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DEMONSTRATING THE EFFECTS OF SHOP FLOW
PROCESS VARIABILITY ON THE AIR FORCE
DEPOT LEVEL REPARABLE ITEM PIPELINE

THESIS

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DEMONSTRATING THE EFFECTS OF SHOP FLOW PROCESS VARIABILITY ON THE AIR FORCE DEPOT LEVEL REPARABLE ITEM PIPELINE

THESIS

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

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Requirement for the Degree of

Master of Science in Logistics Management

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Preface

This study demonstrated the effects shop flow process variability has on the Air Force Depot Level Reparable Item Pipeline. To do this, a simulation model to represent the pipeline was developed that allowed us to manipulate flow time variables, such as mean flow time and variability, and assess their impact on the pipeline. This study may give Air Force leaders a different perspective when managing the pipeline.

A search of the existing literature was conducted to understand the role that variability can play in a process, and to understand the interactions of the various segments of the Depot Level Reparable Item Pipeline. Some of this literature recommended using simulation to improve management of a pipeline. This study is in response to those recommendations. The simulation model developed is a start in developing a complete model of the pipeline. Additions to this simulation model can and should be made to increase its usefulness to management.

This study would not have been possible without outside help. We regret we can only offer thanks to the many people who provided their assistance. Of these people, our heartfelt gratitude goes to Mrs. Trixie Brewer at HQ AFMC. Without her help, we would still be at square one. We must also thank our advisors, Lt Col David A. Diener for providing a stable influence, Maj David K. Peterson for being "Mr. Pipeline," and Capt Dan Hicks for providing guidance with a sense of humor to keep everything in perspective. Each advisor's unique perspective is visible in the final product. Most importantly, we extend our gratitude to our families and friends for their unselfishness and support.

Marvin A. Arostegui and Jon A. Larvick

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Abstract

This study investigated the effects of reducing the mean processing time and variability in the Shop Flow Segment of the Depot Level Reparable Item Pipeline. The measure of interest was the average number of units in the pipeline of a particular type of item (referred to as the average pipeline contents). A literature review revealed that process variability in the pipeline has an impact on its effective operation and cost. A simulation model was developed to determine if reducing mean processing time and/or variability in the Shop Flow Segment would result in a reduction in the average pipeline contents. The pipeline model was based on an existing conceptual model developed in an earlier thesis study; a detailed and constrained model of the Shop Flow Segment was based on an existing model of the Fuel Control Overhaul and Test Unit. The simulation results clearly indicated that a reduction in the mean shop flow time would lead to a reduction in the average pipeline contents. However, initial results did not show a significant impact on average pipeline contents as a result of reducing variability. Further experimentation indicated that for some items under certain conditions, a reduction in variability would result in a reduction in average pipeline contents.

DEMONSTRATING THE EFFECTS OF SHOP FLOW PROCESS VARIABILITY ON THE AIR FORCE DEPOT LEVEL REPARABLE ITEM PIPELINE

I. Introduction

General Issue

The United States Air Force is in the middle of a transition that will ensure it continues to address national security requirements in the face of a changing world environment. Some of the requirements of this new environment are addressed in the concept of "Global Reach, Global Power." Under this concept, the Air Force must be flexible and mobile in order to fight wherever it may be needed (26, 18). Other requirements of the new environment are found in the reality of financial constraints. In the future, the Air Force and the other services must find ways to reduce the cost of accomplishing the mission (3). Central to these requirements is the performance of the Air Force Logistics Pipeline, which is responsible for the procurement, distribution, and repair of items throughout the Air Force. The performance of the logistics pipeline has a direct impact on both the ability of the Air Force to fight wherever it is needed and the cost of accomplishing the mission. In 1988, Maj Gen Charles P. Skipton, then Air Force Assistant Deputy Chief of Staff for Logistics and Engineering, said that "a very large portion of our scarce resources are tied up in the pipeline. . . . Reducing this pipeline would free scarce assets and provide more responsive support to the users" (32).

The Air Force Logistics Pipeline. The Air Force Logistics Pipeline, as described by Bond and Ruth, consists of four subsystems: acquisition, depot, base, and disposal (Figure 1). The acquisition subsystem is responsible for the initial procurement of items to meet the needs of depots and bases. The generic term, item, is used to indicate any

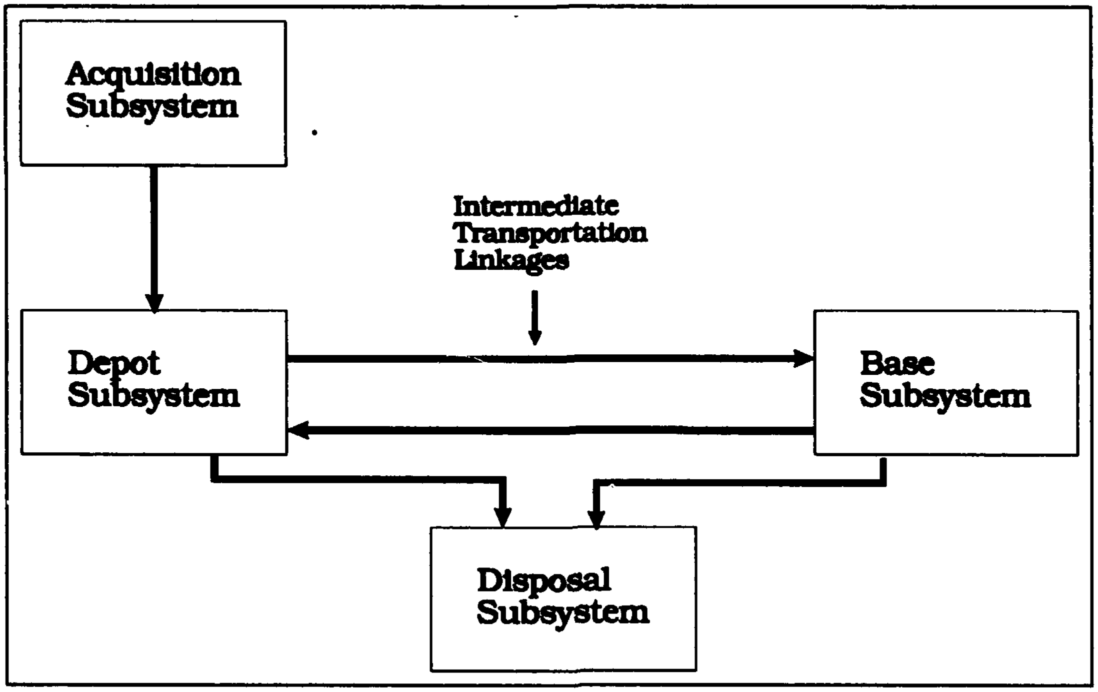

Figure 1. The Air Force Logistics Pipeline (6:169)

"article of materiel which is procured, stocked, stored, issued, or used" (19:372). The base subsystem supports base level operating activities; it both stores items for future use and attempts repairs on items that have failed. If the base subsystem is unable to complete repairs on a failed item, the item is returned to the depot subsystem. The depot subsystem is responsible for storing items for future requirements, attempting repairs on failed items that bases were unable to accomplish, and distributing items to meet the requirements of bases. Items that are repaired at the depot are redistributed to meet base level requirements, or placed in storage to meet future requirements. This cycle of using items at bases, repairing failed items at bases or depots, and reusing the repaired item continues until the item can no longer be economically repaired. At this point, the item enters the disposal subsystem where it exits the logistics pipeline (6:168-205).

An important characteristic of the logistics pipeline is that failed items are repaired and reused. Two terms are used to describe items that flow through the logistics pipeline: reparable and repairable. The term reparable is used to describe items that logistics managers have determined can be economically repaired when they fail. The term repairable is used to describe a broken item that is in need of repair (19:581). Thus, reparable items are the set of all items (in either serviceable or unserviceable condition) with the logistic designation that they can be economically repaired when they fail; and repairable items are the subset of all reparable items that are currently in an unserviceable condition and in need of repair. Repairs may be accomplished at bases or at depots. When bases are unable to fix a repairable item, the item is sent to a depot for repair and redistribution. We will refer to this portion of the logistics pipeline as the Depot Level Reparable Item Pipeline.

The Depot Level Reparable Item Pipeline. The Depot Level Reparable Item Pipeline serves as a major source of resupply for the Air Force (23:1-1). In particular, "it represents the most economic (cheaper to repair than to buy), the most expedient (quicker to repair than to buy), and the most responsive (adapts more quickly to changing requirements) source for filling peacetime and wartime materiel support requirements" (23:1-2). The Depot Level Reparable Item Pipeline, as described by Kettner and Wheatley, consists of six segments: Base Processing, Intransit to depot, Supply-to-Maintenance, Shop Flow, Serviceable Turn-in, and Order and Ship Time (15:119-123). Figure 2 shows the relationship of these segments.

The Depot Level Reparable Item Pipeline begins when a base level activity determines that it cannot repair a failed item. The item is labeled not repairable this station (NRTS) and reported to the depot. When the Base Supply activity receives instructions from the depot to ship the item, it is prepared for shipment and delivered to the base transportation activity. These actions constitute the Base Processing Segment (15:127-129). The Intransit Segment begins with the base transportation activity receiving the repairable item and packing it for shipment. The repairable item is then shipped to the

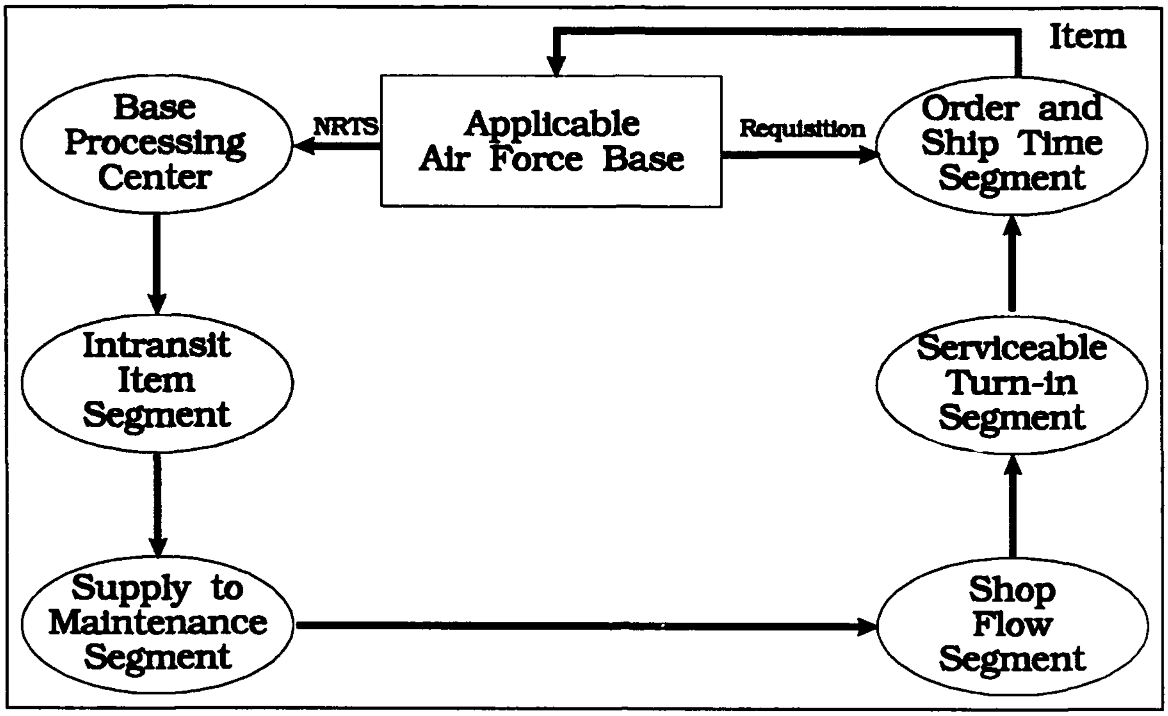

Figure 2. The Depot Level Reparable Item Pipeline (15:126)

appropriate depot for repair. The Intransit Segment ends when the repairable item arrives at the Depot Supply central receiving point, which is the start of the Supply-to-Maintenance Segment (15:130-133). If the depot maintenance activity has previously scheduled a repair requirement for the repairable item, it will be delivered to them; otherwise, the repairable item is placed in storage until a repair requirement is scheduled. The Supply-to-Maintenance Segment ends when the item is received by the depot maintenance activity (15:133-139). This receipt also starts the Shop Flow Segment. The Shop Flow Segment consists of all actions necessary to return the repairable item to a serviceable condition. The Shop Flow Segment ends when the item is declared serviceable (or condemned, in which case the item will exit the pipeline). Alternatively, the Shop Flow Segment ends if the item cannot be repaired because of missing parts or other difficulties; in this case, the item is returned to Depot Supply and eventually rescheduled to re-enter the Shop Flow Segment for repair. If the item is declared serviceable or condemned, the Serviceable Turn-in Segment begins (15:139-147). This segment includes actions required to return the now-repaired item back to the Depot Supply activity for storage or redistribution. Finally, the Order and Ship Time Segment begins when a base submits a requisition to the depot for a serviceable item and ends when the base receives the serviceable item (15:147-155). It is important to note that a base places a requisition at the time an item is declared NRTS. Thus, both the Base Processing Segment and the Order and Ship Time Segment begin simultaneously; however, the base does not generally receive the same physical item that it ships to the depot.

Significance of the Pipeline

The Depot Level Reparable Item Pipeline is of significant importance to the Air Force in terms of mission accomplishment and cost. With respect to mission accomplishment, the pipeline directly affects aircraft availability; that is, the number of aircraft that have all systems fully functional. Crawford states:

> aircraft availability is directly associated with and dependent on pipeline contents, not demand rates. In other words, if every time demand rates jumped up, maintenance was able to repair parts at an accordingly faster rate, the pipeline contents would remain fairly constant, and aircraft availability would remain approximately the same as before the increase in demands. That is the reason for investigating pipeline contents, their stability over time, and our ability to predict them. (10:19).

With respect to cost, the items flowing through the pipeline represent an inventory investment made by the Air Force. More items in the pipeline requires a larger investment. Ploos van Amstel gives us an idea of how the stability of a pipeline can have an impact on cost:

> a reduction in the variation in the time that goods are in a pipeline has a direct bearing on the level of safety stock that is considered to be necessary at the receiving organization. The greater the variation the lower the reliability of the goods arriving on time. A direct consequence of this is that extra safety stock is required to help maintain a desired customer service level.

Clearly, if the variation in lead time is reduced, then so will the extent of this safety stock. (24:13)

Crawford and Ploos van Amstel both emphasize the need for a stable and predictable pipeline. Recently, however, the stability and predictability of the pipeline have been questioned when the pipeline contents estimated by the Recoverable Consumption Item Requirements System (D041) have been compared with the actual contents of the pipeline. The term "pipeline contents" refers to the total number of items of a specific type that are located in any of the Depot Level Reparable Item Pipeline segments. Additionally, the term "flow time" refers to the number of days elapsed from the time an item enters a pipeline segment, until the time the item exits the segment. The D041 uses a combination of actual, computed, estimated, and standard flow times to determine the number of items in each segment of the pipeline at a given point in time (31:18). As an example, suppose that for Inertial Navigation Units (INU), an average of two enter the Shop Flow Segment per day. If the average flow time for INUs in this segment is 10 days (i.e., repair and queue time for INUs), then on any given day there will be an average of 2 times 10, or 20 INUs in the Shop Flow Segment of the pipeline. If this computation is done for all segments, the sum of these numbers would represent the average pipeline contents for INUs. Crawford discovered that the number of items in the pipeline computed by the D041 underestimates the actual contents because the actual flow times exceed the flow times used by the D041. Furthermore, at the time of his study, "there were approximately 2.5 to 3 times more parts [in the pipeline] than D041 expects" (10:24). Perry and others, found that there was significant variability in the time it took parts to flow through three of the pipeline segments: Supply-to-Maintenance, Shop Flow, and Serviceable Turn-in. In their sample of 23 items, 15 items exceeded the average flow time by up to 48 days; seven of the items were below the average flow time by up to 28 days (23: B-27). This variability was also reported in a thesis conducted at the Air Force Institute of Technology (AFIT), which found "variance-to-mean ratios ranging from 2.1

(Supply-to-Maintenance Segment) to 195.7 (Order and Ship Time Segment)" (15:211-212).

Specific Problem

If the Air Force expects to function well in an environment that requires a responsive and economical logistics pipeline, improvements in the stability and predictability of the Depot Level Reparable Item Pipeline must be made. Tsai suggests that it is appropriate to study the Shop Flow Segment of a pipeline in detail when he states that "of the various segments that constitute a component's total pipeline, the reparable segment (which includes units being held in queue as well as those actually undergoing repair) has the potential for an especially high degree of variability" (35:4). Further, Kettner and Wheatley indicate that D041 uses only engineering standards to predict the contents of the Shop Flow Segment without regard to the variability found in this pipeline segment (15:209). Our study focuses on the Shop Flow Segment of the Depot Level Reparable Item Pipeline. Since the Shop Flow Segment is potentially the longest and most variable of the pipeline segments, the variability in flow time for this segment is examined to determine its effect on overall pipeline contents. In particular, the significance of reducing Shop Flow variability alone is examined to determine if there is also a significant reduction in pipeline contents. These results are compared with the effects on pipeline contents when the mean processing times are reduced.

Research Question

This study examines the following research question:

What are the effects of reducing Shop Flow process means and/or variability on the contents of the Depot Level Reparable Item Pipeline?

Investigative Questions

Several investigative questions have been developed to guide the study and to generate the information necessary to answer the research question. The investigative questions ask the following:

1. What are the general theories about the effects of variability on processes?

2. What relevant findings are available from empirical studies on the effects of variability on processes?

3. Are there any models available that represent the flow of reparable items through the Depot Level Reparable Item Pipeline that can be used as the basis for this study?

4. Are there any models available that represent the flow of repairable items through the Shop Flow Segment of the Depot Level Reparable Item Pipeline that can be used as the basis for this study?

5. How can the Depot Level Reparable Item Pipeline be modeled to assess the impact of variability on the contents of the pipeline?

6. What is the impact upon pipeline contents when the mean Shop Flow time and/or its associated variability are reduced?

The investigative questions are answered through: 1) a review of the literature and pertinent Air Force manuals and regulations, 2) interviews with Air Force personnel conducted both to discover new information and to validate our findings, and 3) development of a simulation study of the Depot Level Reparable Item Pipeline.

Scope

This study concentrates on the Shop Flow Segment of the Depot Level Reparable Item Pipeline and on how its variability in flow time affects pipeline contents. The study does not address the entire Air Force Logistics Pipeline; in particular, it does not address the interactions of its acquisition and disposal subsystems.

This study is based on models of the Depot Level Reparable Item Pipeline that are representative of operations in a peacetime environment. Changes that occur in wartime are not considered. The amount of data collected and the number of reparable items considered are limited by data availability and time constraints.

Chapter Summary

This chapter introduced the concept that the Air Force Logistics Pipeline has a direct impact on the Air Force's ability to accomplish its flying mission and on the corresponding cost of procuring, distributing, and repairing spare parts. The logistics pipeline was described as consisting of four subsystems: acquisition, depot, base, and disposal. A portion of this pipeline that consists of shipping unserviceable items from bases to depots, repairing the items, and redistributing serviceable items, is called the Depot Level Reparable Item Pipeline. This pipeline serves as a major source of resupply for the Air Force and consists of six segments: Base Processing, Intransit, Supply-to-Maintenance, Shop Flow, Serviceable Turn-in, and Order and Ship Time. Further, the Depot Level Reparable Item Pipeline must be reliable and predictable in terms of the amount of time it takes for items to flow through all of the pipeline segments. Unfortunately, studies have shown that there is significant variability in the time it takes for items to flow through each of the pipeline segments. In particular, it is suggested that the repair segment of any pipeline has a propensity for high variability. This suggestion led to the research question "What are the relative effects of reducing the mean Shop Flow time and/or its variability on pipeline contents and production leadtime?" The chapter ended with a presentation of the research question, supporting investigative questions, and the study's scope.

II. Literature Review

The Depot Level Reparable Item Pipeline is a complex network of activities designed to repair and distribute reparable items. To understand its organization and functioning, the pipeline has been divided into six logical segments, each with a distinct beginning and ending. These pipeline segments can be further divided into smaller and smaller activities that come closer to describing the actual tasks performed by Air Force personnel. At any of these levels of detail, the divisions of the pipeline can be viewed as processes. Thus, we begin our discussion in this chapter with a review of the concept of a process. We answer two of our investigative questions: "What are the general theories about the effects of variability on processes?" and "What relevant findings are available from empirical studies on the effects of variability on processes?" We then present three models of the Depot Level Reparable Item Pipeline, a general model of how Air Force repair shops work, and a model of an actual Air Force repair shop to answer two more of our investigative questions: "Are there any models available that represent the flow of reparable items through the pipeline?" and "Are there any models available that represent the flow of reparable items through the Shop Flow Segment of the pipeline?"

Processes

A process is defined as a series of actions or operations that transforms inputs to outputs, where outputs are produced over time (20:710). Scherkenbach states that "the outputs of any organization are the results of an interdependent network of processes" (29:10). The Depot Level Reparable Item Pipeline, as a whole, can be viewed as a network of processes, where each of its six segments (Base Processing, Intransit, Supply-to-Maintenance, Shop Flow, Serviceable Turn-in, and Order and Ship Time) is an individual process each consisting of subprocesses, that are in turn composed of their own sub-subprocesses, etc.

Process Variability. It is common for a process or the outputs of a process to exhibit some degree of random behavior, referred to as variability. In statistical terms, variability is the distance between an actual measurement and an average measurement (20:94-98,724). In a manufacturing environment, variability can also be viewed as the difference between an actual measurement and an intended measurement (33:31). Scherkenbach says that variances should not come as a surprise; the world is filled with variability (29:16-17). Even the output of stable processes exhibit variation (20:724).

Views of Process Variability. Process variability, although common, is not commonly recognized, understood, or managed in formal processes (29:21). Some studies treat process variability as something that should be eliminated. While studying cyclic production systems (systems that process products in a specific order and repeat this cycle indefinitely), Sarkar and Zangwill concluded that the elimination of variability is critical because variability reduces effective capacity. In addition, process variability impacts the amount of work-in-process inventory and the length of time for a production cycle (28:444-449). Squires likens variability to the demon in the movie *The Exorcist*. He calls for casting out the variability that possesses a process. However, this exorcising would mean eliminating the demon (variability) entirely; something that is not possible because variance's presence in a process cannot be eliminated, exorcised, or destroyed (33:33).

Since process variability exists in all systems, some researchers direct their attention to process stability. Anderson says that controlling process variation is the key to manufacturing success. Direct control over each process operation will ensure a continuous flow of material through the entire production process and reduce costs. Anderson suggests using statistical process control (SPC) as a tool to accomplish this direct control (1:91). SPC is a method of monitoring and reducing variation to keep a process in or bring a process into a state of statistical control. A process with a stable output distribution, or one that does not change over time, is said to be in control (20:718-725).

Another approach to the treatment of process variability is to determine the effects of specific production decisions on process variability and, in turn, that variability's effect on production. For example, Karmarkar determined that the choice of batch sizes in a manufacturing environment affects the variability of service (processing) times and the variability in the arrival of work at a machine. In turn, these variabilities affect queuing or sequencing delays in the manufacturing process (14:411). Goldratt and Cox give another example of the same impact of variability in their book *The Goal* when they demonstrated what happens in a process consisting of dependent events which exhibit variability. Dependent events are part of a process sequence where the ability to start a process is dependent on the completion of the preceding one. With independent events, the variabilities of processes are incidental to each process and average out over time. In the case of dependent events, whenever a process has to wait for the preceding one, its variability is no longer just incidental to the process and thus not independent. In this case, instead of the intuitive result of process times averaging out over time, there is an accumulation of variabilities (mostly of waiting) because a process' idle time can never be recovered (12:86-101).

How does this relate to the Depot Level Reparable Item Pipeline? Ploos van Amstel says that variation in the time goods are in a pipeline lowers the reliability of goods arriving on time. (24:13). Studies have shown that variation in repair and processing times exist within the Air Force Reparable Item Pipeline. For example, Crawford found that pipeline contents are extremely variable about their mean (10:24) and Kettner and Wheatley said that "a statistical analysis of data collected for each segment of the depot-level reparable pipeline showed significant variance present" (15:211). Given that the Depot Level Reparable Item Pipeline can be viewed as a network of processes, we now need to explicitly define the pipeline's processes to study the effects of their variability on the overall pipeline.

Models of the Depot Level Reparable Item Pipeline

Having reviewed some characteristics of processes and their dynamics, we now review several models that conceptualize how the Depot Level Reparable Item Pipeline is organized and how items flow through it. This review covers the Recoverable Consumption Item Requirements System (D041), a conceptual model developed by Kettner and Wheatley, and the Dyna-METRIC model.

Recoverable Consumption Item Requirements System (D041). The D041 is a management information system used by the Air Force to compute the world-wide requirements for reparable items. Thus, it not only considers the quantity of all items needed to support the pipeline, but also the quantity of all items needed to support bases and to replace losses to the Air Force inventory system. A brief description of the different requirements computed by the D041 is necessary to see how the Depot Level Reparable Item Pipeline fits in relation to the overall requirement for reparable items.

The Air Force gross requirement computed by D041 is broken up into 11 specific quantities. These quantities are: organizational and intermediate maintenance (OIM) operating requirement, total OIM base stock level requirement, OIM depot stock level requirement, Management of Items Subject To Repair (MISTR) non-job-routed (NJR) requirement, Programmed Depot Maintenance (PDM) NJR requirement, engine NJR requirement, total overhaul condemnations requirement, total overhaul stock level requirement, prepositioned requirement, prestocked requirement, and additive requirement (11:7-28). A brief description of each of these requirements is provided in Table 1.

TABLE 1

D041 REQUIREMENTS COMPUTATION ELEMENTS

OIM operating requirement	the number of items required to replace the failures that become a demand on the Base Supply system (11:7-17).
Total OIM base stock level	the number of items required to cover the requisitioning process, the base repair cycle, the base safety level, and any base adjusted stock levels (11:7-19).
OIM depot stock level	the number of items required at the depot to cover base condemnations, depot condemnations, job-routed repair condemnations, and a portion of the depot repair cycle related to non job-routed NRTS (11:7-20).
MISTR non-job-routed requirement	the number of items required "to replace unserviceables removed and shipped to another repair facility during the depot overhaul repair of the NHA [next higher assembly] or end item" (11:7-21).
PDM non-job-routed requirement	the number of items required "to replace unserviceables removed and shipped to another repair facility during the depot overhaul of the aircraft or missile" (11:7-22).
Engine non-job-routed requirement	the number of items required to cover the unserviceables removed and shipped to another facility during engine overhaul (11:7-23).
Total overhaul condemnations requirement	the number of items required to cover the condemnations during job-routed repair at the depot (11:7-25).
Total overhaul stock level requirement	the number of items required to support the depot overhaul line in case of demand fluctuations (11:7-27).
Prepositioned requirement	the number of items required to cover wartime needs and managed as War Readiness Spares Kits and Base Level Self-Sufficiency Spares (11:7-27).
Prestocked requirement	the number of items categorized as Other War Readiness Materiel (OWRM) (11:7-28).
Additive requirement	an additional requirement that is entered by the person managing this item (11:7-28).

The number of items necessary to fill the Depot Level Reparable Item Pipeline are a subset of the total OIM base stock level and the OIM depot stock level. A portion of the total OIM base stock level is intended to cover the time required to complete the requisitioning process (order and ship time). These items are considered part of the pipeline. The remainder of the pipeline requirement is a portion of the OIM depot stock level intended to cover the depot repair cycle for items that could not be repaired at bases. The depot repair cycle is a process consisting of five segments: Base Processing, Intransit, Supply-to-Maintenance, Shop Flow, and Serviceable Turn-in. The next section presents a conceptual model of the pipeline that clarifies how the depot repair cycle and the requisitioning process fit together to make up the Depot Level Reparable Item Pipeline.

Conceptual Model of the Depot Level Reparable Item Pipeline. Kettner and Wheatley developed a simplified model of the Depot Level Reparable Item Pipeline that consists of six segments and three elements that have an impact on the pipeline (Figure 3). Kettner and Wheatley expanded this basic model into a series of flow charts that depict the flow of reparable items from the time an item is declared not repairable this station (NRTS), until it is either condemned, or repaired and returned to storage or redistributed to an operating base. The flow charts detail the various processes and decisions made throughout the pipeline. The following discussion of Kettner and Wheatley's model is drawn from their thesis report, in particular from Chapter IV where they describe their pipeline models in detail.

The Depot Level Reparable Item Pipeline begins when a failed item that was removed from an aircraft is declared NRTS by the base maintenance activity. The item is transferred to Base Supply which stores it until shipping instructions are received. These activities constitute the Base Processing Segment as depicted in Figure 4 (15:127-129).

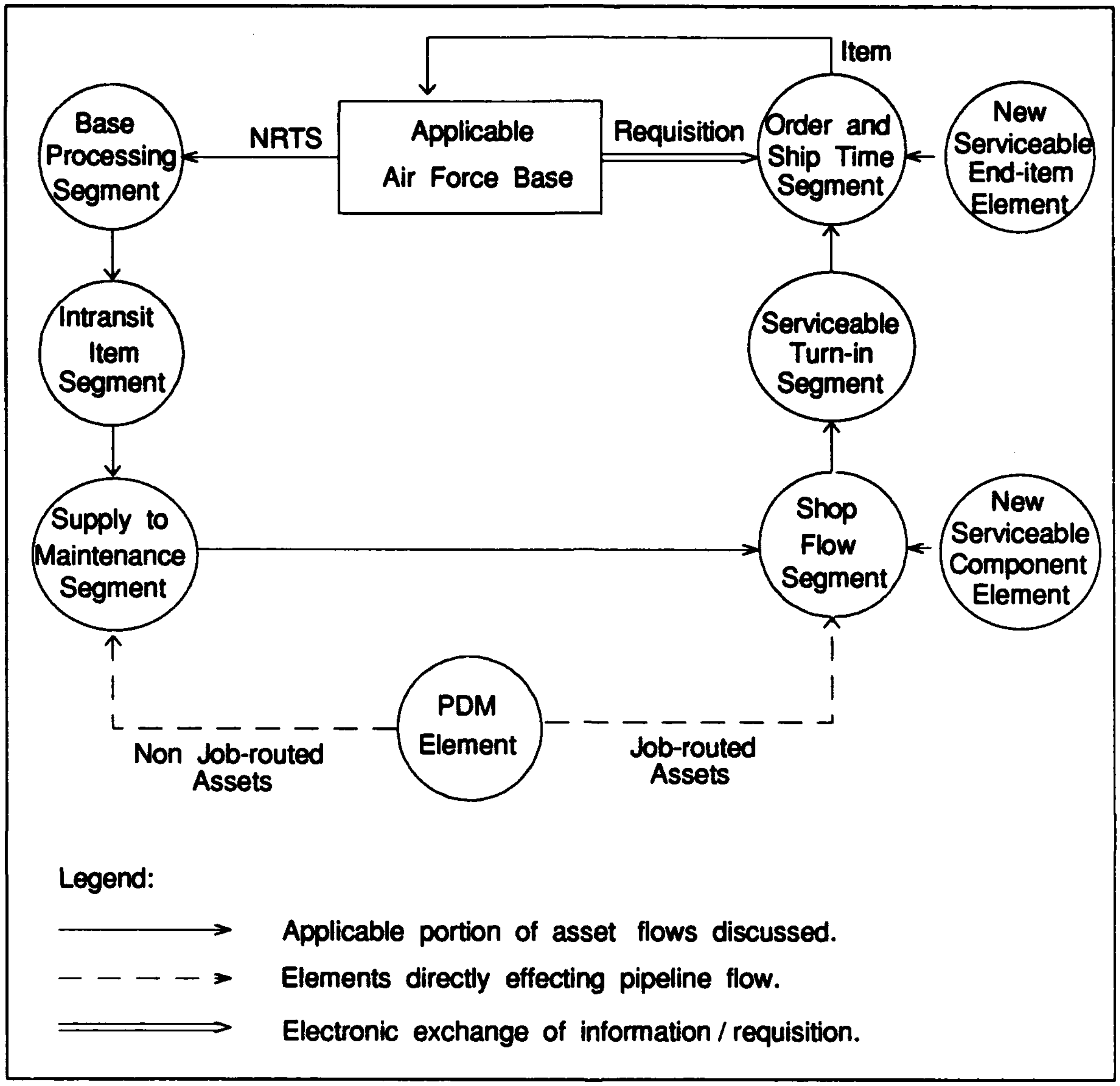

Figure 3. Enhanced Model of the Depot Level Reparable Item Pipeline (15:126)

The Intransit Segment begins when the repairable item is delivered to the base transportation activity for shipment to the depot (Figure 5). The base transportation activity prepares the item for shipment and coordinates transportation by surface or air carriers depending on the shipment's priority. Figure 6 shows the events that occur when the item arrives at the depot and it is delivered to Depot Supply (15:130-133).

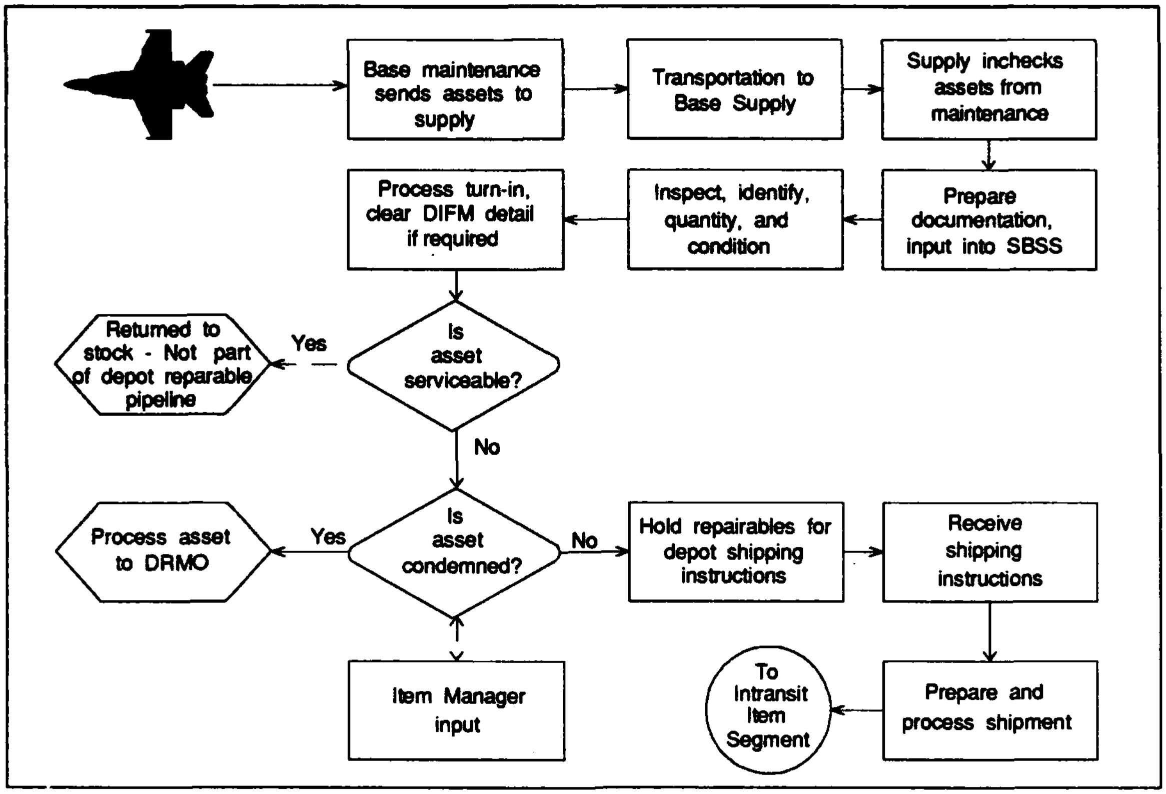

Figure 4. Base Processing Segment (15:128)

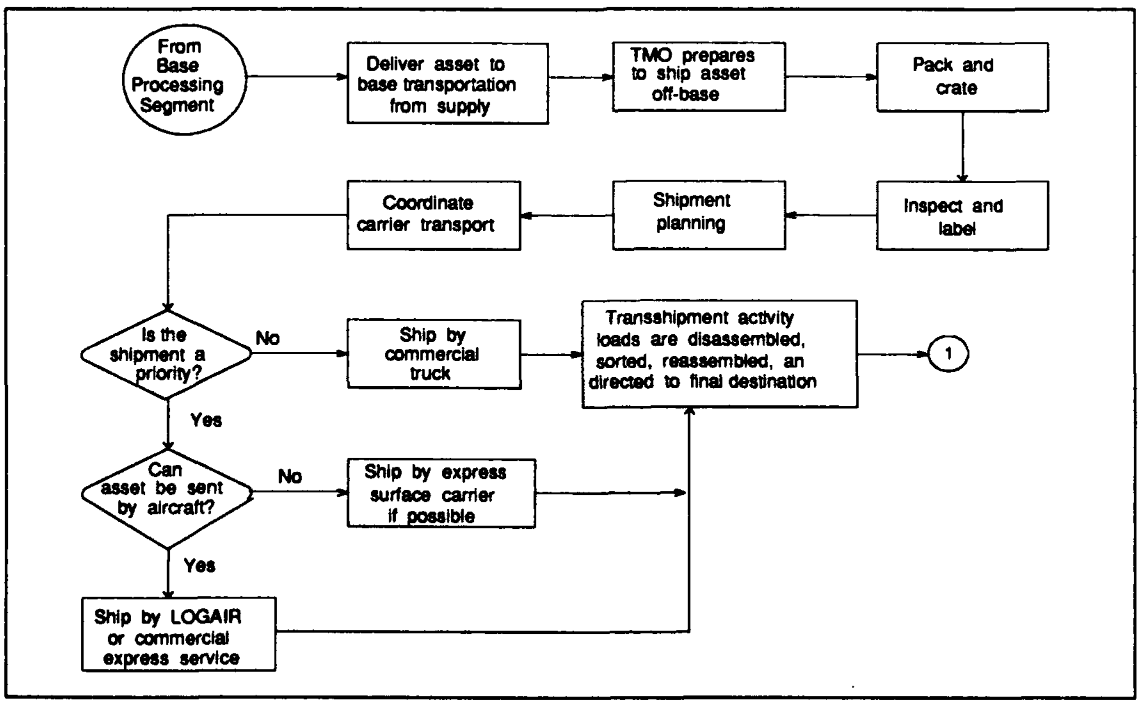

Figure 5. Reparable Intransit Segment, Part 1 (15:131)

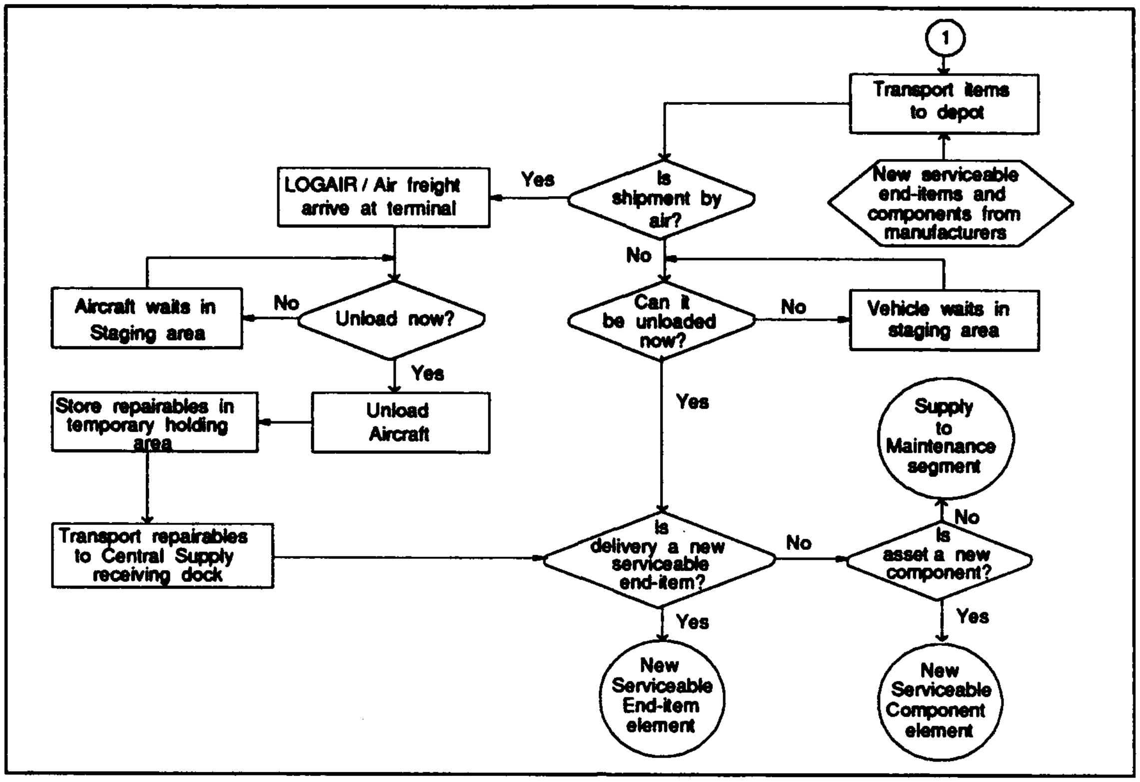

Figure 6. Reparable Intransit Segment, Part 2 (15:132)

The Supply-to-Maintenance Segment begins when the repairable item arrives at Depot Supply's central receiving (Figure 7). The item is in-checked and moved to a processing area. If depot maintenance does not have the item scheduled for repair, the item is sent to a storage location where it will wait until it is scheduled. Alternatively, if a repair schedule for the item already exists, the item is moved to depot maintenance (15:133-139).

