Mean Square	F Value	Pr > F
SUPPLY	2	0.3064373	0.1532187	19.29	0.0001
SCRAP	2	552.9070638	276.4535319	34800.05	0.0001
SUPPLY*SCRAP	4	0.2493120	0.0623280	7.85	0.0001
PROCTIME	4	0.0246193	0.0061548	0.77	0.5429
SUPPLY*PROCTIME	8	0.0323415	0.0040427	0.51	0.8487
SCRAP*PROCTIME	8	0.0526304	0.0065788	0.83	0.5788

TABLE E-6

THE SAS SYSTEM:THE MULTIPLE COMPARISON PROCEDURE FOR THE CUSTOMER SERVICE LEVEL FACTOR : SUPPLY QUANTITY UNCERTAINTY

T tests (LSD) for variable: CUST

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 180 MSE= 0.007944
Critical Value of T= 1.97
Least Significant Difference= 0.0287

Means with the same letter are not significantly different.

T Grouping	Mean	N	SUPPLY
A	98.12315	75	1
A	98.10798	75	2
B	98.03839	75	0

The SAS System

Analysis of Variance Procedure

Bonferroni (Dunn) T tests for variable: CUST

NOTE: This test controls the type I experimentwise error rate, but generally has a higher type II error rate than REGWQ.

Alpha= 0.05 df= 180 MSE= 0.007944
Critical Value of T= 2.42
Minimum Significant Difference= 0.0352

Means with the same letter are not significantly different.

Bon Grouping	Mean	N	SUPPLY
A	98.12315	75	1
A	98.10798	75	2
B	98.03839	75	0

TABLE E-7

THE SAS SYSTEM:THE MULTIPLE COMPARISON PROCEDURE FOR THE CUSTOMER SERVICE LEVEL FACTOR : PROCESS QUANTITY UNCERTAINTY

T tests (LSD) for variable: CUST

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 180 MSE= 0.007944
Critical Value of T= 1.97
Least Significant Difference= 0.0287

Means with the same letter are not significantly different.

T Grouping	Mean	N	SCRAP
A	99.98641	75	0
B	98.13570	75	0.5
C	96.14742	75	1

The SAS System

Analysis of Variance Procedure

Bonferroni (Dunn) T tests for variable: CUST

NOTE: This test controls the type I experimentwise error rate, but generally has a higher type II error rate than REGWQ.

Alpha= 0.05 df= 180 MSE= 0.007944
Critical Value of T= 2.42
Minimum Significant Difference= 0.0352

Means with the same letter are not significantly different.

Bon Grouping	Mean	N	SCRAP
A	99.98641	75	0
B	98.13570	75	0.5
C	96.14742	75	1

TABLE E-8

THE SAS SYSTEM:THE MULTIPLE COMPARISON PROCEDURE FOR THE CUSTOMER SERVICE LEVEL FACTOR : PROCESS TIMING UNCERTAINTY

T tests (LSD) for variable: CUST

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 180 MSE= 0.007944
Critical Value of T= 1.97
Least Significant Difference= 0.0371

Means with the same letter are not significantly different.

T Grouping	Mean	N	PROCTIME
A	98.11052	45	5
A	98.08744	45	3
A	98.08460	45	4
A	98.08421	45	2
A	98.08244	45	1

The SAS System

Analysis of Variance Procedure

Bonferroni (Dunn) T tests for variable: CUST

NOTE: This test controls the type I experimentwise error rate, but generally has a higher type II error rate than REGWQ.

Alpha= 0.05 df= 180 MSE= 0.007944
Critical Value of T= 2.84
Minimum Significant Difference= 0.0534

Means with the same letter are not significantly different.

Bon Grouping	Mean	N	PROCTIME
A	98.11052	45	5
A	98.08744	45	3
A	98.08460	45	4
A	98.08421	45	2
A	98.08244	45	1

APPENDIX F

THE LEAST SIGNIFICANT DIFFERENCE TEST (LSD) FOR TOTAL COSTS AND CUSTOMER SERVICE LEVEL UNDER BOTH SUPPLY QUANTITY UNCERTAINTY AND PROCESS QUANTITY UNCERTANITY (PERCENT SCRAP)

APPENDIX F

THE LEAST SIGNIFICANT DIFFERENCE TEST (LSD) FOR TOTAL COSTS AND CUSTOMER SERVICE LEVEL UNDER BOTH SUPPLY QUANTITY UNCERTAINTY AND PROCESS QUANTITY UNCERTAINTY (PERCENT SCRAP)

A. The LSD Test for Total Costs:

- The first step: Order the average of total costs in each combination from the maximum value to the minimum value.

