

**ANIMATED STUDY SIMULATION OF ALTERNATIVES
FOR TOW LAUNCH PRODUCTION
AT THE RADFORD ARMY AMMUNITION PLANT**

By

Dan A. Cremer

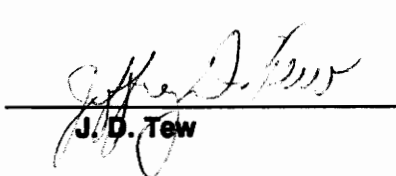
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APPROVED:



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ABSTRACT

ANIMATED SIMULATION TO STUDY MATERIAL HANDLING SYSTEMS FOR TOW LAUNCH PRODUCTION AT THE RADFORD ARMY AMMUNITION PLANT

By

Dan A. Cremer

Committee Chairman: R.J. Reasor

The objective of this project is to investigate the present process required to manufacture the TOW Launch propellant and anticipate the resources required to manufacture a reduced amount of demand. This will be done using animated simulation techniques.

The Radford Army Ammunition Plant was designed for extremely high volumes of propellant manufacturing. Due to the recent cut backs in defense spending, the demands for such high volumes no longer exists. However, the plant continues to operate in a high volume mode. A method to determine the resources which can be eliminated as production is scaled down, and still not be delinquent on any orders, is required. This method would help define the resource capacities under the present mode of operation.

Acknowledgement

The undertaking and completion of this project would not have been possible without the careful guidance from Professor R. J. Reasor, Industrial and Systems Engineering at Virginia Polytechnic Institute and State University, to whom I express my sincere appreciation. Further acknowledgement is extended to Dr. J. D. Tew and Dr. W. J. Fabrycky for serving on my advisory committee.

My deepest appreciation extends to my wife and children who had to make sacrifices while I completed this degree.

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CHAPTER I: INTRODUCTION

OVERVIEW

The Radford Army Ammunition Plant (RAAP) is located next to Blacksburg in the state of Virginia. This plant is a "Government Owned-Company Operated" or a GOCO plant. Hercules Incorporated has been the contractor for this plant since its origination on August 16, 1940. At that time, Hercules was the second largest manufacturer of smokeless powder. The facility covers 2,400 acres of land, contains more than 400 manufacturing buildings, 26 storage areas, and 156 other structures such as laboratories, office buildings, bunkhouses, firehouses, cafeterias, guard stations, and a hospital. There are forty-three miles of roads, 17 miles of fence, 12 miles of railroad track, and 800 miles of telephone wires on the plant.

There are over one hundred different types of propellant and supporting products which it is capable of manufacturing. Figure 1, RAAP Process Flows, depicts the main flows of the basic products presently produced at the plant. All propellants produced are derived from three basic types of smokeless propellant - Single base, Double base, and Triple base propellant. The names come from the number of different constituents which make up the energetic portion of the propellant. The energetic portion of the Single base propellants is Nitrocellulose. The energetic portions of the double base propellant are Nitrocellulose and Nitroglycerine. The energetic portions of the Triple base propellant include NitroGuanadine as well as the constituents of the Double base propellant.

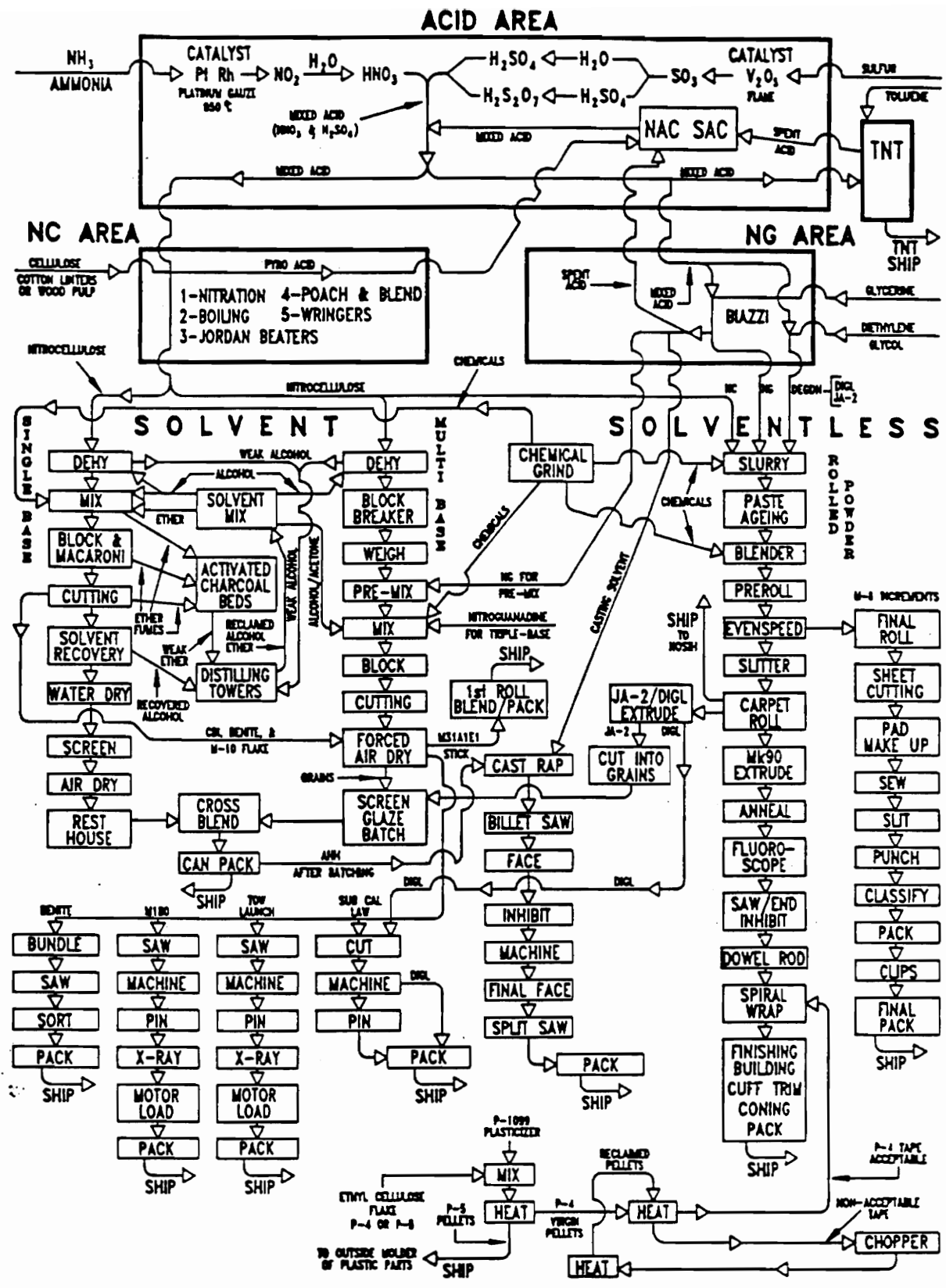


Figure 1: RAAP Process Flows

Propellant can be manufactured by using the Solventless, Cast, and/or Solvent wet processes. In the Solventless process, the propellant is blended while it is in the form of a water wet paste prior to further processing. The Cast process is used to make large propellant grains from smaller components in a mold. The process of most interest for this paper is the Solvent wet process. The M7 propellant used to make TOW Launch grains is made using the Solvent wet process. The process involves mixing propellant ingredients with a solvent mixture containing combinations of Diethyl-ether and acetone. A more detailed description of the process can be found in Appendix I of this report. Other propellants may also use alcohol in this solvent mixture as well. The solvent is used to enhance the mixing process and create a homogenous dough. The propellant is extruded into its' desired form and solvent is almost completely driven out of the propellant.

The facility was built in the 1940's to support World War II efforts. It was designed for extremely high volume, batch manufacturing. At full capacity, the facility employed as many as 9,000 people late in 1941. Between 1941 and 1945, Hercules produced 1.2 billion pounds of smokeless powder, 828.6 million pounds of TNT, 27.7 million pounds of Pentolite (a special high explosive used with TNT), and 159.2 tons of anhydrous ammonia.

Presently due to the cut backs in defense spending, much smaller and more varied orders are being procured with much less efficiency per pounds than seen in the past. Presently, production orders require under one hundred thousand pounds of propellant per month and all resources are vastly under-utilized. Therefore, production planning is almost non-existent. Due to this lack of planning, operators and resources are constantly being utilized at high capacities and then closed down completely. This is also due to the use of the traditional "large batch" processing method of manufacturing which the plant is accustomed to using in the past. Most of the products being produced on plant today are

In their mature or declining life cycles. In the future, the plant will need to change to accommodate new developing products and relatively small orders, or it will be forced to close due to extreme inefficiencies caused by its' original design.

It would be beneficial to develop an animated simulation model of this process to help management evaluate changes in future operating strategies. The model also provides a training tool to illustrate the processes involved for producing propellant. The model provides information on work-in-process inventories , utilization of resources, and the output of materials. A simulation modelling approach should be used so that cycle times, scrap rates, and rework rates can be investigated using probabilistic values.