The Shop Flow Segment begins when the repairable item arrives at depot maintenance's delivery point where it is inducted into the repair process (Figures 8 and 9). If the maintenance shop is ready to repair the item, the item is delivered to the shop; otherwise, it is placed in temporary storage within depot maintenance. At the maintenance shops, various repair processes can take place depending on the requirements of the specific item. Some of these processes include inspection, tests, fault isolation,

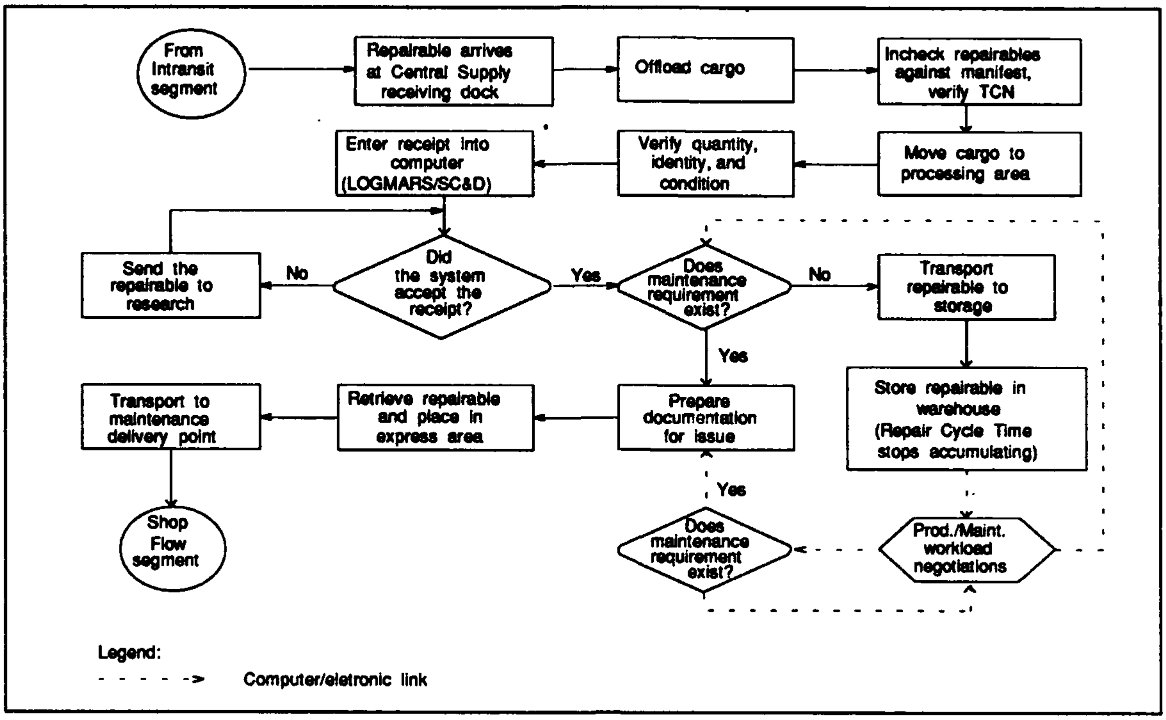

Figure 7. Supply-to-Maintenance Segment (15:134)

disassembly, cleaning, non-destructive inspections of sub-components, sub-component repair or condemnation/replacement, and assembly. The Shop Flow Segment ends when the repairable item is either certified as fully serviceable, still repairable (hold for further action), or condemned and tagged as appropriate (15:139-147).

The Serviceable Turn-in Segment begins when the item is tagged serviceable, unserviceable, or condemned by the depot repair activity (Figure 10). The item is moved to the maintenance holding area for a return delivery to the Depot Supply activity (or the programmed depot maintenance activity as described below). If the item is declared condemned by the depot repair activity, the item is transferred to the disposal subsystem of the Air Force Logistics Pipeline. Alternatively, if the item is declared serviceable, a check is made to determine if a requisition for the item exists. If a requisition exists, the reparable item enters the Order and Ship Time Segment; otherwise, the item is placed in storage to meet future requirements (15:147-150)

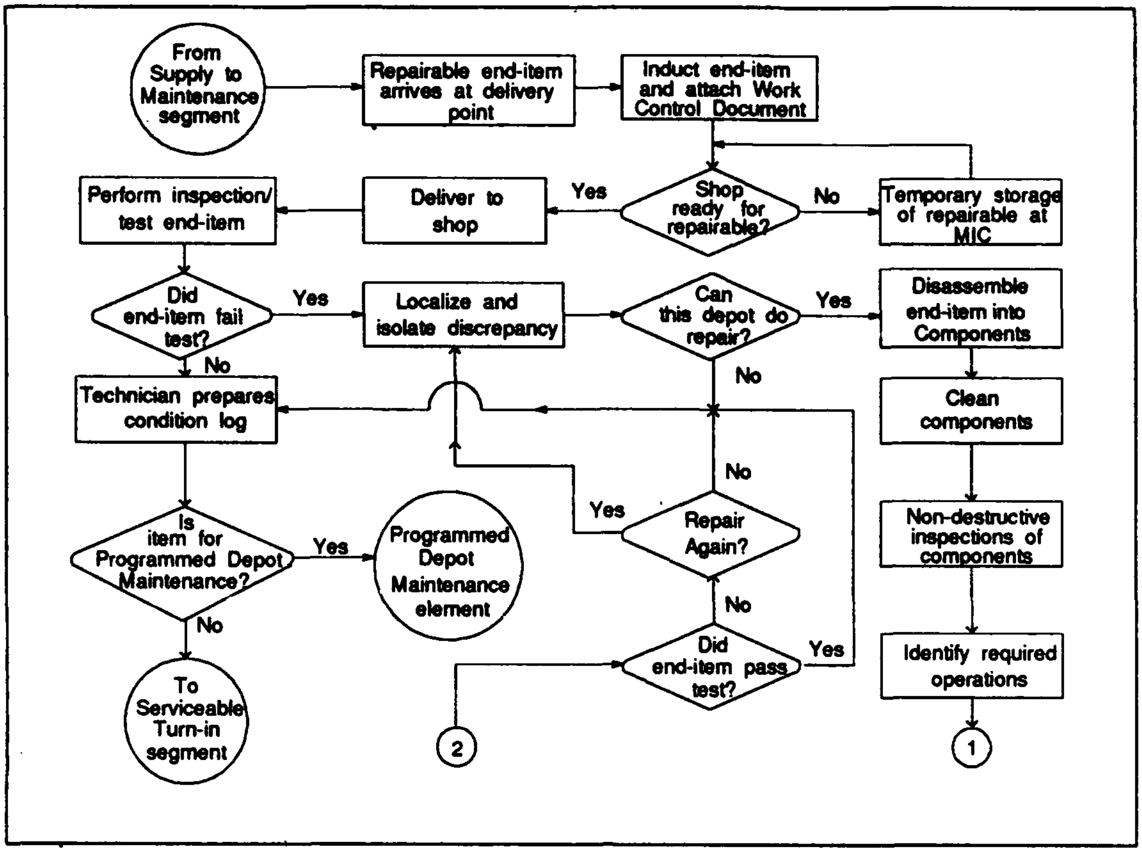

Figure 8. Shop Flow Segment, Part 1 (15:140)

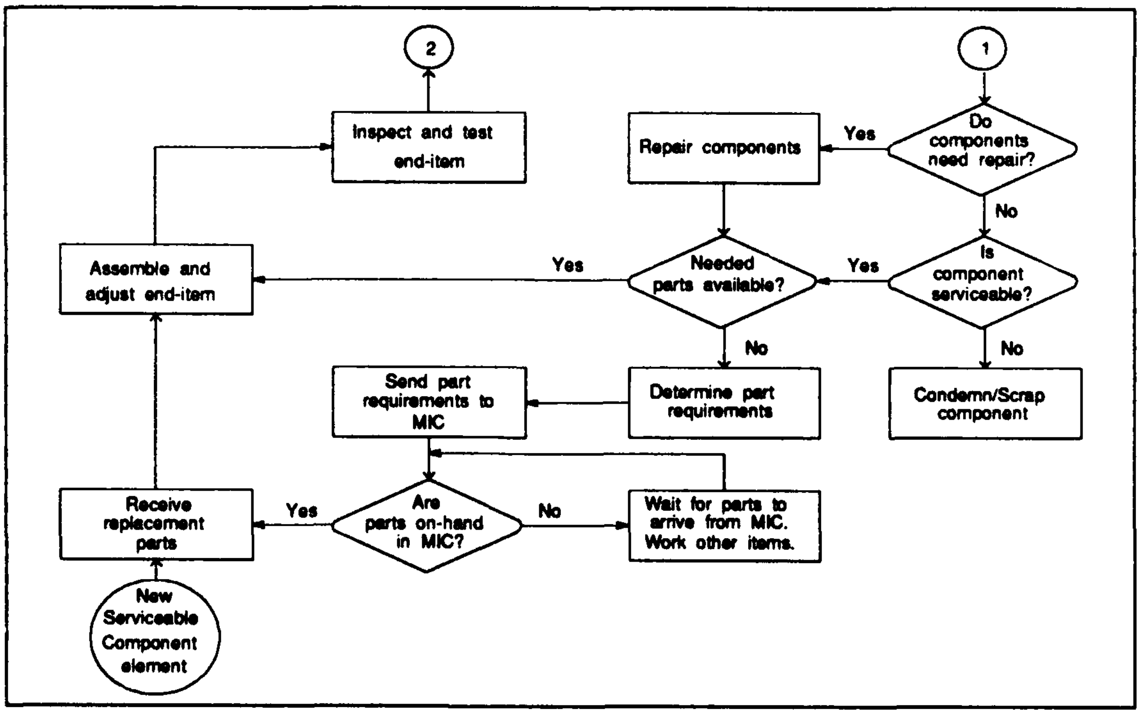

Figure 9. Shop Flow Segment, Part 2 (15:141)

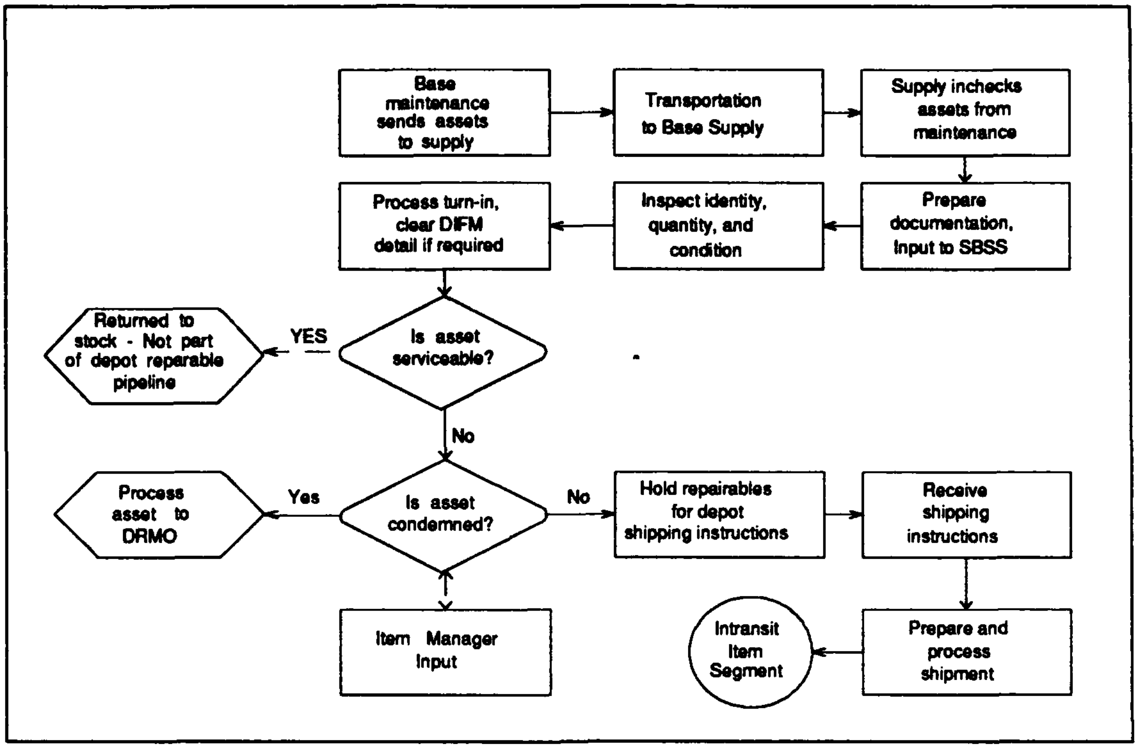

Figure 10. Serviceable Turn-In Segment (15:148)

The Order and Ship Time Segment consists of three elements: order time, processing time and shipping time (Figure 11). The order time begins when a reparable item is declared NRTS at a base, and the Base Supply activity places a requisition for a replacement. The requisition is entered into the base level supply computer and travels through electronic channels to the depot level computer. The order time ends and the processing time begins when the requisition is received by the Depot Supply computer. The processing time includes generating an issue document at the depot warehouse, picking the appropriate item, and delivering it to the depot transportation or the depot shipping section. If the customer is a base, the item is given to the depot transportation activity; otherwise, if the customer is programmed depot maintenance, the item is given to the depot on-base delivery section. If the item is delivered to the depot transportation activity, the processing time continues with mode of transportation and carrier selection (Figure 12). The processing time ends and the shipping time begins when the item is

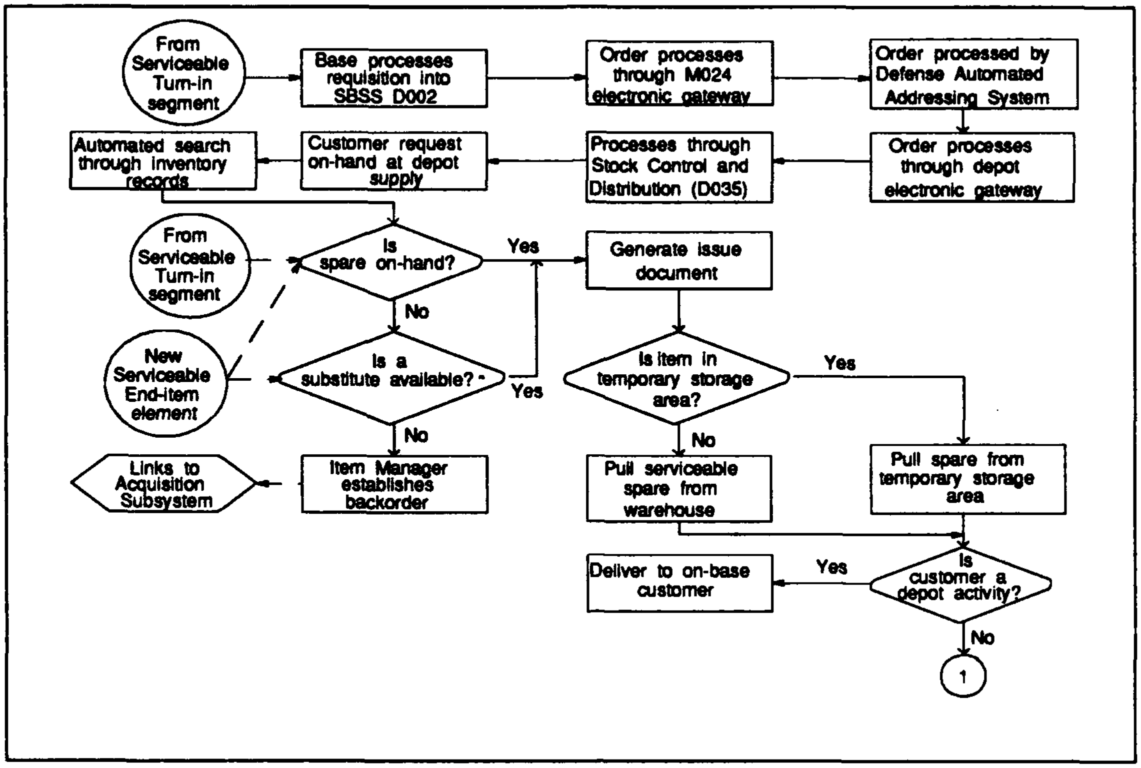

Figure 11. Order and Ship Time Segment, Part 1 (15:151)

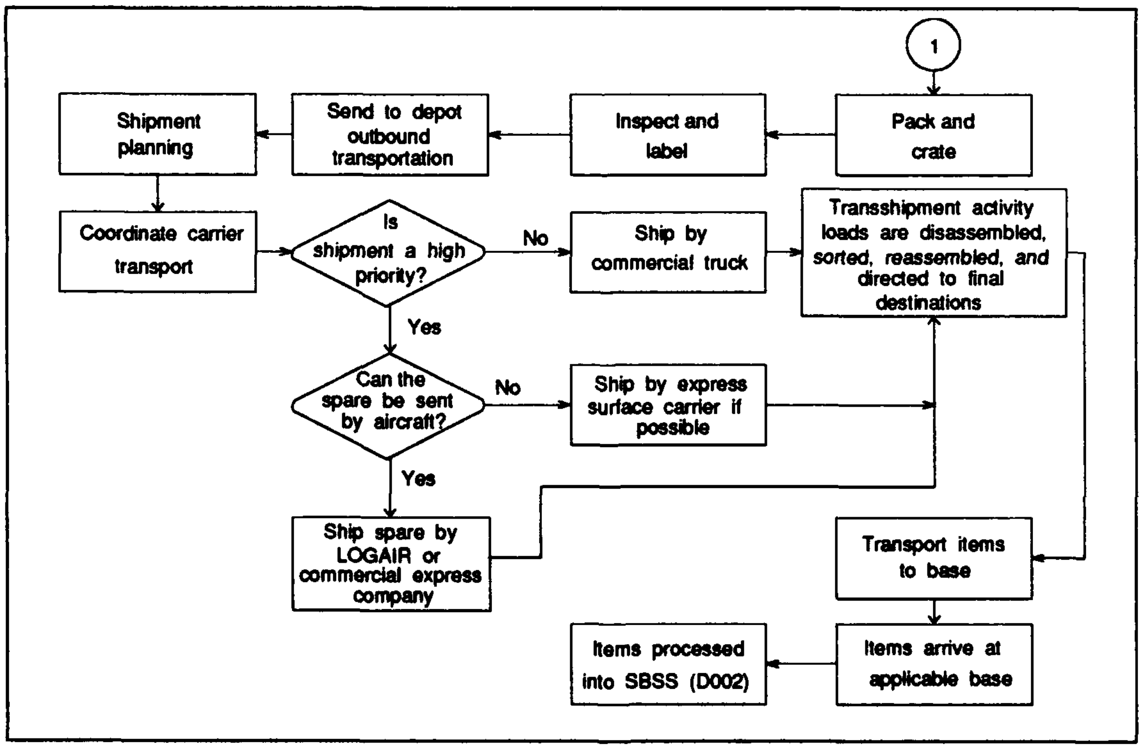

Figure 12. Order and Ship Time Segment, Part 2 (15:152)

received by the selected carrier. The shipping time ends when the item arrives at the appropriate base and is received by the Base Supply activity (15:150-155).

Three additional elements that impact the operation of the reparable item pipeline are identified by Kettner and Wheatley: programmed depot maintenance, new serviceable end-item, and new serviceable component. The first element, programmed depot maintenance, is responsible for conducting aircraft overhauls (Figure 13). When a broken reparable

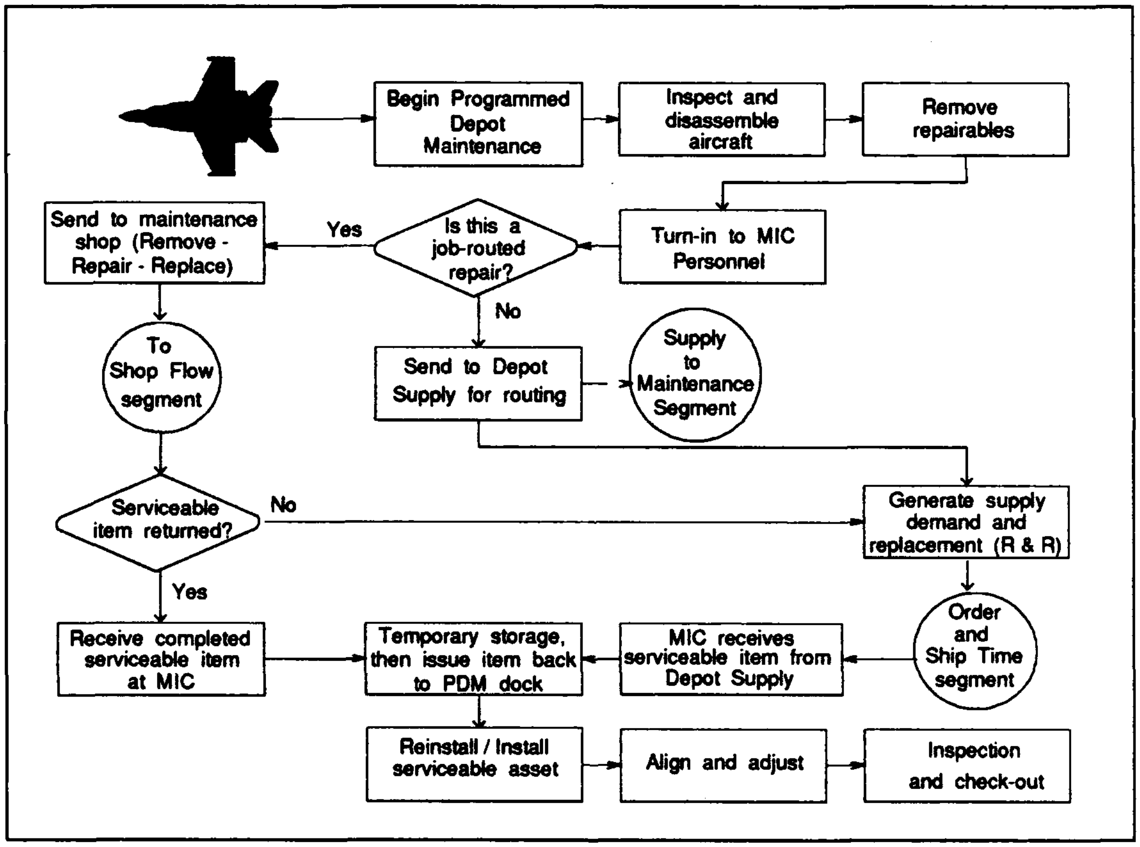

Figure 13. Programmed Depot Maintenance Element (15:156)

item is removed from an aircraft undergoing overhaul at the depot, a determination is made if another unit of the same type can take its place or if the same physical unit must be reinstalled. In the former case, the removed item is sent to the Depot Supply activity where it enters the Supply-to-Maintenance Segment, and a requisition is made for a serviceable item which will be received from the Order and Ship Time Segment. Repair on the removed item is referred to as a non-job-routed repair. If the original unit must be reinstalled, then it is sent directly to the appropriate repair shop where it enters the Shop Flow Segment. This type of repair is referred to as a job-routed repair (15:155-158).

The new serviceable end-item element represents the procurement of new end-items from industry. Figure 14 shows a link from the acquisition subsystem of the Air

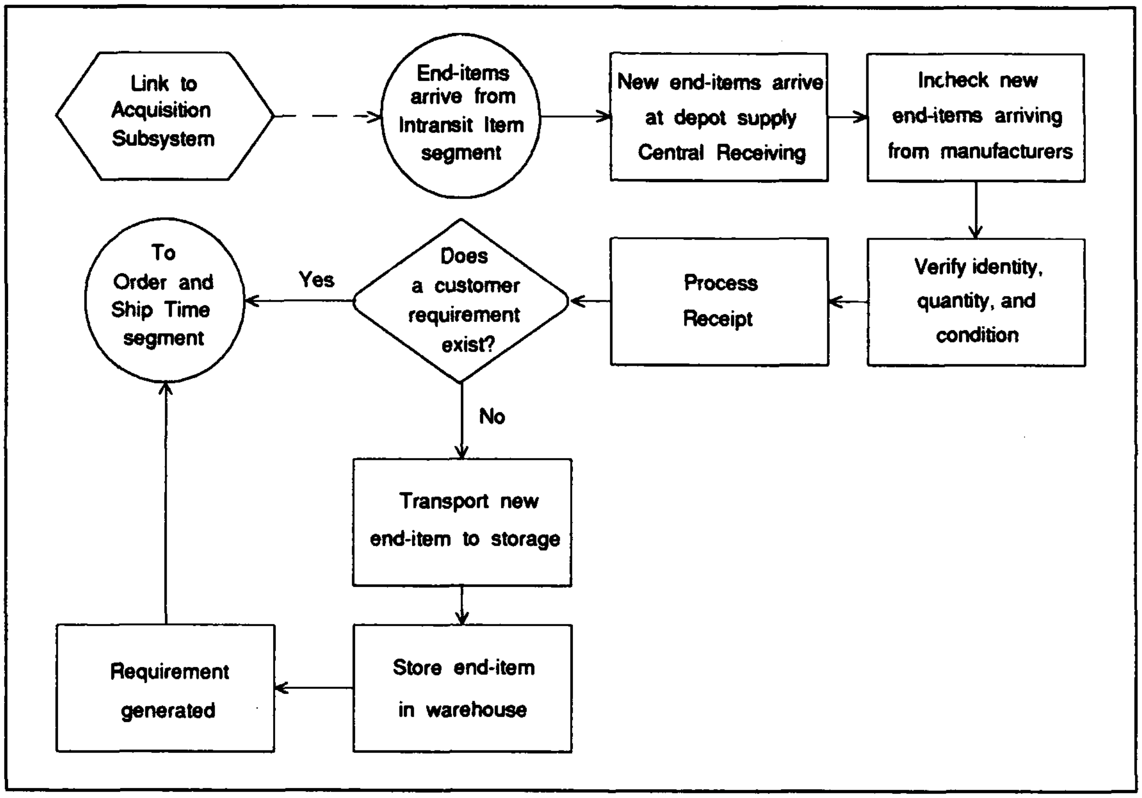

Figure 14. New Serviceable End-Item Element (15:159)

Force Logistics Pipeline described by Bond and Ruth into the Depot Level Reparable Item Pipeline. New end-items are received by the Depot Supply activity and in-checked. The new end-item immediately enters the Order and Ship Time Segment if it has been backordered; otherwise, it is placed in storage to meet future requirements (15:158-160).

Another link from the acquisition subsystem into the depot level reparable item pipeline is the new serviceable component element, shown in Figure 15. Components are

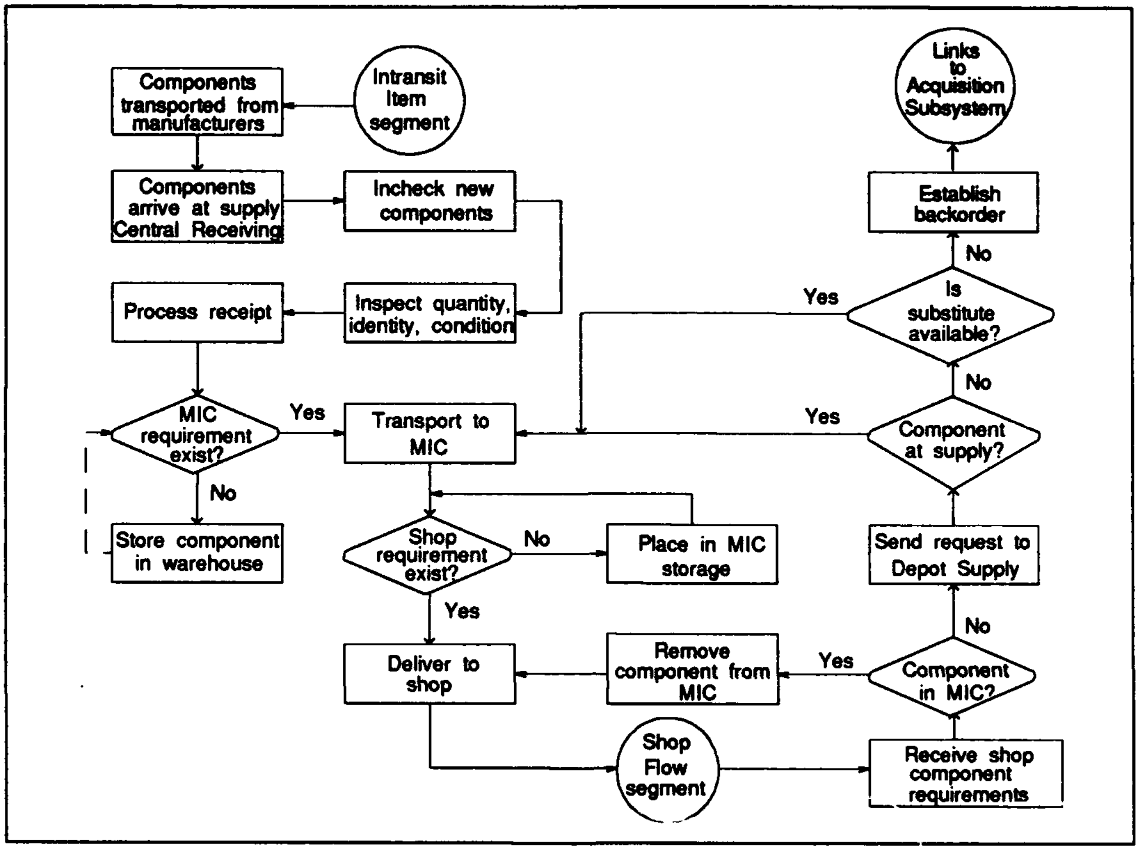

Figure 15. New Serviceable Component Element (15:162)

parts that are needed to fix end-items undergoing repair. As new components arrive at the Depot Supply activity, if depot maintenance has a need for them, the new components are delivered to the repair shop where they are used to repair an end-item currently in the Shop Flow Segment. If there is no immediate need for the new component at the repair shops, the new component is placed in storage to meet future requirements (15:160-164).

The Dyna-METRIC Model Version 5 (13). There are several versions of the Dyna-METRIC (Dynamic Multi-Echelon Technique for Recoverable Item Control) model that are designed to address the effects of logistics decisions on force readiness and sustainability. Of interest to this research is Version 5, because of its deliberate modeling of constrained repair using stochastic simulation. All of the Dyna-METRIC models relate "logistics resources and policies to wartime readiness" (13:v). Given a flying program scenario, performance characteristics of the logistics system, and failure characteristics of aircraft components, Dyna-METRIC Version 5 simulates the generation of repairable items and their flow through repair pipelines to determine the impact of the logistics system on aircraft availability. The following discussion describes Dyna-METRIC's view of the logistics system, how the generation of unserviceable items is calculated, and how constrained repair is modeled.

Dyna-METRIC's View of Logistics (13:4-5). Dyna-METRIC's model of the logistics system consists of five echelons: flightline, base repair, centralized intermediate repair facilities (CIRFs), depot repair, and commercial suppliers. The echelons are connected by a pipeline that moves repairable items to the next higher echelon whenever a part cannot be repaired at the lower echelon. Repairable items enter the pipeline at the flightline when they are removed from an aircraft. They are then moved to the base repair segment. If the item can be repaired, it becomes part of the local base stocks; otherwise, the item is moved to the CIRF. If the item can be repaired at the CIRF, it becomes part of the CIRF's stock; otherwise, it is moved to the depot echelon where the item is repaired or condemned. Each of the repair echelons (base, CIRF, and depot) consist of three segments: administrative, repair, and in-transit to next echelon. The administrative and in-transit segments are modeled as unconstrained segments. The repair segments are modeled as constrained segments, where each repair facility has a limited number of resources capable of repairing specific items one at a time. Since different items may compete for the same limited resources, the individual item pipelines are interdependent at any particular echelon of repair.

Generation of Repairable Items (13:10). Dyna-METRIC models the number of repairable items entering the repair system as one of three probability distributions. The selection of which probability distribution to use is based on the variance-to-mean ratio (VTMR) of the item's demand. A binomial distribution is used for VTMR's less than one; a Poisson distribution is used for VTMR's of one; and, a negative binomial distribution is used for VTMR's greater than one. These distributions are used to determine the number of repairable items that enter the base repair echelon on a given day. The number of items that cannot be repaired at bases and thus move up to the next echelon is determined by multiplying the number of items that enter the base repair echelon by the NRTS rate for the particular item. Focusing on our study, the number of unserviceable items that move to the CIRF or depot for repair represent the number of unserviceable items that enter the Depot Level Reparable Item Pipeline.

Modeling Constrained Repair (13:11). Dyna-METRIC models limited resources by allowing repairable items to wait for repair if a repair resource is not available. Dyna-METRIC's constrained repair model defines a relationship between repairable items and repair resources where each type of item can be repaired by a single type of repair resource. Each type of repair resource may repair several types of items. A repair resource can be located at any or all of the repair echelons. Each repair echelon can have a combination of different types of repair resources and multiple servers for each type of resource.

When a repairable item enters the repair segment of an echelon, the item is assigned to the queue for the appropriate repair resource. If a repair server is available, the item is processed with a fixed or an exponentially distributed repair time; otherwise, the item waits for a repair server. The many-to-one relationship between unserviceable items and repair resources coupled with limited repair servers results in a model where pipelines can be interdependent. To illustrate, consider a system of three items (I1, I2, and

I3) and two repair resources (R1 and R2) with one server each. Resource R1 can repair I1 and I2 items, and resource R2 repairs only I3 items. If resource R1 is busy, any item I1 or I2 that arrives will have to wait in R1's queue. In this case, the pipelines for I1 and I2 items are interdependent because the arrival of repairable items of one type affects the availability of repair resources for the other. Alternatively, the pipeline for I3 items is independent of the other two pipelines because it is linked to a different type of repair resource.

Models of Air Force Repair Shops

The Dyna-SCORE Model (35). Dyna-SCORE (Dynamic Simulation of Constrained Repair) is a model based on the depot avionics component repair shops. The model includes the repair process itself and four auxiliary processes: repairable item generations, machine shop, harness shop, and resupply of failed components needed to complete repairs on an item (Figure 16). The repair process is modeled in detail while the auxiliary processes are modeled as some amount of delay time based on a probability distribution (uniform or exponential). The following discussion is a description of the repair process.