No.	Combination	Symbol	Total Costs($)
1.	Level of supply:2, Level of Scrap 0%	μ_1	42714
2.	Level of supply:1, Level of Scrap 0%	μ_2	39612.3
3.	Level of supply:2, Level of Scrap 1%	μ_3	3082.4
4.	Level of supply:0, Level of Scrap 1%	μ_4	2957.42
5.	Level of supply:1, Level of Scrap 1%	μ_5	2908.9
6.	Level of supply:2, Level of Scrap 0.5%	μ_6	2514.28
7.	Level of supply:1, Level of Scrap 0.5%	μ_7	1819.86
8.	Level of supply:0, Level of Scrap 0.5%	μ_8	1481.6
9.	Level of supply:0, Level of Scrap 0%	μ_9	0.0

- The second step: Calculation LSD for each pair of combinations. If the difference between each pair is greater than or equal the LSD value, the mean of the first combination is greater than the second combination.

$LSD = t_{df\ of\ obs.,\ \alpha/2}\ [(\ MS\ within)*(1/n_1\ +1/n_1)]^{1/2}$

Thus;

$$LSD\ (1,2) = 1.97[(63569558)(2/25)]^{1/2}$$

$$= 4442.58$$

$$= LSD\ (1,3)=LSD(1,4),..LSD(1,9)$$

$$= LSD\ (2,3)=LSD(1,4),..LSD(2,9)$$

:

:

$$= LSD\ (7,9)=LSD(8,9)$$

$\mu_1 - \mu_2 = 3101.7 < LSD$: not significant so, $\mu_1 = \mu_2$

$\mu_1 - \mu_3 = 39631.6 > LSD$: significant so, $\mu_1 > \mu_3$

:

:

$\mu_1 - \mu_9 = 42714 > LSD$: significant so, $\mu_1 > \mu_9$

Thus: $\mu_1 = \mu_2 > \mu_3 > \mu_4 \ldots > \mu_9$

$\mu_3 - \mu_4 = 124.98 < LSD$: not significant so, $\mu_3 = \mu_4$

$\mu_3 - \mu_5 = 173.5 < LSD$: not significant so, $\mu_3 = \mu_5$

:

:

$\mu_3 - \mu_9 = 3082.4 < LSD$: not significant so, $\mu_3 = \mu_9$

Thus: $\mu_3 = \mu_4 = \mu_5 = \ldots = \mu_9$

Conclusions:

1. $\mu_1 = \mu_2 > \mu_3 > \mu_4 \ldots > \mu_9$
2. $\mu_3 = \mu_4 = \mu_5 = \ldots = \mu_9$

B. The LSD Test for Customer Service Levels:

To calculate the multiple comparisons between each pair of combinations, it is prepared the same way as the total cost method.

- The first step:

No.	Combination	Symbol	Customer Service Level (%)
1.	Level of supply:0, Level of Scrap 0%	μ_1	100
2.	Level of supply:1, Level of Scrap 0%	μ_2	99.98944
3.	Level of supply:2, Level of Scrap 0%	μ_3	99.9698
4.	Level of supply:1, Level of Scrap 0.5%	μ_4	98.17867
5.	Level of supply:2, Level of Scrap 0.5%	μ_5	98.1646
6.	Level of supply:0, Level of Scrap 0.5%	μ_6	98.063828
7.	Level of supply:1, Level of Scrap 1%	μ_7	96.20135
8.	Level of supply:2, Level of Scrap 1%	μ_8	96.18955
9.	Level of supply:0, Level of Scrap 1%	μ_9	96.05135

- The second step:

$$LSD = t_{df\ of\ obs.,\ \alpha/2}\ [(\ MS\ within)*(1/n_1\ +1/n_1)]^{1/2}$$

Thus;

$$LSD\ (1,2) = 1.97[(0.0079441)(2/25)]^{1/2}$$

$= 0.05$

$= LSD\ (1,3)=LSD(1,4),..LSD(1,9)$

$= LSD\ (2,3)=LSD(1,4),..LSD(2,9)$

:

:

$= LSD\ (7,9)=LSD(8,9)$

$\mu_1 - \mu_2 = 0.01$ < LSD : not significant so, $\mu_1 = \mu_2$

$\mu_1 - \mu_3 = 0.02$ < LSD : not significant so, $\mu_1 = \mu_3$

$\mu_1 - \mu_4 = 1.1211$ > LSD : significant so, $\mu_1 > \mu_4$

:

:

$\mu_1 - \mu_9 = 3.95$ > LSD : significant so, $\mu_1 > \mu_9$

Thus: $\mu_1 = \mu_2 = \mu_3 > \mu_4 \ldots > \mu_9$

$\mu_4 - \mu_5 = 0.014$ < LSD : not significant so, $\mu_4 = \mu_5$

$\mu_4 - \mu_6 = 0.115$ > LSD : significant so, $\mu_4 > \mu_6$

:

:

$\mu_4 - \mu_9 = 2.127$ > LSD : significant so, $\mu_4 > \mu_9$

Thus: $\mu_4 = \mu_5 > \mu_6 \ldots > \mu_9$

$\mu_6 - \mu_7 = 1.86$ > LSD : significant so, $\mu_6 > \mu_7$

:

:

$\mu_6 - \mu_9 = 2.012$ > LSD : significant so, $\mu_6 > \mu_9$

Thus: $\mu_6 > \mu_7 > \ldots > \mu_9$

$\mu_7 - \mu_8 = 0.02$ < LSD : not significant so, $\mu_7 = \mu_8$

$\mu_7 - \mu_9 = 0.15$ > LSD : significant so, $\mu_7 > \mu_9$

Thus: $\mu_7 = \mu_8 > \mu_9$

$\mu_8 - \mu_9 = 0.13$ > LSD : significant so, $\mu_8 > \mu_9$

Conclusions:

1. $\mu_1 = \mu_2 = \mu_3 > \mu_4 \quad ... > \mu_9$

2. $\mu_4 = \mu_5 > \mu_6 > \mu_7 \quad ... > \mu_9$

3. $\mu_7 = \mu_8 > \mu_9$

APPENDIX G

THE STATISTICS RESULTS FROM SAS SYSTEM

FOR THE HOLDING COSTS

APPENDIX G

THE STATISTICS RESULTS FROM SAS SYSTEM FOR THE HOLDING COSTS

TABLE G-1
THE SAS SYSTEM: ANALYSIS OF VARIANCE PROCEDURE
CLASS LEVEL INFORMATION

Class	Levels	Values
SUPPLY	3	0 1 2
SCRAP	3	0 1 0.5
PROCTIME	5	1 2 3 4 5

Number of observations in data set = 225

TABLE G-2

THE SAS SYSTEM ANALYSIS OF VARIANCE PROCEDURE
INDEPENDENT VARIABLE: HOLDING COST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	44	65131515155	1480261708	23.27	0.0001
Error	180	11448098763	63600549		
Corrected Total	224	76579613918			

R-Square	C.V.	Root MSE	HCOST Mean
0.850507	85.26083	7974.995	9353.644

Source	DF	Anova SS	Mean Square	F Value	Pr > F
SUPPLY	2	9907368278	4953684139	77.89	0.0001
SCRAP	2	36775573264	18387786632	289.11	0.0001
SUPPLY*SCRAP	4	18448555616	4612138904	72.52	0.0001
PROCTIME	4	3408	852	0.00	1.0000
SUPPLY*PROCTIME	8	4008	501	0.00	1.0000
SCRAP*PROCTIME	8	5395	674	0.00	1.0000

TABLE G-3

THE SAS SYSTEM : THE MULTIPLE COMPARISON PROCEDURE
FACTOR : SUPPLY QUANTITY UNCERTAINTY

T tests (LSD) for variable: HCOST

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 180 MSE= 63600549
Critical Value of T= 1.97
Least Significant Difference= 2569.8

Means with the same letter are not significantly different.

T Grouping	Mean	N	SUPPLY
A	14687	75	2
A	13374	75	1
B	0	75	0

The SAS System

Analysis of Variance Procedure

Bonferroni (Dunn) T tests for variable: HCOST

NOTE: This test controls the type I experimentwise error rate, but generally has a higher type II error rate than REGWQ.