Problem and Objective

This project focused on the manufacturing processes required to produce the TOW Launch propellant. There are 30 separate operations required to produce TOW Launch propellant. A detailed description and a flow diagram of these operations can be found in Appendix I, Figure 5 and 6 of this report. Presently, 72 mixes (one HPC lot of cotton) is released for production (approximately every four month period) to fulfill present requirements. This project investigated and defined the resources necessary to support a 50% reduction in demand. Alternative equipment configurations were investigated using the simulation model to determine the minimum resources needed to meet required shipping schedules. The primary performance measure examined was the percentage of shipping requirements attained by the total resources. Actual shipping requirements, capacities, etc. are information which should not be disclosed due to proprietary or security reasons. Queues and resource utilization were examined to identify opportunities for resource reduction.

Due to government regulations, each batch processed through the Forced Air Dry operation is considered an HPC lot. Each HPC lot is subjected to a series of expensive ballistic testing. If lot sizes are reduced, the cost per pound of propellant (for ballistic testing) will be higher. However, this cost may be offset by the reduction in total system cycle time, or the decrease in fluctuation of utilization of manpower. Cost is addressed only indirectly through minimization of resource requirements in this study.

Chapter II: Review of Applicable Literature

Usefulness of Simulation As An Analytical Tool

Simulation is becoming increasingly more important as a tool for the manufacturing environment. As hardware and software capabilities become more extensive and less expensive, the cost of simulation become less significant compared to the returns which simulation can offer. Simulation can be helpful to a business throughout its' life cycle (ie. start-up, growth, maturity, and decline). As a business progresses through each of the phases of it's cycle, the material handling needs change as well as the resource requirements. During the early stages, the batch process is preferred so that the business is flexible to the customer's needs. But as production demands increase, batch processing may become less feasible. Simulation can be utilized during the investigation of alternative mode of operations. Black Diamond Corporation was observed to use simulation to investigate effects of making changes involving layouts, batch sizes, purchase of new equipments, reduction of down time for equipments, and elimination of rework operations [J. Lewis, 1991].

Foreign competitors have motivated U.S. companies to be more productive and quality has become a more important marketing strategy than price. The key to maximizing both profits and productivity is by control of input costs and by using efficient processes. A small business has a more difficult time doing these things while preparing for expansion than a large government owned installation like RAAP. At the start, a small business produces products in a batch process. However, it is during the growth stage that internal

efficiency and quality becomes vulnerable. Simulation combined with industrial engineering principles can boost productivity in such cases [J. Lewis, 1991]. At RAAP, the reverse is taking place. In the past, the internal inefficiencies and the lack of quality which were normally absorbed by high volumes will no longer be tolerable in future smaller production lots.

Deterministic Approach

At each operation, parameters such as batch sizes, cycle times, or available resources can be altered to examine the system's performance. If each of these parameters are only examined at two levels each, the number of factors would be 90 (for 30 stations and three parameters), at two levels each would make the number of combinations 2^{90} or 1.238×10^{27} . Even if a designed experiment such as the Taguchi method were to be investigated, the design which would be used would be an L_{128} (orthogonal array consisting of 128 rows and 128 columns used to evaluate 128 factors with two levels each) and the minimum of 128 experiments would be required for each replication. However, through closer examination, interactions must be considered because changing one factor may affect the quality of the next operation and thus affect the other factors. The L_{128} design will only allow for 37 interactions. If there are any more interactions than 37, the next design matrix would be an L_{256} which would consist of 256 experiments for each iteration. The analysis is further complicated because the system's performance can be measured in terms of costs, queue sizes, utilizations, output, or quality. Therefore, a deterministic approach to this problem would require many experiments and large amounts of data reduction.

R. J. Reynolds Tobacco Company, a subsidiary of RJR Nabisco, used simulation methodology to solve similar material handling problems due to the complexity of a

deterministic model. They conducted a study to determine the in-process storage requirements for a proposed material separation process. This process involved the separation of composite material from manufacturing into individual components. A computer simulation was developed that followed the flow from the manufacturing floor, to a composite material storage area, to a material separation line, to a component storage area, and back to the manufacturing floor. Lotus imported the file of data from the simulation and created an XY graph of time versus number of containers in storage. The benefit of using simulation allowed the company to play 'what if' games with input parameters. As a result of the simulation, management discovered that they would need more physical space to accommodate 995 containers if they adopted a newly proposed material separation process. The separation process was previously done off plant which required excessive material handling and quality controls [R.E. Camp, 1993].

The previous example seems almost overly simplistic. However, it points out how efficient simulation can be for determining the storage capacity requirements as opposed to a deterministic approach. A warm up period of eighteen days was required to accumulate a "normal" level of containers required because the simulation started with an empty queue. The statistics used for the simulation was kept simple but effective. The software package WITNESS was used to build the model. The results showed exactly how many containers could be accommodated in each area and how many hours worth of composite material would be segregated in one shift.

Materials Handling Cases

Factory production and inventory control is generally handled in three ways: material requirements planning (MRP), Kanban or 'just in time' (JIT), and optimized production

technology (OPT). These three approaches can be called Push, Pull, and Squeeze [Ramsay, et.al., 1990]. In their article, "Push, Pull And Squeeze Shop Floor Control With Computer Simulation", a simple simulation model was developed to test each method's applicability under varying circumstances. The differences between the techniques are highlighted in the article as follows: the Push technique proved susceptible to failing to recognize deviations from the schedule; and the Pull technique showed itself to be very sensitive to the lack of prioritization found in the STATUS variable. The Squeeze method appeared to be the most useful of the three approaches. However like the other two methods, it "lacked the intelligence to switch from producing one product to another simply because it continues to have authority to produce the first part" even when the need for the second part arises. RAAP uses the MRP or the "push" method of production and inventory planning. This, combined with fluctuating demands, causes continuous over utilization of a facility for a short time and idle facilities the rest of the time.

Hughes Aircraft Company Radar Systems Group is working to automate its' storeroom operations. The new system combines six storerooms in a single automated facility. Its' basic elements are a powered conveyor, robotics inserters and extractors, double stacked horizontal carousels and tote pans. A bi-level powered belt conveyor is used to transport totes throughout the system. Totes are conveyed to workstations via the upper level and returned to carousels via the lower level. The analysis of potential design concepts became increasingly difficult as the number of elements and relationships increased, thus making the system more complex [Gogg and Sands, 1990]. A high level or "macro" level model was developed first to depict the interrelationship between the major elements of the system. Then lower level models were developed to analyze individual components. Hughes chose WITNESS software, to simulate and design the automation system. Finding acceptable system operation under varying conditions became an essential part of system

planning and this simulation helped speed the identification of possible flaws and defects. System problems pointed out by this simulation could not be intuitively identified during the planning stages. This article was one of the most encompassing articles found on the usefulness of simulation. It pointed out that "the investment of time, effort, and money in this (simulation) planning process yielded a visibility of the future operating problems without experiencing them in actual operation."

WITNESS, as described by these articles, resembles ProModel in that it is a special purpose simulator which concentrates on manufacturing and requires significantly less time to program than a general purpose simulator. These special purpose software systems seem easy to use and yet they are not limited. Teledyne used PROMODEL Version 4.1 to simulate the upgrade of a process of an entire facility to include in-line computer processing, prior to actual construction. The plant produced Nickel and Titanium superalloys. A proposal was made to eliminate batch processing and associated inefficiencies by linking each operation with a variety of conveyors. The whole simulation was done on a CompuAdd 386 20 MHz microcomputer with 2 megabytes of RAM, an 80 megabyte hard drive, and a VGA monitor [Marmon, 1991]. Questions to be answered by this simulation were: how much faster is in-line versus batch processing? How much more capacity will be gained? And will reduced cycle times and increased capacity justify the high cost of automated material handling? The objective was to provide results to aid in the design and justification of the in-line finishing cell.

Most articles about computerized simulation focus on a particular case study or a single manufacturing process. Simulation is used in many manufacturing related activities at Honeywell's Micro Switch Division. Simulation can be a flexible tool in diverse applications. WITNESS, by AT&T-ISTEL Corp, was chosen because of programming ease and adaptability. Simulation at Micro Switch is used in ways that include justifying new office equipment

(more CAD stations in this case), analyzing assembly processes for production or productivity enhancements, analyzing fabrication equipment to reduce setup/changeover time, assisting in production operation layout, and analyzing material handling systems in multi-floor facilities. Situations reviewed here show how computerized simulation and industrial engineering skills can combine in beneficial ways [Dwyer and Korwin, 1990].

Simulation offered the solution to Hong Kong Air Cargo Terminals Ltd (HKACT) as it planned to accommodate Terminal 1 overload and continue cargo growth. HKACT needed to build the terminal vertically since land was scarce. In addition, HKACT needed to evaluate system features quickly and carefully before the final design and construction, since the investment was enormous, the design was unique and other reasons. AutoSimulation's AutoMod II silicon graphics workstation was used and the accurate, detailed model was completed in just three months. Simulation made it possible to predict potential problems with a degree of accuracy and solve them before the terminal was built [Luk, 1990].