The Dyna-SCORE model is based on the depot level shops that conduct repairs on avionics components. Several types of avionics components can flow through the model, where each component consists of various sub-components. Following the arrival of a repairable item, it is inspected for mechanical defects. If any are found, the item is routed to the machine shop where it spends some item-specific amount of time undergoing mechanical repairs. (Dyna-SCORE supports uniform and exponential probability distributions to model processing times). When the item returns from the machine shop, or if the item had no mechanical defects, it is placed in a queue for a test station. Each item must be tested by a specific type of test station. A shop has various types of test

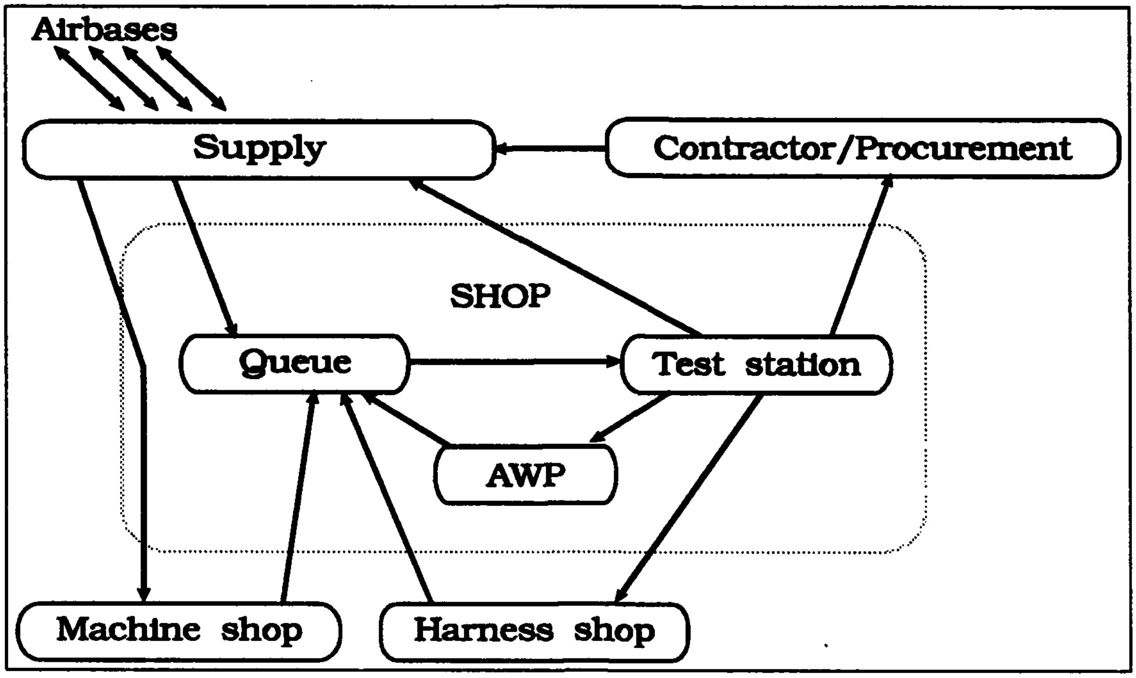

Figure 16. The Dyna-SCORE Model (35:15)

stations each capable of testing one or more kinds of items. For each type of test station, a shop can have one or more servers.

Testing begins when an item arrives at a test station, and continues for some amount of time. A probability exists that the test will result in sending the item to the harness shop where it will spend an item-specific amount of time before returning to the test stand queue. Alternatively, the test may find a failed sub-component. This situation results in a requisition for a serviceable sub-component. In the meantime, the item is placed in awaiting-parts status for a time equal to the sub-component resupply time. When the sub-component arrives, the item is again placed in the test station queue for further testing. The cycle continues until no additional failed sub-components are found and the item is declared serviceable. The Dyna-SCORE model allows for cases where the shop is unable to complete repairs on an item. In these cases, the item is condemned or sent to a higher level repair facility. In either case, the item exits the scope of the model.

Industrial Process Improvement (IPI) Simulation. The model described here is one of a series of IPI characterizations of repair processes at the five Air Logistics Centers. The study focuses on the identification of process and operational improvements within the Fuel Control Overhaul and Test Unit (their office symbol LIPPCE is used as a shorthand throughout this study to refer to this repair unit) at the Oklahoma City Air Logistics Center (OC-ALC). In the development of this characterization, the McDonnell Aircraft Company (MCAIR) constructed a computer simulation model of the existing repair processes performed in LIPPCE (21:E-1). The purpose of the model was to substantiate key recommendations for possible process and operational improvements (21:E-1).

To construct this model, process performance data were collected by MCAIR engineers. These data originated from a wide variety of sources. Planning, production, scheduling, and engineering personnel provided fuel control workload and process breakdown information. Manpower information and operational work data were provided by production management. Equipment breakdown information was obtained from equipment logbooks and maintenance records. Historical flow time data were obtained from production logbooks and work control documents (21:6.2-1 to 6.2-2).

To validate the completed model, a comparison between the simulation results and actual historical data (including production quantities obtained from scheduling personnel) for the last quarter of FY90 and the first three quarters of FY91 was made. Following this validation, the model was updated to include FY92 workload and manpower data (21:6.2-1 to 6.2-2). The overhaul process represented by the validated model is now described.

The fuel control repair process (Figure 17) can be divided into two distinct operations: overhaul and test. Additionally, the repair process is differentiated by the extent of repair required. For example, after initial tests and inspections, fuel controls are designated as either A-jobs (major overhaul) or I-jobs (minor repair) (21:6.1-1 to 6.1-3).

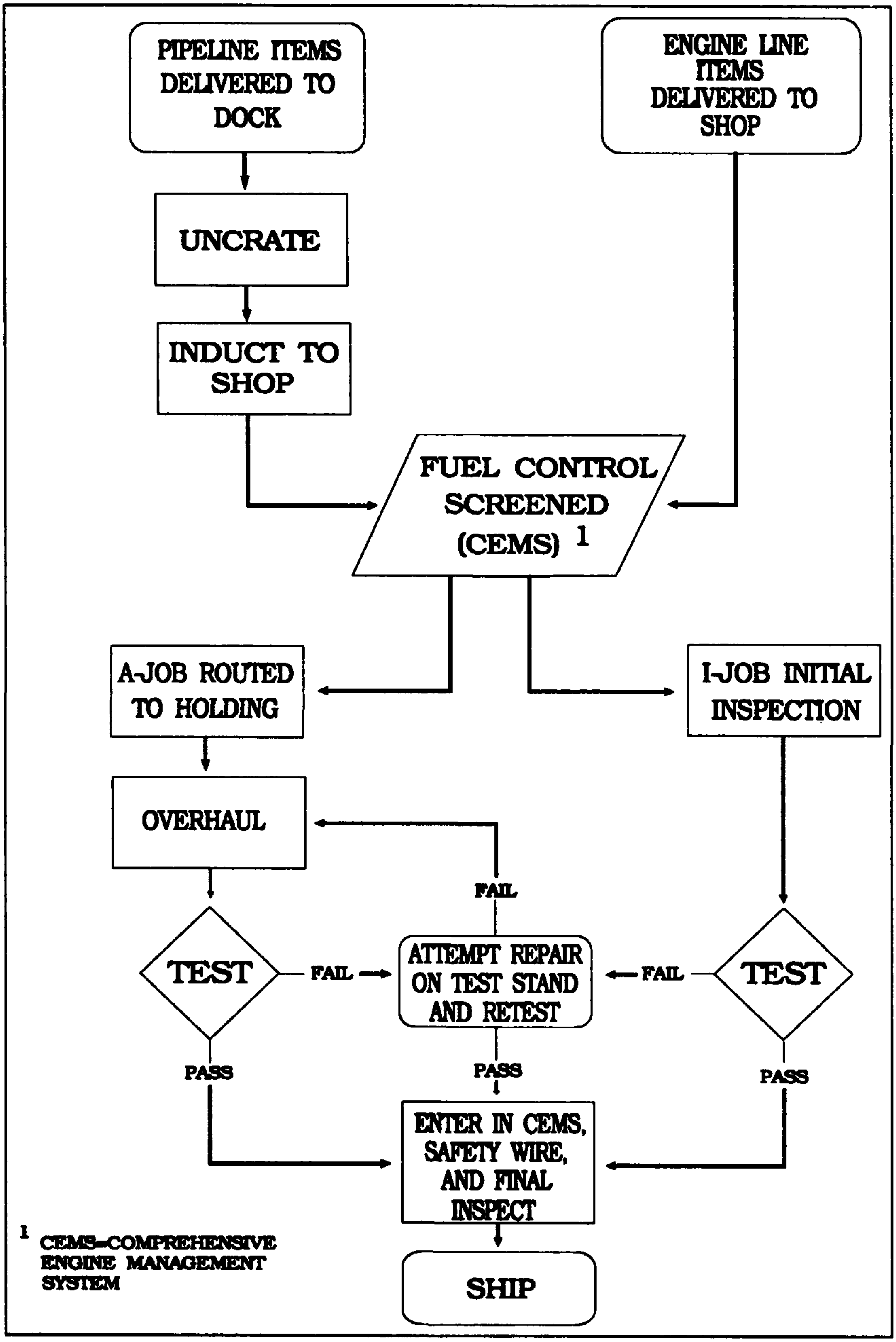

Figure 17. Fuel Control Overhaul and Test Unit Model (21:6.1-2)

Fuel controls arrive at LIPPCE directly from the engine overhaul line or from Depot Supply (Supply-to-Maintenance Segment of the Depot Level Reparable Item Pipeline). The first step in the repair process is to request and examine a Comprehensive Engine Management System (CEMS) report. This report provides the technician with historical information on the fuel control's maintenance and performance. These data are used in conjunction with required inspection parameters to determine the extent of the repair required (A-job or I-job status). If there are no signs of contamination or external/internal damage, the fuel controls undergo a minor overhaul. Damaged or contaminated fuel controls are given a major overhaul.

Once the repair requirements for a fuel control have been determined, an overhaul technician takes the control to a test stand, and inspects and replaces those components that are damaged or not in compliance with technical specifications. The overhaul technician also performs measurements of critical tolerances and specifications, providing calibration and adjustment as required. This is a relatively simple procedure for I-job fuel controls. However, since A-jobs require complete disassembly of the fuel control (in excess of 4500 component parts), this procedure is extremely complex and may take two to five times longer than an I-job of the same control type.

Once test stand operations are complete, the fuel control undergoes functional tests such as determining and setting flow rates and pressure ratios. If a fuel control fails a particular portion of its functional test, an attempt is made to repair it while it is still undergoing testing. If this fails, the fuel control is returned to overhaul for correction of the defect. If the control was originally designated an I-job, it is redesignated an A-job at this time for complete tear-down and inspection.

After a fuel control has passed its functional test, it is routed for application of safety wire, final inspection, and final paperwork. The fuel control's status is updated in the CEMS and it is routed either to Depot Supply (Serviceable Turn-in Segment of the

Depot Level Reparable Item Pipeline) or to the engine overhaul line for installation (21:6.1-1 to 6.1-3).

The simulation model of the Fuel Control Overhaul and Test Unit developed by MCAIR models the repair process just described. MCAIR engineers identified constraints in the repair process caused by facilities, equipment, manpower support functions, planning, scheduling, engineering, technical services, and material support and incorporated them into the simulation model (21:6.1-4 to 6.1-13).

Chapter Summary

With the notion that the Depot Level Reparable Item Pipeline is a network of processes, this chapter started with a brief discussion of processes and process variability. We established that variability is a natural characteristic of any process, and that variability accumulates in any sequence of dependent processes. We then presented several models that represent the flow of reparable items through the pipeline. Each of these models has something to contribute to this study. The D041 model shows the overall picture for reparable items and how the pipeline fits into this picture. The model by Kettner and Wheatley provides a solid, conceptual foundation for understanding the flow of items through the pipeline. The Dyna-METRIC Version 5 model uses three probability distributions that model the generation of repairable items under differe . circumstances. The Dyna-METRIC model also suggests that the proper way to model the Shop Flow Segment of the pipeline is through constrained repair, where items flowing through this segment compete for limited repair resources. The Dyna-SCORE model indicates that the repair process consists of various sequential steps each taking some amount of time. Throughout the repair process, there are places where this sequence can be interrupted as the result of a probabilistic event. These interruptions lead to a delay in the repair process (awaiting-parts status) or other processing that takes additional time. Like Dyna-

METRIC, Dyna-SCORE models constrained repair by limiting the number of items that can be under repair at the same time by limiting the number of repair resources. Finally, the IPI simulation model of the Fuel Control Overhaul and Test Unit depicts the specific shop flow through one depot repair facility. This model gives a general idea of the inspect, overhaul, and test process that reparable items go through in the Shop Flow Segment of the pipeline.

The information presented in this chapter serves to provide an understanding of the organization and function of the Depot Level Reparable Item Pipeline with a particular interest in the repair process. Given that variability is of significant importance in processes with interdependent events and that the pipeline is characterized by constrained, interdependent processes, then process variability should be of importance in the pipeline. A model that incorporates sufficient detail can now be developed to observe the flow of items through the pipeline; in particular, a model can be developed to observe how process variability in the repair process (Shop Flow Segment) affects pipeline contents.

III. Methodology

This chapter describes the methods used to answer the research question. It begins with a brief restatement of the research problem and a description of the proposed solution technique. This is followed by a background review of the solution technique. The chapter ends with a presentation of the method that is implemented.

We begin with a brief restatement of the research problem. The Depot Level Reparable Item Pipeline serves as a major source of resupply for the Air Force by repairing inoperative items and redistributing these items to the bases. Previous studies have shown that flow times through each of the pipeline segments exhibit significant variability around their means, and that the mean flow times exceed the expected flow times. In particular, Tsai suggests that the Shop Flow Segment has the potential for high variability (35:4). This study addresses the question "What are the effects of reducing shop flow process means and/or variability on the contents of the pipeline?"

Solution Approach

The Depot Level Reparable Item Pipeline is a very complex system that encompasses five depots servicing up to 221 Air Force bases and manages over 16,000 reparable items with active demand. On any given day, there are over 970,000 items flowing through the pipeline with one third of them, over 323,000, having started as NRTS items at bases (25). Further, not only does each segment of the pipeline have a different behavior, each type of item entering the pipeline has a different arrival rate and a different shop flow process. To capture this complexity, a simulation study was selected as the solution technique. In addition, simulation provides the greatest flexibility in modeling the stochastic nature of the pipeline. Bowersox and Closs indicate that "simulations gain popularity as the overall planning situation increases in complexity" and that "the capability to introduce the impact of uncertainty inherent in simulation render it a more useful analysis methodology [over analytical methods]" (7:140-141).

Background on Simulation Modeling

Balci provides a framework for conducting a simulation study that combines simulation processes with concurrent verification processes. His framework consists of ten phases as shown in Figure 18. The dashed lines represent the processes that must take place to move from one stage to the next and the solid lines represent credibility assessment stages. The credibility stages ensure that a particular process was properly completed. Balci emphasizes that "assessing the acceptability and credibility of simulation results is not something that is done after the simulation results are obtained. Assessment of accuracy . . . must be done right after completing each phase of a simulation study" (3:62). Balci also indicates that his framework "should not be interpreted as strictly sequential. . . . [It] is iterative in nature and reverse transitions are expected" (3:62). The following discussion covers the ten processes of Balci's framework to include the tests that can be applied to verify the proper completion of a process. The discussion concludes with a more detailed description of two of the credibility assessment stages: model and data validation.

Problem Formulation. This is the process of translating a problem identified by management into a structured, well-defined problem. The objective is to have a formulated problem that addresses the actual management problem and can be solved (3:62). To substantiate that the problem is well-formulated, Balci and Nance suggest that "the formulated problem must be evaluated by the people who are intimately knowledgeable of the problem(s) based on experience and training" (4:81).

Investigation of Solution Techniques. During this process, various solution techniques are evaluated to determine the most appropriate one for the formulated

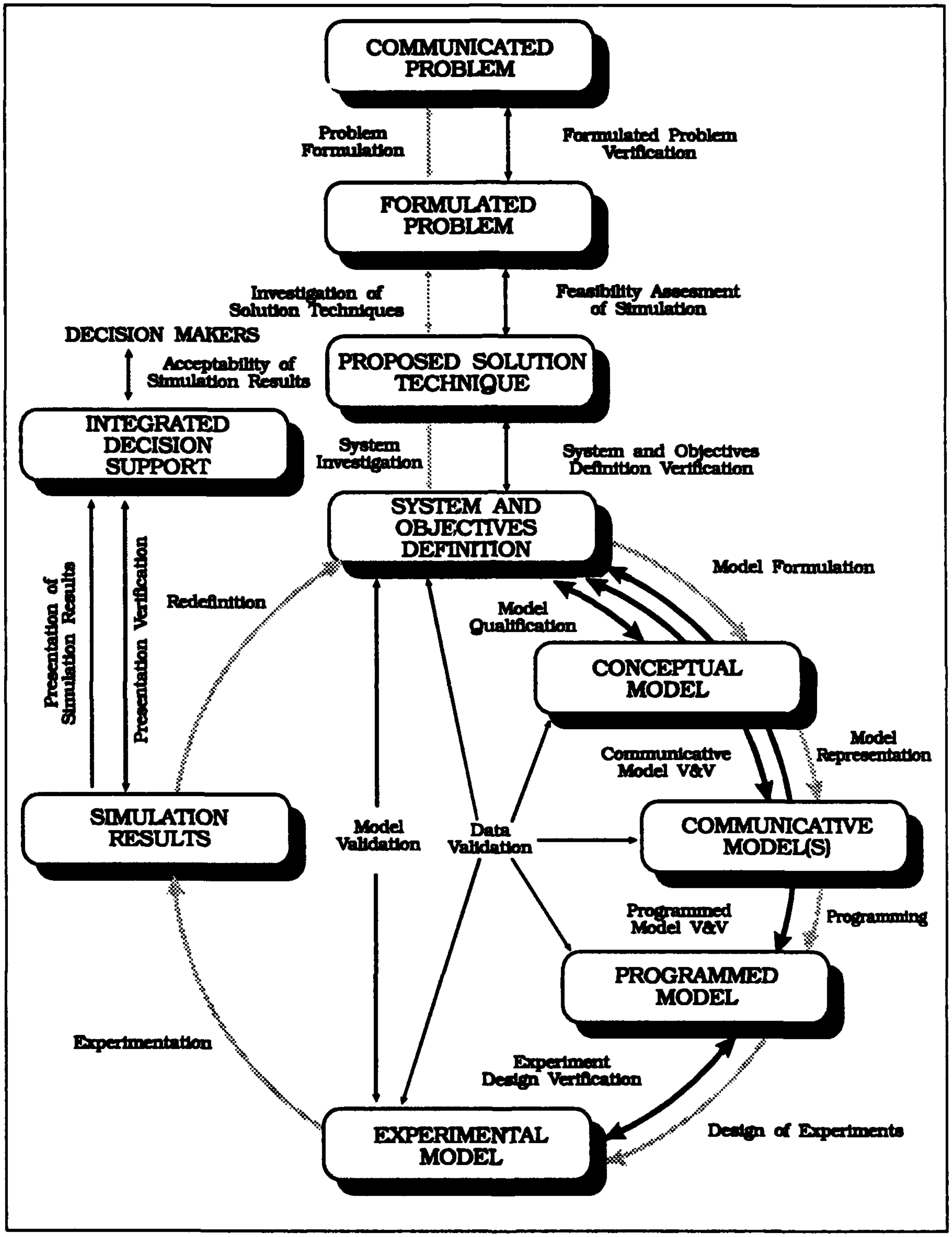

Figure 18. Life Cycle of a Simulation Study (3:63)

problem. Balci says that "the question is not to bring a solution to the problem, but to bring a sufficiently credible one which will be accepted and used by the decision maker(s)" (3:62). Assuming a simulation is used, then a feasibility assessment must be made. Issues of cost, time, and benefits must be addressed as well as whether the problem can be solved using simulation (3:67).

System Investigation. This process involves examining the characteristics of the system under study in preparation for developing a system model. Six characteristics for examination are: 1) the amount of change the system undergoes over time; 2) the environment, which consists of the input variables that affect the system; 3) the potential for counterintuitive behavior in the system; 4) the possibility that the system drifts to low performance as components deteriorate; 5) the interdependencies among events; and 6) the organization and relationship of subsystems (27:36-37). Verifying this process involves justifying the identified characteristics and explicitly defining the objectives of the study (3:67).

Model Formulation. This is the process of developing an abstraction of the real system referred to as a conceptual model. A balance must be achieved where enough detail is included to capture the essence of the system under study, but not so much detail that the model becomes unnecessarily complex. Balci indicates that this process also includes an analysis of the input data. The various parameters that describe the operation of a system may not all be known. In this case, Balci suggests that heuristic procedures, such as using triangular or beta probability distributions may be needed (3:64). The verification of the conceptual model's credibility "deals with the justification that all assumptions made are appropriate and the conceptual model provides an adequate representation of the system with respect to the study objectives" (3:67).

Model Representation. Starting with the conceptual model, a communicative model is now developed. The communicative model serves many purposes, including presentation of the conceptual model to various audiences and development of a programmed model. There may be several versions of this model in terms of form and detail as appropriate for their purpose. Different forms include flow charts, diagrams, structured English, etc. (3:64). Verification of the communicative model confirms that there is sufficient agreement between the model and the system under study for some pre-defined environmental conditions (3:67).

Programming. This task translates the communicative model into a computer program that when executed simulates the behavior of the system under study as defined by the communicative model. The result of this process is a programmed model developed using general purpose programming languages or special purpose simulation languages. Programmed model verification is the determination that the programmed model is a correct translation of the communicative model (34:559). Whitner and Balci list 35 different techniques that can be used to conduct programmed model verification along with measures of their effectiveness and importance to model verification. These techniques are categorized as informal analysis, static analysis, dynamic analysis, symbolic analysis, constraint analysis, and formal analysis. Examples of these techniques are desk-checking, which involves looking at the program code and mentally verifying its logic, and which is rated as limited in effectiveness and high in importance; top-down testing, which involves testing the code as it is developed from a general model to a detailed model, and which is rated as moderate to high in effectiveness and high in importance; and assertion checking, which involves placing statements in the programmed model that check the state of the model with its expected behavior, and which is rated as very high in effectiveness and very high in importance (34:561-567).

Design of Experiments. A designed experiment is one where the analyst determines which variables are to be controlled and at what levels, to determine their impact on the object being observed (20:860-862). During this process, decisions are made such as how many and which alternatives will be simulated, which variables will be changed between simulations, and how many times each simulation will be executed (30:13). In order to achieve statistical estimates that are precise and free of bias, appropriate choices must be made for the length of each simulation run, the number of independent runs, initial conditions, and length of the warm-up period (16:33). Verification of the experimental design addresses issues such as the generation of random numbers, the appropriateness of statistical methods used to analyze simulation output in light of their assumptions, the appropriateness and effect of the selected initial conditions of the model, and the selection of identical experimental conditions between sets of simulations that compare alternative policies (3:67).

Experimentation. This is the process of using the programmed model under the parameters established in the experimental design to obtain data for analysis (3:65).

Redefinition. The programmed model and the experimental design parameters may need updating to obtain new results, to incorporate system changes, or to study new alternatives or solutions (3:65).

Presentation of Simulation Results. During this process, the analyst interprets and integrates the results for presentation to an appropriate audience. Balci says "the presentation should be made with respect to the intended use of the model" (3:65).

Model Validation. Model validation is the process of determining how well the conceptual and communicative models represent the actual system (9:552). Sargent suggests 15 techniques for conducting model validation. Six of these techniques are event validity, which compares events in the simulation model with events in the real system; face validity, which consists of asking experts if they consider the behavior of the model reasonable; fixed values, which sets all model variables to a fixed value making comparisons with hand calculations easier; historical data validation, which runs part of the data collected through the system and compares model outputs to system outputs;

internal validity, which measures the amount of internal variance among several runs of the model; and traces, which follow the behavior of entities through the model to check internal logic (27:33-34).

Data Validation. Balci says the purpose of data validation is to "confirm that the data used throughout the model development phases are accurate, complete, unbiased, and appropriate in their original and transformed forms" (3:67). The following issues should be addressed: accuracy of measurements or estimates, reliability of data collection instruments, accuracy of transformations, representation of dependence between input variables, and timeliness of the data (3:67).

Description of the Implemented Simulation Study

This research method adheres to Balci's framework as described above. The following discussion parallels the ten phases in Balci's framework and reports the results of each phase.

Communicated Problem. Studies such as those by Crawford, Perry and others, and Kettner and Wheatley clearly show that flow time variability is prominent in the Depot Level Reparable Item Pipeline. This variability results in an unreliable pipeline full of uncertainty and low confidence in any predictions about pipeline contents. Moreover, it is not clear if management actions intended to reduce flow time variability might result in greater benefits than alternative actions intended to reduce the mean flow time. This problem led to the present study.

Formulated Problem. The communicated problem is translated into the main research question of this study. Specifically, the research question asks "What are the effects of reducing shop flow process means and/or variability on the contents of the Depot Level Reparable Item Pipeline?"

Solution Technique. As discussed at the beginning of the chapter, the solution technique is simulation. This technique was selected as most appropriate in view of the complexity and stochastic nature of the Depot Level Reparable Item Pipeline. Unfortunately, existing models such as Dyna-METRIC and Dyna-SCORE do not allow the degree of detail needed to answer the research question. Specifically, Dyna-METRIC only allows deterministic or exponentially distributed processing times for repair processes which would not permit manipulation of the repair time variability. And in the case of Dyna-SCORE, only the Shop Flow Segment of the pipeline is fully represented. As a result, a new simulation model of the pipeline is developed in this study to meet the requirements of the research.

System and Objectives Definition. The system modeled is that of the Depot Level Reparable Item Pipeline which consists of six segments: Base Processing, Intransit, Supply-to-Maintenance, Shop Flow, Serviceable Turn-in, and Order and Ship Time. The inputs to this system are reparable items that have been declared NRTS at bases. The outputs of the system are repaired items. The simulation study's objective is to measure pipeline contents at various levels of the Shop Flow Segment's mean flow time and at various levels of its associated variability. The following assumptions are made:

1. The Base Processing, Intransit, Supply-to-Maintenance, Serviceable Turn-in, and Order and Ship Time segments are unconstrained; the Shop Flow Segment is constrained.

2. The flow time probability distributions for the Base Processing, Intransit, Supply-to-Maintenance, Serviceable Turn-in, and Order and Ship Time Segments are similar for all types of items within each segment.

3. The NRTS arrival process is Poisson-distributed.

4. No parts are lost to the system (no condemnations).

5. There are sufficient repair parts eliminating awaiting parts conditions.

Conceptual Model. Our baseline model begins with the six pipeline segments described above. The model is extended to include the NRTS-generation process which feeds the Base Processing Segment. Each item has its own NRTS-generation process and is independent of the NRTS-generation processes of other items. The characteristics of the Base Processing, Intransit, Supply-to-Maintenance, Serviceable Turn-in, and Order and Ship Time Segments are treated as common for all items. However, the Shop Flow Segment is expanded to indicate that different items may have different shop flows. Each particular shop flow is common to some items, but not to all items.

Communicative Model. A simplified communicative model is developed for concept presentation (Figure 19). This model shows the initial generation of NRTS reparable items at a generic base. Each type of item has a particular NRTS arrival rate that is Poisson-distributed. The item enters the pipeline at the Base Processing Segment, and proceeds to the Intransit and Supply-to-Maintenance Segments. Each of these segments consists of a processing distribution represented by a mean flow time and a standard deviation that are common to all items. Several shop flows are modeled, each responsible for conducting repairs on certain reparable items. An item flowing through the pipeline is routed to the appropriate Shop Flow Segment. Each Shop Flow Segment consists of a single flow-time distribution with a mean and a standard deviation; or the segment consists of several processes, each with an individual distribution and a limited capacity. After the reparable item completes the Shop Flow Segment, it moves into the Serviceable Turn-in Segment which has a flow-time distribution that is common to all items. The Order and Ship Time segment begins at the same time a NRTS-generation occurs. If an item of the same type that entered the Base Processing Segment is available, the processing and shipment of this item is represented by a processing distribution that is common to all items. If an item is not available when requisitioned, then the order-and-ship time is extended until an item is repaired.

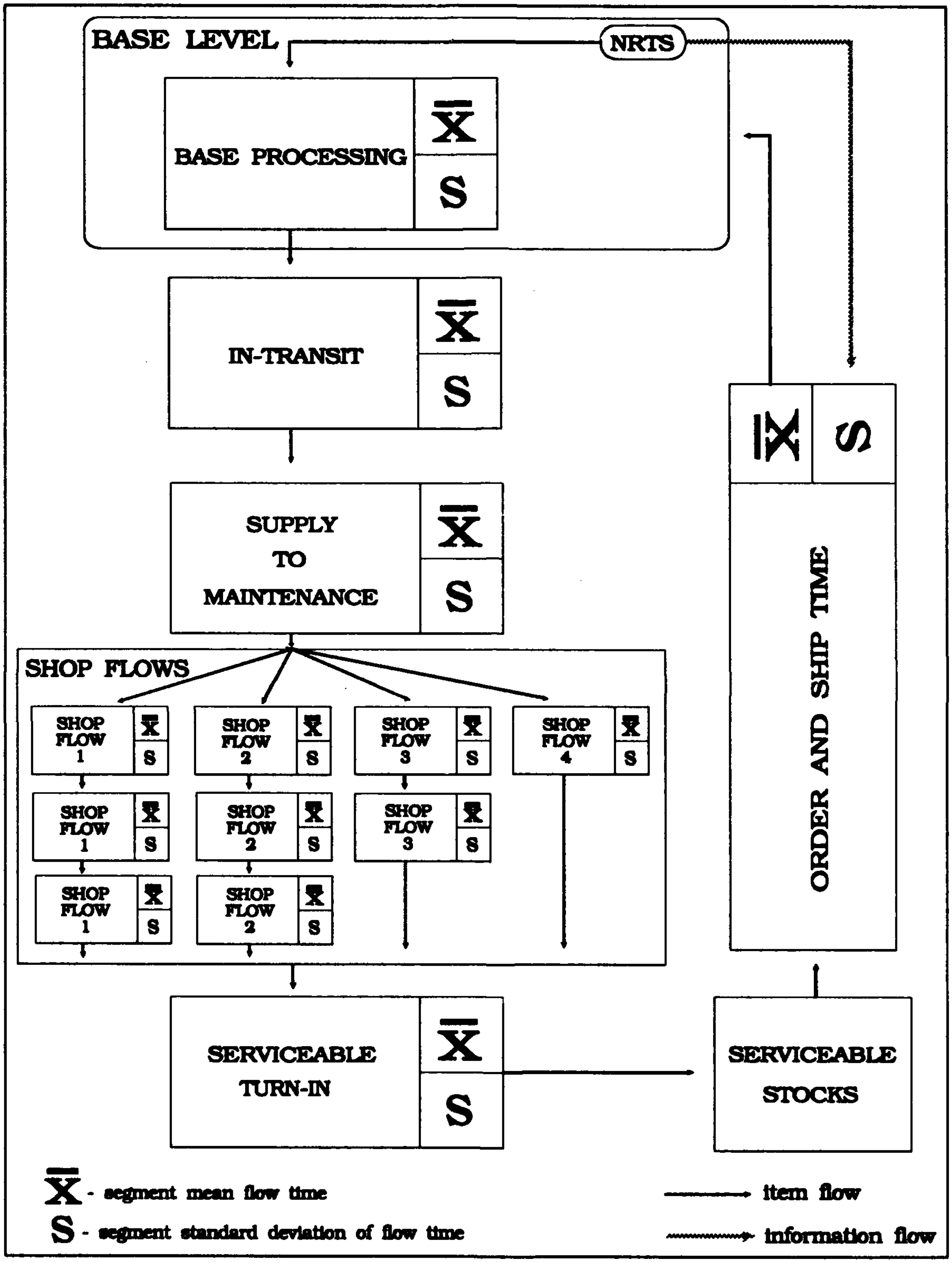

Figure 19. Communicative Model

Programmed Model. The programmed model was developed in two stages using the GPSS/H discrete-event simulation language. In the first stage, a pilot model was developed where all of the pipeline segments were unconstrained. In the second stage, the Shop Flow Segment was expanded to represent a constrained repair shop.

The pilot model was developed as a building block in anticipation of the constrained model. The simplicity of the pilot model allowed the authors to concentrate on both developing a modeling structure that could be expanded into the constrained model, and developing an experiment. After having gained some experience with the pilot model, a constrained model was developed. The first step was to write the program code to represent the Shop Flow Segment. The repair shop selected is the one described in Chapter II under the Industrial Process Improvement (IPI) Simulation section. It is the Fuel Control Overhaul and Test Unit (their office symbol LIPPCE is used as a shorthand throughout this study to refer to this repair unit). A verified and validated simulation model of this repair shop was available. Unfortunately, the IPI simulation model was written in the WITNESS simulation language. Since the authors did not have access to a WITNESS language processor, the IPI simulation model was translated into GPSS/H. The authors contacted the original programmer, Scott Broman, MCAIR, to get answers to several questions regarding the model dynamics and characteristics of the WITNESS language (8). The translation process was carefully conducted. The various flows were first flowcharted, then individually coded and tested before they were all put together. This collection of shop flows was then inserted into the original pilot model. The last step was to update the pilot model. The NRTS generation rates were updated to reflect the interarrival times for the parts repaired by LIPPCE. The processing time probability distributions for the Supply-to-Maintenance and Serviceable Turn-in Segments were changed from lognormal to gamma to better represent their flow time characteristics as reported by Kettner and Wheatley (15:201). Similarly, the processing time probability distribution for the Order and Ship Time Segment was changed from lognormal to gamma based on a goodness-of-fit test of data collected for this research. Finally, new code was added to generate several customized reports to include pipeline contents, Shop Flow Segment contents, and Shop Flow Segment flow times and their variance-to-mean ratios. Chapter IV contains a complete description of the constrained model; additionally, the GPSS/H code is provided at Appendix A.

Model Verification. Model verification was an continuous process. Three methods of verification were utilized: top-down development testing, desk checking, and a static check by the GPSS/H compiler. As discussed in the programming section, the programmed model was developed in sections from a general model to a detailed model. At each step of development, a static check by the GPSS/H compiler identified any syntax errors which were immediately corrected. Also, a mental walk through the model ensured that there were no logic errors. Finally, the standard GPSS/H output and the customized output were reviewed to ensure that the model was behaving as expected. This was particularly necessary as each of the shop flow repair processes were developed since their dynamic complexity and numerous symbols provided the potential for errors to go undetected by both the static and desk check. The incremental development and testing of each section made verification of the overall model much simpler. Since each section had been previously verified, it was only necessary to allow the GPSS/H compiler to conduct a static check on the overall model to detect any syntax errors introduced when all the sections were put together. During execution of the final model, only two types of runtime warnings are encountered. The first one is a division by zero attempt when computing variance-to-mean ratios for a customized report. The warning appears whenever the mean processing time for a particular part in a replication is zero. The quotient is automatically set to zero and the warning has no effect on the operation of the model. The second warning is a lack of precision to accommodate a very small processing time generated by the gamma distribution macro. The processing time is set to zero and this action does affect the operation of the model. The effect, however, appears to be minimal and the warning is generated only a few times during the execution of 1080 replications of the model.

Model Validation. The validation process for this model was limited to a determination of whether it sufficiently represented the processes in the pipeline for the purposes of the research. Given the assumptions and objectives of the research, it was not necessary nor possible to have a model that replicated the pipeline exactly. However, the need for credibility required that the model be based on actual processes and actual flow time data. The model developed meets these criteria. However, after some initial experimentation it was evident that some modifications would be needed to the Shop Flow Segment of the model. In particular, the original WITNESS simulation developed by MCAIR contained some processes modeled using deterministic times. Since these processes were not varying in accordance with the experimental design, the final results would not accurately reflect the effects of changing mean processing time and its variability. The model was modified by replacing the deterministic times with uniform probability distributions. The mean of each uniform distribution was set equal to the deterministic time it was replacing, and the upper and lower limits were set at reasonable levels. As an example, an inspection process lasting one hour was replaced with a uniformly distributed process lasting between 30 and 90 minutes. These distributions became a part of the model at its nominal levels of mean processing time and variability. The parameters for the uniform distribution were then manipulated to meet the experimental design criteria described below.

A second modification was required for triangular distributions when their lower bound was close to zero. With these distributions, it was not possible to obtain a case where the distribution was at a low mean processing time and a high processing time variability. Similarly, an attempt to increase variability to a high level resulted in an increase in the mean processing time. To solve the problem, these distributions were moved from the nominal case to the case for low mean processing time and high variability. The nominal case distributions were then recomputed to match the experimental design criteria. The effect in the model was that the mean processing time for the nominal case increased as the new distributions have double the original mean. To illustrate this procedure, the modification made to the triangular distribution for a bench testing process is used as an example. The nominal triangular distribution is described by the parameters 1, 6, and 40, representing the processing time lower bound, mode, and upper bound respectively (in hours). The variability (75.056) in this distribution cannot be increased without also changing the mean (15.667) of the distribution. Therefore, this distribution is used instead to represent the case for a low mean and high variability. But now a nominal case distribution is needed. The nominal case distribution is constructed by recognizing that it should have twice the mean of the low-mean, high-variability distribution and two-thirds the variability (in accordance with the experimental model described below). The resulting nominal case distribution is described by the parameters 15.831, 28.140, and 50.039 with a mean of 31.337 and variability of 50.035. The nominal triangular distribution is then used to build the triangular distributions for all other experimental cases. The benefit is that the desired relationships between levels of mean processing time and variability are possible without changing the fundamental operating characteristics of the repair flows. Without the modifications it would not have been possible to achieve the objectives of this research.

Experimental Model. The experimental model developed is designed to answer one of the investigative questions: "What is the impact upon pipeline contents when the mean shop flow time and/or its associated variability are reduced?" The principal statistic of interest is average pipeline contents. The average pipeline contents is computed by the simulation software as the number of items in the pipeline averaged over the last 260 days of simulated time (100 days of initial warm-up are not counted). The items in the pipeline are those that have entered the Base Processing Segment and have not exited the pipeline by going into depot or base stocks. The two principal factors of interest are shop flow mean processing time and shop flow variability. Each of these principal factors are examined at three levels: the existing or nominal level, a low level (50% of the nominal value), and a high level (150% of the nominal value). To further understand the effects of these factors on the pipeline, two environmental factors are included in the analysis. The environmental factors are defined as the mean processing time and the variability of the remaining five segments. These factors are set at two levels: a low level (50% of the nominal value), and a high level (150% of the nominal value). The principal factors use a 2x3 factorial design resulting in 9 possible experiments. Each of these experiments is repeated over the four combinations of environmental factors for a combined total of 36 experiments. Table 2 shows the resulting combinations of 36 experiments that were conducted.

For each experiment, 30 replications of the simulation model are executed to allow large sample statistical tests. Analysis of variance (ANOVA) tests are used to determine if there is any significant effect on pipeline contents (the dependent variable) from changes in the principal experimental factors. The simulation results are presented for each of the six different fuel controls modeled. For each fuel control, the 36 experiments are grouped into the four environmental combinations and ANOVA tests are conducted to determine if there are any significant effects on pipeline contents from changing shop flow mean processing time. The same tests are conducted to determine if there are any significant effects on pipeline contents from changing shop flow variability. The results of the simulation runs and statistical tests are presented in Chapter V.