Alpha= 0.05 df= 180 MSE= 63600549
Critical Value of T= 2.42
Minimum Significant Difference= 3147.1

Means with the same letter are not significantly different.

Bon Grouping	Mean	N	SUPPLY
A	14687	75	2
A	13374	75	1
B	0	75	0

TABLE G-4

THE SAS SYSTEM : THE MULTIPLE COMPARISON PROCEDURE
FACTOR : SUPPLY QUANTITY UNCERTAINTY

T tests (LSD) for variable: HCOST

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 180 MSE= 63600549
Critical Value of T= 1.97
Least Significant Difference= 2569.8

Means with the same letter are not significantly different.

T Grouping	Mean	N	SCRAP
A	27432	75	0
B	533	75	0.5
B			
B	96	75	1

The SAS System

Analysis of Variance Procedure

Bonferroni (Dunn) T tests for variable: HCOST

NOTE: This test controls the type I experimentwise error rate, but generally has a higher type II error rate than REGWQ.

Alpha= 0.05 df= 180 MSE= 63600549
Critical Value of T= 2.42
Minimum Significant Difference= 3147.1

Means with the same letter are not significantly different.

Bon Grouping	Mean	N	SCRAP
A	27432	75	0
B	533	75	0.5
B	96	75	1

TABLE G-5

THE SAS SYSTEM : THE MULTIPLE COMPARISON PROCEDURE
FACTOR: PROCESSING TIMING UNCERTAINTY

T tests (LSD) for variable: HCOST

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 180 MSE= 63600549
Critical Value of T= 1.97
Least Significant Difference= 3317.5

Means with the same letter are not significantly different.

T Grouping	Mean	N	PROCTIME
A	9361	45	5
A	9355	45	3
A	9351	45	4
A	9351	45	1
A	9350	45	2

The SAS System

Analysis of Variance Procedure

Bonferroni (Dunn) T tests for variable: HCOST

NOTE: This test controls the type I experimentwise error rate, but generally has a higher type II error rate than REGWQ.

Alpha= 0.05 df= 180 MSE= 63600549
Critical Value of T= 2.84
Minimum Significant Difference= 4778.3

Means with the same letter are not significantly different.

Bon Grouping	Mean	N	PROCTIME
A	9361	45	5
A	9355	45	3
A	9351	45	4
A	9351	45	1
A	9350	45	2

TABLE G-6

THE HOLDING COSTS UNDER SUPPLY QUANTITY UNCERTAINTY AND PROCESS QUANTITY UNCERTAINTY

The SAS System
Analysis of Variance Procedure

Level of SUPPLY	Level of SCRAP	N	HCOST Mean	HCOST SD
0	0	25	0.0000	0.0000
0	1	25	0.0000	0.0000
0	0.5	25	0.0000	0.0000
1	0	25	39604.3000	14245.8956
1	1	25	62.9400	9.8872
1	0.5	25	454.3600	54.7048
2	0	25	42692.0000	16553.9117
2	1	25	225.9800	20.4738
2	0.5	25	1143.2200	154.3355

APPENDIX H

THE RESULTS FROM SAS SYSTEM

FOR THE STOCKOUT COSTS

APPENDIX H

THE RESULTS FROM SAS SYSTEM

FOR THE STOCKOUT COSTS

TABLE H-1

THE SAS SYSTEM : ANALYSIS OF VARIANCE PROCEDURE FOR THE STOCKOUT COST

CLASS LEVEL INFORMATION

Class	Levels	Values
SUPPLY	3	0 1 2
SCRAP	3	0 1 0.5
PROCTIME	5	1 2 3 4 5

Number of observations in data set = 225

TABLE H-2

THE SAS SYSTEM : ANALYSIS OF VARIANCE PROCEDUREDEPENDENT VARIABLE: STOCKOUT COST

Sum of Source	Mean DF	Squares	Square	F Value	Pr > F
Model	44	309935561.2	7043990.0	3252.84	0.0001
Error	180	389788.6	2165.5		
Corrected Total	224	310325349.8			