The two main systems that were examined at HKACT were the Bulk storage system (BSS) and the Container storage system (CSS). The simulation model of the BSS concentrated on the feasibility of the proposed control logic, queuing problems at the input and output (I/O) areas, management of empty boxes and bins, scheduling of stacker cranes, and utilization of storage racks. Simulation models of the CSS examined investigation of the utilization and operation cycle time of high-speed elevators, empty container elevators, and floor level shuttle cars. Examination of the storage capacity, detection of specific bottlenecks, and what-if analysis evaluating control strategies for material flow were also simulated.

The Benefits of Animation

Simulation modeling is growing in popularity, due in large part to the easy-to-use animation [Law, 1991]. Animation's chief appeal is its' ability to communicate the "crux" of a simulation. Animation represents key elements of a system on a computer screen as icons. These icons change color, shape or position with a change in the simulation. Animation also allows for a way of debugging of a simulation program. It can show when a simulation model is invalid and can encourage suggestions to improve the system. Animation makes it easier to understand the behavior of a system and makes it easier to train operational workers. However, animation should not be used as a substitute for careful analysis of data output by the simulation.

Animation for the model proved to be especially useful for this project. During the development of the model, animation was not only useful in detecting the blocks where problems with the code arose, but it also proved useful during model validation. Someone who is familiar with the process can, by examining the animation, verify the accuracy of how the model depicts material movement moves through the process at RAAP. For instance, although the data output gathered were statistically correct in one model, animation was used to detect an unlikely traffic problem while the AGVs were in route. Animation also makes presenting this model to management a lot easier. A graphical output of the project's animated background is illustrated in Figure 2: Graphical Output Of Animation Background.

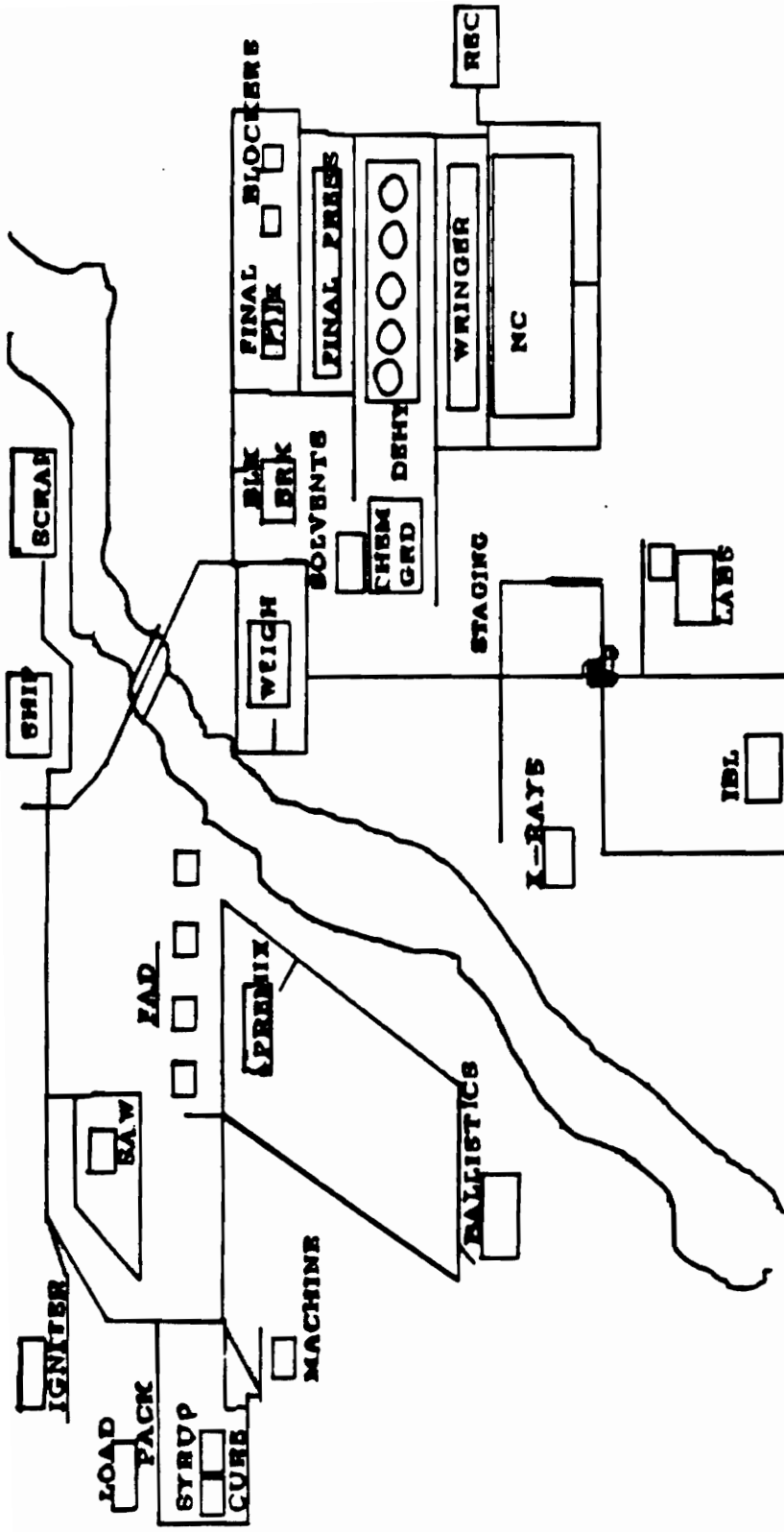


Figure 2: Graphical Output Of Animation Background.

About SIMAN And Cinema

SIMAN IV is a powerful, general-purpose simulation software package which is equipped with capabilities to expand through its' link with FORTRAN. It is capable of network modeling, discrete event scheduling, continuous modeling or a combination of these for combined discrete-continuous models.

The SIMAN software divides the model into two parts - the "model" and the "experiment". This allows the user to change parameters and variables using only the experiment section of the model. In the experiment section of the model, the user may change parameters such as the batch sizes, the time between cotton batch releases, the time between NG manufacture, the time between chemical preparation, the number of resources for each station, the mix sizes, the cycle times at each station, the number of vehicles to be used, the number of operators/inspectors available, and the speed limit of the vehicles. If while changing the cycle time or mix sizes, the rework or scrap rates change for the Final Mix or the Sawing Operation, the user may also make adjustments to these variables accordingly.

This "model" component and "experiment" component framework is based on the theoretical concepts developed by Zeigler (1976). The model describes the physical elements of the system (machines, workers, storage points, transporters, information, parts flow, etc.) and their logical interrelationships. The experiment specifies the experimental conditions under which the model is to run, including elements such as initial conditions, resource availability, type of statistics gathered, and length of run. The experiment frame also includes the analyst's specifications for such things as the schedules for resource availability, the routing of entities, etc. Experimental conditions are specified external to the

model description so that they can be changed without modifying the basic model definition.

Once a model and experiment have been defined, they are linked and executed by SIMAN to generate the simulated response of the system. As the simulation is executed, SIMAN automatically saves the responses specified in the experiment. The SIMAN Output Processor can then be used to generate plots, tables, bar charts, histograms, correlograms, and confidence intervals from the saved data. The data can also be displayed by using commercially available mainframe, minicomputer, or microcomputer presentation-quality graphics packages.

SIMAN is supported by Cinema for its animation. The user builds the animation layout by using a built-in drawing package in Cinema or layouts can be imported from AUTOCAD DXF files. Entities, Queues, Resources, etc. must be defined the same as appears in the SIMAN program. The user links the SIMAN program with the Cinema animation on the last line of the experiment section of the program. CSIMAN part of the software runs the animation and allows the user to see a real time graphical animation of the SIMAN model with jobs or customers moving through the system.

The Advanced Manufacturing Systems Division (AMSD) at Cincinnati Milacron is taking on an increasing amount of engineering consulting work. Since 1966, the division has designed numerous flexible manufacturing systems. At present, Cincinnati Milacron is modernizing a facility for a European aerospace manufacturer. AMSD makes extensive use of the SIMAN modeling language. In the late 1970s, AMSD developed its own Fortran-based simulation model and used it for nearly a decade. This program contained about 15,000 lines of code and was very difficult to use and maintain. Now with the help of SIMAN, simulation can be used more readily and more frequently. The reasons for the growing popularity of computer simulation is that it is not time consuming, it is inexpensive, and

there are an increasing number of customers who will not buy a major manufacturing system, let alone a facility, without having been shown some kind of simulated results.

Another heavy user of SIMAN includes Westinghouse Electric Operations Systems (OS) group. It uses simulation to decide whether an improvement to the plant, or expansion, or technology should be the course of change it wants to seek. A model was developed to track truck movements at ground level and subterranean level in the Waste Isolation Pilot Project (WIPP) in Carlsbad, New Mexico [Industrial Engineering, June 1990]. AUTOCAD and other CAD schematics were typically imported into the Cinema package for animation.

SIMAN was chosen as the simulation language and Cinema was used to animate the simulation. Although the software chosen proved to be a powerful package, the main reason for this choice was its availability at Virginia Tech.