TABLE 2

COMBINATION OF EXPERIMENTAL FACTORS

	Environment Mean	L	L	H	H
	Var	L	H	L	H
Shop Flow Mean	**Var**				
L	L	X	X	X	X
L	N	X	X	X	X
L	H	X	X	X	X
N	L	X	X	X	X
N	N	X	X	X	X
N	H	X	X	X	X
H	L	X	X	X	X
H	N	X	X	X	X
H	H	X	X	X	X

L = Low
N = Nominal
H = High

Data Validation. The data requirements for this simulation were satisfied from data reported by Kettner and Wheatley (15) and from the MCAIR simulation documentation (22). Data collected specifically for this simulation included the NRTS generation rates for each of the parts modeled, the stock levels at the depot, and flow time data for the Order and Ship Time Segment. The NRTS interarrival rates were obtained from the D041 Factor Analysis reports dated 31 March 92 and 21 July 92. These rates were validated by comparing them with another set of rates obtained from HQ AFMC/XPS. Table 3 shows that both sets of rates are close; in particular, fuel controls with high demand in one set also have high demand in the other set (and similarly for fuel controls with low demand). The stock levels at the depot were obtained from a Weapons System Management Information System (WSMIS) report dated 6 July 92. This report provides a snapshot picture of the location of assets throughout the Air Force. The stock

TABLE 3

NRTS INTERARRIVAL RATES FROM D041 AND HQ AFMC COMPARISON

Nomenclature	D041	HQ AFMC/XPS
TF30-P111 Main Fuel Control	21.8 days	18.6 days
TF30-P111 Afterburner Control	13.8	13.5
F101 Main Engine Control	18.9	16.8
F101 Augmentor	25.7	15.1
F110 Main Engine Control	9.6	4.3
F110 Augmentor	11.8	4.3

levels at the depot on the report date were used as a starting condition for the simulation model. The data for the Order and Ship Time Segment were obtained from the Air Force Logistics Information File (AFLIF). Materiel receipt acknowledgment transactions for the modeled fuel controls were extracted from the AFLIF database. The data set consisted of 186 transactions and showed a mean processing time of 42.3 days with a standard deviation of 44.44. To validate these data, they were informally compared with data reported by Kettner and Wheatley for other reparable items. Their data showed a mean of 47.8 days with a standard deviation of 82.2 (15:192). Both sets of data are similar; this finding also supports the assumption that segment flow-times are independent of part types.

Simulation Results. For each of the 36 experiments conducted, the simulation model produces a summary output page. This summary contains the pipeline contents at the end of each of the 30 experimental runs for each of the 6 fuel controls modeled. The average pipeline contents for the 30 experimental runs is also listed, along with the standard deviation and a 95% confidence interval.

To answer the pertinent investigative question, statistical tests are conducted as described in the design of experiment. The results of these tests are presented and discussed in Chapter V.

Chapter Summary

This chapter presented the solution approach to answer the research question, a simulation study. A background review of the process involved in conducting a simulation study was provided. This review identified ten processes: problem formulation, investigation of solution technique, system investigation, model formulation, model representation, programming, design of experiments, experimentation, redefinition, and presentation of simulation results. Finally, a description of the method that was implemented was given. This description covered the results from each of the ten processes of a simulation study.

IV. The Simulation Model

This chapter presents a detailed description of the simulation model. It begins with a description of the six fuel controls modeled and the NRTS generation process. This is followed by a description of how each of the six Depot Level Reparable Item Pipeline segments are modeled. This description includes the sources of data and a full description of the various repair processes in the Shop Flow Segment.

Fuel Controls Modeled

Six different items are modeled. The selection of which items to model was a function of the repair processes selected for the Shop Flow Segment. The items and the repair processes are those of the Fuel Control Overhaul and Test Unit (their office symbol LIPPCE is used as a shorthand throughout this study to refer to this repair unit) as modeled by MCAIR. Twenty-two different types of fuel controls are repaired by LIPPCE; of these, six accounted for 57% of their workload during the fourth quarter of FY91 (22:6-1 to 6-2). These six fuel controls are the items modeled and can be grouped by their corresponding aircraft engine: TF30-P111 main and afterburner fuel controls (F-111 aircraft), F101 main engine control and augmentor (B-1 aircraft), and F110 main engine control and augmentor (F-16 aircraft) (22:5-1). Table 4 shows a summary of the parts modeled.

NRTS Generations and Initial Depot Stocks

The NRTS generation rate for the six modeled fuel controls were obtained from the D041 Factor Analysis printout dated 31 Mar 92. This printout lists the number of NRTS generations from all bases over eight quarters. The NRTS generation rate used for each of the six fuel controls is the average of eight quarterly NRTS generation rates.

These NRTS generation rates were converted into interarrival rates for use in the Poisson distributed arrival process. Table 5 shows the actual NRTS interarrival rates used in the simulation.

TABLE 4

PARTS MODELED

National Stock Number	Nomenclature	Aircraft	Model Name
2915-01-206-0702PQ	TF30-P111 Main Fuel Control	F-111	M111
2915-01-185-1863PQ	TF30-P111 Afterburner Control	F-111	A111
2915-01-248-9033JF	F101 Main Engine Control	B-1	M101
2915-01-148-2108JF	F101 Augmentor	B-1	A101
2915-01-305-4970PR	F110 Main Engine Control	F-16	M110
2915-01-200-0119PR	F110 Augmentor	F-16	A110

TABLE 5

FUEL CONTROLS NRTS INTERARRIVAL RATES

Nomenclature	Interarrival Rate (days)
TF30-P111 Main Fuel Control	21.8
TF30-P111 Afterburner Control	13.8
F101 Main Engine Control	18.9
F101 Augmentor	25.7
F110 Main Engine Control	9.6
F110 Augmentor	11.8

The number of serviceable fuel controls available for issue at the depot is incorporated into the model to simulate the requisitioning process. As each NRTS is generated, a requisition is simulated by taking a serviceable fuel control from the depot stocks and placing it in the Order and Ship Time Segment. If no serviceable fuel control is available, then a backorder is simulated. Backorders are filled as soon as a serviceable fuel control is available. The numbers of serviceable fuel controls at Oklahoma City ALC were obtained from a Weapon System Management Information System (WSMIS) report dated 6 July 92. Table 6 summarizes the initial depot serviceable stocks.

TABLE 6

INITIAL DEPOT STOCKS

Nomenclature	Initial Depot Stock
TF30-P111 Main Fuel Control	1
TF30-P111 Afterburner Control	3
F101 Main Engine Control	4
F101 Augmentor	17
F110 Main Engine Control	8
F110 Augmentor	28

Base Processing Segment

The Base Processing Segment is modeled as an unconstrained process. Based on the assumption that the processing for this segment is essentially the same for all parts, data already collected for another thesis are used. The data collected by Kettner and Wheatley showed an average flow time of 3.1 days with a standard deviation of 3.3 days. The Kolmogorov-Smirnov (K-S) test applied by Kettner and Wheatley revealed that the data did not fit any of the ten theoretical distributions which they tested (uniform, triangular, normal, lognormal, exponential, Erlang, gamma, Weibull, beta, beta-pert) (15:171). A lognormal distribution was used to model this pipeline segment because it allows easy manipulation of both the mean and variability and because it is commonly used to model time to accomplish a task (17:164).

Intransit Segment

The Intransit Segment is also modeled as an unconstrained process using data from Kettner and Wheatley. Their data showed an average flow time of 19.4 days with a standard deviation of 26.4 days. The K-S test revealed that these data fit a lognormal distribution (15:173). Thus, the Intransit Segment is modeled using a lognormal distribution with the above parameters.

Supply-to-Maintenance Segment

The Supply-to-Maintenance Segment is modeled as an unconstrained process using data reported by Kettner and Wheatley. The data they reported were provided by HQ AFLC/LGSC and covered the period June 1989 to May 1990. The Supply-to-Maintenance Segment is divided into two parts and the data are provided for each part. The first half showed a flow time of 2.4 days with a standard deviation of 2.2 days. The second half showed a flow time of 7.8 days with a standard deviation of 6.9 days. The K-S tests showed that the first half did not fit any of the ten theoretical distributions tested, but the second half fit a gamma distribution (15:176-179). In summary, this segment is modeled in two parts to fit the data available. The first half is modeled using a lognormal distribution for the same reasons noted under the Base Processing Segment description. The second half is modeled using a gamma distribution.

Shop Flow Segment

The Shop Flow Segment is modeled as a constrained segment based on the simulation model of the Fuel Control Test and Overhaul Unit developed by MCAIR. There are four distinct repair flows some of which share resources: the F101 and F110 Main Engine Controls (MECs) repair flow; the F101 and F110 Augmentor repair flow; the TF30-P111 Main Fuel Control repair flow; and the TF30-P111 Afterburner Control repair flow. The basic repair flows consist of the following processes: inspection, bench testing, repair/overhaul, and final bench testing. The processing times are modeled using a combination of deterministic times and uniform, normal, or triangular probability distributions. Some of the required actions have limited resources such as personnel, bench test machines, and overhaul machines. These limitations are built into the model and affect the overall repair time. Additionally, machine breakdowns are also modeled adding to the constrained nature of the model. The flowcharts depicting the repair flows identify constrained processes by using capital letters (e.g., INSPECT1). The number in the resource name identifies the specific limited resource that may be shared by more than one repair flow. Other processes and decisions are shown in mixed case letters (e.g., Disassemble) and represent zero-time processes. Additionally, the name of each subassembly is shown after a disassembly process. While describing each of the repair processes, the capacity for limited resources is listed. The capacity of a resource refers to the number of fuel controls that can be processed simultaneously and is related to the number of machines such as test stands that are available. Each of the four repair flows is now described in detail.

F101 and F110 Main Engine Controls (MECs) Repair Flow. As shown in Figure 20, this repair flow starts with an inspection process and is followed by a bench testing process. At the end of the bench test, a probability function classifies the repairable item as a minor or major overhaul job (Table 7). The probabilities for classifying job types are derived from the original WITNESS model by MCAIR. Minor overhaul jobs consist of a repair process and a test process. Major overhaul jobs consist of disassembly of each fuel control into two separate parts, a repair process for each subassembly, an assembly process, and a test process. For minor and major overhaul jobs, the inspection, bench testing, and repair processes are modeled as constrained resources. Notice that the bench test stand (TEST1) and the overhaul machine (REPAIR2) are shared by both minor and major overhauls. Table 8 summarizes the capacity limitations for each of these processes. These capacities are also derived from the original WITNESS model by MCAIR.

F101 and F110 Augmentors Repair Flow. Figure 21 shows the augmentors repair flow. This flow is much simpler because all jobs are considered minor overhaul jobs. The

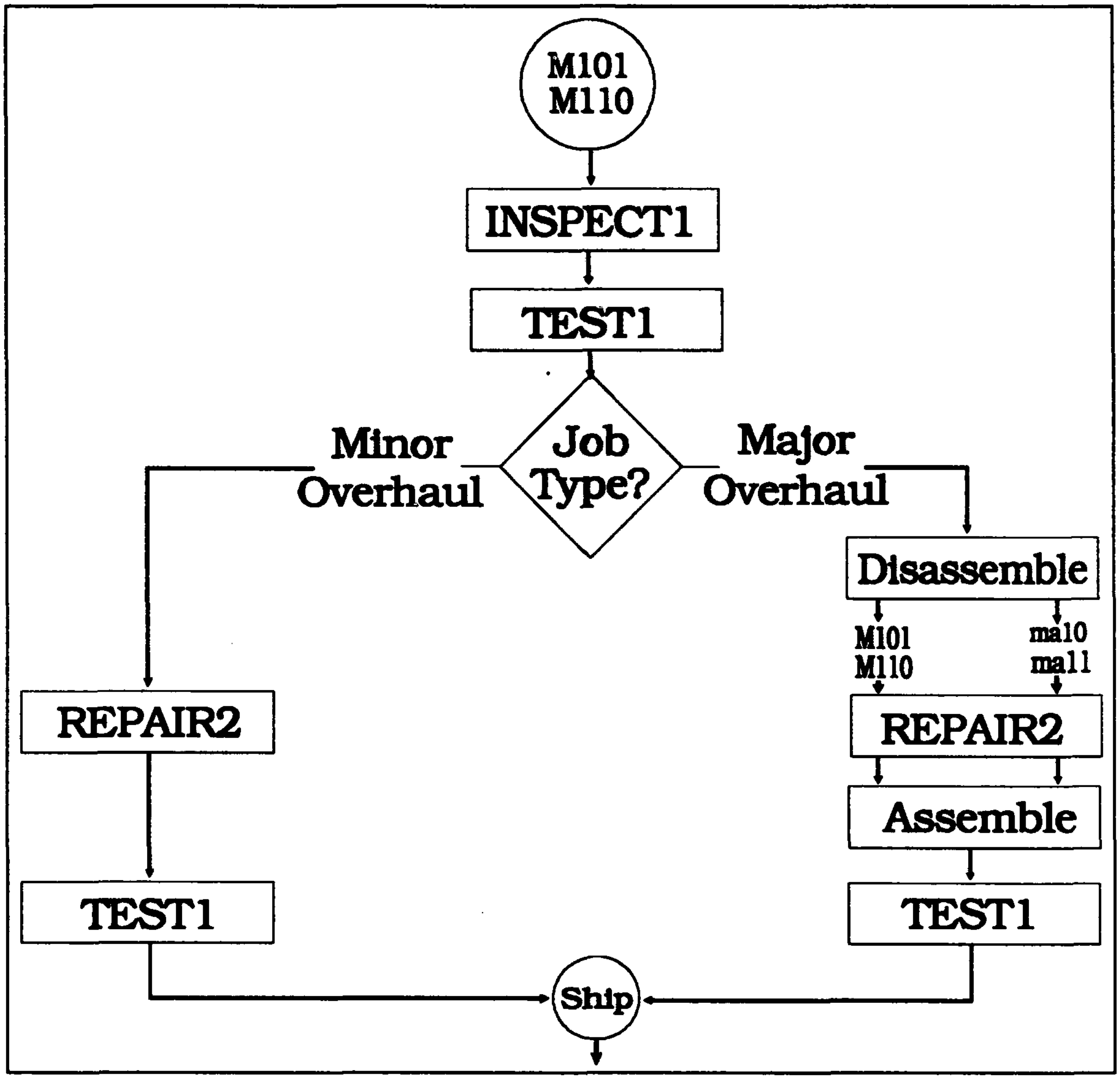

Figure 20. F101 and F110 Main Engine Controls Repair Flow

TABLE 7

F101/F110 MECs MINOR AND MAJOR OVERHAUL PROBABILITIES
(22:8-101)

Nomenclature	Minor Overhaul Probability	Major Overhaul Probability
F101 Main Engine Control	80%	20%
F110 Main Engine Control	85%	15%

TABLE 8

F101/F110 MAIN ENGINE CONTROLS REPAIR
FLOW RESOURCE CAPACITIES
(22:8-54 to 8-58)

Process	Capacity
INSPECT1	1
TEST1	4
REPAIR2	2

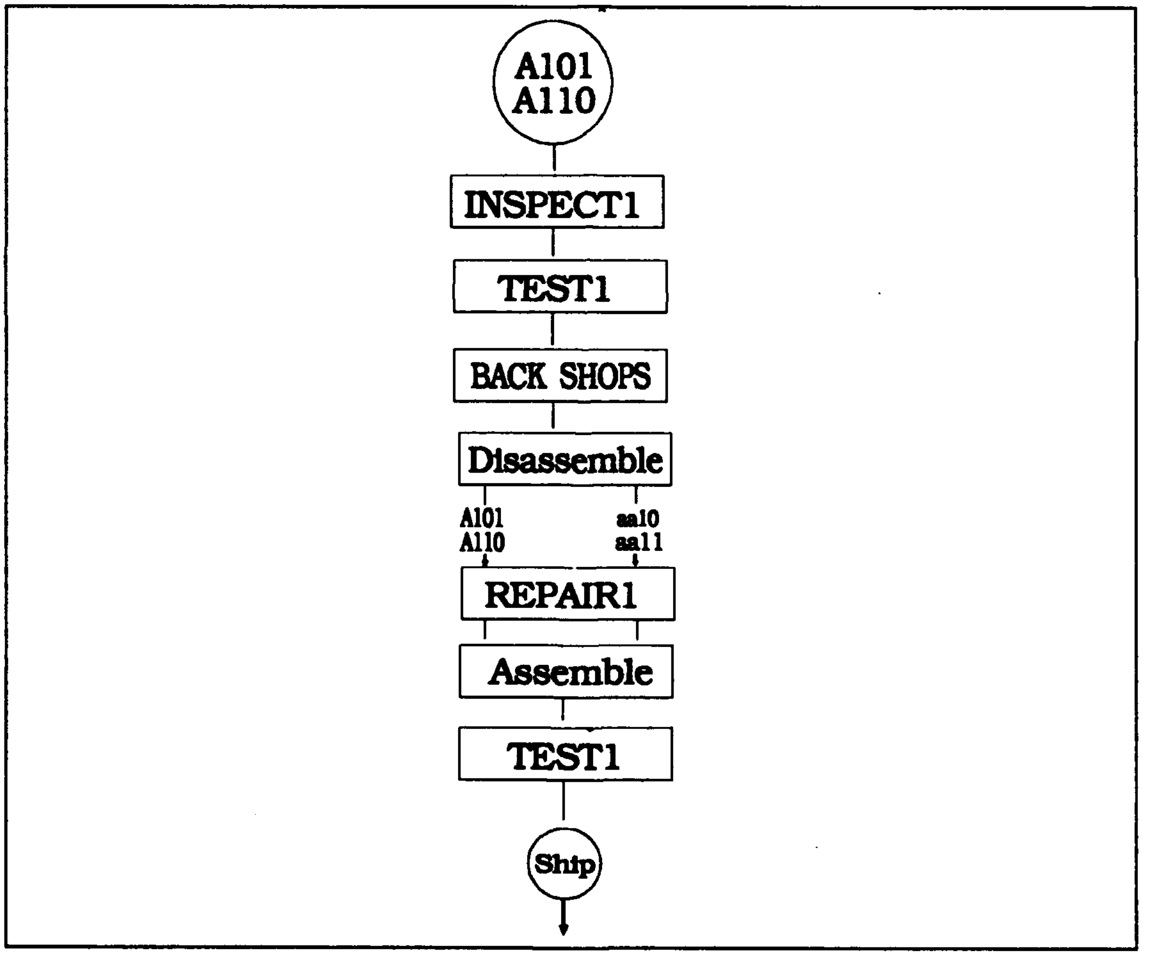

Figure 21. F101 and F110 Augmentor Repair Flow

inspection and bench test stand resources (INSPECT1 and TEST1) are shared with the MEC repair flow. The back shops process represents a delay time between the testing and disassembly processes and has an unlimited capacity. The overhaul resource (REPAIR1) is unique to this flow and has a capacity of one job at a time.

TF30-P111 Main Fuel Control Repair Flow. Figure 22 shows the repair flow for this fuel control. It starts with its own inspection and bench test processes and is followed by minor or major overhaul job classification (Table 9). Minor overhaul jobs consist of a

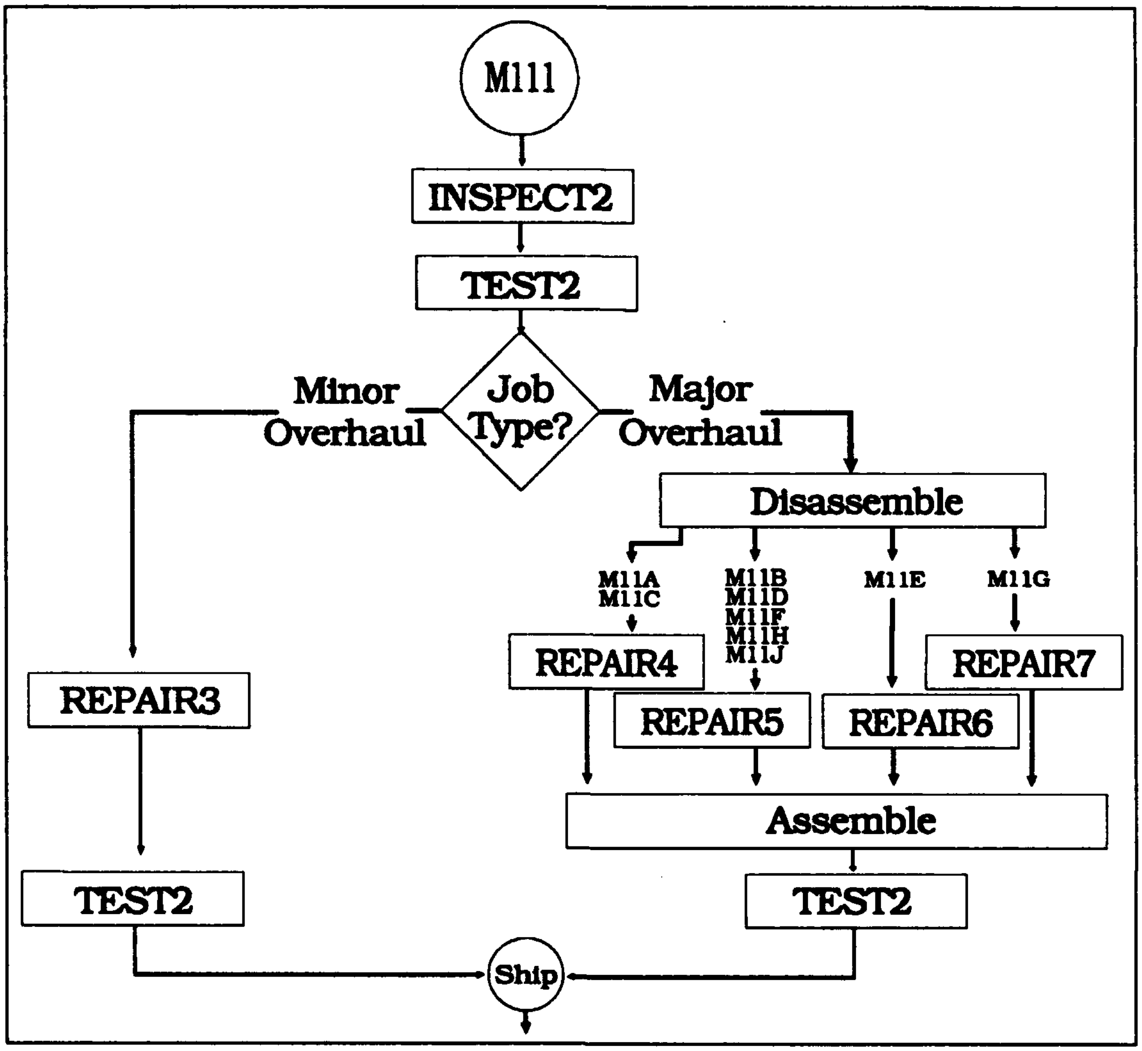

Figure 22. TF30-P111 Main Fuel Control Repair Flow

TABLE 9

TF30-P111 MAIN FUEL CONTROL MINOR AND MAJOR OVERHAUL PROBABILITIES (22:8-102)

Nomenclature	Minor Overhaul Probability	Major Overhaul Probability
TF30-P111 Main Fuel Control	61%	39%

repair process and a final bench test process. Major overhaul jobs consist of a disassembly process, repair processes, an assembly process, and a final bench test process. Following the disassembly process, notice that subassemblies are repaired in one of four types of machines, with some subassemblies using the same type of machine. For minor and major overhaul jobs, the inspection, bench testing, and repair processes are modeled as constrained resources. Table 10 summarizes the capacities of the constrained resources.

TABLE 10

TF30-P111 MAIN FUEL CONTROLS REPAIR FLOW RESOURCE CAPACITIES (22:8-54 TO 8-58)

Process	Capacity	Process	Capacity
INSPECT2	1	REPAIR5	1
TEST2	4	REPAIR6	2
REPAIR3	8	REPAIR7	1
REPAIR4	1		

TF30-P111 Afterburner Control Repair Flow. Figure 23 shows the repair process for the afterburner control. The repair flow starts with an inspection process followed by a bench test process. The afterburner controls are then classified by a probability function into minor or major overhaul jobs (Table 11). Minor overhaul jobs consist of a repair process and a final bench test process. Major overhaul jobs consist of two disassembly processes, repair processes, assembly processes, additional repairs, and a final bench test.

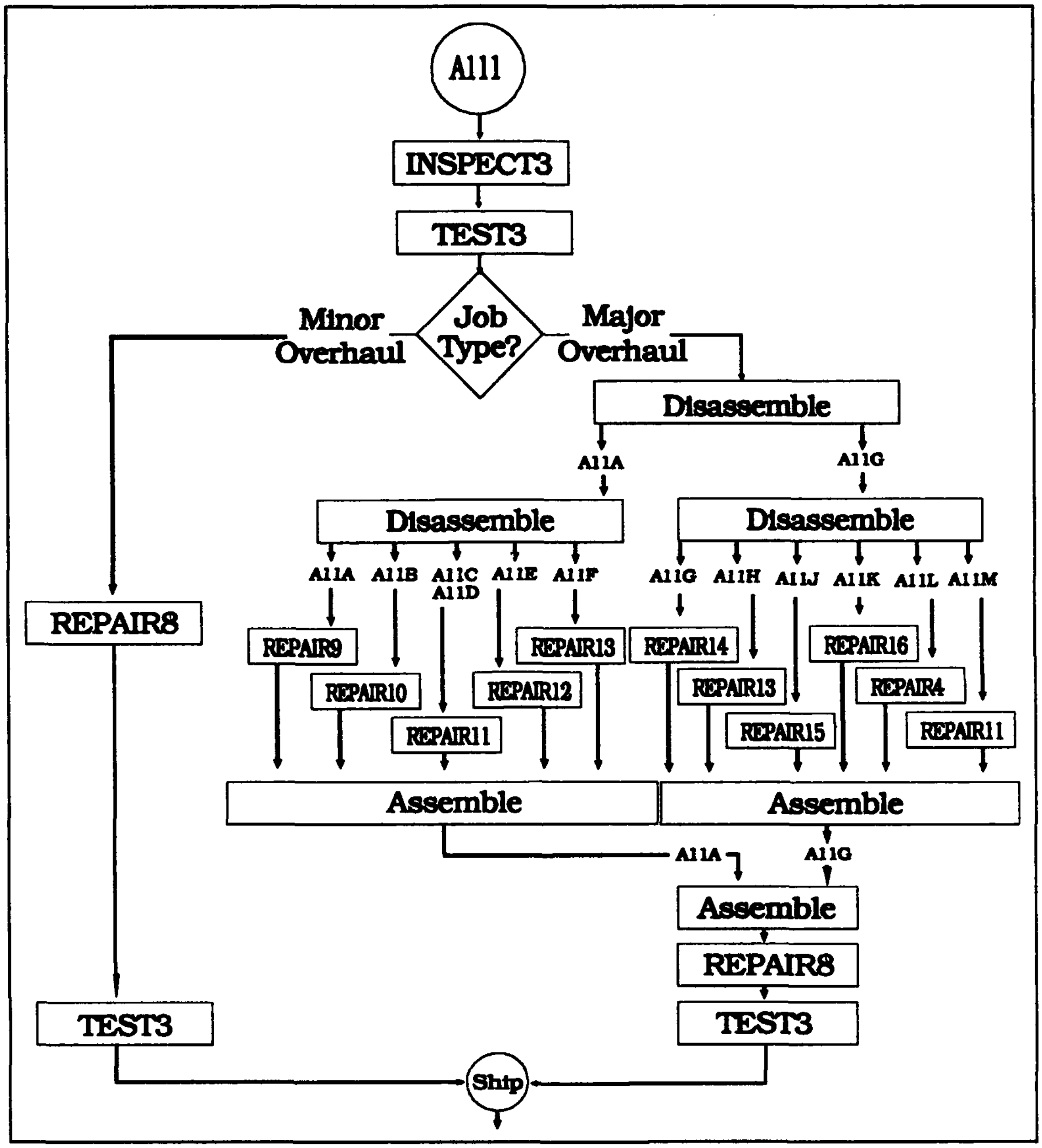

Figure 23. TF30-P111 Afterburner Control Repair Flow

TABLE 11

TF30-P111 AFTERBURNER CONTROL MINOR AND MAJOR OVERHAUL PROBABILITIES

(22:8-102)

Nomenclature	Minor Overhaul Probability	Major Overhaul Probability
TF30-P111 Afterburner Control	43%	57%

Afterburner controls are first disassembled into two major subassemblies. Each major subassembly is in turn disassembled into various minor subassemblies. Each minor subassembly undergoes repair in one of nine resources, some of which are shared by various subassemblies. The minor subassemblies are then reassembled into the major subassemblies, which are in turn reassembled into an afterburner control. For both minor and major overhaul jobs, inspection, bench test stand, and repair processes are modeled as constrained resources. Table 12 summarizes the capacity limitations for the afterburner control repair process.

TABLE 12

TF30-P111 AFTERBURNER CONTROLS REPAIR FLOW RESOURCE CAPACITIES (22:8-54 TO 8-58)

Process	Capacity	Process	Capacity
INSPECT3	1	REPAIR11	1
TEST3	4	REPAIR12	1
REPAIR4	1	REPAIR13	1
REPAIR8	8	REPAIR14	2
REPAIR9	2	REPAIR15	1
REPAIR10	2	REPAIR16	1

Serviceable Turn-in Segment

The Serviceable Turn-in Segment is modeled as an unconstrained process using data reported by Kettner and Wheatley. The data reported were provided by HQ AFLC/LGSC and cover the period June 1989 to May 1990. The data show an average flow time of 4.9 days with a standard deviation of 3.8 days. The K-S test showed that the data did not fit any of the ten theoretical distributions tested. However, the K-S test showed that the gamma distribution had the closest test statistic to the critical value (15:187-188). Therefore, the Serviceable Turn-in Segment is modeled using a gamma distribution with the above parameters.

Order and Ship Time Segment

The Order and Ship Time Segment is modeled as an unconstrained process. Data for this segment were collected for the six fuel controls modeled from the Air Force Logistics Information File (AFLIF). Materiel Receipt Acknowledgment transactions were extracted from AFLIF and analyzed to determine this segment's flow time. The data set consisted of 186 transactions. The materiel receipt processing date was compared with the requisitioning date to determine the time elapsed. The data showed an average flow time of 42.31 days with a standard deviation of 44.44 days. A K-S test was then used to fit a theoretical distribution to the data that could be used in the simulation model. The K-S test showed that the data fit a gamma distribution (critical value = .0997 and K-S statistic = .0531) with shape parameter .9055 and scale parameter 46.67.

Chapter Summary

This chapter presented a detailed description of the simulation model. The flow of six types of fuel controls through the Depot Level Reparable Item Pipeline are modeled based on Kettner and Wheatley's conceptual model of the pipeline, MCAIR's model of the Fuel Control Overhaul and Test Unit (LIPPCE), existing flow times data, and new flow time data collected from the Air Force Logistics Information File (AFLIF). Of the six pipeline segments, five are modeled as unconstrained processes. Lognormal and gamma probability distributions are used to represent the flow times for each of these segments based on existing and new data. The flow times for the Base Processing, Intransit, Supply-to-Maintenance, and Serviceable Turn-in Segments are based on data previously collected and reported by Kettner and Wheatley. The flow time for the order and ship time is based on new data collected from AFLIF. The Shop Flow Segment, which is the principal segment of interest, is modeled in detail as a constrained set of processes. The model is based on a simulation model of the Fuel Control Overhaul and Test Unit. Four repair processes are modeled which use and share limited resources. The final result is a simulation that models the repair process from the time a broken part is declared NRTS by a base until it is repaired and redistributed to another base.

V. Data Analysis and Discussion

The previous chapters of this study built the basis for this chapter by answering a number of the investigative questions listed in Chapter I. Questions 1 and 2 are answered in the early portion of the Literature Review (Chapter II) and give an understanding of variability's effect on processes. Questions 3 and 4 are also answered in the Literature Review, which described the Depot Level Reparable Item Pipeline along with some available models to use as the basis for this study. This led directly into the development of the simulation model described in Chapter IV which answered question 5.

This chapter includes the data generated by the simulation model as well as the results of the statistical analyses. These analyses answer the final question "What is the impact upon pipeline contents when the mean shop flow time and/or its associated variability are reduced?"

This chapter is organized in three sections. The first section describes the results of the base case experiment as described in the experimental design section of Chapter III. The second section describes the results of a modified experiment. In this experiment, the variability in the model is increased to observe the effects on pipeline contents. Finally, the third section presents a second set of results from the modified experiment. Instead of looking at pipeline contents, the focus is narrowed to only the shop flow contents. Each section includes a discussion of the rationale for each of the experiments and a discussion of the results.

Base Case Experiment

The base case experiment described in Chapter III is composed of two factors, mean shop flow time and shop flow variability, at three levels of analysis (.5 x Nominal, Nominal, and 1.5 x Nominal, where nominal refers to the existing conditions in the modeled repair shop). Each of the resulting nine factor-level combinations is examined across the four combinations of environmental factors. ANOVA tests are conducted to detect any effects from the different levels in mean shop flow time, shop flow variability, and the interaction of both factors on average pipeline contents. The test of hypothesis is:

H_0: The treatment means are all equal
H_a: At least two treatment means differ

Data are collected separately from the simulation model for each of the six fuel controls modeled. These data are further subdivided and analyzed separately for each of the types of jobs, minor overhaul (I-Jobs) and major overhaul (A-Jobs). These subdivisions are necessary because each of the fuel controls has a different flow with its own set of flow times and its own degree of variability. Further, for four of the fuel controls, minor overhauls and major overhauls have different processing time distributions making separate analysis necessary. The results are thus presented for each of the six fuel controls, with an additional subdivision for the fuel controls with minor and major overhauls. The next few paragraphs are a detailed description of the tables summarizing the results.

Experiment Results. The average pipeline contents for the TF30-P111 Main Fuel Control (M111) fuel control over all possible combinations of shop flow mean processing time and shop flow process variability are shown in Table 13 (summary table for other fuel controls are found at Appendix B). The left two columns in the table indicate the factor-level combinations for the shop flow factors. For each of these factor-level combinations, four average pipeline contents are listed horizontally corresponding to the environmental factor-level combinations as labeled on top of each column. The environmental factors are included to obtain a broad picture of the effects of shop flow process mean and variability over a variety of pipeline conditions.

TABLE 13

M111 AVERAGE PIPELINE CONTENTS (I-JOBS)

Shop Flow Mean	Shop Flow Variability	Environment: Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
.5xNominal	.5xNominal	.580	.490	1.416	1.193
.5xNominal	Nominal	.578	.489	1.419	1.197
.5xNominal	1.5xNominal	.578	.489	1.413	1.204
Nominal	.5xNominal	.725	.628	1.580	1.348
Nominal	Nominal	.723	.626	1.575	1.336
Nominal	1.5xNominal	.725	.634	1.577	1.344
1.5xNominal	.5xNominal	.880	.808	1.752	1.491
1.5xNominal	Nominal	.879	.798	1.756	1.491
1.5xNominal	1.5xNominal	.875	.790	1.758	1.485

Table 14 shows the p-values for the first ANOVA test which looks at the overall effects of each factor on average pipeline contents. The first line of each section, labeled "Mean," shows the statistical significance of mean shop flow time over various environmental conditions. For each environmental factor-level combination, the ANOVA test gathers observations into three groups representing the three levels of mean shop flow time. The resulting p-value from the test indicates whether changing the mean shop flow time has any significant effect on average pipeline contents. The second line of each section, labeled "Variability," shows the statistical significance of shop flow process variability over various environmental conditions. For each environmental factor-level combination, the ANOVA test gathers observations into three groups representing the three levels of shop flow process variability. The resulting p-value from the test indicates whether there is any significant effect on average pipeline contents from changing the shop flow process variability. The third line of each section, labeled "Mean x Var," shows the statistical significance of both shop flow process mean and variability over various environmental conditions. For each environmental factor-level combination, the ANOVA

TABLE 14

ANOVA RESULTS OF SHOP FLOW MEAN AND VARIABILITY EFFECTS

		Shop Flow	Environment: Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
M111	I-Job	Mean	**.0001**	**.0001**	**.0012**	**.0003**
		Variability	.9992	.9925	1.0000	.9992
		Mean x Var	1.0000	.9994	1.0000	.9999
	A-Job	Mean	**.0001**	**.0001**	**.0001**	**.0001**
		Variability	.9942	.9999	.9997	.9996
		Mean x Var	1.0000	1.0000	1.0000	1.0000
A111	I-Job	Mean	**.0005**	**.0001**	**.0240**	**.0073**
		Variability	.9960	.9995	.9952	.9991
		Mean x Var	.9999	.9997	.9999	1.0000
	A-Job	Mean	**.0001**	**.0001**	**.0001**	**.0002**
		Variability	.9976	.9936	.9992	.9956
		Mean x Var	.9999	.9999	.9999	1.0000
M101	I-Job	Mean	**.0001**	**.0001**	**.0021**	**.0003**
		Variability	.9960	.9992	.9995	.9992
		Mean x Var	1.0000	1.0000	1.0000	1.0000
	A-Job	Mean	**.0001**	**.0001**	**.0013**	**.0013**
		Variability	.9844	.9987	.9999	.9952
		Mean x Var	1.0000	.9996	.9996	1.0000
A101		Mean	**.0001**	**.0001**	**.0001**	**.0001**
		Variability	.9970	.9992	.9999	.9985
		Mean x Var	1.0000	1.0000	1.0000	1.0000
M110	I-Job	Mean	**.0001**	**.0001**	**.0001**	**.0001**
		Variability	.9997	.9989	.9993	.9966
		Mean x Var	1.0000	1.0000	1.0000	1.0000
	A-Job	Mean	**.0001**	**.0001**	**.0001**	**.0001**
		Variability	.9975	.9962	.9996	.9995
		Mean x Var	1.0000	1.0000	1.0000	1.0000
A110		Mean	**.0001**	**.0001**	**.0001**	**.0001**
		Variability	.9995	.9965	.9996	.9999
		Mean x Var	1.0000	1.0000	1.0000	1.0000

Bold values are significant at the 90% confidence level

test gathers observations into nine groups representing the nine factor-level combinations of shop flow process mean and variability. The resulting p-value from the test indicates whether there is any significant effect on average pipeline contents from changing the shop flow process and variability.

The second ANOVA test examines the effects of shop flow variability alone; the resulting p-values are shown in Table 15. This ANOVA test first groups all observations into the four environmental factor-level combinations. Then, for each of these environmental groups, the observations are subdivided into three groups representing the three levels of shop flow process mean. This sub-grouping includes observations from each of the three levels of shop flow process variability and the ANOVA p-value for this subgroup indicates whether there is any significant effect from shop flow process variability at a single level of shop flow process mean.

Discussion. The simulation results for the base case experiment clearly indicate that a change in the shop flow mean processing time has a significant effect on overall pipeline contents at the 90% confidence level for all of the fuel controls over all environmental conditions. Clearly, a reduction in the mean processing time results in a significant reduction in pipeline contents. Conversely, an increase in the mean processing time results in more fuel controls tied up in the pipeline. This effect can be seen in Table 13. Notice that pipeline contents consistently increase between each level of mean shop flow time (e.g., .580 to .725 to .880 for the .5xNominal variability case and the first environment column). This effect is consistent throughout all environments and all fuel controls and job types (the remaining pipeline contents tables are found at Appendix B).