R-Square	C.V.	Root MSE	STKC Mean
0.998744	3.247227	46.53485	1433.064

Source	DF	Anova SS	Mean Square	F Value	Pr > F
SUPPLY	2	245342.1	122671.1	56.65	0.0001
SCRAP	2	309506092.4	154753046.2	71463.22	0.0001
SUPPLY*SCRAP	4	180645.5	45161.4	20.86	0.0001
PROCTIME	4	281.5	70.4	0.03	0.9980
SUPPLY*PROCTIME	8	1427.2	178.4	0.08	0.9996
SCRAP*PROCTIME	8	433.9	54.2	0.03	1.0000

TABLE H-3

THE SAS SYSTEM : THE MULTIPLE COMPARISON PROCEDURE
FACTOR : SUPPLY QUANTITY UNCERTAINTY

T tests (LSD) for variable: STKC

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 180 MSE= 2165.492
Critical Value of T= 1.97
Least Significant Difference= 14.995

Means with the same letter are not significantly different.

T Grouping	Mean	N	SUPPLY
A	1479.427	75	0
B	1414.733	75	2
B	1405.033	75	1

The SAS System

Analysis of Variance Procedure

Bonferroni (Dunn) T tests for variable: STKC

NOTE: This test controls the type I experimentwise error rate, but generally has a higher type II error rate than REGWQ.

Alpha= 0.05 df= 180 MSE= 2165.492
Critical Value of T= 2.42
Minimum Significant Difference= 18.364

Means with the same letter are not significantly different.

Bon Grouping	Mean	N	SUPPLY
A	1479.427	75	0
B	1414.733	75	2
B	1405.033	75	1

TABLE H-4

THE SAS SYSTEM : THE MULTIPLE COMPARISON PROCEDURE
FACTOR : PROCESS QUANTITY UNCERTAINTY

The SAS System

Analysis of Variance Procedure

T tests (LSD) for variable: STKC

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 180 MSE= 2165.492
Critical Value of T= 1.97
Least Significant Difference= 14.995

Means with the same letter are not significantly different.

T Grouping	Mean	N	SCRAP
A	2882.747	75	1
B	1406.213	75	0.5
C	10.233	75	0

The SAS System

Analysis of Variance Procedure

Bonferroni (Dunn) T tests for variable: STKC

NOTE: This test controls the type I experimentwise error rate, but generally has a higher type II error rate than REGWQ.

Alpha= 0.05 df= 180 MSE= 2165.492
Critical Value of T= 2.42
Minimum Significant Difference= 18.364

Means with the same letter are not significantly different.

Bon Grouping	Mean	N	SCRAP
A	2882.747	75	1
B	1406.213	75	0.5
C	10.233	75	0

TABLE H-5

THE SAS SYSTEM : THE MULTIPLE COMPARISON PROCEDURE
FACTOR : PROCESS TIMING UNCERTAINTY

The SAS System
Analysis of Variance Procedure

T tests (LSD) for variable: STKC

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 180 MSE= 2165.492
Critical Value of T= 1.97
Least Significant Difference= 19.358

Means with the same letter are not significantly different.

T Grouping	Mean	N	PROCTIME
A	1434.156	45	2
A	1433.978	45	1
A	1433.511	45	5
A	1432.556	45	4
A	1431.122	45	3

The SAS System

Analysis of Variance Procedure

Bonferroni (Dunn) T tests for variable: STKC

NOTE: This test controls the type I experimentwise error rate, but generally has a higher type II error rate than REGWQ.

Alpha= 0.05 df= 180 MSE= 2165.492
Critical Value of T= 2.84
Minimum Significant Difference= 27.882

Means with the same letter are not significantly different.

Bon Grouping	Mean	N	PROCTIME
A	1434.156	45	2
A	1433.978	45	1
A	1433.511	45	5
A	1432.556	45	4
A	1431.122	45	3

TABLE H-6

THE STOCKOUT COSTS UNDER SUPPLY QUANTITY UNCERTAINTY AND PROCESS TIMING UNCERTAINTY

The SAS System
Analysis of Variance Procedure

Level of SUPPLY	Level of SCRAP	N	------------STKC------------ Mean	SD
0	0	25	0.00000	0.0000000
0	1	25	2957.40000	22.3177807
0	0.5	25	1480.88000	13.9845748
1	0	25	8.00000	12.0804594
1	1	25	2841.60000	47.1725556
1	0.5	25	1365.50000	52.2033284
2	0	25	22.70000	25.6368875
2	1	25	2849.24000	68.7112194
2	0.5	25	1372.26000	72.2338679

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