CHAPTER III: APPROACH TO THE PROBLEM

Modelling Methodology

The purpose of this project is to illustrate to the user a method of investigation for different alternatives for the material handling and the manufacture of TOW Launch propellant. The 30 operations required to manufacture TOW Launch propellant are performed in two different areas. Currently, one HPC lot of cotton (72 mixes) is released for production (approximately one every four months). The first 13 operations are performed in an area of the plant referred to as the "Green Lines". Each mix is transferred to the "Rocket Area" where the remaining operations are performed. Each entity in the model represents a mix in the Green Lines or a Sublot in the Rocket Area. Each operation has been simplified to a basic cycle time which includes parts handling, average setup, and processing time so that the whole process can be examined at a macro level. Maintenance is performed during idle periods. Each cycle time was examined and found to be distributed Lognormally with mean μ and variance σ^2 .

In order to simplify the model, some operations were combined, when possible, without invalidating the model. The Pressing, Cutting and Boarding operations were combined because they all take place at the same station, and one is done immediately after the other to the same mix. Therefore, these operations can be viewed as one operation with one total cycle time from a systems view point. Operations 16 through 21 and operations 25 and 26 were also combined for the same reasons. Therefore, 30 operations were reduced to 22

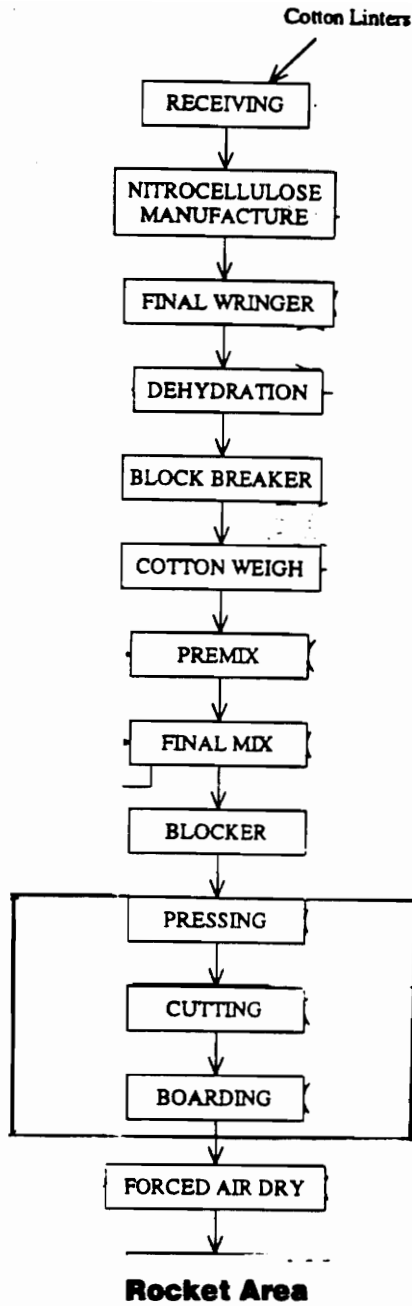
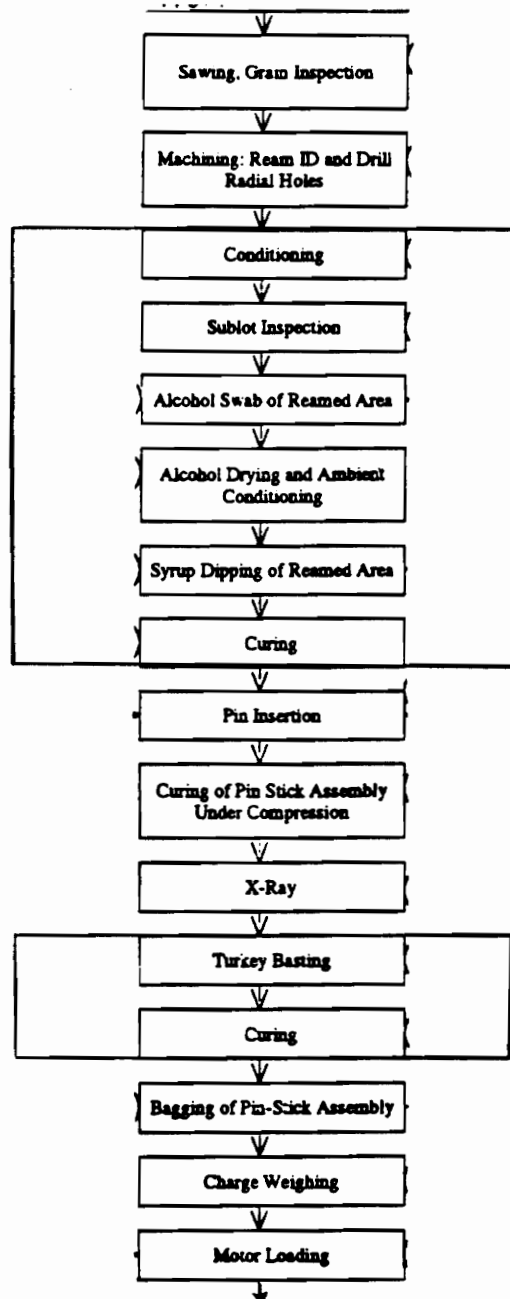


Figure 3: Green Lines Operations Combined For Simulation Model

From Green Lines



Ship

Figure 4: Rocket Area Operations Combined For Simulation Model

operations for the model and their cycle times adjusted accordingly. Figures 3 and 4 illustrate the operations which were combined.

Table 1 illustrates the resources and their capacities for operations after they have been combined for modeling. At each resource, the actual cycle time is not published for proprietary reasons. If a fifty percent reduction in demand was anticipated and the resources were to be reduced accordingly to approximate proportions, the resulting number of resources and their capacity is presented in the third column. At some operations, a 50% reduction does not affect the number of resources because only one is presently being used. Other resources will be reduced by more than 50% because an odd number is being used. The resulting scenario will be simulated to determine if the reduced shipping schedule can be supported by the reduced operating capability. Adjustments will then be made as necessary to identify the minimum resources needed to support required shipping schedules.

Some operations required external production material as in the case of the Mixing operation which required Nitroglycerin, and the Turkey Basting operation which required syrup were assumed to have other production systems in place to handle the needed material. This assumption can be made because there have always been plenty of these auxiliary materials in stock and they have never been the bottleneck in the past. However, in the future this model can be modified to predict how much of these materials are needed and at what interval so that a just-in-time type production plan can be implemented.

Automatic Guided Vehicles are used to simulate trucks because the distance constraint requirements between vehicles while in route could be handled more easily using zone requirements already present in AGV movements built into the software. Otherwise, the movements of the AGV's on a two way track are identical to that of the "truck like" vehicles in actual use. At the beginning of the simulation, the AGV's all start in the middle of the

Table 1: Existing And Reduced Resource Capacities

<u>Operation</u>	<u>Number of Resources Presently Available and Their Capacity</u>	<u>50% Reduction</u>
0 AGV Trans.	5 Capacity = 1 Mix each or 4 sublots only after FAD	2 Capacity = 1 Mix each or 4 sublots only after FAD
1 Receiving	1 Capacity = 1 Mix each	1 Capacity = 1 Mix each
2 NC Mfg	1 Capacity = 1 Mix each	1 Capacity = 1 Mix each
3 Wring	2 Capacity = 1 Mix each	1 Capacity = 1 Mix each
4 Dehy	2 Capacity = 1 Mix each	1 Capacity = 1 Mix each
5 Block Brk	2 Capacity = 1 Mix each	1 Capacity = 1 Mix each
6 Cotton Wt.	1 Capacity = 1 Mix each	1 Capacity = 1 Mix each
7 Premix	4 Capacity = 1 Mix each	2 Capacity = 1 Mix each
8 Final Mix	2 Capacity = 1 Mix each	1 Capacity = 1 Mix each
9 Blocker	2 Capacity = 1 Mix each	1 Capacity = 1 Mix each
10 Press+Brd.	6 Capacity = 1 Mix each	3 Capacity = 1 Mix each
11 FAD	4 Capacity = 72 Mix each	2 Capacity = 72 Mixes
12 Sawing	1 Capacity = 1 Mix each	1 Capacity = 1 Mix each
13 Machine	2 Capacity = 1 Mix each	1 Capacity = 1 Mix each
14 Preparation	3 Capacity = 1 Mix each	1 Capacity = 1 Mix each
15 Pin	3 Capacity = 1 Mix each	1 Capacity = 1 Mix each
16 Cure2	3 Capacity = 1 Mix each	1 Capacity = 1 Mix each
17 X-ray	1 Capacity = 1 Mix each	1 Capacity = 1 Mix each
18 Turkey Bst	3 Capacity = 1 Mix each	1 Capacity = 1 Mix each
19 Bag	3 Capacity = 6 Mix each	1 Capacity = 6 Mix each
20 Weigh	2 Capacity = 1 Mix each	1 Capacity = 1 Mix each
21 Motor Ld	1 Capacity = 4 Mix each	1 Capacity = 4 Mix each
22 Ship	1 Capacity = 4 Mix each	1 Capacity = 4 Mix each

plant at a "staging" area. This is a reasonable estimate of their average position because when the lot is released for production, the vehicle would either be at the staging location or scattered throughout the plant completing other tasks. All vehicles check to see if they are needed at another station immediately after every delivery. If so, they service the next station without staging. If not, they return to the staging area. The number of stagings are counted to determine if adequate staging is being performed and if a reduction in the number of AGVs are possible. Output for AGVs include the percentage of "busy" time as well as the percentage of "active" but not delivering times. This simulation of staging is acceptable because operators telephone the central office prior to leaving a serviced station. If there is no station of the same product to immediately service, the driver prepares the truck to service another product or returns to the staging area.