The results for the effects of variability are not significant. Furthermore, the effects of variability are unpredictable. Notice the first column of numbers in Table 13. The first three numbers (.580, .578 and .578) indicate a reduction or no change as variability increases. The next three numbers (.725, .723, and .725) show an initial

TABLE 15

ANOVA RESULTS OF SHOP FLOW VARIABILITY EFFECTS

		Shop Flow Mean	Environment: Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
M111	I-Jobs	.5xNominal	.9998	.9994	.9993	.9940
		Nominal	.9995	.9914	.9994	.9956
		1.5xNominal	.9982	.9776	.9994	.9984
	A-Jobs	.5xNominal	.9996	.9951	.9995	.9997
		Nominal	.9970	.9996	.9999	.9973
		1.5xNominal	.9964	.9963	.9989	.9985
A111	I-Jobs	.5xNominal	.9838	.9799	.9802	.9940
		Nominal	.9977	.9930	.9990	.9998
		1.5xNominal	.9997	.9996	.9977	.9988
	A-Jobs	.5xNominal	.9701	.9784	.9851	.9841
		Nominal	.9994	.9999	.9998	.9998
		1.5xNominal	.9970	.9994	.9975	.9998
M101	I-Jobs	.5xNominal	.9985	.9993	.9997	.9968
		Nominal	.9982	.9994	.9995	.9986
		1.5xNominal	.9987	.9952	.9957	1.0000
	A-Jobs	.5xNominal	.9726	.9791	.9761	.9982
		Nominal	.9961	.9836	.9929	.9966
		1.5xNominal	.9988	.9983	.9964	.9938
A101		.5xNominal	.9958	1.0000	.9998	.9992
		Nominal	.9976	.9997	.9999	.9992
		1.5xNominal	.9990	.9988	.9998	.9998
M110	I-Jobs	.5xNominal	.9981	.9988	.9982	.9981
		Nominal	1.0000	.9989	.9994	.9923
		1.5xNominal	.9973	.9998	.9995	.9983
	A-Jobs	.5xNominal	.9974	.9986	.9977	.9997
		Nominal	.9995	.9995	1.0000	.9990
		1.5xNominal	.9967	.9969	.9997	.9995
A110		.5xNominal	.9981	.9938	.9985	.9994
		Nominal	.9996	.9987	.9997	.9998
		1.5xNominal	.9998	.9999	.9999	.9999

decrease and then an increase in pipeline contents as variability increases. The last three numbers (.880, .879, and .875) show a paradoxical decrease in pipeline contents as variability increases. These unpredictable effects can be seen throughout all environment and all fuel controls and job types. The natural explanation would be that variability in shop flow processing time does not have a significant effect on pipeline contents. However, this is not consistent with the literature that was reviewed in Chapter II. It is possible that the amount of variability introduced into the model was not sufficiently high to make a difference. To investigate this possibility, the base case experiment was modified to introduce more variability into shop flow processes. This modified experiment is described below.

Modified Experiment

The base case experiment results did not yield a significant effect on pipeline contents from the levels of shop flow processing time variability. In this experiment, the levels of variability are changed so that the low level of variability is essentially a deterministic case with no processing time variability. Further, the high level of variability is the most variability that could be induced given the existing processing time distributions. The process of inducing this variability is now described.

The Shop Flow Segment is modeled with a combination of uniform, triangular, and normal probability distributions. To obtain the low variability case, the end points of uniform distribution are both set to equal the mean processing time. For triangular distributions, it is not possible to set all three parameters to the same number because this results in a software error. In this case, the mode of the distribution is set to the mean of the distribution, and the upper and lower bounds are set to plus or minus .0001, making the distribution essentially deterministic. For normal distributions, the standard deviation is set to 0 allowing for no variance.

In order to obtain a highly variable case, the lower bound of each uniform distribution is set to 0. The distribution is then balanced by extending the upper bound by an amount equal to the shift in the lower bound. In this manner, the mean is kept the same, and variability is maximized. Triangular distributions are similarly handled. The lower bound is set to 0, and the upper bound is shifted an equal amount in order to preserve the shape and the mean. For normal distributions, the standard deviation is set to three times the nominal standard deviation. This effectively multiplies the variance nine-fold, a significant increase from the 1.5 increase in the base case experiment.

Experiment Results. Although the primary interest in this experiment is to look at the effects of variability, all of the statistics generated for the base case experiment are computed. The tables summarizing pipeline contents are found at Appendix C. Table 16 shows the ANOVA results for the effects of mean shop flow time, variability, and their interaction. The ANOVA results for the effects of shop flow variability alone are presented in Table 17. The tables are in the same format as those described above for the base case experiment.

Discussion. The results of this experiment again show that mean shop flow time has a significant impact on pipeline contents as evidenced by the p-values in bold type in Table 16. Unfortunately, variability does not have a significant effect on pipeline contents at the 90% confidence level as in the first experiment. The pipeline contents tables found at Appendix C show the same unpredictable patterns described in the base case experiment. Again, the results seem inconsistent with the findings in the literature review. At this point it is necessary to narrow the focus and examine if variability is having an effect on shop flow contents. The hypothesis is that perhaps variability from the Shop Flow Segment alone is not enough to make a significant change on the whole pipeline.

Shop Flow Contents Experiment

The model for the increased variability experiment is used to examine shop flow contents. Actually, the model already has the capability to generate shop flow contents

TABLE 16

ANOVA RESULTS OF SHOP FLOW MEAN AND VARIABILITY EFFECTS (MODIFIED EXPERIMENT)

		Shop Flow	Environment Low Mean Low Var	 Low Mean High Var	 High Mean Low Var	 High Mean High Var
M111	I-Job	Mean	**.0001**	**.0001**	**.0016**	**.0005**
		Variability	.9716	.9940	.9913	.9932
		Mean x Var	.9999	.9982	1.0000	1.0000
	A-Job	Mean	**.0001**	**.0001**	**.0001**	**.0001**
		Variability	.9645	.9867	.9976	.9687
		Mean x Var	.9998	.9999	1.0000	1.0000
A111	I-Job	Mean	**.0007**	**.0001**	**.0176**	**.0072**
		Variability	.9995	.9610	.9951	.9998
		Mean x Var	.9998	.9997	1.0000	.9999
	A-Job	Mean	**.0001**	**.0001**	**.0001**	**.0002**
		Variability	.3860	.5928	.6534	.8231
		Mean x Var	.9992	.9997	.9993	1.0000
M101	I-Job	Mean	**.0001**	**.0001**	**.0022**	**.0003**
		Variability	.9817	.9987	1.0000	.9959
		Mean x Var	.9998	.9997	1.0000	1.0000
	A-Job	Mean	**.0001**	**.0001**	**.0017**	**.0021**
		Variability	.8984	.7523	.7425	.8709
		Mean x Var	.9890	.9323	1.0000	.9987
A101		Mean	**.0001**	**.0001**	**.0001**	**.0001**
		Variability	.9788	.9917	.9649	.9667
		Mean x Var	.9997	.9982	1.0000	1.0000
M110	I-Job	Mean	**.0001**	**.0001**	**.0001**	**.0001**
		Variability	.6633	.6379	.8886	.8186
		Mean x Var	.9053	.9684	.9798	.9829
	A-Job	Mean	**.0001**	**.0001**	**.0001**	**.0001**
		Variability	.9697	.9888	.9988	.9994
		Mean x Var	.9998	.9994	.9997	1.0000
A110		Mean	**.0001**	**.0001**	**.0001**	**.0001**
		Variability	.9618	.8959	.9993	.9987
		Mean x Var	.9999	1.0000	.9997	.9996

Bold values are significant at the 90% confidence level

TABLE 17

ANOVA RESULTS OF SHOP FLOW VARIABILITY EFFECTS (MODIFIED EXPERIMENT)

		Shop Flow Mean	Environment: Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
M111	I-Jobs	.5xNominal	.9940	.9561	.9885	.9907
		Nominal	.9945	.9901	.9929	.9946
		1.5xNominal	.9754	.9801	.9996	.9970
	A-Jobs	.5xNominal	.9727	.9901	.9972	.9881
		Nominal	.9989	.9816	.9945	.9928
		1.5xNominal	.9757	.9988	.9996	.9833
A111	I-Jobs	.5xNominal	.9857	.9576	.9887	.9916
		Nominal	.9964	.9979	.9997	.9986
		1.5xNominal	.9966	.9791	.9997	.9977
	A-Jobs	.5xNominal	.6340	.8670	.9194	.9355
		Nominal	.7767	.8598	.8742	.9475
		1.5xNominal	.7146	.7939	.8109	.9263
M101	I-Jobs	.5xNominal	.9975	.9967	.9995	.9952
		Nominal	.9781	.9948	.9996	.9989
		1.5xNominal	.9892	.9884	.9982	.9975
	A-Jobs	.5xNominal	.6461	.3359	.8324	.7997
		Nominal	.9717	.9838	.9115	.9777
		1.5xNominal	.9962	.9976	.9435	.9895
A101		.5xNominal	.9387	.9832	.9688	.9832
		Nominal	.9857	.9966	.9771	.9750
		1.5xNominal	.9964	.9645	.9976	.9967
M110	I-Jobs	.5xNominal	.9977	.9982	.9948	.9956
		Nominal	.3602	.5365	.7135	.6754
		1.5xNominal	.9864	.9061	.9990	.9923
	A-Jobs	.5xNominal	.9189	.9589	.9869	.9986
		Nominal	.9997	.9899	.9998	.9976
		1.5xNominal	.9946	.9903	.9874	.9993
A110		.5xNominal	.9119	.9047	.9720	.9709
		Nominal	.9909	.9694	.9995	.9968
		1.5xNominal	.9977	.9759	.9934	.9938

data, so this experiment consists simply of conducting the statistical analyses on these data.

Experiment Results. Although the primary interest in this experiment is to look at the effects of variability, all of the statistics generated for the base case experiment are computed. The tables summarizing pipeline contents are found at Appendix D. The ANOVA results for the effects of mean shop flow time, variability, and their interaction are presented in Table 18. The ANOVA results for the effects of shop flow variability alone are presented in Table 19. The tables are in the same format as those described above for the base case experiment.

Discussion. Concentrating on Table 19 which breaks out the effects of variability over the three levels of mean processing times, there are three cases where significant results are obtained. Variability has a significant effect on shop flow contents for the M110 fuel control, but only when the mean processing time is at its nominal value. When the mean processing time is increased or decreased, variability no longer has a significant effect. Notice also that this is true only for the minor overhaul shop flow (I-Jobs). The second case is for the A111 fuel control, major overhauls (A-Jobs). In this case, variability has a significant effect on shop flow contents but only at the .5xNominal mean processing time. As the mean processing time increases, variability no longer has a significant effect. Notice also that variability is significant for only three of the four different environments at the 90% confidence level. Finally, the third case is for the M101 fuel control, major overhauls. In this case, variability has a significant effect on shop flow contents when the mean processing time is at the .5xNominal level. For each of these cases where variability has a significant effect on shop flow contents, the effect did not extend to the overall pipeline. However, comparing the corresponding tables (Tables 17 and 19) indicates that the effects of shop flow processing time variability were strongest in the overall pipeline at the same points where variability was significant for the shop flow

TABLE 18

ANOVA RESULTS OF SHOP FLOW MEAN AND VARIABILITY EFFECTS (SHOP FLOW CONTENTS)

			Environment			
		Shop Flow	Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
M111	I-Job	Mean	**.0001**	**.0001**	**.0001**	**.0001**
		Variability	.7614	.9538	.7899	.8593
		Mean x Var	.9993	.9966	.9954	.9987
	A-Job	Mean	**.0001**	**.0001**	**.0001**	**.0001**
		Variability	.8496	.9730	.9013	.8309
		Mean x Var	.9993	.9999	1.0000	1.0000
A111	I-Job	Mean	**.0001**	**.0001**	**.0001**	**.0001**
		Variability	.9736	.3714	.6273	.9016
		Mean x Var	.9648	.9918	.9959	.8718
	A-Job	Mean	**.0001**	**.0001**	**.0001**	**.0001**
		Variability	**.0623**	**.0670**	**.0152**	**.0440**
		Mean x Var	.9897	.9790	.9374	.9793
M101	I-Job	Mean	**.0001**	**.0001**	**.0001**	**.0001**
		Variability	.8124	.9629	.9714	.9803
		Mean x Var	.9966	.9970	.9999	.9998
	A-Job	Mean	**.0001**	**.0001**	**.0001**	**.0001**
		Variability	.7037	.4727	.1073	.3676
		Mean x Var	.9318	.6478	.9965	.9533
A101		Mean	**.0001**	**.0001**	**.0001**	**.0001**
		Variability	.9753	.9859	.9268	.9425
		Mean x Var	.9985	.9944	.9999	1.0000
M110	I-Job	Mean	**.0001**	**.0001**	**.0001**	**.0001**
		Variability	.1245	**.0309**	.1262	.1823
		Mean x Var	.2952	.2383	**.0841**	.3101
	A-Job	Mean	**.0001**	**.0001**	**.0001**	**.0001**
		Variability	.9368	.9668	.9972	.9818
		Mean x Var	.9988	.9971	.9930	.9995
A110		Mean	**.0001**	**.0001**	**.0001**	**.0001**
		Variability	.9292	.8472	.9979	.9848
		Mean x Var	.9999	.9999	.9974	.9963

Bold values are significant at the 90% confidence level

TABLE 19

ANOVA RESULTS OF SHOP FLOW VARIABILITY EFFECTS (SHOP FLOW CONTENTS)

		Shop Flow Mean	Environment: Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
M111	I-Jobs	.5xNominal	.6978	.6301	.3344	.5280
		Nominal	.9698	.9924	.9406	.9814
		1.5xNominal	.9022	.9980	.9959	.9897
	A-Jobs	.5xNominal	.6822	.8658	.7644	.6917
		Nominal	.9901	.9784	.9425	.9487
		1.5xNominal	.9455	.9999	.9926	.9561
A111	I-Jobs	.5xNominal	.3570	.1820	.2795	.3353
		Nominal	.9846	.8830	.9609	.9225
		1.5xNominal	.9859	.7285	.9187	.8191
	A-Jobs	.5xNominal	**.0440**	.1430	**.0545**	**.0959**
		Nominal	.4294	.4049	.2454	.3203
		1.5xNominal	.4472	.4114	.2415	.3828
M101	I-Jobs	.5xNominal	.9407	.9907	.9383	.9855
		Nominal	.8434	.9839	.9994	.9960
		1.5xNominal	.9243	.9560	.9848	.9836
	A-Jobs	.5xNominal	**.0347**	**.0078**	**.0221**	**.0176**
		Nominal	.8903	.9747	.4741	.7956
		1.5xNominal	.9935	.9945	.7614	.9631
A101		.5xNominal	.8479	.8993	.8356	.8745
		Nominal	.9686	.9885	.9516	.9680
		1.5xNominal	.9921	.9541	.9970	.9962
M110	I-Jobs	.5xNominal	.9659	.9222	.9248	.9951
		Nominal	**.0005**	**.0001**	**.0001**	**.0011**
		1.5xNominal	.9434	.7769	.9995	.9754
	A-Jobs	.5xNominal	.5920	.8603	.7822	.9143
		Nominal	.9991	.9804	.9980	.9926
		1.5xNominal	.9924	.9666	.9612	.9878
A110		.5xNominal	.8011	.7055	.8138	.7655
		Nominal	.9805	.9473	.9981	.9852
		1.5xNominal	.9941	.9778	.9859	.9870

Bold vaules are significant at the 90% confidence level contents. This seems to confirm the hypothesis that changes in shop flow processing time variability are not sufficient to have a significant effect on pipeline contents.

An important observation not revealed in Table 19 is the direction of change in average shop flow contents as variability changes. Recall that in Table 13 an unpredictable effect in pipeline contents was evident. A close look at Tables 42, 44, and 46 found at Appendix D reveal that in this experiment the general impact is for average shop flow contents to go down as variability is reduced. For the three cases of the A111 fuel control that are significant, Table 42 reveals a downward trend in average shop flow contents as variability is reduced. For the first environment column, average shop flow contents are .333, .343, and .410 corresponding to the three levels of variability: .5xNominal, Nominal, and 1.5xNominal. The same effect is found in Table 44. The exception is one case in Table 46. For the first environment, average shop flow contents are .879, .878, and 1.020 corresponding to the three levels of variability: .5xNominal, Nominal, and 1.5xNominal. Notice that average shop flow contents went up as variability was reduced from the Nominal case to the .5xNominal case. However, the remaining significant cases in this table do show the expected downward trend. Clearly, when variability has a significant impact on average shop flow contents, the general impact is that a reduction in variability results in a reduction in average contents.

Another observation that can be made from this experiment by looking at Table 19 is that for all but one of the fuel controls, the p-value is much lower for the low mean processing time than for the other two levels. Although the p-values do not show a significant effect from variability, they indicate that there is a relationship between the effects of variability and mean processing time. In particular, average shop flow contents are more sensitive to changes in variability as the variance-to-mean ratio goes up. The exception seems to be the M110 fuel control, where the p-values are lowest for the nominal mean processing time.

Chapter Summary

This chapter presented the results from three experiments. The first experiment was the base case experiment described in Chapter III. The results clearly indicate that a reduction in the shop flow mean processing time alone would have a significant effect on the overall pipeline contents. However, the effects of shop flow processing time variability do not prove to be significant. A second experiment was developed by modifying the simulation model to introduce as much variability as possible. This second experiment also fails to show a significant effect from shop flow processing time variability on the overall pipeline contents. At this point, a third experiment using the same modified model was conducted that concentrated on shop flow contents to determine if perhaps variability has a significant effect in the Shop Flow Segment, but the effect does not extend to the overall pipeline contents. This experiment shows a significant effect but only for three of the fuel controls and only at a single level of shop flow mean processing time. However, it was noted that the effects of variability are generally stronger at the lower levels of mean processing time. It was further noted that when variability is significant, the general trend is for average shop flow contents to go down as variability is reduced. With this information, investigative question five can be answered by saying that changes in shop flow mean processing times have a significant impact on pipeline contents, but that changes in its associated variability do not prove to have a significant impact.

VI. *Conclusions and Recommendations*

This chapter reviews the major issues covered in this study. First, the major findings of the literature review are summarized. This is followed by a review of the simulation results and some conclusions. The chapter ends with a few recommendations for further research on this topic.

Literature Review Findings

The literature review established that variability is a natural characteristic of processes that can be controlled. Focusing on the processes of the Depot Level Reparable Item Pipeline, it was further established that these processes exhibit variability. In particular, the Shop Flow Segment of the pipeline is prone to high levels of variability. These facts led to the research question which attempts to determine the relative effects of reducing shop flow process mean and/or its associated variability.

To address the research question, a simulation model of the pipeline was developed. The model is based on a conceptual model presented by Kettner and Wheatley. The model was enhanced by adding the processing characteristics of an Air Force repair shop in detail. The resulting overall model simulates the operation of the pipeline based on the characteristics derived from actual data. The Shop Flow Segment includes resource constraints, a mix of parts and job types, stochastic processing, and machine breakdowns.

Simulation Results

The simulation results clearly indicate that a reduction in shop flow mean processing time will result in a reduction in the number of items tied up in the repair pipeline. This was true over a variety of environmental conditions and for all items and job types modeled.

When reducing shop flow process variability, simulation results do not show a significant effect on overall pipeline contents. Further experimentation showed that for some items and job types, process variability does have an effect, but is limited to the Shop Flow Segment contents.

Conclusions

Based on the repair process and parts modeled, it is clear that in managing the Depot Level Reparable Pipeline a reduction in the Shop Flow Segment mean processing time will result in fewer items in the pipeline. However, at some point further reductions in the mean processing time are no longer feasible. What remains is the variability in the process. The simulation results from this research would seem to indicate that even when all variability is eliminated, the number of items in the pipeline will not change significantly. This conclusion, however, may only extend to the circumstances of the repair process and the parts modeled.

Recommended Future Research

The simulation model developed for this research is a start, but much more can be done. All but one of the pipeline segments are modeled as unconstrained processes represented by a single probability distribution. Clearly the model can be enhanced to more closely represent the processes within each segment to include constraints. A drawback of this approach is that the more complex the simulation model becomes, the more difficult it is to understand the dynamic interaction of various stochastic processes and to isolate the cause-effect relationship of experimental variables. An alternative approach would be to build several simple models that can be analyzed in depth.

Another suggestion is to apply some of the concepts found in the Theory of Constraints to the management of the pipeline. In developing the simulation model, it was evident that only a few of the processes for each flow would really have a constraining effect. In particular, processes with a short duration should not have a significant impact on the overall shop flow when they are positioned in front of another process with a much longer duration. Looking at the effects of variability in these longer processes alone would simplify the simulation effort.

Finally, since the effects of variability in this study do not prove to be highly significant, it would be interesting to purposely pick repair processes that are known to be highly variable for another study. A parallel research effort by Benson and Hession (5) looked at the pipeline processing times from the point of view of statistical process control. A simulation study of the items they found to be out of statistical control might show that variability does have an effect on pipeline contents. Alternatively, such a study could confirm the findings of this research study.

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*************************************************************************
*
*
* FILE       : PIPELINE.GPS
* VERSION    : 2.1
* DATE       : AUGUST 1992
* AUTHOR(S)  : CAPT AROSTEGUI
*            : CAPT LARVICK
*
* BASE TIME: HOURS (8 HOUR DAYS)
*
* DESCRIPTION: Simulation of the Depot Level Reparable Item Pipeline.
* The pipeline is a process of six subprocesses that transforms broken
* parts into serviceable parts.  The six segments are: base processing,
* intransit, supply-to-maintenance, shop flow, serviceable turn-in, and
* order and ship time.  Broken parts (not reparable this station)
* enter the pipeline at bases.  The parts are repaired while in the
* shop flow segment, and are returned to bases in the order and ship
* time segment.  However, the part sent by a base is not necessarily
* the same part received.  A part is sent from depot stocks to a base
* as soon as the base requisitions it (same time as NRTS gen).  If
* a part is not in depot stocks, a backorder is established and
* the part is sent as soon as one is repaired.  The objective of
* this simulation is to look at pipeline contents at various levels
* of process variability within the segments, in particular the shop
* flow segment.
*
*************************************************************************

*=====================================================================
* COMPILER DIRECTIVES AND INITIAL CONTROL STATEMENTS
*

           SIMULATE
           REALLOCATE   COM,500000
           OPERCOL      60

*----- DECLARATIONS SECTION ------------------------------------------

 OUTI      FILE      'PIPELINE.OUTI'          Pipeline contents
 OUTA      FILE      'PIPELINE.OUTA'
 FLW       FILE      'PIPELINE.FLW'           Pipeline flowtimes
 VTMI      FILE      'PIPELINE.VTMI'          Shop flow VTMRs
 VTMA      FILE      'PIPELINE.VTMA'
 SFCI      FILE      'PIPELINE.SFCI'          Shop flow contents
 SFCA      FILE      'PIPELINE.SFCA'
 SFTI      FILE      'PIPELINE.SFTI'          Shop flow time
 SFTA      FILE      'PIPELINE.SFTA'
* TIM      FILE      'PIPELINE.TIM'           Processing times file
 ANVI      FILE      'PIPELINE.ANVI'          Data points for ANOVA
 ANVA      FILE      'PIPELINE.ANVA'
 SFAI      FILE      'PIPELINE.SFAI'          SF data pts for ANOVA
 SFAA      FILE      'PIPELINE.SFAA'          SF data pts for ANOVA
 INP11     FILE      'PLNTRI11.INP'           Triang dist input
 INP12     FILE      'PLNTRI12.INP'
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  INP13       FILE      'PLNTRI13.INP'
  INP21       FILE      'PLNTRI21.INP'
  INP22       FILE      'PLNTRI22.INP'
  INP23       FILE      'PLNTRI23.INP'
  INP24       FILE      'PLNTRI24.INP'
  INP31       FILE      'PLNTRI31.INP'
  INP32       FILE      'PLNTRI32.INP'
  INP33       FILE      'PLNTRI33.INP'
  UNI11       FILE      'PLNUNI11.INP'          Uniform dist input
  UNI12       FILE      'PLNUNI12.INP'
  UNI13       FILE      'PLNUNI13.INP'
  UNI21       FILE      'PLNUNI21.INP'
  UNI22       FILE      'PLNUNI22.INP'
  UNI23       FILE      'PLNUNI23.INP'
  UNI24       FILE      'PLNUNI24.INP'
  UNI31       FILE      'PLNUNI31.INP'
  UNI32       FILE      'PLNUNI32.INP'
  UNI33       FILE      'PLNUNI33.INP'
* PLC1        FILE      'M101.PLC'              Steady state data files
* PLC2        FILE      'M110.PLC'
* PLC3        FILE      'A101.PLC'
* PLC4        FILE      'A110.PLC'
* PLC5        FILE      'M111.PLC'
* PLC6        FILE      'A111.PLC'

              INTEGER   &I,&J,&K,&N,&EM,&EV,&LM,&LV
              INTEGER   &REP,&DAYS,&HRSDAY,&DAYRES,&INTERPLC,&INTERTAB
              INTEGER   &NUMENV,&NUMLEV
              REAL      &NORM,&NORS,&LOGNORM
              REAL      &GAMVAR,&RVGAM1,&RVGAM2,&RVGAM3,&RVGAM4,&RVGAM5
              REAL      &RVGAM6,&RVGAM7,&RVGAM8,&RVGAM9,&RVGAMA
              CHAR*11   &ENVDESC(2),&LEVDESC(4)
              CHAR*20   &MEAS1
              INTEGER   &RINTER
              REAL      &T95

              INTEGER   &NUMPARTS
              CHAR*20   &PARTN(6)
              REAL      &GENRT(6)
              INTEGER   &DEPOT(6)
              REAL      &BASEM(2),&BASES(2)
              REAL      &ITRANM(2),&ITRANS(2)
              REAL      &SUMX1A(4),&SUMX1B(4),&SUMX2A(4),&SUMX2B(4)
              REAL      &SERVTA(4),&SERVTB(4)
              REAL      &OSTA(4),&OSTB(4)

              INTEGER   &LPART
              INTEGER   &PNAME,&PNAME2,&PNAME3
              INTEGER   &UAM100,&UAM111,&UA0858,&UA2407,&UA0676
              INTEGER   &UA0191,&UAA111

              REAL      &DUMMYT

              REAL      &SFNORM1(3),&SFNORM2(3),&SFNORM3(3),&SFNORM4(3)
              REAL      &SFNORM5(3),&SFNORM6(3),&SFNORM7(3)
              REAL      &SFNORS1(4),&SFNORS2(4),&SFNORS3(4),&SFNORS4(4)
              REAL      &SFNORS5(4),&SFNORS6(4),&SFNORS7(4)

              REAL      &TRI01M,&TRI02M,&TRI03M,&TRI04M
              REAL      &TRI05M,&TRI06M,&TRI07M,&TRI08M
              REAL      &TRI09M,&TRI10M,&TRI11M,&TRI12M
              REAL      &TRI13M,&TRI14M,&TRI15M,&TRI16M
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         REAL     &TRI17M,&TRI18M,&TRI19M,&TRI20M
         REAL     &TRI21M,&TRI22M,&TRI23M,&TRI24M
         REAL     &TRI25M,&TRI26M
         REAL     &TRI01L,&TRI01U,&TRI02L,&TRI02U
         REAL     &TRI03L,&TRI03U,&TRI04L,&TRI04U
         REAL     &TRI05L,&TRI05U,&TRI06L,&TRI06U
         REAL     &TRI07L,&TRI07U,&TRI08L,&TRI08U
         REAL     &TRI09L,&TRI09U,&TRI10L,&TRI10U
         REAL     &TRI11L,&TRI11U,&TRI12L,&TRI12U
         REAL     &TRI13L,&TRI13U,&TRI14L,&TRI14U
         REAL     &TRI15L,&TRI15U,&TRI16L,&TRI16U
         REAL     &TRI17L,&TRI17U,&TRI18L,&TRI18U
         REAL     &TRI19L,&TRI19U,&TRI20L,&TRI20U
         REAL     &TRI21L,&TRI21U,&TRI22L,&TRI22U
         REAL     &TRI23L,&TRI23U,&TRI24L,&TRI24U
         REAL     &TRI25L,&TRI25U,&TRI26L,&TRI26U

         REAL     &UNI01A,&UNI01B,&UNI02A,&UNI02B
         REAL     &UNI03A,&UNI03B,&UNI04A,&UNI04B
         REAL     &UNI05A,&UNI05B,&UNI06A,&UNI06B
         REAL     &UNI07A,&UNI07B,&UNI08A,&UNI08B
         REAL     &UNI09A,&UNI09B,&UNI10A,&UNI10B
         REAL     &UNI11A,&UNI11B,&UNI12A,&UNI12B
         REAL     &UNI13A,&UNI13B

*----- ASSIGNMENTS SECTIONS -------------------------------------------

         LET      &REP=30                 Number of replications
         LET      &DAYS=360               Days to run each rep
         LET      &HRSDAY=8               Hours per day
         LET      &DAYRES=100             Day to reset stats
         LET      &INTERPLC=360           Interval days for PLC files
         LET      &INTERTAB=360           Interval days for TABULATEs
         LET      &NUMENV=2               Environment levels
         LET      &ENVDESC(1)='.5xNominal '
         LET      &ENVDESC(2)='1.5xNominal'
         LET      &NUMLEV=3               Shop Flow experimental levels
         LET      &LEVDESC(1)='.5xNomial  '
         LET      &LEVDESC(2)='Nominal    '
         LET      &LEVDESC(3)='1.5xNominal'
         LET      &LEVDESC(4)='4xNominal  '
         LET      &RINTER=1000            Rnd #'s per replication
         LET      &T95=1.96               T-value for 95% C.I.

         LET      &NUMPARTS=6             Number of parts modeled
         LET      &PARTN(1)='PM101            '
         LET      &PARTN(2)='PM110            '
         LET      &PARTN(3)='PA101            '
         LET      &PARTN(4)='PA110            '
         LET      &PARTN(5)='PM111            '
         LET      &PARTN(6)='PA111            '
         LET      &GENRT(1)=18.9*&HRSDAY        Interarrival mean-PM101
         LET      &GENRT(2)=9.6*&HRSDAY         Interarrival mean-PM110
         LET      &GENRT(3)=25.7*&HRSDAY        Interarrival mean-PA101
         LET      &GENRT(4)=11.8*&HRSDAY        Interarrival mean-PA110
         LET      &GENRT(5)=21.8*&HRSDAY        Interarrival mean-PM111
         LET      &GENRT(6)=13.8*&HRSDAY        Interarrival mean-PA111
         LET      &DEPOT(1)=4                   M101 Initial depot stock
         LET      &DEPOT(2)=8                   M110 Initial depot stock
         LET      &DEPOT(3)=17                  A101 Initial depot stock
         LET      &DEPOT(4)=28                  A110 Initial depot stock
         LET      &DEPOT(5)=1                   M111 Initial depot stock
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     LET   &DEPOT(6)=3                 A111 Initial depot stock
     LET   &BASEM(1)=1.6*&HRSDAY       Base processing mean
*    LET   &BASEM(N)=3.1*&HRSDAY
     LET   &BASEM(2)=4.7*&HRSDAY
     LET   &BASES(1)=2.3*&HRSDAY       Base processing std dev
*    LET   &BASES(N)=3.3*&HRSDAY
     LET   &BASES(2)=4*&HRSDAY
     LET   &ITRANM(1)=9.7*&HRSDAY      Intransit time mean
*    LET   &ITRANM(N)=19.4*&HRSDAY
     LET   &ITRANM(2)=29.1*&HRSDAY
     LET   &ITRANS(1)=18.7*&HRSDAY     Intransit std dev
*    LET   &ITRANS(N)=26.4*&HRSDAY
     LET   &ITRANS(2)=32.3*&HRSDAY
     LET   &SUMX1A(1)=.5882            Supply to maint1 mean
     LET   &SUMX1A(2)=.1958
     LET   &SUMX1A(3)=5.2895
     LET   &SUMX1A(4)=1.7647
     LET   &SUMX1B(1)=2.04             Supply to maint1 std dev
     LET   &SUMX1B(2)=6.13
     LET   &SUMX1B(3)=.6806
     LET   &SUMX1B(4)=2.04
     LET   &SUMX2A(1)=.6373            Supply to maint2 mean
     LET   &SUMX2A(2)=.2125
     LET   &SUMX2A(3)=5.7353
     LET   &SUMX2A(4)=1.9118
     LET   &SUMX2B(1)=6.12             Supply to maint2 std dev
     LET   &SUMX2B(2)=18.35
     LET   &SUMX2B(3)=2.04
     LET   &SUMX2B(4)=6.12
     LET   &SERVTA(1)=.8113            Serv Turn-in time mean
     LET   &SERVTA(2)=.2704
     LET   &SERVTA(3)=7.2772
     LET   &SERVTA(4)=2.4338
     LET   &SERVTB(1)=3.02             Serv Turn-in std dev
     LET   &SERVTB(2)=9.06
     LET   &SERVTB(3)=1.01
     LET   &SERVTB(4)=3.02
     LET   &OSTA(1)=.4526              OST-alphas
     LET   &OSTA(2)=.1509
     LET   &OSTA(3)=4.0739
     LET   &OSTA(4)=1.3583
     LET   &OSTB(1)=46.67              OST-betas
     LET   &OSTB(2)=140.01
     LET   &OSTB(3)=15.56
     LET   &OSTB(4)=46.67

     LET   &UAM100=2             Machines Up and Available
     LET   &UAM111=8                          "
     LET   &UA0858=2                          "
     LET   &UA2407=2                          "
     LET   &UA0676=2                          "
     LET   &UA0191=2                          "
     LET   &UAA111=8                          "

     LET   &SFNORM1(1)=62        BENF100S-M101 A Jobs mean
     LET   &SFNORM1(2)=124
     LET   &SFNORM1(3)=186
     LET   &SFNORS1(1)=22.6      BENF100S-M101 A Jobs std dev
     LET   &SFNORS1(2)=32
     LET   &SFNORS1(3)=39.2
     LET   &SFNORS1(4)=64
     LET   &SFNORM2(1)=26        BENF100S-M110 A Jobs mean
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          LET       &SFNORM2(2)=52
          LET       &SFNORM2(3)=78
          LET       &SFNORS2(1)=4.9       BENF100S-M110 A Jobs std dev
          LET       &SFNORS2(2)=7
          LET       &SFNORS2(3)=8.6
          LET       &SFNORS2(4)=14
          LET       &SFNORM3(1)=6         BENP111MN-M111 I Jobs (init)
          LET       &SFNORM3(2)=12
          LET       &SFNORM3(3)=18
          LET       &SFNORS3(1)=2.8       BENP111MN-M111 I Jobs (init)
          LET       &SFNORS3(2)=4
          LET       &SFNORS3(3)=4.9
          LET       &SFNORS3(4)=8
          LET       &SFNORM4(1)=32.5      BENP111MN-M111 A Jobs (init)
          LET       &SFNORM4(2)=65
          LET       &SFNORM4(3)=130
          LET       &SFNORS4(1)=6.4       BENP111MN-M111 A Jobs (init)
          LET       &SFNORS4(2)=9
          LET       &SFNORS4(3)=11
          LET       &SFNORS4(4)=18
          LET       &SFNORM5(1)=1.8       BENF100S-A101/A110 (init)
          LET       &SFNORM5(2)=3.5
          LET       &SFNORM5(3)=5.3
          LET       &SFNORS5(1)=1.6       BENF100S-A101/A110 (init)
          LET       &SFNORS5(2)=2.25
          LET       &SFNORS5(3)=2.8
          LET       &SFNORS5(4)=4.5
          LET       &SFNORM6(1)=1.8       BENF100S-A101/A110 (post)
          LET       &SFNORM6(2)=3.5
          LET       &SFNORM6(3)=5.3
          LET       &SFNORS6(1)=1.6       BENF100S-A101/A110 (post)
          LET       &SFNORS6(2)=2.25
          LET       &SFNORS6(3)=2.8
          LET       &SFNORS6(4)=4.5
          LET       &SFNORM7(1)=.38       BENP111AB-A111 A/I Jobs (init)
          LET       &SFNORM7(2)=.75
          LET       &SFNORM7(3)=1.13
          LET       &SFNORS7(1)=.18       BENP111AB-A111 A/I Jobs (init)
          LET       &SFNORS7(2)=.25
          LET       &SFNORS7(3)=.31
          LET       &SFNORS7(4)=.5

*----- SYNONYMS ------------------------------------------------------

 IJOB     SYN       1              Minor overhaul job
 AJOB     SYN       2              Major overhaul job
 PM101    SYN       1              Main Engine Control (B-1s)
 PM110    SYN       2              Main Engine Control (F-16s)
 PA101    SYN       3              Augmentor (B-1s)
 PA110    SYN       4              Augmentor (F-16s)
 PM111    SYN       5              Main Engine Control (F-111s)
 PA111    SYN       6              After Burner Control (F-111s)
 PMA10    SYN       7              Subassembly for M101
 PMA11    SYN       8              Subassembly for M110
 PAA10    SYN       9              Subassembly for A101
 PAA11    SYN       10             Subassembly for A110
 PAB10    SYN       11             Subassembly for A101
 PAB11    SYN       12             Subaseembly for A110
 PM11A    SYN       13             Subassembly for M111
 PM11B    SYN       14                  "
 PM11C    SYN       15                  "
 PM11D    SYN       16                  "
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PM11E     SYN       17                  "
PM11F     SYN       18                  "
PM11G     SYN       19                  "
PM11H     SYN       20                  "
PM11J     SYN       21                  "
PA11A     SYN       22                  Subassembly for A111
PA11B     SYN       23                  "
PA11C     SYN       24                  "
PA11D     SYN       25                  "
PA11E     SYN       26                  "
PA11F     SYN       27                  "
PA11G     SYN       28                  "
PA11H     SYN       29                  "
PA11J     SYN       30                  "
PA11K     SYN       31                  "
PA11L     SYN       32                  "
PA11M     SYN       33                  "

*----- STORAGE DECLARATION SECTION -------------------------------------

BENF100S  STORAGE   4                   Test stand (A110/A110/M101/M110)
OCM100    STORAGE   2                   Overhaul (M101/M110)
BENP111MN STORAGE   3                   Test stand (M111)
OCM111    STORAGE   8                   Overhaul (M111)
OC0946    STORAGE   1                   Overhaul subassembly (M111/A111)
OC0959    STORAGE   1                   Overhaul subassembly (M111)
OC2547    STORAGE   1                   Overhaul subassembly (M111)
OC0858    STORAGE   2                   Overhaul subassembly (M111)
BENP111AB STORAGE   6                   Test stand (A111)
OC2407    STORAGE   2                   Overhaul subassembly (A111)
OC0676    STORAGE   2                   Overhaul subassembly (A111)
OC0849    STORAGE   1                   Overhaul subassembly (A111)
OC0944    STORAGE   1                   Overhaul subassembly (A111)
OC0848    STORAGE   1                   Overhaul subassembly (A111)
OC0191    STORAGE   2                   Overhaul subassembly (A111)
OC2553    STORAGE   1                   Overhaul subassembly (A111)
OC4570    STORAGE   1                   Overhaul subassembly (A111)
OCA111    STORAGE   8                   Overhaul (A111)
OC5530    STORAGE   1                   Overhaul (A101/A110)

PC1       STORAGE   5                   Transport to/from location
PC2       STORAGE   5                   "
PC3       STORAGE   5                   "
PC4       STORAGE   2                   "
PC5       STORAGE   3                   "
PC6       STORAGE   11                  "
PC7       STORAGE   6                   "
PC8       STORAGE   11                  "
PC10      STORAGE   4                   "
PC11      STORAGE   15                  "
PC12      STORAGE   15                  "
PC13      STORAGE   15                  "
PC14      STORAGE   8                   "
PC15      STORAGE   10                  "
PC16      STORAGE   10                  "
PC17      STORAGE   11                  "
PC18      STORAGE   20                  "
PC19      STORAGE   11                  "
PC20      STORAGE   7                   "
PC21      STORAGE   7                   "
PC22      STORAGE   7                   "
PC23      STORAGE   4                   "
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 REPMAN      STORAGE    2                 Repair personnel

*----- FUNCTION DECLARATION SECTION -----------------------------------

 PIPE        FUNCTION PF(PART),E6                Assigning pipeline queues
PM101,FN(PIPE1)/PM110,FN(PIPE2)/PA101,FN(PIPE3)/_
PA110,FN(PIPE4)/PM111,FN(PIPE5)/PA111,FN(PIPE6)

 PIPE1       FUNCTION PF(JOBTYPE),S2,Q
IJOB,PM101QI/AJOB,PM101QA

 PIPE2       FUNCTION PF(JOBTYPE),S2,Q
IJOB,PM110QI/AJOB,PM110QA

 PIPE3       FUNCTION PF(JOBTYPE),S2,Q
IJOB,PA101QI/AJOB,PA101QA

 PIPE4       FUNCTION PF(JOBTYPE),S2,Q
IJOB,PA110QI/AJOB,PA110QA

 PIPE5       FUNCTION PF(JOBTYPE),S2,Q
IJOB,PM111QI/AJOB,PM111QA

 PIPE6       FUNCTION PF(JOBTYPE),S2,Q
IJOB,PA111QI/AJOB,PA111QA

 SFQ         FUNCTION PF(PART),E6                Assigning pipeline queues
PM101,FN(SFQ1)/PM110,FN(SFQ2)/PA101,FN(SFQ3)/_
PA110,FN(SFQ4)/PM111,FN(SFQ5)/PA111,FN(SFQ6)

 SFQ1        FUNCTION PF(JOBTYPE),S2,Q
IJOB,PM101SQI/AJOB,PM101SQA

 SFQ2        FUNCTION PF(JOBTYPE),S2,Q
IJOB,PM110SQI/AJOB,PM110SQA

 SFQ3        FUNCTION PF(JOBTYPE),S2,Q
IJOB,PA101SQI/AJOB,PA101SQA

 SFQ4        FUNCTION PF(JOBTYPE),S2,Q
IJOB,PA110SQI/AJOB,PA110SQA

 SFQ5        FUNCTION PF(JOBTYPE),S2,Q
IJOB,PM111SQI/AJOB,PM111SQA

 SFQ6        FUNCTION PF(JOBTYPE),S2,Q
IJOB,PA111SQI/AJOB,PA111SQA

 VTMR        FUNCTION PF(PART),E6
PM101,FN(VTMR1)/PM110,FN(VTMR2)/PA101,FN(VTMR3)/_
PA110,FN(VTMR4)/PM111,FN(VTMR5)/PA111,FN(VTMR6)

 VTMR1       FUNCTION PF(JOBTYPE),S2,T
IJOB,VM101I/AJOB,VM101A

 VTMR2       FUNCTION PF(JOBTYPE),S2,T
IJOB,VM110I/AJOB,VM110A

 VTMR3       FUNCTION PF(JOBTYPE),S2,T
IJOB,VA101I/AJOB,VA101A
```

```
 VTMR4      FUNCTION PF(JOBTYPE),S2,T
IJOB,VA110I/AJOB,VA110A

 VTMR5      FUNCTION PF(JOBTYPE),S2,T
IJOB,VM111I/AJOB,VM111A

 VTMR6      FUNCTION PF(JOBTYPE),S2,T
IJOB,VA111I/AJOB,VA111A


***** SHOP FLOW FUNCTIONS - ASSIGN JOB TYPE ---------------------------

 JOB100     FUNCTION PF(PART),E2              Assign jobtype based on
PM101,FN(JOB101)/PM110,FN(JOB110)          .   part type (M101/M110)

 JOB101     FUNCTION RN20,D2                  Assign jobtype for M101
.2,AJOB/1,IJOB

 JOB110     FUNCTION RN20,D2                  Assign jobtype for M110
.15,AJOB/1,IJOB

 JOB111     FUNCTION PF(PART),E2              Assign job type for M111/A111
PM111,FN(JOBM111)/PA111,FN(JOBA111)

 JOBM111 FUNCTION   RN20,D2                   Assign job type for M111
.39,AJOB/1,IJOB

 JOBA111 FUNCTION   RN20,D2                   Assign job type for A111
.57,AJOB/1,IJOB

***** SHOP FLOW FUNCTIONS - BENCH TESTING ----------------------------

 INSPCT     FUNCTION 0,E1              MACF100S inspection
0,&UNI07A+(FRN9*(&UNI07B-&UNI07A))

 TRAN1      FUNCTION 0,E1
0,&UNI08A+(FRN9*(&UNI08B-&UNI08A))

 TRAN2      FUNCTION 0,E1
0,&UNI09A+(FRN9*(&UNI09B-&UNI09A))

 BT100      FUNCTION PF(PART),E2              Assign initial bench test time
PM101,FN(JT101)/PM110,FN(JT110)                      based on part for
BENF100S

 JT101      FUNCTION PF(JOBTYPE),E2           BENF100S initial bench test
time
IJOB,RVTRI(19,&TRI01L,&TRI01M,&TRI01U)/_      for M101 based on job type
AJOB,RVNORM(19,&SFNORM1(&LM),&SFNORS1(&LV))

 JT110      FUNCTION PF(JOBTYPE),E2           BENF100S initial bench test
time
IJOB,RVTRI(19,&TRI02L,&TRI02M,&TRI02U)/_      for M110 based on job type
AJOB,RVNORM(19,&SFNORM2(&LM),&SFNORS2(&LV))

 BENTME     FUNCTION 0,E1                     BENF100S post-repair
0,&UNI01A+(FRN19*(&UNI01B-&UNI01A))            bench test time

 BTM111     FUNCTION PF(JOBTYPE),E2           BENP111MN initial bench test
IJOB,ABS(RVNORM(15,&SFNORM3(&LM),&SFNORS3(&LV)))/_   for M111
AJOB,ABS(RVNORM(15,&SFNORM4(&LM),&SFNORS4(&LV)))
```

```
 BTM111B FUNCTION   0,E1                        BENP111MN post-repair bench
0,&UNI02A+(FRN15*(&UNI02B-&UNI02A))               test for M111

 BTA111    FUNCTION 0,E1                        BENP111AB initial bench test
0,&UNI03A+(FRN13*(&UNI03B-&UNI03A))               for A111

 BTA111B FUNCTION   0,E1                        BENP111AB post-repair bench
0,&UNI04A+(FRN13*(&UNI04B-&UNI04A))               test for A111

***** SHOP FLOW FUNCTIONS - OVERHAUL PROCESSES ------------------------

 OC100 FUNCTION      PF(PART),E4                Assign repair time for
PM101,FN(OC101)/PM110,FN(OC110)/_                 OCM100 overhaul (M101/M110/
PMA10,1+FN(OCMA1)+FN(OCMA2)/_                     MA10/MA11)
PMA11,1+FN(OCMA1)+FN(OCMA2)

 OC101     FUNCTION PF(JOBTYPE),E2              Repair time for M101
IJOB,RVTRI(18,&TRI03L,&TRI03M,&TRI03U)/_
AJOB,RVTRI(18,&TRI04L,&TRI04M,&TRI04U)

 OC110     FUNCTION PF(JOBTYPE),E2              Repair time for M110
IJOB,RVTRI(18,&TRI05L,&TRI05M,&TRI05U)/_
AJOB,RVTRI(18,&TRI06L,&TRI06M,&TRI06U)

 OCMA1     FUNCTION 0,E1                        Repair time for ma10
0,&UNI05A+(FRN18*(&UNI05B-&UNI05A))               and ma11 (part 1)

 OCMA2     FUNCTION 0,E1                        Process time for ma10
0,&UNI06A+(FRN18*(&UNI06B-&UNI06A))               and ma11 (part 2)

 OC5530    FUNCTION PF(PART),E4                 Assign repair time for
PA101,RVTRI(16,&TRI07L,&TRI07M,&TRI07U)           OC5530 overhaul (A101/A110/
PA110,RVTRI(16,&TRI08L,&TRI08M,&TRI08U)           AA10/AA11)
PAA10,RVTRI(16,&TRI09L,&TRI09M,&TRI09U)
PAA11,RVTRI(16,&TRI10L,&TRI10M,&TRI10U)

 OC46TM    FUNCTION PF(PART),E2         OC0946 subassembly overhaul time
PM11A,FN(OC46A)/PM11C,FN(OC46B)                        (M11A/M11C)

 OC46A     FUNCTION 0,E1                OC946 subassembly overhaul time
0,&UNI10A+(FRN14*(&UNI10B-&UNI10A))             (M11A)

 OC46B     FUNCTION 0,E1                OC0946 subassembly overhaul time
0,&UNI11A+(FRN14*(&UNI11B-&UNI11A))             (M11C)

 OC59TM    FUNCTION 0,E1                OC0959 subassembly overhaul time
0,&UNI12A+(FRN14*(&UNI12B-&UNI12A))             (PM11A,PM11C)

 OC47TM    FUNCTION 0,E1                OC2547 subassembly overhaul time
0,&UNI13A+(FRN14*(&UNI13B-&UNI13A))             (PM11G)

 OC49TM    FUNCTION PF(PART),E3         OC0849 subassembly overhaul time
PA11C,RVTRI(13,&TRI11L,&TRI11M,&TRI11U)/_       (A11C/A11D/A11M)
PA11D,RVTRI(13,&TRI12L,&TRI12M,&TRI12U)/_
PA11M,RVTRI(13,&TRI13L,&TRI13M,&TRI13U)

 OC48TM    FUNCTION PF(PART),E2         OC0848 subassembly overhaul time
PA11F,RVTRI(13,&TRI14L,&TRI14M,&TRI14U)/_       (A11F/A11H)
PA11H,RVTRI(13,&TRI15L,&TRI15M,&TRI15U)

***** SHOP FLOW FUNCTIONS - NAME ASSG, ROUTING, CHAIN SEL -------------
```

```
 SUB100     FUNCTION PF(PART),D4            Assign subassembly name after
PM101,PMA10/PM110,PMA11/PA101,PAA10/PA110,PAA11   disa of
M101/M110/A101/A110

 DISM111 FUNCTION   PF(PART),S10,X          Routes M111 subassemblies
PM111,BT111/PM11A,OC946/PM11B,OC959/_                to their overhaul
machine
PM11C,OC946/PM11D,OC959/PM11E,OC858/_                after disassembly
PM11F,OC959/PM11G,OC547/PM11H,OC959/PM11J,OC959

 DISA111 FUNCTION   PF(PART),S12,X          Routes A111 subassemblies
PA11A,OC407/PA11B,OC676/PA11C,OC849/_                to their overhaul
machine
PA11D,OC849/PA11E,OC944/PA11F,OC848/_                after disassembly
PA11G,OC191/PA11H,OC848/PA11J,OC553/_
PA11K,OC570/PA11L,OC946A/PA11M,OC849

 SUBCH      FUNCTION PF(PART),S19,C         Subassembly chains
PM11A,PM11ACH/PM11B,PM11BCH/PM11C,PM11CCH/PM11D,PM11DCH/PM11E,PM11ECH/_
PM11F,PM11FCH/PM11G,PM11GCH/PM11H,PM11HCH/PM11J,PM11JCH/PA11B,PA11BCH/_
PA11C,PA11CCH/PA11D,PA11DCH/PA11E,PA11ECH/PA11F,PA11FCH/PA11H,PA11HCH/_
PA11J,PA11JCH/PA11K,PA11KCH/PA11L,PA11LCH/PA11M,PA11MCH

***** SHOP FLOW FUNCTIONS - MACHINE BREAKDOWN REPAIR TIMES ------------

 MRF100     FUNCTION RN12,C7
0,0/.027,.5/.351,1.5/.702,2.5/.864,3.5/.972,4.5/1,6.5

 MRM111     FUNCTION RN12,C7
0,0/.011,.5/.397,1.5/.806,2.5/.885,3.5/.976,4.5/1,8.5

 A111MR     FUNCTION RN12,C7
0,0/.011,.5/.392,1.5/.773,2.5/.892,3.5/.963,4.5/1,8.5

 A100MR     FUNCTION RN12,C5
0,.5/.237,1.5/.899,2.5/.949,3.5/1,4.5

 MRM11S     FUNCTION RN12,C6
0,.5/.197,1.5/.731,2.5/.928,3.5/.986,4.5/1,6.5

 A11SMR     FUNCTION RN12,C7
0,0/.013,.5/.473,1.5/.854,2.5/.919,3.5/.971,4.5/1,6.5

 A11AMR     FUNCTION RN12,C5
0,.5/.475,1.5/.865,2.5/.926,3.5/1,4.5

*----- TABLE DECLARATION SECTION --------------------------------------

 PM101A     TABLE     QA(PM101QA),0,10,12         M101 Pipeline contents
 PM110A     TABLE     QA(PM110QA),0,10,12         M110 Pipeline contents
 PA101A     TABLE     QA(PA101QA),0,10,12         A101 Pipeline contents
 PA110A     TABLE     QA(PA110QA),0,10,12         A110 Pipeline contents
 PM111A     TABLE     QA(PM111QA),0,10,12         M111 Pipeline contents
 PA111A     TABLE     QA(PA111QA),0,10,12         A111 Pipeline contents

 PM101I     TABLE     QA(PM101QI),0,10,12         M101 Pipeline contents
 PM110I     TABLE     QA(PM110QI),0,10,12         M110 Pipeline contents
 PA101I     TABLE     QA(PA101QI),0,10,12         A101 Pipeline contents
 PA110I     TABLE     QA(PA110QI),0,10,12         A110 Pipeline contents
 PM111I     TABLE     QA(PM111QI),0,10,12         M111 Pipeline contents
 PA111I     TABLE     QA(PA111QI),0,10,12         A111 Pipeline contents
```

```
BM101I     TABLE    QA(PM101SQI),0,10,12          M101 Shop flow contents
BM110I     TABLE    QA(PM110SQI),0,10,12          M110 Shop flow
BA101I     TABLE    QA(PA101SQI),0,10,12          A101 Shop flow
BA110I     TABLE    QA(PA110SQI),0,10,12          A110 Shop flow
BM111I     TABLE    QA(PM111SQI),0,10,12          M111 Shop flow
BA111I     TABLE    QA(PA111SQI),0,10,12          A111 Shop flow

BM101A     TABLE    QA(PM101SQA),0,10,12          M101 Shop flow contents
BM110A     TABLE    QA(PM110SQA),0,10,12          M110 Shop flow
BA101A     TABLE    QA(PA101SQA),0,10,12          A101 Shop flow
BA110A     TABLE    QA(PA110SQA),0,10,12          A110 Shop flow
BM111A     TABLE    QA(PM111SQA),0,10,12          M111 Shop flow
BA111A     TABLE    QA(PA111SQA),0,10,12          A111 Shop flow

VM101I     TABLE    M1,0,10,12                    Shop flow time
VM110I     TABLE    M1,0,10,12
VA101I     TABLE    M1,0,10,12
VA110I     TABLE    M1,0,10,12
VM111I     TABLE    M1,0,10,12
VA111I     TABLE    M1,0,10,12

VM101A     TABLE    M1,0,10,12
VM110A     TABLE    M1,0,10,12
VA101A     TABLE    M1,0,10,12
VA110A     TABLE    M1,0,10,12
VM111A     TABLE    M1,0,10,12
VA111A     TABLE    M1,0,10,12

TM101I     TABLE    TB(VM101I),0,10,12     M101 Shop flow time
TM110I     TABLE    TB(VM110I),0,10,12     M110 Shop flow
TA101I     TABLE    TB(VA101I),0,10,12     A101 Shop flow
TA110I     TABLE    TB(VA110I),0,10,12     A110 Shop flow
TM111I     TABLE    TB(VM111I),0,10,12     M111 Shop flow
TA111I     TABLE    TB(VA111I),0,10,12     A111 Shop flow

TM101A     TABLE    TB(VM101A),0,10,12     M101 Shop flow time
TM110A     TABLE    TB(VM110A),0,10,12     M110 Shop flow
TA101A     TABLE    TB(VA101A),0,10,12     A101 Shop flow
TA110A     TABLE    TB(VA110A),0,10,12     A110 Shop flow
TM111A     TABLE    TB(VM111A),0,10,12     M111 Shop flow
TA111A     TABLE    TB(VA111A),0,10,12     A111 Shop flow

RM101I     TABLE    TD(VM101I)*TD(VM101I)/TB(VM101I),0,10,12 VTMR of SF
RM110I     TABLE    TD(VM110I)*TD(VM110I)/TB(VM110I),0,10,12
RA101I     TABLE    TD(VA101I)*TD(VA101I)/TB(VA101I),0,10,12
RA110I     TABLE    TD(VA110I)*TD(VA110I)/TB(VA110I),0,10,12
RM111I     TABLE    TD(VM111I)*TD(VM111I)/TB(VM111I),0,10,12
RA111I     TABLE    TD(VA111I)*TD(VA111I)/TB(VA111I),0,10,12

RM101A     TABLE    TD(VM101A)*TD(VM101A)/TB(VM101A),0,10,12 VTMR of SF
RM110A     TABLE    TD(VM110A)*TD(VM110A)/TB(VM110A),0,10,12
RA101A     TABLE    0,0,10,12
RA110A     TABLE    0,0,10,12
RM111A     TABLE    TD(VM111A)*TD(VM111A)/TB(VM111A),0,10,12
RA111A     TABLE    TD(VA111A)*TD(VA111A)/TB(VA111A),0,10,12

*----- MACRO DECLARATION SECTION ---------------------------------------

* The LOGN macro generates a lognormal random variable.  It takes three
* parameters:
*                    #A   The random number stream
```

```
*                    #B   The distribution mean
*                    #C   The distribution standard deviation
* It returns a lognormal variable in the &LOGNORM ampervariable.

 LOGN       STARTMACRO

            BLET       &NORM=LOG((#B*#B)/SQRT(#C*#C+#B*#B))
            BLET       &NORS=SQRT(LOG((#C*#C+#B*#B)/(#B*#B)))
            BLET       &LOGNORM=EXP(RVNORM(#A,&NORM,&NORS))

            ENDMACRO

* The GAMRVG is a gamma random variable generator provided by Wolverine
* Software.
* Use:                 GAMRVG   MACRO a,b,c
* Where:               a = random number stream (integer)
*                      b = shape parameter, alpha (real)
*                      c = scale parameter, beta (real)
* Value is plac-d in: &GAMVAR

 GAMRVG     STARTMACRO

            BLET       &RVGAM1=FRN(#A)
            BLET       &RVGAM2=FRN(#A)
            TEST LE    #B,1.0,*+13
            TEST E     #B,1.0,*+3
*
* for alpha = 1 use Exponential
*
            BLET       &RVGAM9=RVEXPO(#A,1)
            TRANSFER,*+19
*
* for 0 < alpha < 1
*
            BLET       &RVGAM4=(EXP(1)+#B)/EXP(1)
            BLET       &RVGAM5=&RVGAM4*&RVGAM1
            TEST LE    &RVGAM5,1,*+4
            BLET       &RVGAM9=EXP((1/#B)*LOG(&RVGAM5))
            TEST LE    LOG(&RVGAM2),-1*&RVGAM9,*-10
            TRANSFER,*+13
            BLET       &RVGAM9=-1*LOG((&RVGAM4-&RVGAM5)/#B)
            TEST LE    LOG(&RVGAM2),(#B-1)*LOG(&RVGAM9),*-13
            TRANSFER,*+10
*
* for alpha > 1
*
            BLET       &RVGAM3=1/SQRT(2*#B-1)
            BLET       &RVGAM4=#B-LOG(4)
            BLET       &RVGAM8=#B+1/&RVGAM3
            BLET       &RVGAM6=&RVGAM3*LOG(&RVGAM1/(1-&RVGAM1))
            BLET       &RVGAM9=#B*EXP(&RVGAM6)
            BLET       &RVGAMA=&RVGAM1*&RVGAM1*&RVGAM2
            BLET       &RVGAM7=&RVGAM4+&RVGAM8*&RVGAM6-&RVGAM9
            TEST L     &RVGAM7+(1+LOG(4.5))-4.5*&RVGAMA,0,*+2
            TEST GE    &RVGAM7,LOG(&RVGAMA),*-23
*
* put result into &GAMVAR
*
            BLET       &GAMVAR=#C*&RVGAM9

            ENDMACRO
```

```
* The following macro is used to read the triangular distributio values
* for the appropriate experimental levels.  The single macro parameter
* refers to the logical file to read.

 TRIINP     STARTMACRO

            GETLIST FILE=#A,(&TRI01L,&TRI01M,&TRI01U,_
                     &TRI02L,&TRI02M,&TRI02U,&TRI03L,&TRI03M,&TRI03U,_
                     &TRI04L,&TRI04M,&TRI04U,&TRI05L,&TRI05M,&TRI05U,_
                     &TRI06L,&TRI06M,&TRI06U,&TRI07L,&TRI07M,&TRI07U,_
                     &TRI08L,&TRI08M,&TRI08U,&TRI09L,&TRI09M,&TRI09U,_
                     &TRI10L,&TRI10M,&TRI10U,&TRI11L,&TRI11M,&TRI11U,_
                     &TRI12L,&TRI12M,&TRI12U,&TRI13L,&TRI13M,&TRI13U,_
                     &TRI14L,&TRI14M,&TRI14U,&TRI15L,&TRI15M,&TRI15U,_
                     &TRI16L,&TRI16M,&TRI16U,&TRI17L,&TRI17M,&TRI17U,_
                     &TRI18L,&TRI18M,&TRI18U,&TRI19L,&TRI19M,&TRI19U,_
                     &TRI20L,&TRI20M,&TRI20U,&TRI21L,&TRI21M,&TRI21U,_
                     &TRI22L,&TRI22M,&TRI22U,&TRI23L,&TRI23M,&TRI23U,_
                     &TRI24L,&TRI24M,&TRI24U,&TRI25L,&TRI25M,&TRI25U,_
                     &TRI26L,&TRI26M,&TRI26U)

            ENDMACRO

* The next macro is used to read the uniform distribution parameters
* according to the current experimental levels.  The single macro
* parameter refers to the logical file name.

 UNIINP     STARTMACRO

            GETLIST FILE=#A,(&UNI01A,&UNI01B,&UNI02A,&UNI02B,_
                     &UNI03A,&UNI03B,&UNI04A,&UNI04B,&UNI05A,&UNI05B,_
                     &UNI06A,&UNI06B,&UNI07A,&UNI07B,&UNI08A,&UNI08B,_
                     &UNI09A,&UNI09B,&UNI10A,&UNI10B,&UNI11A,&UNI11B,_
                     &UNI12A,&UNI12B,&UNI13A,&UNI13B)

            ENDMACRO

*=======================================================================
* MODEL BLOCK STATEMENTS
*
*----- INITIAL CONDITIONS ----------------------------------------------
* These generations are created as initial stock of each item modeled
* that is available at the depot for immediate distribution.  The number
* was seletected to avoid backorders resulting from the initial empty
state
* of the pipeline.  An alternative would be to interspace these items
* throughout the pipeline.

            GENERATE  0,,,&DEPOT(PM101),,2PF,2PL Start with some in stock
            ASSIGN    PART,PM101,PF              M101
            ASSIGN    JOBTYPE,FN(JOB100),PF
            TRANSFER  ,STOCK

            GENERATE  0,,,&DEPOT(PM110),,2PF,2PL Start with some in stock
            ASSIGN    PART,PM110,PF              M110
            ASSIGN    JOBTYPE,FN(JOB100),PF
            TRANSFER  ,STOCK

            GENERATE  0,,,&DEPOT(PA101),,2PF,2PL Start with some in stock
            ASSIGN    PART,PA101,PF              A101
            ASSIGN    JOBTYPE,IJOB,PF
            TRANSFER  ,STOCK
```

```
          GENERATE  0,,,&DEPOT(PA110),,2PF,2PL Start with some in stock
          ASSIGN    PART,PA110,PF              A110
          ASSIGN    JOBTYPE,IJOB,PF
          TRANSFER  ,STOCK

          GENERATE  0,,,&DEPOT(PM111),,2PF,2PL Start with some in stock
          ASSIGN    PART,PM111,PF              M111
          ASSIGN    JOBTYPE,FN(JOB111),PF
          TRANSFER  ,STOCK

          GENERATE  0,,,&DEPOT(PA111),,2PF,2PL Start with some in stock
          ASSIGN    PART,PA111,PF              A111
          ASSIGN    JOBTYPE,FN(JOB111),PF
          TRANSFER  ,STOCK

*----- NRTS GENERATIONS ---------------------------------------------

          GENERATE  RVEXPO(1,&GENRT(PM101)),,,,,2PF,2PL    Poisson
          ASSIGN    PART,PM101,PF        M101
          ASSIGN    JOBTYPE,FN(JOB101),PF
          TRANSFER  ,STARTQ

          GENERATE  RVEXPO(2,&GENRT(PM110)),,,,,2PF,2PL    Poisson
          ASSIGN    PART,PM110,PF        M110
          ASSIGN    JOBTYPE,FN(JOB101),PF
          TRANSFER  ,STARTQ

          GENERATE  RVEXPO(3,&GENRT(PA101)),,,,,2PF,2PL    Poisson
          ASSIGN    PART,PA101,PF        A101
          ASSIGN    JOBTYPE,IJOB,PF
          TRANSFER  ,STARTQ

          GENERATE  RVEXPO(4,&GENRT(PA110)),,,,,2PF,2PL    Poisson
          ASSIGN    PART,PA110,PF        A110
          ASSIGN    JOBTYPE,IJOB,PF
          TRANSFER,STARTQ

          GENERATE  RVEXPO(5,&GENRT(PM111)),,,,,2PF,2PL    Poisson
          ASSIGN    PART,PM111,PF        M111
          ASSIGN    JOBTYPE,FN(JOB111),PF
          TRANSFER  ,STARTQ

          GENERATE  RVEXPO(6,&GENRT(PA111)),,,,,2PF,2PL    Poisson
          ASSIGN    PART,PA111,PF        A111
          ASSIGN    JOBTYPE,FN(JOB111),PF
          TRANSFER  ,STARTQ

*----- BASE PROCESSING SEGMENT --------------------------------------
* For each item that enters the pipeline, a copy is created at the SPLIT
* block to represent a requisition for a replacement.  The parent item
* continues down the pipeline, while the child is sent to the Order
* and Ship Time segment.

 STARTQ   QUEUE     FN(PIPE)                   Enter pipeline queue
          SPLIT     1,REQ                      Send requisition

 LOGN     MACRO     5,&BASEM(&EM),&BASES(&EV)
*         BPUTPIC   FILE=TIM,PICTURE=TIMDL,    Write travel time data
*                   (&EM,&EV,&LM,&LV,&I,'BP',PF(PART),&LOGNORM)
```

```
BASE      ADVANCE   &LOGNORM                          Lognormal flow

*----- INTRANSIT ITEM SEGMENT ----------------------------------------

LOGN      MACRO     6,&ITRANM(&EM),&ITRANS(&EV)
*         BPUTPIC   FILE=TIM,PICTURE=TIMDL,     Write travel time data
*                   (&EM,&EV,&LM,&LV,&I,'ITT,PF(PART),&LOGNORM)
INTRA     ADVANCE   &LOGNORM                          Lognormal flow

*----- SUPPLY TO MAINTENANCE SEGMENT 1 -------------------------------

GAMRVG    MACRO     7,&SUMX1A(2*(&EM-1)+&EV),&SUMX1B(2*(&EM-1)+&EV)
*         BPUTPIC   FILE=TIM,PICTURE=TIMDL,     Write travel time data
*                   (&EM,&EV,&LM,&LV,&I,'S1T,PF(PART),&GAMVAR)
SUMX1     ADVANCE   &GAMVAR                           Gamma ditributed flow

*----- SUPPLY TO MAINTENANCE SEGMENT 2 -------------------------------

GAMRVG    MACRO     8,&SUMX2A(2*(&EM-1)+&EV),&SUMX2B(2*(&EM-1)+&EV)
*         BPUTPIC   FILE=TIM,PICTURE=TIMDL,     Write travel time data
*                   (&EM,&EV,&LM,&LV,&I,'S2T,PF(PART),&GAMVAR)
SUMX2     ADVANCE   &GAMVAR                           Gamma distributed flow

*----- SHOP FLOW SEGMENT ---------------------------------------------

          MARK
          QUEUE     FN(SFQ)                     Enter shop flow queue
          TEST NE   PF(PART),PM101,CONT0
          TEST NE   PF(PART),PM110,CONT0
          TEST NE   PF(PART),PA101,CONT9
          TEST NE   PF(PART),PA110,CONT9
          TEST NE   PF(PART),PM111,CONT19
          TEST NE   PF(PART),PA111,CONT28
ERR0      TERMINATE 0                     ERROR IF REACHED

**----- M101/M110 FLOW -----------------------------------------------

CONT0     SEIZE     MACF100                     Unpacking, inspect
          ADVANCE   FN(INSPCT)                        Hours
          RELEASE   MACF100

          ENTER     PC2
          ADVANCE   FN(TRAN1)
          LEAVE     PC2

          ENTER     BENF100S                    Bench test
CONT0A    BLET      &DUMMYT=FN(BT100)
          TEST G    &DUMMYT,0,CONT0A
          ADVANCE   &DUMMYT
          LEAVE     BENF100S

          TEST E    PF(JOBTYPE),AJOB,CONT2
          SPLIT     1,CONT1C                    Disassemble
          TRANSFER  ,CONT2
CONT1C    ASSIGN    PART,FN(SUB100),PF          Name subassembly

CONT2     ENTER     PC4                         Transport and processes
          ADVANCE   FN(TRAN2)
          LEAVE     PC4

          ENTER     PC7                         Transport/process cont.
          ADVANCE   FN(TRAN2)
```

```
          LEAVE     PC7

          TEST G    &UAM100,0             Machine available?
          ENTER     OCM100                Overhaul/repair process
          BLET      &UAM100=&UAM100-1     Machine in use
          TEST NE   PF(PART),&LPART,CONT3       Tracking for setup
*         ADVANCE   4                     Setup time

CONT3     ADVANCE   FN(OC100)             Repair time

          BLET      &LPART=PF(PART)       Tracking for setup
          LEAVE     OCM100
          BLET      &UAM100=&UAM100+1     Machine available

          ENTER     PC13                  Transport and processes
          ADVANCE   FN(TRAN2)
          LEAVE     PC13

          ENTER     PC16                  Transport/processes cont.
          ADVANCE   FN(TRAN2)
          LEAVE     PC16

          ENTER     PC15                  Transport/processes cont.
          ADVANCE   FN(TRAN2)
          LEAVE     PC15

          ENTER     PC14                  Transport/processes cont.
          ADVANCE   FN(TRAN2)
          LEAVE     PC14

          ENTER     PC18                  Transport/processes cont.
          ADVANCE   FN(TRAN2)
          LEAVE     PC18

          ENTER     PC20                  Transport/processes cont.
          ADVANCE   FN(TRAN2)
          LEAVE     PC20

          TEST E    PF(PART),PM101,CONT4        Test to assemble M101 to
          TEST E    PF(JOBTYPE),AJOB,CONT5        ma10 if it's an A job
          TEST G    CH(MA10CHAIN),0
          UNLINK    MA10CHAIN,TERM,1
          TRANSFER  ,CONT5

CONT4     TEST E    PF(PART),PM110,CONT4A       Test to assemble M110 to
          TEST E    PF(JOBTYPE),AJOB,CONT5        ma11 if it's an A job
          TEST G    CH(MA11CHAIN),0
          UNLINK    MA11CHAIN,TERM,1
          TRANSFER  ,CONT5

CONT4A    TEST E    PF(PART),PMA10,CONT4B
          LINK      MA10CHAIN,FIFO
CONT4B    LINK      MA11CHAIN,FIFO

CONT5     ENTER     BENF100S              Bench test
          ADVANCE   FN(BENTME)
          LEAVE     BENF100S

          ENTER     PC22                  Transport/processes
          ADVANCE   FN(TRAN2)
          LEAVE     PC22
          TRANSFER  ,EXSF
```

```
*----- A101/A110 FLOW -----------------------------------------------

CONT9      SEIZE     MACF100                  Uncrate and inspect
           ADVANCE   FN(INSPCT)
           RELEASE   MACF100

           ENTER     PC2                      Assign job type
           ADVANCE   FN(TRAN1)
           LEAVE     PC2

           ENTER     BENF100S                 Bench test
CONT9A     BLET      &DUMMYT=RVNORM(19,&SFNORM5(&LM),&SFNORS5(&LV))
           TEST G    &DUMMYT,0,CONT9A
           ADVANCE   &DUMMYT
           LEAVE     BENF100S

           ADVANCE   RVTRI(17,&TRI16L,&TRI16M,&TRI16U) Augbuf Delay
           SPLIT     1,CONT9B
           TRANSFER  ,CONT10
CONT9B     ASSIGN    PART,FN(SUB100),PF       Name subassemblies

CONT10     ENTER     PC4                      Transport and processes
           ADVANCE   FN(TRAN2)
           LEAVE     PC4

           ENTER     PC7                      Transport/process cont.
           ADVANCE   FN(TRAN2)
           LEAVE     PC7

           ENTER     OC5530                   Overhaul/repair process
           ADVANCE   FN(OC5530)               Repair time
           LEAVE     OC5530

           ENTER     PC13                     Transport and processes
           ADVANCE   FN(TRAN2)
           LEAVE     PC13

           ENTER     PC16                     Transport/processes cont.
           ADVANCE   FN(TRAN2)
           LEAVE     PC16

           ENTER     PC15                     Transport/processes cont.
           ADVANCE   FN(TRAN2)
           LEAVE     PC15

           ENTER     PC14                     Transport/processes cont.
           ADVANCE   FN(TRAN2)
           LEAVE     PC14

           ENTER     PC18                     Transport/processes cont.
           ADVANCE   FN(TRAN2)
           LEAVE     PC18

           ENTER     PC20                     Transport/processes cont.
           ADVANCE   FN(TRAN2)
           LEAVE     PC20

           TEST E    PF(PART),PA101,CONT11          Test to assemble A101 to
           TEST G    CH(AA10CHAIN),0                  aa10
           UNLINK    AA10CHAIN,TERM,1
           TRANSFER  ,CONT14
```

```
CONT11      TEST E      PF(PART),PA110,CONT12       Test to assemble A110 to
            TEST G      CH(AA11CHAIN),0               aa11
            UNLINK      AA11CHAIN,TERM,1
            TRANSFER    ,CONT14

CONT12      TEST E      PF(PART),PAA10,CONT13
            LINK        AA10CHAIN,FIFO
CONT13      LINK        AA11CHAIN,FIFO

CONT14      ENTER       BENF100S       Bench test
CONT15      BLET        &DUMMYT=RVNORM(19,&SFNORM6(&LM),&SFNORS6(&LV))
            TEST G      &DUMMYT,0,CONT15
            ADVANCE     &DUMMYT
            LEAVE       BENF100S

            ENTER       PC22                    Transport/processes
            ADVANCE     FN(TRAN2)
            LEAVE       PC22
            TRANSFER    ,EXSF

*----- M111 FLOW ------------------------------------------------------

CONT19      SEIZE       MACM111                 Uncrating, inspecting
            ADVANCE     FN(INSPCT)
            RELEASE     MACM111

            ENTER       PC1                     Transport, processing
            ADVANCE     FN(TRAN1)
            LEAVE       PC1

            ENTER       BENP111MN               Bench test
CONT25      BLET        &DUMMYT=FN(BTM111)
            TEST G      &DUMMYT,0,CONT25
            ADVANCE     &DUMMYT
            LEAVE       BENP111MN

            TEST E      PF(JOBTYPE),AJOB,CONT20     Test for job type
            BLET        &PNAME=PM11A
            SPLIT       9,CONT21
            TRANSFER    ,CONT20

CONT21      ASSIGN      PART,&PNAME,PF          Name subassemblies
            BLET        &PNAME=&PNAME+1

CONT20      ENTER       PC3                     Transport/processes
            ADVANCE     FN(TRAN2)
            LEAVE       PC3

            ENTER       PC8                     Transport/processes
            ADVANCE     FN(TRAN2)
            LEAVE       PC8
            TRANSFER    ,FN(DISM111)

BT111       TEST G      &UAM111,0               Machine available?
            ENTER       OCM111                  Overhaul/repair
            BLET        &UAM111=&UAM111-1       Machine in use
            ADVANCE     RVTRI(14,&TRI17L,&TRI17M,&TRI17U)
            LEAVE       OCM111
            BLET        &UAM111=&UAM111+1       Machine available
            TRANSFER    ,CONT22
```

```
OC946       ENTER       OC0946                  Subassembly repair
            ADVANCE     FN(OC46TM)
            LEAVE       OC0946
            TRANSFER    ,CONT22

OC959       ENTER       OC0959                  Subassembly repair
            ADVANCE     FN(OC59TM)
            LEAVE       OC0959
            TRANSFER    ,CONT22

OC547       ENTER       OC2547                  Subassembly repair
            ADVANCE     FN(OC47TM)
            LEAVE       OC2547
            TRANSFER    ,CONT22

OC858       TEST G      &UA0858,0               Machine available?
            ENTER       OC0858                  Subassembly repair
            BLET        &UA0858=&UA0858-1       Machine in use
            ADVANCE     RVTRI(14,&TRI18L,&TRI18M,&TRI18U)
            LEAVE       OC0858
            BLET        &UA0858=&UA0858+1       Machine available