The plant operates 24 hours per day, 7 days per week. Each simulation time unit in the model represents one hour. The model was run for a simulated four months period or 2880 simulation hours. The data and some of the processes presented for the model has been altered to protect any proprietary interest of Hercules Incorporated or RAAP.

During the actual operation, the mixes are blended to make the same number of sublots at the FAD and Sawing operation. This is simulated and described in the next section. This blending affects the uniformity of the reject rates throughout the lot and is simulated in the Sawing, Machining and X-ray operations.

Model Description

The block diagram and the code for the model are found in the Appendices. The model begins with the creation of batches of cotton, with time between arrivals exponentially distributed, to be inspected at the Receiving station. Throughout the code each Inspector

or each operator represents one resource (ie. they operate one unit of resource). An AGV is then requested and the cotton is transported to the Nitrocellulose manufacturing station. Here an operator and an Inspector are required to monitor the process until a batch is made. The operator and the Inspector is released and the material is sent to the wringer queue. The wringer only processes one mix a time. The AGV picks up the processed mix from the Wringing station and transports it to the Dehydration station where the animation attribute is changed.

The mix is then sent through the Block Breaking, Cotton Weigh, Premix, Final Mix, and Blocking operation using similar mechanisms. At the Final Press and Boarding operation, the yield is about 64 percent and the remaining 36 percent is sent back to the Final mixing operation to be reprocessed as simulated with a branching node.

The good materials are sent to the Forced Air Dry (FAD) operation where a whole HPC lot is accumulated prior to processing. The mixes wait in the FAD queue prior to being combined and processed through temperature cycling. Once this is completed, a sample is sent (via vehicle) for ballistics evaluation. This is a destructive test so the sample is "disposed" at the Ballistics lab. The remaining materials are divided into sets of four "sublots" and waits in an "FADdone" queue for a signal to be given from the Ballistics lab (via telephone). After the signal is received, one set of four sublots are sent to the Sawing operation. After the initial signal, the remaining release signals for the lot are given by the Sawing operation.

At the Sawing operation each set is divided into four Sublots. The Sawing operation processes one Sublot at a time until all four have been processed at which time it sends a signal to the FADdone queue to send another set of four Sublots. At this operation the material is inspected and the rejected material is sent to the Burning Grounds for disposal.

The good material is sent to the Machining operation. At the Machining operation, the rejected grains are also sent to the Burning Grounds for disposal. The remaining materials are then routed to the Grain Preparation, Insert Pin and the Curing operations.

During the cure time the operator is idle. After curing, the materials are transferred to the X-ray operation. Here the grains are inspected internally and the reject grains are disposed of at the Burning Grounds. The good grains are transferred to the Turkey Baste where Basting and Curing of the grains are both done in this operation. After this is done the materials are transferred to the Bagging, Weighing, Motor loading, and Shipping operations. These operations are simply a series of standard "Queue, Seize, Delay, and Release" blocks. At the Shipping operation, a measure of "time in system" is taken (Tally) and the entity is disposed.

Performance Criteria

The purpose of this investigation is to determine the minimum system resource configuration necessary to support reduced production requirements without delinquent shipment. Since this report will not disclose the shipping requirements due to proprietary infringement, performance will be measured in terms of percentage of shipping requirements fulfilled. The first model will be validated by its' capability to produce 100 percent of the shipping requirements, within the 2880 time units allotted with 10 percent variance on the surplus side and no variance on the delinquent side as this is consistent with the present production and shipping policies. Successive modified models will be measured by their ability to produce 100 percent of the reduced requirements with the same variances. This policy of producing surplus is in place because delinquent orders of propellant may mean bottlenecks to more critical systems off plant, while surplus

production is stored without cost in government owned magazines on plant awaiting the next order. Queues and utilization resources (including AGV's) at each operation will be examined to identify opportunities for resource adjustment (decreases or increases, as necessary).

CHAPTER IV: CASE STUDY RESULTS

Model Validation

A model of the system was developed and executed so that a standard batch of cotton which contained 72 mixes of propellant was released at the beginning of a four month cycle. The model was adjusted, by using better estimates of the distances between stations, so that at least 105 percent of the production requirements were met with a variance of 5 percent. Actual scrap and rework data for a one year period were averaged for use in the model. Average queues and utilization of each operation for the model were compared to estimated actual queues and utilizations. For operations which were combined, the average of the total queues were estimated based upon historical experience. Once the model was adjusted, the number of replications was determined by estimating, with 95% confidence, that the average percentage of required shipment is only off by less than 4.0 percent to ensure variance requirement specified is met. The following equation was used:

$$n = (z_{\alpha/2} \sigma / e)^2$$

Where $z_{\alpha/2} = 1.96$ for the estimate of $\mu < 0.05$

and $e = 4.0$

$\sigma = 4.5$ for the ten initial data points generated

Therefore $n = 4.8$ or at least 5 replications.

A typical printout of the data for the model is in the Appendix V. The average queues and utilization for all resources was very low over the simulation time as expected. These

are summarized in Table 2. This number was calculated by taking the weighted time for which the value persists during the simulation. Most of the time the resources sat idle because only one lot at a time is released over a four month period. However, during the time the material is being processed through any particular part of the system, that part may experience very high utilization and maybe even some queue build up. This is recorded in the "maximum" queue column. It is observed that the highest maximum queue values occur at the FAD and the Machining operations. This, again, is very consistent with actual practice. The high queue build up at the FAD occurs by design. The material is purposely accumulated there before the FAD bay is turned on for efficiency reasons. The large queue build up at the machining operation is not significant because the average utilization for the station is less than 20% and, therefore, the queue may be eliminated through better material handling or by better production control methods in the future. The AGV's (trucks in actual practice) have the highest utilization of approximately 80%, which is again expected and consistent with actual practice because of the vast distance requirements between stations due to explosion propagation safety practices.

Analysis Of System and Documentation Of Results

The resources for the model and the lot size were reduced by 50%. The amount produced at the end of 2880 hours of production was compared to the required demands and the results of each of the replications are listed in Table 3. Since the standard deviation

Table 2: Summary Of Simulation Output Data
Average Queues And Utilization For Base Model

<u>OPERATIONS</u>	<u>AVERAGE</u> <u>QUEUE</u>	<u>MAX</u> <u>IN</u> <u>QUEUE</u>	<u>OPERATIONS</u>	<u>AVERAGE</u> <u>UTILIZATION</u>
AGV QUEUE	0.00943	4.0	AGV 1 Time Active	0.87727
NC QUEUE	0.03642	6.0	AGV 2 Time Active	0.88215
NQ(NCPROCQ)	0.163	6.0	AGV 3 Time Active	0.87877
WRINGER QUEUE	0.000081	0.0	AGV 4 Time Active	0.87673
DEHY QUEUE	0.000073	1.0	AGV 5 Time Active	0.49915
BLOCK BREAK QUEUE	0.000052	1.0	AGV Actual Busy	0.80007
WEIGH QUEUE	0.00121	1.0	RECEIVING STATION	0.100000
PREMIX QUEUE	0	0.0	NITROCOTTON STATION	0.249970
FINAL MIX QUEUE	0	0.0	WRINGER STATION	0.100600
BLOCKER QUEUE	0.00375	1.0	DEHYS	0.100260
FINAL PRESS QUEUE	0.00172	1.0	BLOCKBREAKS	0.099230
REMIX QUEUE	0.000086	1.0	WEIGHS	0.125490
FAD QUEUE	14.51	36.0	PREMIX STATION	0.099910
FAD DONE QUEUE	1.009	9.0	FINAL MIX STATION	0.154170
NQ(SAWQ)	0.14776	3.0	BLOCKERS	0.154170
NQ(MACHINEQ)	2.3453	14.0	PRESS AND BOARD	0.153190
MACHINE INSP.Q	0	0.0	FAD BAY	0.003570
GRAIN PREP QUEUE	0.01229	1.0	SAW STATION	0.098510
NQ(PINNINGQ)	0	0.0	SAW INSPECTION	0.000000
NQ(CURE2Q)	0	0.0	MACHINING STATION	0.185640
NQ(CURE2DONE)	0	0.0	MACHINING	0.023260
NQ(XRAYQ)	0	0.0	GRAIN PREP	0.176370
NQ(BASTEQ)	0.02305	1.0	PINNING STATION	0.044280
NQ(BAGQ)	0	0.0	CURING BAY	0.044440
NQ(CHARGEWEIGHQ)	0	0.0	XRAY STATION	0.044460
NQ(MOTORLOADQ)	0	0.0	TURKEYBASTING	0.152040
NQ(SHIPQ)	0	0.0	BAGGING STATION	0.057340
			CHRG WEIGHING	0.038030
			MOTOR LOADING	0.037910
			SHIPPING	0.038230
			BURNING GROUNDS	0.011810