CONT22      ENTER       PC11                    Transport/processes
            ADVANCE     FN(TRAN2)
            LEAVE       PC11
            ENTER       PC14                    Transport/processes
            ADVANCE     FN(TRAN2)
            LEAVE       PC14
            ENTER       PC18                    Transport/processes
            ADVANCE     FN(TRAN2)
            LEAVE       PC18
            ENTER       PC19                    Transport/processes
            ADVANCE     FN(TRAN2)
            LEAVE       PC19

            TEST E      PF(PART),PM111,CONT23         Reassembly process
            TEST E      PF(JOBTYPE),AJOB,CONT24
            TEST G      CH(PM11ACH),0
            UNLINK      PM11ACH,TERM,1
            TEST G      CH(PM11BCH),0
            UNLINK      PM11BCH,TERM,1
            TEST G      CH(PM11CCH),0
            UNLINK      PM11CCH,TERM,1
            TEST G      CH(PM11DCH),0
            UNLINK      PM11DCH,TERM,1
            TEST G      CH(PM11ECH),0
            UNLINK      PM11ECH,TERM,1
            TEST G      CH(PM11FCH),0
            UNLINK      PM11FCH,TERM,1
            TEST G      CH(PM11GCH),0
            UNLINK      PM11GCH,TERM,1
            TEST G      CH(PM11HCH),0
            UNLINK      PM11HCH,TERM,1
            TEST G      CH(PM11JCH),0
            UNLINK      PM11JCH,TERM,1
            TRANSFER    ,CONT24

CONT23      LINK        FN(SUBCH),FIFO

CONT24      ENTER       BENP111MN               Bench test
            ADVANCE     FN(BTM111B)
            LEAVE       BENP111MN
```

```
          ENTER     PC21                    Transport/processes
          ADVANCE   FN(TRAN2)
          LEAVE     PC21
          TRANSFER  ,EXSF

*----- A111 FLOW -------------------------------------------------------

CONT28    SEIZE     MACA111                 Uncrating,inspecting
          ADVANCE   FN(INSPCT)
          RELEASE   MACA111

          ENTER     PC10                    Transport, processing
          ADVANCE   FN(TRAN1)
          LEAVE     PC10

          ENTER     BENP111AB               Bench test
CONT29    BLET      &DUMMYT=RVNORM(14,&SFNORM7(&LM),&SFNORS7(&LV))
          TEST G    &DUMMYT,0,CONT29
          ADVANCE   &DUMMYT
          LEAVE     BENP111AB

          TEST E    PF(JOBTYPE),AJOB,CONT41    Test for job type
          SPLIT     1,CONT31
          ASSIGN    PART,PA11A,PF           Name subassembly A
          TRANSFER  ,CONT30

CONT31    ASSIGN    PART,PA11G,PF           Name subassembly G

CONT30    ENTER     BENP111AB               Bench test
          ADVANCE   FN(BTA111)
          LEAVE     BENP111AB

          TEST E    PF(PART),PA11A,CONT32
          BLET      &PNAME2=PA11B
          SPLIT     5,CONT33
          TRANSFER  ,CONT34

CONT33    ASSIGN    PART,&PNAME2,PF
          BLET      &PNAME2=&PNAME2+1
          TRANSFER  ,CONT34

CONT32    BLET      &PNAME3=PA11H
          SPLIT     5,CONT35
          TRANSFER  ,CONT34

CONT35    ASSIGN    PART,&PNAME3,PF
          BLET      &PNAME3=&PNAME3+1

CONT34    ENTER     PC6                     Transport/processes
          ADVANCE   FN(TRAN2)
          LEAVE     PC6
          TRANSFER  ,FN(DISA111)

OC407     TEST G    &UA2407,0               Machine available?
          ENTER     OC2407                  Overhaul/repair part A11A
          BLET      &UA2407=&UA2407-1       Machine in use
          ADVANCE   RVTRI(13,&TRI19L,&TRI19M,&TRI19U)
          LEAVE     OC2407
          BLET      &UA2407=&UA2407+1       Machine available
          TRANSFER  ,CONT36
```

```
OC676       TEST G     &UA0676,0              Machine available?
            ENTER      OC0676                 Subassembly repair part A11B
            BLET       &UA0676=&UA0676-1      Machine in use
            ADVANCE    RVTRI(13,&TRI20L,&TRI20M,&TRI20U)
            LEAVE      OC0676
            BLET       &UA0676=&UA0676+1      Machine available
            TRANSFER   ,CONT36

OC849       ENTER      OC0849                 Subassembly repair
            ADVANCE    FN(OC49TM)               parts A11C, A11D, A11M
            LEAVE      OC0849
            TRANSFER   ,CONT36

OC944       ENTER      OC0944                 Subassembly repair
            ADVANCE    RVTRI(13,&TRI21L,&TRI21M,&TRI21U)  part A11E
            LEAVE      OC0944
            TRANSFER   ,CONT36

OC848       ENTER      OC0848                 Subassembly repair
            ADVANCE    FN(OC48TM)               parts A11F and A11H
            LEAVE      OC0848
            TRANSFER   ,CONT36

OC191       TEST G     &UA0191,0              Machine available?
            ENTER      OC0191                 Subassembly repair (A11G)
            BLET       &UA0191=&UA0191-1      Machine in use
            ADVANCE    RVTRI(13,&TRI22L,&TRI22M,&TRI22U)
            LEAVE      OC0191
            BLET       &UA0191=&UA0191+1
            TRANSFER   ,CONT36

OC553       ENTER      OC2553                 Subassembly repair
            ADVANCE    RVTRI(13,&TRI23L,&TRI23M,&TRI23U)  part A11J
            LEAVE      OC2553
            TRANSFER   ,CONT36

OC570       ENTER      OC4570                 Subassembly repair
            ADVANCE    RVTRI(13,&TRI24L,&TRI24M,&TRI24U)  part A11K
            LEAVE      OC4570
            TRANSFER   ,CONT36

OC946A      ENTER      OC0946                 Subassembly repair
            ADVANCE    RVTRI(13,&TRI25L,&TRI25M,&TRI25U)  part A11L
            LEAVE      OC0946
            TRANSFER   ,CONT36

CONT36      ENTER      PC12                   Transport/processes
            ADVANCE    FN(TRAN2)
            LEAVE      PC12
            ENTER      PC15                   Transport/processes
            ADVANCE    FN(TRAN2)
            LEAVE      PC15
            ENTER      PC14                   Transport/processes
            ADVANCE    FN(TRAN2)
            LEAVE      PC14
            ENTER      PC17                   Transport/processes
            ADVANCE    FN(TRAN2)
            LEAVE      PC17

            TEST E     PF(PART),PA11A,CONT37        Reassembly process
            TEST G     CH(PA11BCH),0
            UNLINK     PA11BCH,TERM,1
```

```
          TEST G    CH(PA11CCH),0
          UNLINK    PA11CCH,TERM,1
          TEST G    CH(PA11DCH),0
          UNLINK    PA11DCH,TERM,1
          TEST G    CH(PA11ECH),0
          UNLINK    PA11ECH,TERM,1
          TEST G    CH(PA11FCH),0
          UNLINK    PA11FCH,TERM,1
          TRANSFER  ,CONT38

CONT37 TEST E       PF(PART),PA11G,CONT39
          TEST G    CH(PA11HCH),0
          UNLINK    PA11HCH,TERM,1
          TEST G    CH(PA11JCH),0
          UNLINK    PA11JCH,TERM,1
          TEST G    CH(PA11KCH),0
          UNLINK    PA11KCH,TERM,1
          TEST G    CH(PA11LCH),0
          UNLINK    PA11LCH,TERM,1
          TEST G    CH(PA11MCH),0
          UNLINK    PA11MCH,TERM,1
          TRANSFER  ,CONT38

CONT39    LINK      FN(SUBCH),FIFO

CONT38    TEST E    PF(PART),PA11A,CONT40
          TEST G    CH(PA11GCH),0
          UNLINK    PA11GCH,TERM,1
          ASSIGN    PART,PA111,PF
          TRANSFER  ,CONT41

CONT40    LINK      PA11GCH,FIFO

CONT41    ENTER     PC5                      Transport/processes
          ADVANCE   FN(TRAN2)
          LEAVE     PC5

          ENTER     PC6                      Transport/processes
          ADVANCE   FN(TRAN2)
          LEAVE     PC6

          TEST G    &UAA111,0                Machine available?
          ENTER     OCA111                   Overhaul/repair
          BLET      &UAA111=&UAA111-1        Machine in use
          ADVANCE   RVTRI(13,&TRI26L,&TRI26M,&TRI26U)
          LEAVE     OCA111
          BLET      &UAA111=&UAA111+1        Machine available

          ENTER     PC12                     Transport/processes
          ADVANCE   FN(TRAN2)
          LEAVE     PC12
          ENTER     PC15                     Transport/processes
          ADVANCE   FN(TRAN2)
          LEAVE     PC15
          ENTER     PC14                     Transport/processes
          ADVANCE   FN(TRAN2)
          LEAVE     PC14
          ENTER     PC17                     Transport/processes
          ADVANCE   FN(TRAN2)
          LEAVE     PC17

          ENTER     BENP111AB                Bench test
```

```
          ADVANCE   FN(BTA111B)
          LEAVE     BENP111AB

          ENTER     PC23                    Transport/processes
          ADVANCE   FN(TRAN2)
          LEAVE     PC23
          TRANSFER,EXSF

EXSF      DEPART    FN(SFQ)                 Exit shop flow queue
          TABULATE  FN(VTMR)                Check flowtime for VTMR comp
          TRANSFER  ,STSVT                  Go to serviceable turn-in

*----- MODEL MACHINE BREAKDOWNS --------------------------------------

          GENERATE  0,,,2                   OCM100 machine breakdowns
BRK1      ADVANCE   RVEXPO(12,134)          MTBF
          BLET      &UAM100=&UAM100-1       Machine breaks (not avail)
          ENTER     REPMAN                  Get a repair person
          ADVANCE   FN(MRF100)              Repair time
          LEAVE     REPMAN
          BLET      &UAM100=&UAM100+1       Machine repaired and avail
          TRANSFER  ,BRK1

          GENERATE  0,,,8                   OCM111 machine breakdowns
BRK2      ADVANCE   RVEXPO(12,102)          MTBF
          BLET      &UAM111=&UAM111-1       Machine breaks (not avail)
          ENTER     REPMAN                  Get a repair person
          ADVANCE   FN(MRM111)              Repair time
          LEAVE     REPMAN
          BLET      &UAM111=&UAM111+1       Machine repaired and avail
          TRANSFER  ,BRK2

          GENERATE  0,,,1                   OC0946 machine breakdowns
BRK3      ADVANCE   RVEXPO(12,394)          MTBF
          SUNAVAIL  OC0946                  Machine breaks (not avail)
          ENTER     REPMAN                  Get a repair person
          ADVANCE   FN(MRM11S)              Repair time
          LEAVE     REPMAN
          SAVAIL    OC0946                  Machine repaired and avail
          TRANSFER  ,BRK3

          GENERATE  0,,,1                   OC0959 machine breakdowns
BRK4      ADVANCE   RVEXPO(12,2076)               MTBF
          SUNAVAIL  OC0959                  Machine breaks (not avail)
          ENTER     REPMAN                  Get a repair person
          ADVANCE   FN(MRM11S)              Repair time
          LEAVE     REPMAN
          SAVAIL    OC0959                  Machine repaired and avail
          TRANSFER  ,BRK4

          GENERATE  0,,,1                   OC2547 machine breakdowns
BRK5      ADVANCE   RVEXPO(12,658)          MTBF
          SUNAVAIL  OC2547                  Machine breaks (not avail)
          ENTER     REPMAN                  Get a repair person
          ADVANCE   FN(MRM11S)              Repair time
          LEAVE     REPMAN
          SAVAIL    OC2547                  Machine repaired and avail
          TRANSFER  ,BRK5

          GENERATE  0,,,2                   OC0858 machine breakdowns
BRK6      ADVANCE   RVEXPO(12,96)           MTBF
          BLET      &UA0858=&UA0858-1       Machine breaks (not avail)
```

```
          ENTER      REPMAN               Get a repair person
          ADVANCE    FN(MRM11S)           Repair time
          LEAVE      REPMAN
          BLET       &UA0858=&UA0858+1    Machine repaired and avail
          TRANSFER   ,BRK6

          GENERATE   0,,,2                OC2407 machine breakdowns
BRK7      ADVANCE    RVEXPO(12,430)       MTBF
          BLET       &UA2407=&UA2407-1    Machine breaks (not avail)
          ENTER      REPMAN               Get a repair person
          ADVANCE    FN(A11AMR)           Repair time
          LEAVE      REPMAN
          BLET       &UA2407=&UA2407+1    Machine repaired and avail
          TRANSFER   ,BRK7

          GENERATE   0,,,2                OC0676 machine breakdowns
BRK8      ADVANCE    RVEXPO(12,1235)           MTBF
          BLET       &UA0676=&UA0676-1    Machine breaks (not avail)
          ENTER      REPMAN               Get a repair person
          ADVANCE    FN(A11SMR)           Repair time
          LEAVE      REPMAN
          BLET       &UA0676=&UA0676+1    Machine repaired and avail
          TRANSFER   ,BRK8

          GENERATE   0,,,1                OC0849 machine breakdowns
BRK9      ADVANCE    RVEXPO(12,4108)           MTBF
          SUNAVAIL   OC0849               Machine breaks (not avail)
          ENTER      REPMAN               Get a repair person
          ADVANCE    FN(A11SMR)           Repair time
          LEAVE      REPMAN
          SAVAIL     OC0849               Machine repaired and avail
          TRANSFER   ,BRK9

          GENERATE   0,,,1                OC0944 machine breakdowns
BRK10     ADVANCE    RVEXPO(12,486)       MTBF
          SUNAVAIL   OC0944               Machine breaks (not avail)
          ENTER      REPMAN               Get a repair person
          ADVANCE    FN(A11SMR)           Repair time
          LEAVE      REPMAN
          SAVAIL     OC0944               Machine repaired and avail
          TRANSFER   ,BRK10

          GENERATE   0,,,1                OC0848 machine breakdowns
BRK11     ADVANCE    RVEXPO(12,1207)           MTBF
          SUNAVAIL   OC0848               Machine breaks (not avail)
          ENTER      REPMAN               Get a repair person
          ADVANCE    FN(A11SMR)           Repair time
          LEAVE      REPMAN
          SAVAIL     OC0848               Machine repaired and avail
          TRANSFER   ,BRK11

          GENERATE   0,,,2                OC0191 machine breakdowns
BRK12     ADVANCE    RVEXPO(12,117)       MTBF
          BLET       &UA0191=&UA0191-1    Machine breaks (not avail)
          ENTER      REPMAN               Get a repair person
          ADVANCE    FN(A11AMR)           Repair time
          LEAVE      REPMAN
          BLET       &UA0191=&UA0191+1    Machine repaired and avail
          TRANSFER   ,BRK12

          GENERATE   0,,,1                OC2553 machine breakdowns
BRK13     ADVANCE    RVEXPO(12,1468)           MTBF
```

```
          SUNAVAIL  OC2553              Machine breaks (not avail)
          ENTER     REPMAN              Get a repair person
          ADVANCE   FN(A11SMR)          Repair time
          LEAVE     REPMAN
          SAVAIL    OC2553              Machine repaired and avail
          TRANSFER  ,BRK13

          GENERATE  0,,,1               OC4570 machine breakdowns
BRK14     ADVANCE   RVEXPO(12,879)      MTBF
          SUNAVAIL  OC4570              Machine breaks (not avail)
          ENTER     REPMAN              Get a repair person
          ADVANCE   FN(A11SMR)          Repair time
          LEAVE     REPMAN
          SAVAIL    OC4570              Machine repaired and avail
          TRANSFER  ,BRK14

          GENERATE  0,,,8               OCA111 machine breakdowns
BRK15     ADVANCE   RVEXPO(12,111)      MTBF
          BLET      &UAA111=&UAA111-1   Machine breaks (not avail)
          ENTER     REPMAN              Get a repair person
          ADVANCE   FN(A111MR)          Repair time
          LEAVE     REPMAN
          BLET      &UAA111=&UAA111+1   Machine repaired and avail
          TRANSFER  ,BRK15

          GENERATE  0,,,1               OC5530 machine breakdowns
BRK16     ADVANCE   RVEXPO(12,461)      MTBF
          SUNAVAIL  OC5530              Machine breaks (not avail)
          ENTER     REPMAN              Get a repair person
          ADVANCE   FN(A100MR)          Repair time
          LEAVE     REPMAN
          SAVAIL    OC5530              Machine repaired and avail
          TRANSFER  ,BRK16

*----- SERVICEABLE TURN-IN SEGMENT -----------------------------------
* After completing the serviceable turn-in segment, an item exits the
* pipeline queue before going into stock.  It also unlinks a backordered
* requisition from the BKORDR chain, if one is waiting.  The item then
* moves into the STOCK user chain.  If a backordered requisition was
* unlinked, the item will in turn be unlinked by this requisition.
* Otherwise, it will wait in stock for a requisition.

STSVT     ADVANCE   0
GAMRVG    MACRO     10,&SERVTA(2*(&EM-1)+&EV),&SERVTB(2*(&EM-1)+&EV)
*         BPUTPIC   FILE=TIM,PICTURE=TIMDL,   Write travel time data
*                   (&EM,&EV,&LM,&LV,&I,'ST',PF(PART),&GAMVAR)
SERVT     ADVANCE   &GAMVAR                   Gamma distributed flow

          UNLINK    BKORDR,FILL,1,      Unlink a backorder
                    (PART)PF,PF(PART)   if any
          DEPART    FN(PIPE)            Depart pipeline-go to stock
STOCK     LINK      STOCK,FIFO          Item goes into stock

*----- ORDER AND SHIP TIME SEGMENT -----------------------------------
* This segment begins with the arrival of a requisition from the Base
* Processing segment.  If an item is available in the STOCK user chain,
* it is unlinked and destroyed.  The requisition takes the place of the
* item and enters the OST.  If an item is not available in STOCK,
* the requisition moves to the BKORDR chain and waits for an item to
* unlink it.  Notice that while an item is in STOCK, it is not part of
* the pipeline.  The item does not enter the pipeline until there is
* an active requisition.
```

```
 REQ        ADVANCE    0                            Enter a requisition

 FILL       UNLINK     STOCK,TERM,1,(PART)PF,_      Try to get item from
stock
                       PF(PART),STKOUT              otherwise go to stockout

 GAMRVG     MACRO      11,&OSTA(2*(&EM-1)+&EV),&OSTB(2*(&EM-1)+&EV)
*           BPUTPIC    FILE=TIM,PICTURE=TIMDL,_     Write travel time data
*                      (&EM,&EV,&LM,&LV,&I,'OT',PF(PART),&GAMVAR)
            QUEUE      FN(PIPE)                     Back in the pipeline
 OSTBL      ADVANCE    &GAMVAR                      Gamma distributed flow
            DEPART     FN(PIPE)                     Exit the pipeline

 TERM       TERMINATE 0                             Kill transactions

 STKOUT     LINK       BKORDR,FIFO                  Backorder requisition

*----- CONTROL TRANSACTIONS SECTION -----------------------------------
* The first control transaction is used to collect model data.
* The transaction executes every &INTERDAT days and writes the current
* contents of pipeline queues to the PLC files.  This data is used to
* plot the behavior of queues over time and to determine steady-state
* conditions.  This transaction is created with priority 2 so that it
* will also execute on the last day of the simulation prior to the
* terminating control transaction.
* The next control transaction executes once on &DAYRES and resets the
* statistical accumulators.  This reset ensures that the effects of an
* initially empty pipeline do not bias the results.
* The last control transaction executes once after &DAYS days and
* results in the tabulation of pipeline contents, shop flow segment
* contents, and shop flow segment flow time.  The transaction then
* ends the simulation replication.

*           GENERATE &INTERPLC*&HRSDAY,,,,2         Collect raw data
*           BPUTPIC    FILE=PLC1,PICTURE=DATL,_
*                      (&EM,&EV,&LM,&LV,&I,'PM101',Q(PM101Q))
*           BPUTPIC    FILE=PLC2,PICTURE=DATL,_
*                      (&EM,&EV,&LM,&LV,&I,'PM110',Q(PM110Q))
*           BPUTPIC    FILE=PLC3,PICTURE=DATL,_
*                      (&EM,&EV,&LM,&LV,&I,'PA101',Q(PA101Q))
*           BPUTPIC    FILE=PLC4,PICTURE=DATL,_
*                      (&EM,&EV,&LM,&LV,&I,'PA110',Q(PA110Q))
*           BPUTPIC    FILE=PLC5,PICTURE=DATL,_
*                      (&EM,&EV,&LM,&LV,&I,'PM111',Q(PM111Q))
*           BPUTPIC    FILE=PLC6,PICTURE=DATL,_
*                      (&EM,&EV,&LM,&LV,&I,'PA111',Q(PA111Q))
*           TERMINATE 0

            GENERATE &DAYRES*&HRSDAY,,,1     1 XACT for reset
            BRESET     TB(PM101A),TB(PM110A),_      Reset except tables
                       TB(PA101A),TB(PA110A),_
                       TB(PM111A),TB(PA111A),_
                       TB(PM101I),TB(PM110I),_
                       TB(PA101I),TB(PA110I),_
                       TB(PM111I),TB(PA111I),_
                       TB(BM101I),TB(BM110I),_
                       TB(BA101I),TB(BA110I),_
                       TB(BM111I),TB(BA111I),_
                       TB(BM101A),TB(BM110A),_
                       TB(BA101A),TB(BA110A),_
                       TB(BM111A),TB(BA111A),_
```

```
        TB(TM101I),TB(TM110I),_
        TB(TA101I),TB(TA110I),_
        TB(TM111I),TB(TA111I),_
        TB(TM101A),TB(TM110A),_
        TB(TA101A),TB(TA110A),_
        TB(TM111A),TB(TA111A),_
        TB(RM101I),TB(RM110I),_
        TB(RA101I),TB(RA110I),_
        TB(RM111I),TB(RA111I),_
        TB(RM101A),TB(RM110A),_
        TB(RA101A),TB(RA110A),_
        TB(RM111A),TB(RA111A)
TERMINATE 0

GENERATE &DAYS*&HRSDAY          Stop after &DAYS
TABULATE PM101I                 M101 Pipeline contents
TABULATE PM110I                 M110 Pipeline contents
TABULATE PA101I                 A101 Pipeline contents
TABULATE PA110I                 A110 Pipeline contents
TABULATE PM111I                 M111 Pipeline contents
TABULATE PA111I                 A111 Pipeline contents
TABULATE PM101A                 M101 Pipeline contents
TABULATE PM110A                 M110 Pipeline contents
TABULATE PA101A                 A101 Pipeline contents
TABULATE PA110A                 A110 Pipeline contents
TABULATE PM111A                 M111 Pipeline contents
TABULATE PA111A                 A111 Pipeline contents
TABULATE BM101I                 M101 Shop flow contents
TABULATE BM110I                 M110 Shop flow contents
TABULATE BA101I                 A101 Shop flow contents
TABULATE BA110I                 A110 Shop flow contents
TABULATE BM111I                 M111 Shop flow contents
TABULATE BA111I                 A111 Shop flow contents
TABULATE BM101A                 M101 Shop flow contents
TABULATE BM110A                 M110 Shop flow contents
TABULATE BA101A                 A101 Shop flow contents
TABULATE BA110A                 A110 Shop flow contents
TABULATE BM111A                 M111 Shop flow contents
TABULATE BA111A                 A111 Shop flow contents
TABULATE TM101I                 M101 Shop flow time
TABULATE TM110I                 M110 Shop Flow time
TABULATE TA101I                 A101 Shop flow time
TABULATE TA110I                 A110 Shop flow time
TABULATE TM111I                 M111 Shop flow time
TABULATE TA111I                 A111 Shop flow time
TABULATE TM101A                 M101 Shop flow time
TABULATE TM110A                 M110 Shop Flow time
TABULATE TA101A                 A101 Shop flow time
TABULATE TA110A                 A110 Shop flow time
TABULATE TM111A                 M111 Shop flow time
TABULATE TA111A                 A111 Shop flow time
TABULATE RM101I                 M101 Shop flow VTMR
TABULATE RM110I                 M110 Shop flow VTMR
TABULATE RA101I                 A101 Shop flow VTMR
TABULATE RA110I                 A110 Shop flow VTMR
TABULATE RM111I                 M111 Shop flow VTMR
TABULATE RA111I                 A111 Shop flow VTMR
TABULATE RM101A                 M101 Shop flow VTMR
TABULATE RM110A                 M110 Shop flow VTMR
TABULATE RA101A                 A101 Shop flow VTMR
TABULATE RA110A                 A110 Shop flow VTMR
TABULATE RM111A                 M111 Shop flow VTMR
```

```
          TABULATE RA111A                     A111 Shop flow VTMR
          TERMINATE 1

*=========================================================================
* CONTROL STATEMENTS
*

* This loop runs through the &NUMLEV different levels for the
* Shop Flow mean processing tims.

          DO &LM=1,&NUMLEV

* This next loop runs through the &NUMLEV different levels for the
* Shop Flow flow variability.

             DO &LV=1,&NUMLEV

* The following IF structure selects the file that contains the values
* for the shop flow triangular distributions based on the experimental
* levels.  The actual GETLIST statement is coded as a macro.

                  IF (&LM=1)AND(&LV=1)
TRIINP            MACRO     INP11
UNIINP            MACRO     UNI11
                  ELSEIF (&LM=1)AND(&LV=2)
TRIINP            MACRO     INP12
UNIINP            MACRO     UNI12
                  ELSEIF (&LM=1)AND(&LV=3)
TRIINP            MACRO     INP13
UNIINP            MACRO     UNI13
                  ELSEIF (&LM=2)AND(&LV=1)
TRIINP            MACRO     INP21
UNIINP            MACRO     UNI21
                  ELSEIF (&LM=2)AND(&LV=2)
TRIINP            MACRO     INP22
UNIINP            MACRO     UNI22
                  ELSEIF (&LM=2)AND(&LV=3)
TRIINP            MACRO     INP23
UNIINP            MACRO     UNI23
                  ELSEIF (&LM=2)AND(&LV=4)
TRIINP            MACRO     INP24
UNIINP            MACRO     UNI23
                  ELSEIF (&LM=3)AND(&LV=1)
TRIINP            MACRO     INP31
UNIINP            MACRO     UNI31
                  ELSEIF (&LM=3)AND(&LV=2)
TRIINP            MACRO     INP32
UNIINP            MACRO     UNI32
                  ELSEIF (&LM=3)AND(&LV=3)
TRIINP            MACRO     INP33
UNIINP            MACRO     UNI33
                  ENDIF

* Experiments are conducted under &NUMENV different environments for
* mean processing time and variability.  The first of the next two loops
* is for the levels of environment mean processin time and the second
* is for the levels of environment variability.

                  DO &EM=1,&NUMENV
                     DO &EV=1,&NUMENV

* The parameters for an environment, Shop Flow mean processing time, and
```

```
* Shop Flow variability are now set.  An experiment with &REPS can
* now be done.  The random number streams are set so that each exp
* uses the same set of numbers, and each replication within a set starts
* with the same set. Then, the vars that track the number of machines
* up and available for multiple server machines are reset.

* First, output the header for the detailed reports for this set of reps
* The first report is pipeline contents, the second shop flow contents,
* the third shop flow time, the fourth shop flow times VTMR.

                        PUTPIC FILE=OUTI,PICTURE=POLICY,(&ENVDESC(&EM),_
                         &ENVDESC(&EV),&LEVDESC(&LM),_
                         &LEVDESC(&LV))

                        PUTPIC FILE=OUTA,PICTURE=POLICY,(&ENVDESC(&EM),_
                         &ENVDESC(&EV),&LEVDESC(&LM),_
                         &LEVDESC(&LV))

                        PUTPIC FILE=SFCI,PICTURE=FLWCON,(&ENVDESC(&EM),_
                         &ENVDESC(&EV),&LEVDESC(&LM),_
                         &LEVDESC(&LV))

                        PUTPIC FILE=SFCA,PICTURE=FLWCON,(&ENVDESC(&EM),_
                         &ENVDESC(&EV),&LEVDESC(&LM),_
                         &LEVDESC(&LV))

                        PUTPIC FILE=SFTI,PICTURE=FLWTIM,(&ENVDESC(&EM),_
                         &ENVDESC(&EV),&LEVDESC(&LM),_
                         &LEVDESC(&LV))

                        PUTPIC FILE=SFTA,PICTURE=FLWTIM,(&ENVDESC(&EM),_
                         &ENVDESC(&EV),&LEVDESC(&LM),_
                         &LEVDESC(&LV))

                        PUTPIC FILE=VTMI,PICTURE=FLWVTM,(&ENVDESC(&EM),_
                         &ENVDESC(&EV),&LEVDESC(&LM),_
                         &LEVDESC(&LV))

                        PUTPIC FILE=VTMA,PICTURE=FLWVTM,(&ENVDESC(&EM),_
                         &ENVDESC(&EV),&LEVDESC(&LM),_
                         &LEVDESC(&LV))

* Report to user current experimental settings.

                        PUTPIC PICTURE=EXL,(&EM,&EV,&LM,&LV)

* Do replications of the experiment.

                        DO &I=1,&REP

                     RMULT   100000+(&I-1)*&RINTER,_
                             200000+(&I-1)*&RINTER,_
                             300000+(&I-1)*&RINTER,_
                             400000+(&I-1)*&RINTER,_
                             500000+(&I-1)*&RINTER,_
                             600000+(&I-1)*&RINTER,_
                             700000+(&I-1)*&RINTER,_
                             800000+(&I-1)*&RINTER,_
                             900000+(&I-1)*&RINTER,_
                            1000000+(&I-1)*&RINTER,_
                            1100000+(&I-1)*&RINTER,_
                            1200000+(&I-1)*&RINTER,_
```

```
                    1300000+(&I-1)*&RINTER,_
                    1400000+(&I-1)*&RINTER,_
                    1500000+(&I-1)*&RINTER,_
                    1600000+(&I-1)*&RINTER,_
                    1700000+(&I-1)*&RINTER,_
                    1800000+(&I-1)*&RINTER,_
                    1900000+(&I-1)*&RINTER,_
                    2000000+(&I-1)*&RINTER

* Prior to each experiment, reset the machines up and available counters
* that may have changed during the previous replication (CLEAR does not
* affect ampervariable settings).

              LET &UAM100=2          Machines Up and Available
              LET &UAM111=8             "
              LET &UA0858=2             "
              LET &UA2407=2             "
              LET &UA0676=2             "
              LET &UA0191=2             "
              LET &UAA111=8             "

              START 1,NP

* The following statements write the results from this replication
* to the ANOVA files for later analysis.  The first set outputs points
* for overall pipeline contents.  The second set outputs points for
* shop flow segment contents.

              PUTPIC FILE=ANVI,PICTURE=ANVL,('M101',_
                     &EM,&EV,&LM,&LV,QA(PM101QI))
              PUTPIC FILE=ANVI,PICTURE=ANVL,('M110',_
                     &EM,&EV,&LM,&LV,QA(PM110QI))
              PUTPIC FILE=ANVI,PICTURE=ANVL,('A101',_
                     &EM,&EV,&LM,&LV,QA(PA101QI))
              PUTPIC FILE=ANVI,PICTURE=ANVL,('A110',_
                     &EM,&EV,&LM,&LV,QA(PA110QI))
              PUTPIC FILE=ANVI,PICTURE=ANVL,('M111',_
                     &EM,&EV,&LM,&LV,QA(PM111QI))
              PUTPIC FILE=ANVI,PICTURE=ANVL,('A111',_
                     &EM,&EV,&LM,&LV,QA(PA111QI))

              PUTPIC FILE=ANVA,PICTURE=ANVL,('M101',_
                     &EM,&EV,&LM,&LV,QA(PM101QA))
              PUTPIC FILE=ANVA,PICTURE=ANVL,('M110',_
                     &EM,&EV,&LM,&LV,QA(PM110QA))
              PUTPIC FILE=ANVA,PICTURE=ANVL,('A101',_
                     &EM,&EV,&LM,&LV,QA(PA101QA))
              PUTPIC FILE=ANVA,PICTURE=ANVL,('A110',_
                     &EM,&EV,&LM,&LV,QA(PA110QA))
              PUTPIC FILE=ANVA,PICTURE=ANVL,('M111',_
                     &EM,&EV,&LM,&LV,QA(PM111QA))
              PUTPIC FILE=ANVA,PICTURE=ANVL,('A111',_
                     &EM,&EV,&LM,&LV,QA(PA111QA))

              PUTPIC FILE=SFAI,PICTURE=ANVL,('M101',_
                     &EM,&EV,&LM,&LV,QA(PM101SQI))
              PUTPIC FILE=SFAI,PICTURE=ANVL,('M110',_
                     &EM,&EV,&LM,&LV,QA(PM110SQI))
              PUTPIC FILE=SFAI,PICTURE=ANVL,('A101',_
                     &EM,&EV,&LM,&LV,QA(PA101SQI))
              PUTPIC FILE=SFAI,PICTURE=ANVL,('A110',_
                     &EM,&EV,&LM,&LV,QA(PA110SQI))
```

```
                    PUTPIC FILE=SFAI,PICTURE=ANVL,('M111',_
                          &EM,&EV,&LM,&LV,QA(PM111SQI))
                    PUTPIC FILE=SFAI,PICTURE=ANVL,('A111',_
                          &EM,&EV,&LM,&LV,QA(PA111SQI))

                    PUTPIC FILE=SFAA,PICTURE=ANVL,('M101',_
                          &EM,&EV,&LM,&LV,QA(PM101SQA))
                    PUTPIC FILE=SFAA,PICTURE=ANVL,('M110',_
                          &EM,&EV,&LM,&LV,QA(PM110SQA))
                    PUTPIC FILE=SFAA,PICTURE=ANVL,('A101',_
                          &EM,&EV,&LM,&LV,QA(PA101SQA))
                    PUTPIC FILE=SFAA,PICTURE=ANVL,('A110',_
                          &EM,&EV,&LM,&LV,QA(PA110SQA))
                    PUTPIC FILE=SFAA,PICTURE=ANVL,('M111',_
                          &EM,&EV,&LM,&LV,QA(PM111SQA))
                    PUTPIC FILE=SFAA,PICTURE=ANVL,('A111',_
                          &EM,&EV,&LM,&LV,QA(PA111SQA))

* The next output statements write the results of the just completed
* replication to the detailed report files.  The first set is for
* overall pipeline contents, the second for shop flow segment contents,
* and the third for shop flow segment flow time.

                    PUTPIC FILE=OUTI,PICTURE=OUTD,(&I,QA(PM101QI),_
                       QA(PM110QI),QA(PA101QI),QA(PA110QI),_
                       QA(PM111QI),QA(PA111QI))

                    PUTPIC FILE=OUTA,PICTURE=OUTD,(&I,QA(PM101QA),_
                       QA(PM110QA),QA(PA101QA),QA(PA110QA),_
                       QA(PM111QA),QA(PA111QA))

                    PUTPIC FILE=SFCI,PICTURE=OUTD,(&I,QA(PM101SQI),_
                       QA(PM110SQI),QA(PA101SQI),_
                       QA(PA110SQI),QA(PM111SQI),_
                       QA(PA111SQI))

                    PUTPIC FILE=SFCA,PICTURE=OUTD,(&I,QA(PM101SQA),_
                       QA(PM110SQA),QA(PA101SQA),_
                       QA(PA110SQA),QA(PM111SQA),_
                       QA(PA111SQA))

                    PUTPIC FILE=SFTI,PICTURE=OUT2,(&I,_
                       TB(VM101I),TD(VM101I),_
                       TB(VM110I),TD(VM110I),_
                       TB(VA101I),TD(VA101I),_
                       TB(VA110I),TD(VA110I),_
                       TB(VM111I),TD(VM111I),_
                       TB(VA111I),TD(VA111I))

                    PUTPIC FILE=SFTA,PICTURE=OUT2,(&I,_
                       TB(VM101A),TD(VM101A),_
                       TB(VM110A),TD(VM110A),_
                       TB(VA101A),TD(VA101A),_
                       TB(VA110A),TD(VA110A),_
                       TB(VM111A),TD(VM111A),_
                       TB(VA111A),TD(VA111A))

                    PUTPIC FILE=VTMI,PICTURE=OUTD,(&I,_
                       TD(VM101I)*TD(VM101I)/TB(VM101I),_
                       TD(VM110I)*TD(VM110I)/TB(VM110I),_
                       TD(VA101I)*TD(VA101I)/TB(VA101I),_
                       TD(VA110I)*TD(VA110I)/TB(VA110I),_
```

```
   TD(VM111I)*TD(VM111I)/TB(VM111I),_
   TD(VA111I)*TD(VA111I)/TB(VA111I))

PUTPIC FILE=VTMA,PICTURE=OUTD,(&I,_
   TD(VM101A)*TD(VM101A)/TB(VM101A),_
   TD(VM110A)*TD(VM110A)/TB(VM110A),_
   0,_
   0,_
   TD(VM111A)*TD(VM111A)/TB(VM111A),_
   TD(VA111A)*TD(VA111A)/TB(VA111A))

CLEAR    TB(PM101I),TB(PM110I),_ Except tables
   TB(PA101I),TB(PA110I),_
   TB(PM111I),TB(PA111I),_
   TB(PM101A),TB(PM110A),_
   TB(PA101A),TB(PA110A),_
   TB(PM111A),TB(PA111A),_
   TB(BM101I),TB(BM110I),_
   TB(BA101I),TB(BA110I),_
   TB(BM111I),TB(BA111I),_
   TB(BM101A),TB(BM110A),_
   TB(BA101A),TB(BA110A),_
   TB(BM111A),TB(BA111A),_
   TB(TM101I),TB(TM110I),_
   TB(TA101I),TB(TA110I),_
   TB(TM111I),TB(TA111I),_
   TB(TM101A),TB(TM110A),_
   TB(TA101A),TB(TA110A),_
   TB(TM111A),TB(TA111A),_
   TB(RM101I),TB(RM110I),_
   TB(RA101I),TB(RA110I),_
   TB(RM111I),TB(RA111I),_
   TB(RM101A),TB(RM110A),_
   TB(RA101A),TB(RA110A),_
   TB(RM111A),TB(RA111A)

   ENDDO

* The next output statements write the summary for the lastest exp.
* Output includes average pipeline contents for each part modeled,
* the standard deviation, and 95% C.I.  The first set is for overall
* pipeline contents, the second set is for shop flow segment contents,
* and the third set is for shop flow segment flow time.