Table 3: Tabulated Results For Throughput After A 50% Reduction

<u>Replication(n)</u>	<u>Percent of Required</u>
1.	100
2.	96
3.	100
4.	96
5.	96
6.	96
7.	96
8.	96
9.	100
10.	96
11.	96
12.	96
13.	96

**Table 4: Average Queues And Utilizations For 50% Reduction Before Adjustments
Were Made To AGV's And Machining Stations**

<u>OPERATIONS</u>	<u>AVERAGE QUEUE</u>	<u>AVERAGE MAX IN QUEUE</u>	<u>OPERATIONS</u>	<u>AVERAGE UTILIZATION</u>
AGV QUEUE	0.670490	12.5	AGV 1 Time Active	0.618285
NC QUEUE	0.111275	4.5	AGV 2 Time Active	0.568770
NQ(NCPROCQ)	0.164630	4.5	AGV Actual Busy	0.237100
WRINGER QUEUE	0.000000	0.0		
DEHY QUEUE	0.000083	1.0	RECEIVING STATION	0.175075
BLOCK BREAK QUEUE	0.000304	1.0	NITROCOTTON STATION	0.125075
WEIGH QUEUE	0.001237	1.0	WRINGER STATION	0.049155
PREMIX QUEUE	0.000000	0.0	DEHYS	0.049600
FINAL MIX QUEUE	0.000000	0.0	BLOCKBREAKS	0.050200
BLOCKER QUEUE	0.000087	1.0	WEIGHS	0.062330
FINAL PRESS QUEUE	0.000307	1.0	PREMIX STATION	0.049705
REMIX QUEUE	0.000000	0.0	FINAL MIX STATION	0.066665
FAD QUEUE	3.618550	36.0	BLOCKERS	0.066665
FAD DONE QUEUE	0.274475	9.0	PRESS AND BOARD	0.066910
NQ(SAWQ)	0.074585	3.0	FAD BAY	0.003470
NQ(MACHINEQ)	0.439230	8.5	SAW STATION	0.049725
MACHINE INSP.Q	0.000000	0.0	SAW INSPECTION	0.000000
GRAIN PREP QUEUE	0.023115	1.5	MACHINING STATION	0.094345
NQ(PINNINGQ)	0.000000	0.0	MACHINING	0.011810
NQ(CURE2Q)	0.000000	0.0	GRAIN PREP	0.091645
NQ(CURE2DONE)	0.000000	0.0	PINNING STATION	0.022775
NQ(XRAYQ)	0.000000	0.0	CURING BAY	0.022915
NQ(BASTEQ)	0.010205	1.0	XRAY STATION	0.022965
NQ(BAGQ)	0.000000	0.0	TURKEYBASTING	0.070760
NQ(CHARGEWEIGHQ)	0.000000	0.0	BAGGING STATION	0.026640
NQ(MOTORLOADQ)	0.000000	0.0	CHRG WEIGHING	0.017725
NQ(SHIPQ)	0.000000	0.0	MOTOR LOADING	0.017670
			SHIPPING	0.017785
			BURNING GROUNDS	0.007290

is less than 2, the number of replications required was much less than 13 (per the above method of calculation) to ensure the true average. The data illustrates that the process is not capable of meeting the expected output of 100 percent with a ten percent variance on the positive side. Therefore, the utilization and queue data for the process was examined to identify necessary resource adjustments.

The average queues and utilization for each of these replications are summarized in Table 4. These averages were obtained by importing each replication into a Lotus file and averaging 13 replications (thirteen was arbitrarily used because it is larger than 5 which was the minimum required). It was noted that the resources that had the largest maximum queues were the FAD, AGV's, and Machining operations. Again, the FAD queue can be discarded. One more AGV was added and one more machining station was added to this model making a total of three AGV's and two Machining stations. The model was run again for 2880 hours per replications and the amount produced was compared to the shipping requirements. The results are tabulated in Table 5: Tabulated Results For Throughput After A 50% Reduction Of Resources and Adjustments Are Made to Bottlenecks. The results of this model were compared to the results of the original model to see if a difference could be detected between the two using a confidence interval-t-test.

To determine if there is any statistically significant difference between one system or the other, performance measures were evaluated using the *paired-t confidence interval* test. Although other methods can be used to compare the two systems, this technique is utilized for two reasons. First, the variance between the two systems for each iteration does not have to be assumed as equal. They would have to be assumed equal for methods like a two-sample-t method. Secondly, the data between one system and the other do not have to be independent. Only the data within one system need to be independent.¹²

Table 5: Tabulated Results For Throughput After A 50% Reduction Of Resources and Adjustments Are Made to Bottlenecks

<u>Replication(n)</u>	<u>% of Required For</u> <u>Adjusted Model</u>	<u>% of Required For</u> <u>Original Model</u>	<u>Difference (d)</u>
1	108	108	0
2	104	106	-2
3	104	108	-4
4	104	106	-2
5	108	104	4
6	108	104	4
7	104	104	0
8	104	104	0
9	104	104	0
10	104	104	0
11	108	106	2
12	108	104	4
13	108	106	2

Calculations to determine if the difference (d) was significant between the two system were made using the following methods:

$$d_{avg} = \text{SUM}(d_i)/n$$

$$s(d) = \text{SQRT}((\text{SUM}(d_i - d_{avg})^2)/n - 1)$$

$$s(d_{avg}) = s(d)/\text{SQRT}(n)$$

$$h = t_{n-1, 1-\alpha/2} s(d_{avg})$$

The results were as follows for a 0.95 confidence interval on δ :

$$\mathbf{d_{avg} = .462}$$

$$\mathbf{s(d) = 2.73}$$

$$\mathbf{n = 13}$$

$$\mathbf{s(d_{avg}) = 0.76}$$

$$\mathbf{t_{n-1, .975} = 2.18}$$

$$\mathbf{h = 1.65}$$

$$\mathbf{C.I. = [-1.19, 2.11]}$$

Since the confidence interval of the "throughput performance measure" for the two systems is between -1.19 and 2.11, it can be concluded with 95 percent confidence that this interval contains the difference of the average throughput for the two systems. However, since the interval contains a 0, it can be asserted that there is no difference between the two systems.

CHAPTER V: SUMMARY AND CONCLUSION

Summary

The Radford Army Ammunition Plant was designed for extremely high volumes of propellant manufacturing. Due to the recent cut backs in defense spending, the demands for such high volumes no longer exists. However, the plant continues to operate in a high volume mode. A method to determine the resources which can be eliminated as production is scaled down, and still not be delinquent on any orders, is required. This method would help define the resource capacities under the present mode of operation.

A simulation model was built to reflect the present modes of operation for a typical time period. Animation of the model was used in conjunction with data analysis to help validate the model. The demands and resources for the model was then reduced and the model was run for the same time period. The output was measured in terms of percentage of demand met. Adjustments were made so that the model would produce the required percentage of demands which would be equivalent to the original system. This defined the new resource capacity for the new demand under existing mode of operation.

It was found that the overall utilization of all stations are insignificant over the four month production period simulated. However, during the time when the material is actually being passed through the stations, some stations experience queue build up. Due to the present mode of operation at RAAP, facilities are continually being used at full capacity and then shut down completely for extended periods of time. This inefficiency has been accepted in the past, but as the plant prepares to compete with other propellant manufacturing plants, for a smaller propellant market, it will be forced to plan for more efficient use of the facilities. This could be accomplished through the use of a more

continuous production planning techniques. Simulation modelling principles could help in this task.

Even though the utilization of the AGV's (trucks) were high, a large part of the "active" time on the trucks were due to staging. This could be prevented by planning operations so that one station could be serviced right after another. There were 72 mixes and 22 different stations in each simulation, which makes approximately 1584 separate moves the trucks would have to make (not including rework or scrap) to complete the lot. During this time, there were an average of 1400 staging operations due to lack of demand while the truck was already out. Eliminating some of this staging may reduce the demands for vehicles.

In the future, RAAP may look into a more continuous mode of operation utilizing smaller batches and better planning. Due to the lack of experience in this mode of operation, simulation would be an ideal tool for RAAP's future planning. Animation of the model will also help in the presentation of the model to management and key production personnel.

Recommendation And Future Work

Other parameters may be investigated using this model. The success of a simulation project is dependent on the simulation knowledge which the participants share and by those who will be impacted by the results of the project. It is usually the simulation user's responsibility to show management the basic methodologies and principles, and the benefits which can be expected through simulation. Although only one parameter was investigated for this project, this model could be used to explore the consequences of changing other parameters for each operation in the process. By varying parameters and variables in the experiment section of the software, the user can illustrate unlimited numbers of possibilities for future improvements. However, care must be taken to examine

all effects of changing each factor when Investigating other modes of operation. Changing one known factor may have large effects on unknown parameters which may make the model invalid. For example, if the Mixing operation were to be examined closely, the cycle time could be reduced by changing the mix size. Besides having effects on the arrival times at the next operation, this would also change the quality of the material so that the rework rates for the process would also have to be adjusted.