   LET &N=SQRT(&REP)

   PUTPIC FILE=OUTA,PICTURE=OUTM,_
    (TB(PM101A),TB(PM110A),_
    TB(PA101A),TB(PA110A),TB(PM111A),TB(PA111A))
   PUTPIC FILE=OUTA,PICTURE=OUTS,_
    (TD(PM101A),TD(PM110A),_
    TD(PA101A),TD(PA110A),TD(PM111A),TD(PA111A))
   PUTPIC FILE=OUTA,PICTURE=OUTL,(_
          TB(PM101A)-&T95*TD(PM101A)/&N,_
          TB(PM110A)-&T95*TD(PM110A)/&N,_
          TB(PA101A)-&T95*TD(PA101A)/&N,_
          TB(PA110A)-&T95*TD(PA110A)/&N,_
          TB(PM111A)-&T95*TD(PM111A)/&N,_
          TB(PA111A)-&T95*TD(PA111A)/&N)
   PUTPIC FILE=OUTA,PICTURE=OUTU,(_
          TB(PM101A)+&T95*TD(PM101A)/&N,_
          TB(PM110A)+&T95*TD(PM110A)/&N,_
```

```
        TB(PA101A)+&T95*TD(PA101A)/&N,_
        TB(PA110A)+&T95*TD(PA110A)/&N,_
        TB(PM111A)+&T95*TD(PM111A)/&N,_
        TB(PA111A)+&T95*TD(PA111A)/&N)

PUTPIC FILE=OUTI,PICTURE=OUTM,_
 (TB(PM101I),TB(PM110I),_
 TB(PA101I),TB(PA110I),TB(PM111I),TB(PA111I))
PUTPIC FILE=OUTI,PICTURE=OUTS,_
 (TD(PM101I),TD(PM110I),_
 TD(PA101I),TD(PA110I),TD(PM111I),TD(PA111I))
PUTPIC FILE=OUTI,PICTURE=OUTL,(_
 TB(PM101I)-&T95*TD(PM101I)/&N,_
 TB(PM110I)-&T95*TD(PM110I)/&N,_
 TB(PA101I)-&T95*TD(PA101I)/&N,_
 TB(PA110I)-&T95*TD(PA110I)/&N,_
 TB(PM111I)-&T95*TD(PM111I)/&N,_
 TB(PA111I)-&T95*TD(PA111I)/&N)
PUTPIC FILE=OUTI,PICTURE=OUTU,(_
 TB(PM101I)+&T95*TD(PM101I)/&N,_
 TB(PM110I)+&T95*TD(PM110I)/&N,_
 TB(PA101I)+&T95*TD(PA101I)/&N,_
 TB(PA110I)+&T95*TD(PA110I)/&N,_
 TB(PM111I)+&T95*TD(PM111I)/&N,_
 TB(PA111I)+&T95*TD(PA111I)/&N)

PUTPIC FILE=SFCI,PICTURE=OUTM,_
 (TB(BM101I),TB(BM110I),_
 TB(BA101I),TB(BA110I),TB(BM111I),TB(BA111I))
PUTPIC FILE=SFCI,PICTURE=OUTS,_
 (TD(BM101I),TD(BM110I),_
 TD(BA101I),TD(BA110I),TD(BM111I),TD(BA111I))
PUTPIC FILE=SFCI,PICTURE=OUTV,_
 (TD(BM101I)*TD(BM101I),_
 TD(BM110I)*TD(BM110I),TD(BA101I)*TD(BA101I),_
 TD(BA110I)*TD(BA110I),TD(BM111I)*TD(BM111I),_
 TD(BA111I)*TD(BA111I))
PUTPIC FILE=SFCI,PICTURE=OUTL,(_
 TB(BM101I)-&T95*TD(BM101I)/&N,_
 TB(BM110I)-&T95*TD(BM110I)/&N,_
 TB(BA101I)-&T95*TD(BA101I)/&N,_
 TB(BA110I)-&T95*TD(BA110I)/&N,_
 TB(BM111I)-&T95*TD(BM111I)/&N,_
 TB(BA111I)-&T95*TD(BA111I)/&N)
PUTPIC FILE=SFCI,PICTURE=OUTU,(_
 TB(BM101I)+&T95*TD(BM101I)/&N,_
 TB(BM110I)+&T95*TD(BM110I)/&N,_
 TB(BA101I)+&T95*TD(BA101I)/&N,_
 TB(BA110I)+&T95*TD(BA110I)/&N,_
 TB(BM111I)+&T95*TD(BM111I)/&N,_
 TB(BA111I)+&T95*TD(BA111I)/&N)

PUTPIC FILE=SFCA,PICTURE=OUTM,_
 (TB(BM101A),TB(BM110A),_
 TB(BA101A),TB(BA110A),TB(BM111A),TB(BA111A))
PUTPIC FILE=SFCA,PICTURE=OUTS,_
 (TD(BM101A),TD(BM110A),_
 TD(BA101A),TD(BA110A),TD(BM111A),TD(BA111A))
PUTPIC FILE=SFCA,PICTURE=OUTV,_
 (TD(BM101A)*TD(BM101A),_
 TD(BM110A)*TD(BM110A),TD(BA101A)*TD(BA101A),_
 TD(BA110A)*TD(BA110A),TD(BM111A)*TD(BM111A),_
```

```
 TD(BA111A)*TD(BA111A))
PUTPIC FILE=SFCA,PICTURE=OUTL,(_
 TB(BM101A)-&T95*TD(BM101A)/&N,_
 TB(BM110A)-&T95*TD(BM110A)/&N,_
 TB(BA101A)-&T95*TD(BA101A)/&N,_
 TB(BA110A)-&T95*TD(BA110A)/&N,_
 TB(BM111A)-&T95*TD(BM111A)/&N,_
 TB(BA111A)-&T95*TD(BA111A)/&N)
PUTPIC FILE=SFCA,PICTURE=OUTU,(_
 TB(BM101A)+&T95*TD(BM101A)/&N,_
 TB(BM110A)+&T95*TD(BM110A)/&N,_
 TB(BA101A)+&T95*TD(BA101A)/&N,_
 TB(BA110A)+&T95*TD(BA110A)/&N,_
 TB(BM111A)+&T95*TD(BM111A)/&N,_
 TB(BA111A)+&T95*TD(BA111A)/&N)

PUTPIC FILE=SFTI,PICTURE=OUTM,_
 (TB(TM101I),TB(TM110I),_
 TB(TA101I),TB(TA110I),TB(TM111I),TB(TA111I))
PUTPIC FILE=SFTI,PICTURE=OUTS,_
 (TD(TM101I),TD(TM110I),_
 TD(TA101I),TD(TA110I),TD(TM111I),TD(TA111I))
PUTPIC FILE=SFTI,PICTURE=OUTV,_
 (TD(TM101I)*TD(TM101I),_
 TD(TM110I)*TD(TM110I),TD(TA101I)*TD(TA101I),_
 TD(TA110I)*TD(TA110I),TD(TM111I)*TD(TM111I),_
 TD(TA111I)*TD(TA111I))
PUTPIC FILE=SFTI,PICTURE=OUTL,(_
 TB(TM101I)-&T95*TD(TM101I)/&N,_
 TB(TM110I)-&T95*TD(TM110I)/&N,_
 TB(TA101I)-&T95*TD(TA101I)/&N,_
 TB(TA110I)-&T95*TD(TA110I)/&N,_
 TB(TM111I)-&T95*TD(TM111I)/&N,_
 TB(TA111I)-&T95*TD(TA111I)/&N)
PUTPIC FILE=SFTI,PICTURE=OUTU,(_
 TB(TM101I)+&T95*TD(TM101I)/&N,_
 TB(TM110I)+&T95*TD(TM110I)/&N,_
 TB(TA101I)+&T95*TD(TA101I)/&N,_
 TB(TA110I)+&T95*TD(TA110I)/&N,_
 TB(TM111I)+&T95*TD(TM111I)/&N,_
 TB(TA111I)+&T95*TD(TA111I)/&N)

PUTPIC FILE=SFTA,PICTURE=OUTM,_
 (TB(TM101A),TB(TM110A),_
 TB(TA101A),TB(TA110A),TB(TM111A),TB(TA111A))
PUTPIC FILE=SFTA,PICTURE=OUTS,_
 (TD(TM101A),TD(TM110A),_
 TD(TA101A),TD(TA110A),TD(TM111A),TD(TA111A))
PUTPIC FILE=SFTA,PICTURE=OUTV,_
 (TD(TM101A)*TD(TM101A),_
 TD(TM110A)*TD(TM110A),TD(TA101A)*TD(TA101A),_
 TD(TA110A)*TD(TA110A),TD(TM111A)*TD(TM111A),_
 TD(TA111A)*TD(TA111A))
PUTPIC FILE=SFTA,PICTURE=OUTL,(_
 TB(TM101A)-&T95*TD(TM101A)/&N,_
 TB(TM110A)-&T95*TD(TM110A)/&N,_
 TB(TA101A)-&T95*TD(TA101A)/&N,_
 TB(TA110A)-&T95*TD(TA110A)/&N,_
 TB(TM111A)-&T95*TD(TM111A)/&N,_
 TB(TA111A)-&T95*TD(TA111A)/&N)
PUTPIC FILE=SFTA,PICTURE=OUTU,(_
 TB(TM101A)+&T95*TD(TM101A)/&N,_
```

```
        TB(TM110A)+&T95*TD(TM110A)/&N,_
        TB(TA101A)+&T95*TD(TA101A)/&N,_
        TB(TA110A)+&T95*TD(TA110A)/&N,_
        TB(TM111A)+&T95*TD(TM111A)/&N,_
        TB(TA111A)+&T95*TD(TA111A)/&N)

       PUTPIC FILE=VTMI,PICTURE=OUTM,_
        (TB(RM101I),TB(RM110I),_
        TB(RA101I),TB(RA110I),TB(RM111I),TB(RA111I))
       PUTPIC FILE=VTMI,PICTURE=OUTS,_
        (TD(RM101I),TD(RM110I),_
        TD(RA101I),TD(RA110I),TD(RM111I),TD(RA111I))
       PUTPIC FILE=VTMI,PICTURE=OUTV,_
        (TD(RM101I)*TD(RM101I),_
        TD(RM110I)*TD(RM110I),TD(RA101I)*TD(RA101I),_
        TD(RA110I)*TD(RA110I),TD(RM111I)*TD(RM111I),_
        TD(RA111I)*TD(RA111I))
       PUTPIC FILE=VTMI,PICTURE=OUTL,(_
        TB(RM101I)-&T95*TD(RM101I)/&N,_
        TB(RM110I)-&T95*TD(RM110I)/&N,_
        TB(RA101I)-&T95*TD(RA101I)/&N,_
        TB(RA110I)-&T95*TD(RA110I)/&N,_
        TB(RM111I)-&T95*TD(RM111I)/&N,_
        TB(RA111I)-&T95*TD(RA111I)/&N)
       PUTPIC FILE=VTMI,PICTURE=OUTU,(_
        TB(RM101I)+&T95*TD(RM101I)/&N,_
        TB(RM110I)+&T95*TD(RM110I)/&N,_
        TB(RA101I)+&T95*TD(RA101I)/&N,_
        TB(RA110I)+&T95*TD(RA110I)/&N,_
        TB(RM111I)+&T95*TD(RM111I)/&N,_
        TB(RA111I)+&T95*TD(RA111I)/&N)

       PUTPIC FILE=VTMA,PICTURE=OUTM,_
        (TB(RM101A),TB(RM110A),_
        TB(RA101A),TB(RA110A),TB(RM111A),TB(RA111A))
       PUTPIC FILE=VTMA,PICTURE=OUTS,_
        (TD(RM101A),TD(RM110A),_
        TD(RA101A),TD(RA110A),TD(RM111A),TD(RA111A))
       PUTPIC FILE=VTMA,PICTURE=OUTV,_
        (TD(RM101A)*TD(RM101A),_
        TD(RM110A)*TD(RM110A),TD(RA101A)*TD(RA101A),_
        TD(RA110A)*TD(RA110A),TD(RM111A)*TD(RM111A),_
        TD(RA111A)*TD(RA111A))
       PUTPIC FILE=VTMA,PICTURE=OUTL,(_
        TB(RM101A)-&T95*TD(RM101A)/&N,_
        TB(RM110A)-&T95*TD(RM110A)/&N,_
        TB(RA101A)-&T95*TD(RA101A)/&N,_
        TB(RA110A)-&T95*TD(RA110A)/&N,_
        TB(RM111A)-&T95*TD(RM111A)/&N,_
        TB(RA111A)-&T95*TD(RA111A)/&N)
       PUTPIC FILE=VTMA,PICTURE=OUTU,(_
        TB(RM101A)+&T95*TD(RM101A)/&N,_
        TB(RM110A)+&T95*TD(RM110A)/&N,_
        TB(RA101A)+&T95*TD(RA101A)/&N,_
        TB(RA110A)+&T95*TD(RA110A)/&N,_
        TB(RM111A)+&T95*TD(RM111A)/&N,_
        TB(RA111A)+&T95*TD(RA111A)/&N)

       CLEAR

    ENDDO
ENDDO
```

```
        ENDDO
        ENDDO

*=====================================================================
* PICTURE STATEMENTS
*

 POLICY PICTURE      LINES=8

=====================================================================
 Experiment: ENV Mean:***********, ENV V:***********
             SF  Mean:***********, SF  V:***********

                ---------------- AVERAGE PIPELINE CONTENTS -------------
 Rep            M101       M110       A101       A110       M111       A111

 FLWCON PICTURE      LINES=8

=====================================================================
 Experiment: ENV Mean:***********, ENV Var:**********
             SF  Mean:***********, SF Var :**********

                ------------- AVERAGE SHOP FLOW CONTENTS -------------
 Rep            M101       M110       A101       A110       M111       A111

 FLWVTM PICTURE      LINES=8

=====================================================================
 Experiment: ENV Mean:***********, ENV Var:**********
             SF  Mean:***********, SF Var :**********

                ----------------- SHOP FLOW TIME VTMR ----------------
 Rep            M101       M110       A101       A110       M111       A111

 OUTD       PICTURE   LINES=1
  **          ***.***    ***.***    ***.***    ***.***    ***.***    ***.***

 FLWTIM PICTURE      LINES=8

=====================================================================
 Experiment: ENV Mean:***********, ENV Var:**********
             SF  Mean:***********, SF Var :**********

      ---------------------- AVERAGE SHOP FLOW TIME (HOURS) ------------
----------
 Rep     M101          M110          A101          A110          M111
A111

 OUT2       PICTURE   LINES=1
  **   ***.* ***.*  ***.* ***.*  ***.* ***.*  ***.* ***.*  ***.* ***.*
***.* ***.*

 OUTM       PICTURE   LINES=2
 -------------------------------------------------------------------
 Ave          ***.***    ***.***    ***.***    ***.***    ***.***    ***.***
```

```
OUTS        PICTURE   LINES=2
---------------------------------------------------------------------
StdDev        ***.***    ***.***    ***.***    ***.***    ***.***    ***.***
OUTV        PICTURE   LINES=2
---------------------------------------------------------------------
Variance     ****.***   ****.***   ****.***   ****.***   ****.***   ****.***
OUTR        PICTURE   LINES=2
---------------------------------------------------------------------
VTMR         ***.***    ***.***    ***.***    ***.***    ***.***    ***.***
OUTL        PICTURE   LINES=2
---------------------------------------------------------------------
L 95% C.I.    ***.***    ***.***    ***.***    ***.***    ***.***    ***.***
OUTU        PICTURE   LINES=4
---------------------------------------------------------------------
U 95% C.I.    ***.***    ***.***    ***.***    ***.***    ***.***    ***.***
---------------------------------------------------------------------
```

```
ANVL        PICTURE   LINES=1
**** * * * * ***.**

TIMDL       PICTURE   LINES=1
* * * * ** ** * ***.**

DATL        PICTURE   LINES=1
* * * * * ***** ***.**

EXL         PICTURE   LINES=1
ENV M = *    ENV V = *    SF M = *    SF V = *

       END
```

Appendix B: Tables of Pipeline Contents (Base Case Experiment)

TABLE 20

M111 AVERAGE PIPELINE CONTENTS (A-JOBS)

Shop Flow Mean	Shop Flow Variability	Environment: Low Mean Low Var	Environment: Low Mean High Var	Environment: High Mean Low Var	Environment: High Mean High Var
.5xNominal	.5xNominal	.493	.456	.999	1.018
.5xNominal	Nominal	.496	.462	.997	1.020
.5xNominal	1.5xNominal	.496	.455	.994	1.019
Nominal	.5xNominal	.673	.651	1.169	1.208
Nominal	Nominal	.680	.653	1.169	1.198
Nominal	1.5xNominal	.680	.651	1.171	1.201
1.5xNominal	.5xNominal	.923	.939	1.419	1.429
1.5xNominal	Nominal	.923	.927	1.421	1.432
1.5xNominal	1.5xNominal	.923	.937	1.426	1.437

TABLE 21

A111 AVERAGE PIPELINE CONTENTS (I-JOBS)

Shop Flow Mean	Shop Flow Variability	Environment: Low Mean Low Var	Environment: Low Mean High Var	Environment: High Mean Low Var	Environment: High Mean High Var
.5xNominal	.5xNominal	.565	.489	1.448	1.322
.5xNominal	Nominal	.568	.487	1.444	1.320
.5xNominal	1.5xNominal	.581	.500	1.467	1.330
Nominal	.5xNominal	.683	.602	1.546	1.419
Nominal	Nominal	.677	.602	1.547	1.421
Nominal	1.5xNominal	.677	.595	1.551	1.422
1.5xNominal	.5xNominal	.795	.714	1.653	1.538
1.5xNominal	Nominal	.793	.714	1.657	1.533
1.5xNominal	1.5xNominal	.796	.713	1.648	1.530

TABLE 22

A111 AVERAGE PIPELINE CONTENTS (A-JOBS)

Shop Flow Mean	Shop Flow Variability	Environment: Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
.5xNominal	.5xNominal	.970	.977	2.263	2.139
.5xNominal	Nominal	.967	.979	2.264	2.154
.5xNominal	1.5xNominal	.988	1.001	2.290	2.180
Nominal	.5xNominal	1.313	1.287	2.597	2.462
Nominal	Nominal	1.309	1.288	2.599	2.467
Nominal	1.5xNominal	1.312	1.286	2.596	2.463
1.5xNominal	.5xNominal	1.644	1.580	2.924	2.784
1.5xNominal	Nominal	1.652	1.577	2.928	2.780
1.5xNominal	1.5xNominal	1.656	1.583	2.912	2.784

TABLE 23

M101 AVERAGE PIPELINE CONTENTS (I-JOBS)

Shop Flow Mean	Shop Flow Variability	Environment: Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
.5xNominal	.5xNominal	.756	.714	1.917	1.953
.5xNominal	Nominal	.760	.711	1.919	1.940
.5xNominal	1.5xNominal	.758	.713	1.915	1.947
Nominal	.5xNominal	.929	.894	2.097	2.119
Nominal	Nominal	.932	.889	2.097	2.121
Nominal	1.5xNominal	.933	.890	2.092	2.114
1.5xNominal	.5xNominal	1.182	1.137	2.326	2.342
1.5xNominal	Nominal	1.188	1.150	2.313	2.344
1.5xNominal	1.5xNominal	1.187	1.147	2.331	2.344

TABLE 24

M101 AVERAGE PIPELINE CONTENTS (A-JOBS)

Shop Flow		Environment			
		Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
Mean	Variability				
.5xNominal	.5xNominal	.287	.247	.648	.501
.5xNominal	Nominal	.289	.247	.650	.506
.5xNominal	1.5xNominal	.298	.255	.669	.505
Nominal	.5xNominal	.399	.356	.766	.606
Nominal	Nominal	.403	.358	.771	.611
Nominal	1.5xNominal	.405	.349	.755	.603
1.5xNominal	.5xNominal	.536	.474	.910	.703
1.5xNominal	Nominal	.536	.474	.904	.708
1.5xNominal	1.5xNominal	.540	.471	.899	.716

TABLE 25

A101 AVERAGE PIPELINE CONTENTS

Shop Flow		Environment			
		Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
Mean	Variability				
.5xNominal	.5xNominal	1.433	1.494	2.544	2.527
.5xNominal	Nominal	1.438	1.494	2.548	2.520
.5xNominal	1.5xNominal	1.448	1.496	2.544	2.529
Nominal	.5xNominal	2.339	2.399	3.440	3.406
Nominal	Nominal	2.340	2.394	3.437	3.398
Nominal	1.5xNominal	2.352	2.392	3.443	3.409
1.5xNominal	.5xNominal	3.257	3.308	4.358	4.328
1.5xNominal	Nominal	3.245	3.317	4.355	4.323
1.5xNominal	1.5xNominal	3.253	3.302	4.352	4.332

TABLE 26

M110 AVERAGE PIPELINE CONTENTS (I-JOBS)

Shop Flow Mean	Shop Flow Variability	Environment: Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
.5xNominal	.5xNominal	1.505	1.554	4.015	3.872
.5xNominal	Nominal	1.500	1.553	4.025	3.865
.5xNominal	1.5xNominal	1.505	1.560	4.022	3.861
Nominal	.5xNominal	1.969	1.989	4.485	4.296
Nominal	Nominal	1.969	1.993	4.482	4.322
Nominal	1.5xNominal	1.969	1.992	4.477	4.311
1.5xNominal	.5xNominal	2.583	2.569	5.073	4.875
1.5xNominal	Nominal	2.594	2.573	5.079	4.878
1.5xNominal	1.5xNominal	2.587	2.571	5.079	4.865

TABLE 27

M110 AVERAGE PIPELINE CONTENTS (A-JOBS)

Shop Flow Mean	Shop Flow Variability	Environment: Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
.5xNominal	.5xNominal	.548	.532	1.122	1.141
.5xNominal	Nominal	.549	.535	1.121	1.138
.5xNominal	1.5xNominal	.551	.536	1.128	1.137
Nominal	.5xNominal	.783	.763	1.328	1.365
Nominal	Nominal	.781	.761	1.328	1.365
Nominal	1.5xNominal	.779	.764	1.329	1.371
1.5xNominal	.5xNominal	1.045	1.035	1.561	1.608
1.5xNominal	Nominal	1.043	1.040	1.564	1.603
1.5xNominal	1.5xNominal	1.052	1.044	1.561	1.603

TABLE 28

A110 AVERAGE PIPELINE CONTENTS

Shop Flow		Environment			
		Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
Mean	Variability				
.5xNominal	.5xNominal	3.134	3.103	5.691	5.599
.5xNominal	Nominal	3.136	3.114	5.695	5.610
.5xNominal	1.5xNominal	3.146	3.129	5.709	5.611
Nominal	.5xNominal	5.123	5.092	7.680	7.555
Nominal	Nominal	5.132	5.097	7.689	7.554
Nominal	1.5xNominal	5.127	5.108	7.690	7.563
1.5xNominal	.5xNominal	7.178	7.085	9.713	9.582
1.5xNominal	Nominal	7.181	7.089	9.714	9.582
1.5xNominal	1.5xNominal	7.173	7.092	9.708	9.577

TABLE 29

M111 AVERAGE PIPELINE CONTENTS (I-JOBS)

Shop Flow Mean	Shop Flow Variability	Environment: Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
.5xNominal	.5xNominal	.580	.487	1.418	1.211
.5xNominal	Nominal	.578	.489	1.419	1.197
.5xNominal	1.5xNominal	.587	.504	1.437	1.207
Nominal	.5xNominal	.725	.630	1.579	1.343
Nominal	Nominal	.723	.626	1.575	1.336
Nominal	1.5xNominal	.732	.636	1.594	1.331
1.5xNominal	.5xNominal	.869	.806	1.759	1.489
1.5xNominal	Nominal	.879	.798	1.756	1.491
1.5xNominal	1.5xNominal	.890	.788	1.754	1.481

TABLE 30

M111 AVERAGE PIPELINE CONTENTS (A-JOBS)

Shop Flow Mean	Shop Flow Variability	Environment: Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
.5xNominal	.5xNominal	.494	.458	1.000	1.027
.5xNominal	Nominal	.496	.462	.997	1.020
.5xNominal	1.5xNominal	.513	.469	1.006	1.039
Nominal	.5xNominal	.675	.648	1.179	1.189
Nominal	Nominal	.680	.653	1.169	1.198
Nominal	1.5xNominal	.678	.666	1.182	1.205
1.5xNominal	.5xNominal	.925	.935	1.418	1.432
1.5xNominal	Nominal	.926	.927	1.421	1.432
1.5xNominal	1.5xNominal	.949	.933	1.416	1.456

TABLE 31

A111 AVERAGE PIPELINE CONTENTS (I-JOBS)

Shop Flow Mean	Shop Flow Variability	Environment: Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
.5xNominal	.5xNominal	.567	.490	1.449	1.320
.5xNominal	Nominal	.568	.487	1.444	1.320
.5xNominal	1.5xNominal	.581	.507	1.461	1.333
Nominal	.5xNominal	.684	.598	1.544	1.416
Nominal	Nominal	.677	.602	1.547	1.421
Nominal	1.5xNominal	.678	.601	1.548	1.415
1.5xNominal	.5xNominal	.795	.711	1.658	1.541
1.5xNominal	Nominal	.793	.714	1.657	1.533
1.5xNominal	1.5xNominal	.785	.727	1.660	1.531

TABLE 32

A111 AVERAGE PIPELINE CONTENTS (A-JOBS)

Shop Flow Mean	Shop Flow Variability	Environment: Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
.5xNominal	.5xNominal	.955	.973	2.263	2.146
.5xNominal	Nominal	.967	.979	2.264	2.154
.5xNominal	1.5xNominal	1.040	1.038	2.326	2.221
Nominal	.5xNominal	1.319	1.285	2.589	2.468
Nominal	Nominal	1.309	1.288	2.599	2.467
Nominal	1.5xNominal	1.393	1.361	2.683	2.542
1.5xNominal	.5xNominal	1.663	1.572	2.914	2.782
1.5xNominal	Nominal	1.652	1.577	2.928	2.780
1.5xNominal	1.5xNominal	1.771	1.677	3.050	2.880

TABLE 33

M101 AVERAGE PIPELINE CONTENTS (I-JOBS)

Shop Flow Mean	Shop Flow Variability	Environment: Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
.5xNominal	.5xNominal	.757	.712	1.915	1.956
.5xNominal	Nominal	.760	.711	1.919	1.940
.5xNominal	1.5xNominal	.755	.705	1.913	1.948
Nominal	.5xNominal	.934	.889	2.093	2.121
Nominal	Nominal	.932	.889	2.097	2.121
Nominal	1.5xNominal	.952	.879	2.091	2.129
1.5xNominal	.5xNominal	1.185	1.138	2.320	2.344
1.5xNominal	Nominal	1.188	1.150	2.313	2.344
1.5xNominal	1.5xNominal	1.203	1.161	2.325	2.355

TABLE 34

M101 AVERAGE PIPELINE CONTENTS (A-JOBS)

Shop Flow Mean	Shop Flow Variability	Environment: Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
.5xNominal	.5xNominal	.289	.243	.647	.496
.5xNominal	Nominal	.289	.247	.650	.506
.5xNominal	1.5xNominal	.334	.307	.703	.548
Nominal	.5xNominal	.403	.354	.770	.603
Nominal	Nominal	.403	.358	.771	.611
Nominal	1.5xNominal	.419	.363	.814	.622
1.5xNominal	.5xNominal	.534	.479	.902	.712
1.5xNominal	Nominal	.536	.474	.904	.708
1.5xNominal	1.5xNominal	.527	.475	.943	.724

TABLE 35

A101 AVERAGE PIPELINE CONTENTS

Shop Flow		Environment			
		Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
Mean	Variability				
.5xNominal	.5xNominal	1.433	1.502	2.537	2.509
.5xNominal	Nominal	1.438	1.494	2.548	2.520
.5xNominal	1.5xNominal	1.481	1.526	2.587	2.552
Nominal	.5xNominal	2.348	2.409	3.442	3.405
Nominal	Nominal	2.340	2.394	3.437	3.398
Nominal	1.5xNominal	2.375	2.413	3.493	3.460
1.5xNominal	.5xNominal	3.269	3.334	4.365	4.314
1.5xNominal	Nominal	3.245	3.317	4.355	4.323
1.5xNominal	1.5xNominal	3.248	3.252	4.380	4.343

TABLE 36

M110 AVERAGE PIPELINE CONTENTS (I-JOBS)

Shop Flow		Environment			
		Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
Mean	Variability				
.5xNominal	.5xNominal	1.506	1.554	4.011	3.868
.5xNominal	Nominal	1.500	1.553	4.025	3.865
.5xNominal	1.5xNominal	1.505	1.560	4.028	3.881
Nominal	.5xNominal	1.965	1.989	4.481	4.298
Nominal	Nominal	1.969	1.993	4.482	4.322
Nominal	1.5xNominal	2.113	2.131	4.625	4.464
1.5xNominal	.5xNominal	2.594	2.573	5.087	4.876
1.5xNominal	Nominal	2.594	2.573	5.079	4.878
1.5xNominal	1.5xNominal	2.616	2.636	5.078	4.901

TABLE 37

M110 AVERAGE PIPELINE CONTENTS (A-JOBS)

Shop Flow Mean	Shop Flow Variability	Environment: Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
.5xNominal	.5xNominal	.549	.530	1.120	1.139
.5xNominal	Nominal	.549	.535	1.121	1.138
.5xNominal	1.5xNominal	.573	.548	1.138	1.145
Nominal	.5xNominal	.779	.760	1.331	1.365
Nominal	Nominal	.781	.761	1.328	1.365
Nominal	1.5xNominal	.781	.749	1.329	1.354
1.5xNominal	.5xNominal	1.041	1.026	1.552	1.599
1.5xNominal	Nominal	1.043	1.040	1.564	1.603
1.5xNominal	1.5xNominal	1.054	1.044	1.536	1.595

TABLE 38

A110 AVERAGE PIPELINE CONTENTS

Shop Flow Mean	Shop Flow Variability	Environment: Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
.5xNominal	.5xNominal	3.126	3.093	5.703	5.581
.5xNominal	Nominal	3.136	3.114	5.695	5.610
.5xNominal	1.5xNominal	3.209	3.187	5.765	5.668
Nominal	.5xNominal	5.128	5.090	7.696	7.585
Nominal	Nominal	5.132	5.097	7.689	7.554
Nominal	1.5xNominal	5.166	5.161	7.702	7.587
1.5xNominal	.5xNominal	7.194	7.105	9.702	9.589
1.5xNominal	Nominal	7.181	7.089	9.714	9.582
1.5xNominal	1.5xNominal	7.209	7.176	9.657	9.533

Appendix D: Tables of Pipeline Contents (Shop Flow Contents)

TABLE 39

M111 AVERAGE PIPELINE CONTENTS (I-JOBS)

Shop Flow		Environment			
		Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
Mean	Variability				
.5xNominal	.5xNominal	.147	.153	.171	.142
.5xNominal	Nominal	.148	.154	.170	.142
.5xNominal	1.5xNominal	.159	.170	.193	.158
Nominal	.5xNominal	.296	.306	.341	.282
Nominal	Nominal	.296	.306	.340	.283
Nominal	1.5xNominal	.302	.310	.351	.287
1.5xNominal	.5xNominal	.450	.458	.510	.426
1.5xNominal	Nominal	.451	.458	.509	.427
1.5xNominal	1.5xNominal	.465	.456	.513	.431

TABLE 40

M111 AVERAGE PIPELINE CONTENTS (A-JOBS)

Shop Flow		Environment			
		Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
Mean	Variability				
.5xNominal	.5xNominal	.177	.193	.171	.172
.5xNominal	Nominal	.179	.196	.174	.173
.5xNominal	1.5xNominal	.195	.205	.285	.186
Nominal	.5xNominal	.351	.384	.346	.341
Nominal	Nominal	.352	.387	.346	.344
Nominal	1.5xNominal	.357	.394	.358	.353
1.5xNominal	.5xNominal	.603	.662	.599	.583
1.5xNominal	Nominal	.608	.664	.601	.586
1.5xNominal	1.5xNominal	.628	.662	.607	.600

TABLE 41

A111 AVERAGE PIPELINE CONTENTS (I-JOBS)

Shop Flow		Environment			
		Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
Mean	Variability				
.5xNominal	.5xNominal	.107	.106	.108	.105
.5xNominal	Nominal	.107	.107	.109	.100
.5xNominal	1.5xNominal	.122	.123	.124	.114
Nominal	.5xNominal	.213	.213	.217	.210
Nominal	Nominal	.212	.216	.217	.207
Nominal	1.5xNominal	.210	.220	.222	.203
1.5xNominal	.5xNominal	.323	.322	.327	.317
1.5xNominal	Nominal	.326	.327	.327	.315
1.5xNominal	1.5xNominal	.319	.342	.338	.301

TABLE 42

A111 AVERAGE PIPELINE CONTENTS (A-JOBS)

Shop Flow		Environment			
		Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
Mean	Variability				
.5xNominal	.5xNominal	.333	.309	.337	.315
.5xNominal	Nominal	.343	.314	.343	.322
.5xNominal	1.5xNominal	.410	.366	.403	.382
Nominal	.5xNominal	.691	.618	.670	.632
Nominal	Nominal	.680	.623	.678	.640
Nominal	1.5xNominal	.760	.690	.756	.721
1.5xNominal	.5xNominal	1.036	.924	.999	.954
1.5xNominal	Nominal	1.023	.926	1.004	.954
1.5xNominal	1.5xNominal	1.14	1.03	1.13	1.074

TABLE 43

M101 AVERAGE PIPELINE CONTENTS (I-JOBS)

Shop Flow Mean	Shop Flow Variability	Environment: Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
.5xNominal	.5xNominal	.152	.159	.148	.154
.5xNominal	Nominal	.155	.156	.146	.152
.5xNominal	1.5xNominal	.156	.156	.143	.152
Nominal	.5xNominal	.331	.342	.317	.325
Nominal	Nominal	.329	.338	.315	.324
Nominal	1.5xNominal	.345	.342	.315	.326
1.5xNominal	.5xNominal	.575	.591	.548	.561
1.5xNominal	Nominal	.571	.595	.545	.555
1.5xNominal	1.5xNominal	.591	.609	.540	.564

TABLE 44

M101 AVERAGE PIPELINE CONTENTS (A-JOBS)

Shop Flow Mean	Shop Flow Variability	Environment: Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
.5xNominal	.5xNominal	.107	.110	.126	.108
.5xNominal	Nominal	.108	.113	.127	.109
.5xNominal	1.5xNominal	.152	.175	.180	.160
Nominal	.5xNominal	.219	.223	.248	.214
Nominal	Nominal	.220	.225	.249	.218
Nominal	1.5xNominal	.236	.230	.289	.238
1.5xNominal	.5xNominal	.350	.346	.383	.337
1.5xNominal	Nominal	.353	.341	.383	.337
1.5xNominal	1.5xNominal	.346	.341	.419	.351

TABLE 45

A101 AVERAGE PIPELINE CONTENTS

Shop Flow Mean	Shop Flow Variability	Environment: Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
.5xNominal	.5xNominal	.900	.890	.894	.873
.5xNominal	Nominal	.903	.884	.907	.874
.5xNominal	1.5xNominal	.943	.917	.946	.910
Nominal	.5xNominal	1.818	1.791	1.809	1.762
Nominal	Nominal	1.809	1.775	1.806	1.763
Nominal	1.5xNominal	1.850	1.796	1.856	1.798
1.5xNominal	.5xNominal	2.751	2.715	2.727	2.660
1.5xNominal	Nominal	2.731	2.692	2.723	2.669
1.5xNominal	1.5xNominal	2.721	2.647	2.741	2.681

TABLE 46

M110 AVERAGE PIPELINE CONTENTS (I-JOBS)

Shop Flow Mean	Shop Flow Variability	Environment: Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
.5xNominal	.5xNominal	.413	.400	.410	.408
.5xNominal	Nominal	.410	.401	.416	.409
.5xNominal	1.5xNominal	.414	.406	.415	.410
Nominal	.5xNominal	.879	.843	.863	.861
Nominal	Nominal	.878	.846	.865	.862
Nominal	1.5xNominal	1.020	.984	1.022	1.002
1.5xNominal	.5xNominal	1.495	1.426	1.463	1.430
1.5xNominal	Nominal	1.496	1.425	1.464	1.425
1.5xNominal	1.5xNominal	1.520	1.470	1.463	1.444

TABLE 47

M110 AVERAGE PIPELINE CONTENTS (A-JOBS)

Shop Flow Mean	Shop Flow Variability	Environment: Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
.5xNominal	.5xNominal	.218	.220	.188	.203
.5xNominal	Nominal	.217	.225	.189	.206
.5xNominal	1.5xNominal	.243	.235	.202	.215
Nominal	.5xNominal	.448	.450	.387	.414
Nominal	Nominal	.451	.450	.387	.419
Nominal	1.5xNominal	.449	.440	.389	.414
1.5xNominal	.5xNominal	.712	.716	.607	.652
1.5xNominal	Nominal	.716	.723	.614	.662
1.5xNominal	1.5xNominal	.724	.739	.592	.653

TABLE 48

A110 AVERAGE PIPELINE CONTENTS

Shop Flow Mean	Shop Flow Variability	Environment: Low Mean Low Var	Low Mean High Var	High Mean Low Var	High Mean High Var
.5xNominal	.5xNominal	1.989	1.961	1.969	1.983
.5xNominal	Nominal	1.993	1.982	1.963	1.993
.5xNominal	1.5xNominal	2.068	2.055	2.033	2.062
Nominal	.5xNominal	3.996	3.941	3.968	3.963
Nominal	Nominal	4.002	3.953	3.956	3.948
Nominal	1.5xNominal	4.040	4.012	3.966	3.985
1.5xNominal	.5xNominal	6.053	5.979	5.985	5.977
1.5xNominal	Nominal	6.043	5.965	5.993	5.965
1.5xNominal	1.5xNominal	6.078	6.030	5.939	5.927

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13. ABSTRACT *(Maximum 200 words)*
This study investigated the effects of reducing the mean processing time and variability in the Shop Flow Segment of the Depot Level Reparable Item pipeline. The measure of interest was the average number of units in the pipeline of a particular type of item (referred to as the average pipeline contents). A literature review revealed that process variability in the pipeline has an impact on its effective operation and cost. A simulation model was developed to determine if reducing mean processing time and/or variability in the Shop Flow Segment would result in a reduction in the average pipeline contents. The pipeline model was based on an existing conceptual model developed in an earlier thesis study; a detailed and constrained model of the Shop Flow Segment was based on an existing model of the Fuel Control Overhaul and Test Unit. The simulation results clearly indicated that a reduction in the mean shop flow time would lead to a reduction in the average pipeline contents. However, initial results did not show a significant impact on average pipeline contents as a result of reducing variability. Further experimentation indicated that for some items under certain conditions, a reduction in variability would result in a reduction in average pipeline contents.

14. SUBJECT TERMS
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