Another example is if the Receiving operation was to be examined. If a controlled change was made to the batch sizes, the cycle time would be affected. The quality down stream of the process may also be affected due to different batch sizes and, therefore, other yields would be affected. Here, making a known change to one factor could influence other factors in ways which are unknown and are significant to the model's validity. Therefore, it is recommended that parameters and variables in the model should only be determined by someone who has sufficient experience with the process to detect other possible process impacts which may not be accounted for by the model.

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Appendix I

TOW Launch Manufacturing

The flow diagrams for the M7 for TOW Launch and the TOW Launch processes are illustrated in Figures 5 and 6. The main areas involved for the production of TOW Launch are the Green Lines, the Finishing Area and the Rocket Area. However, the process actually starts out in the Nitrocellulose Area where approximately 12,000 pound batches of cotton linters are nitrated at one time to make Nitrocotton (NC). After the nitration process, samples are taken to the laboratory to analyze for the extent of nitration. Adjustments are made to the batch and the material is then transferred to the wringer in the form of a water wet slurry. The wringer wrings out the water from the NC to approximately 14% moisture. At this point the NC appears in as a white powder.

The NC is then transferred to the Green Lines where further reduction in moisture is done at the dehydration presses. Here the NC is loaded into the presses in approximately 100 pound increments. After the water has sufficiently been removed from the NC, the NC become cylindrical blocks as a result of high pressures from the presses. A sample is taken to the chemical laboratory during this time to ensure proper dehydration of the NC.

The NC is then transferred to the block breaking station where it is broken back up into a white powder for further processing. The NC is then taken to the Cotton weigh station to be weighed to determine NG and chemical additions. A Total Volatiles test is done during Cotton Weigh to determine the amount of NC required to form a mix.

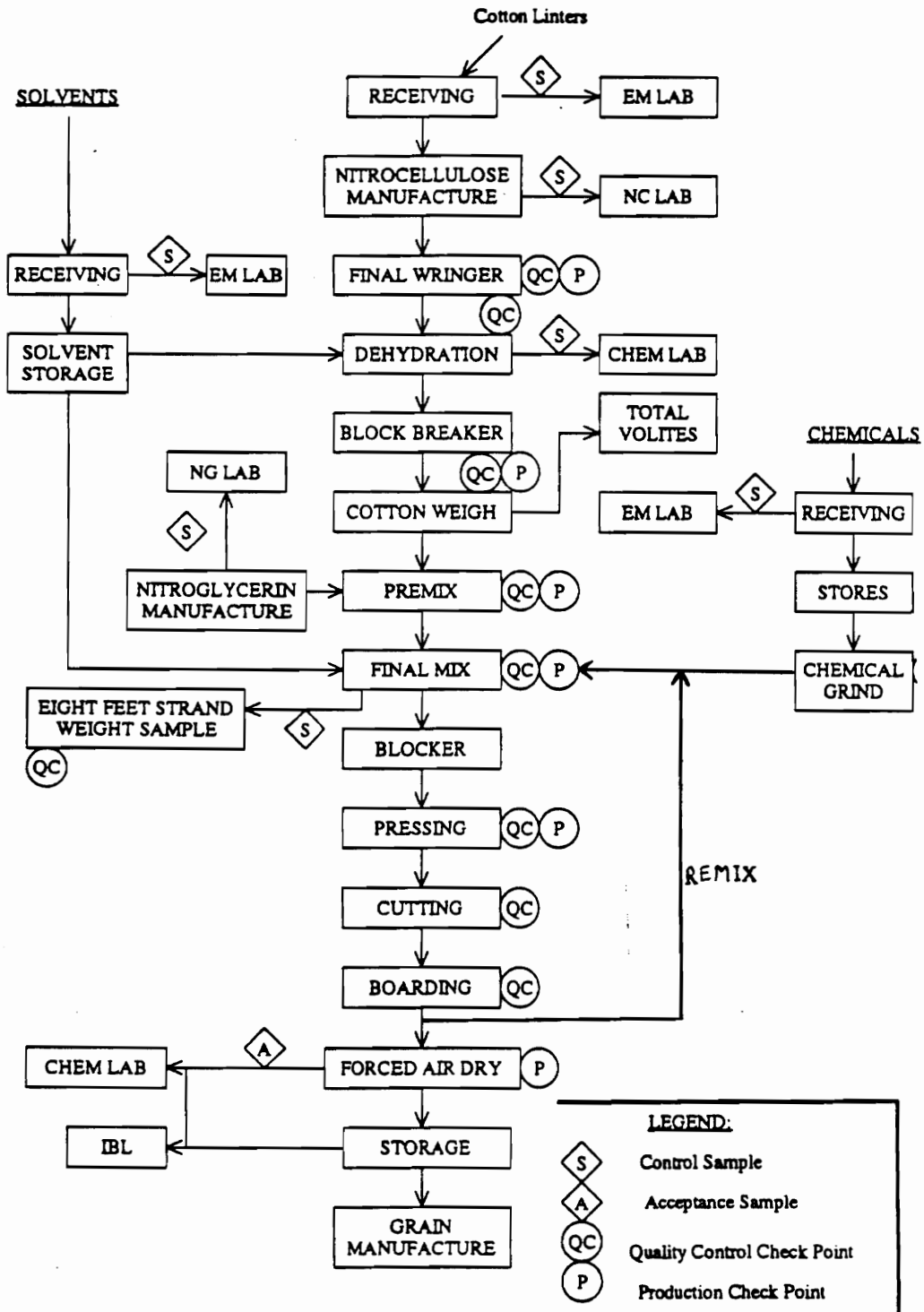


Figure 5: Green Lines Manufacturing Flow Chart For M7 Propellant For TOW Launch Motor

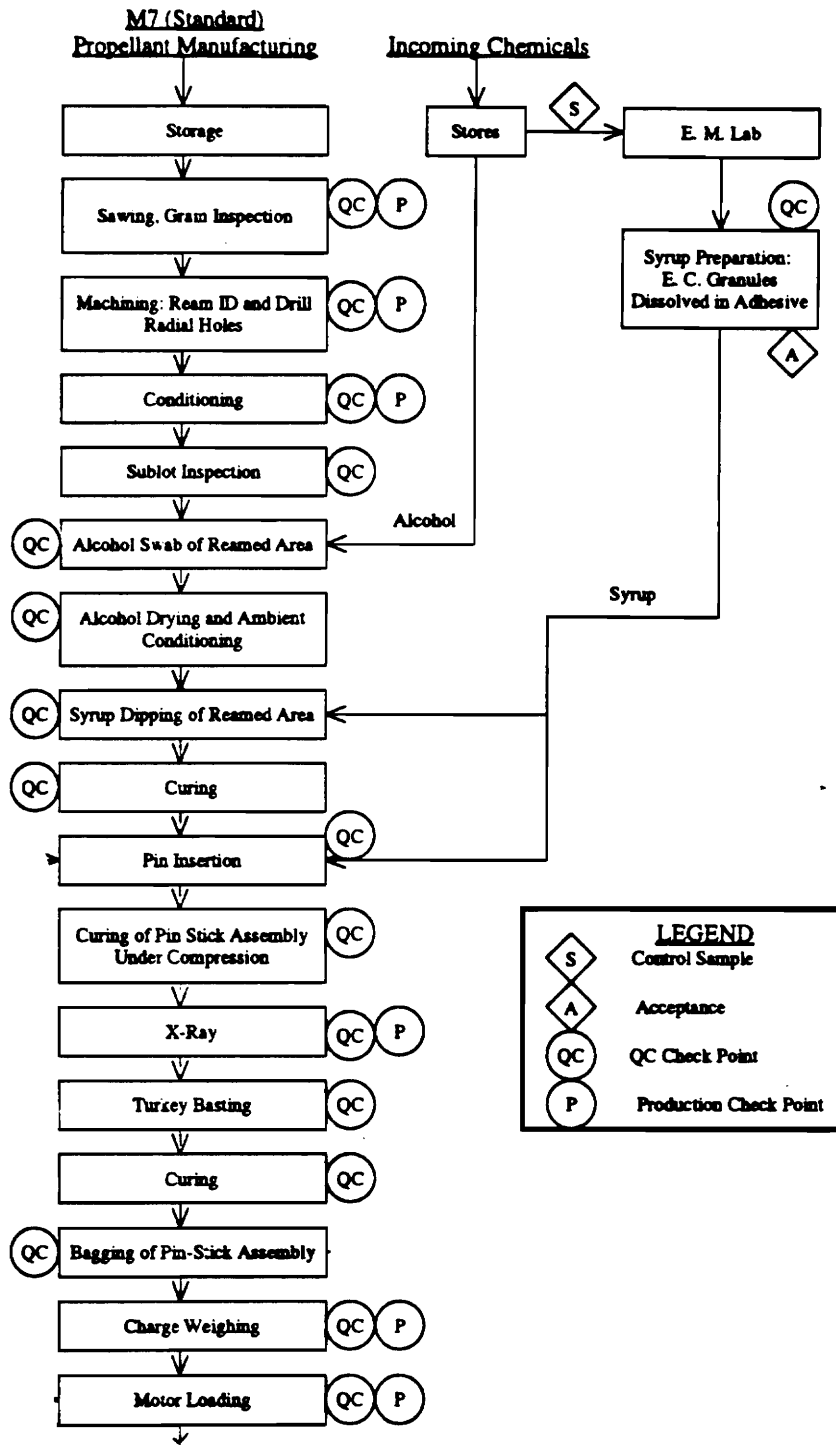


Figure 6: Rocket Area Manufacturing Flow Chart For TOW Launch Motor

The NC is then transferred to the Premix Area where Nitroglycerine (NG) is added and stirred in plastic tubs. Mix numbers are assigned to each mix and the contents are referred to as "Premixes". The Premixes are transferred to the Green Lines where alcohol and acetone (or solvents), and trace amounts of other chemicals are combined and mixed in a 800 pound capacity mixer to make a homogeneous mixture. Each of these ingredients are purchased and are independently inspected. At this point, the material appears as a black dough. The color comes from the Carbon Black added at the beginning of the mix cycle. The maximum amount of material which can be processed through the mixers are dependent on the rate at which NC can be made and mixed independently with NG and carbon black. The rest of the chemicals and solvents do not limit the maximum production rate or these have not been the limiting factors in the past. The Green Lines presently produces approximately 500 to 600 pound mixes and releases in batch quantities of approximately 72 mixes for each lot. For the purpose of this study, a lot can also be released as approximately 36 mixes.

After the material is processed through the mixing operation, it is transferred to the blocking operation where the mix is pressed in a low pressure press and made into cylindrical "billets" approximately 4 inches in diameter. These billets are then transferred to the pressing operation where another vertical press pushes the billets through a die to make approximately 0.75 inch strands with a single perforation through the center. During this process, the operators inspect the strands for surface imperfections and/or blisters caused by the die or air pockets in the propellant. The rejected portions of the strands are cut off and sent back to the Mixing operation as "remix". The process normally produces an average of 36 percent remix. Figure 7 depicts the percentage of remix over a thirteen month period. Although Figure 7 shows that the variance from month to month is extremely high, the actual amounts per production unit are very uniform. Due to accounting problems,

the remixes are not calculated accurately on a per month basis but is accurate on a yearly basis. The remix is then mixed with the "virgin" mixes and are processed as a normal mix. There are two mixers, two low pressure blockers, six four inch presses, and one boarding station. There are 5 +/- 3 boards per mix and 17 +/- 1 strands on each board. These strands are placed on eight feet boards and sent to the Forced Air Dry (FAD) area to be dried in heated bays.

One mix at a time is carried to the FAD Bays and the lot is released from the Green Lines for FAD cycling in increments of approximately 72 mixes, and it is dried in the FAD bays on the boards in which it was transported. Although this is not labor intensive, it is very time consuming. The process time through the FAD accounts for over eighty hours of the entire total processing time. However there are 21 bays, each of which can hold approximately three lots of propellant if needed. This operation involves a series of temperature cycling until the proper total volatile (TV) level is reached. This is determined by the laboratory which takes one day to obtain test results. Most of the volatiles are driven from the propellant during this operation so the strands become hard and plastic textures ready to be sawed.

Before the Sawing Operation can begin, the lot must first be evaluated using an "evaluation" subplot. A subplot consists of randomly mixed propellant grains from mixes. There are approximately 280 grains in each subplot (accounted for in pounds). This sample evaluation subplot is ballistically tested prior to processing the rest of the lot.

The strands in the rest of the lot are then transported to the Sawing Operation where they are sawed into 14 inch grains. From this operation until the end, the grains are being processed in what is considered the "Rocket Area". During this operation the reject rate is approximately five percent as depicted from historical data on Figure 8. Most of the rejections are caused by unacceptably crooked grains or grains with defective surfaces due

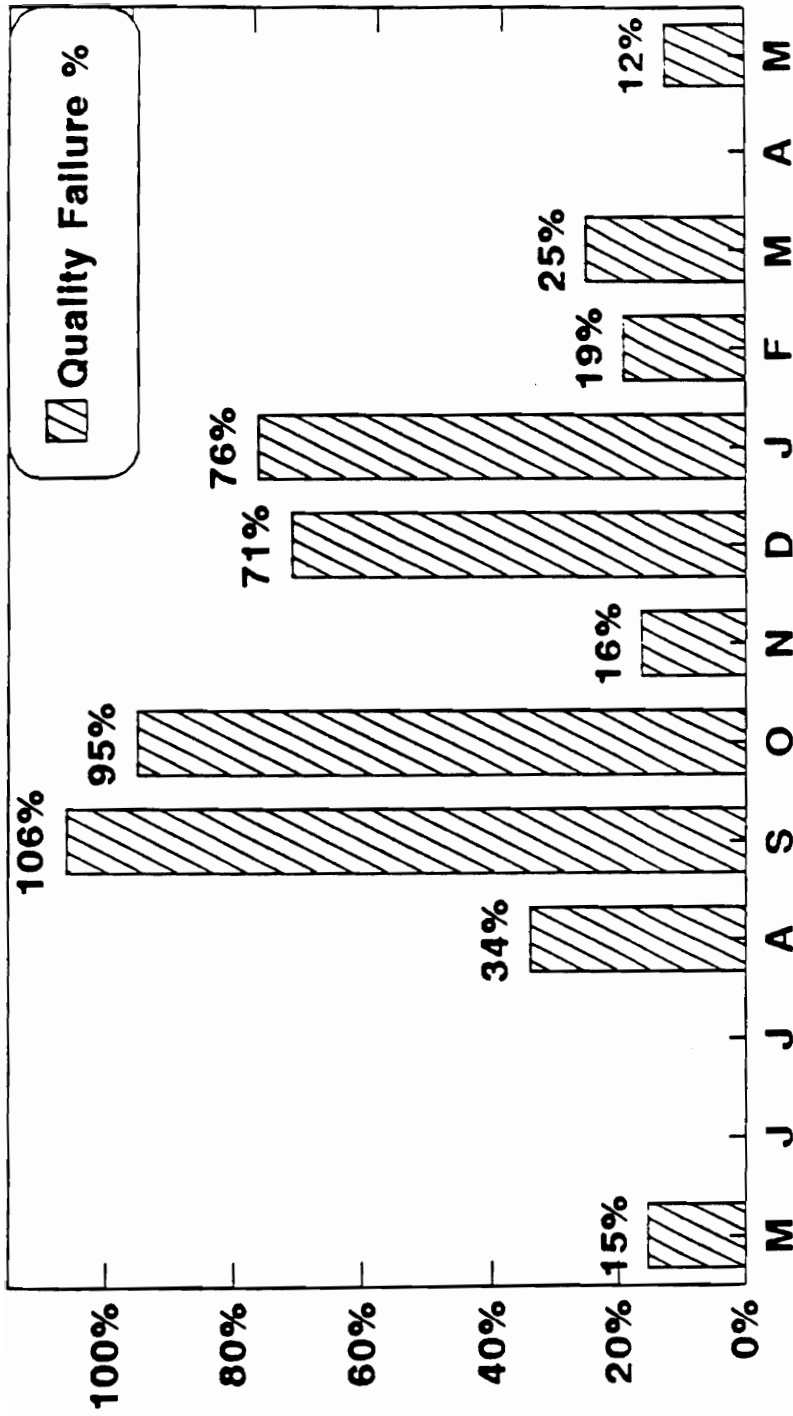


Figure 7: M7 F/TOW 1991 - 1992 Green Lines Area Rework

to pinholes and/or other deformities. These scrapped grains are transported to the Incinerator where they are disposed.

The good grains are then transported to the Machining Operation where three radial holes are drilled into the sides of each grain and the grains are reamed and face on one end to accommodate an insert called a "pin" in later operations. During this operation, the reject rates are approximately five percent as depicted on Figure 9. Rejects at this operation are mainly caused by machining difficulties encountered.

The grains are then transported to the Grain Preparation station where the grains are cleaned and cured to prepare for the Pinning Operation. At the Pinning Operation, a plastic jacketed pin is dipped into a syrup-solvent and inserted into the machined end of each grain. The purpose of this pin is to hold the grains in place during propellant burning in the launch motor. The pinned grains are loaded into cabinets containing trays and are transported to curing bays in the Rocket Area to be cured.

Once curing has taken place, they are transported to the X-ray Operation to be inspected for internal voids or defects. Voids or internal defects may cause unsymmetrical burning of the grains in the motor. At this operation, approximately twenty percent of the grains get scrapped for this reason. Figure 10 depicts the historical data to be used.

After X-ray, the grains are transported to the "Turkey Baste" Operation. At this operation the grains are placed into a fixture with the unpinned end up. The same syrup-solvent used at the pinning operation is injected into the perforation of the grains using a basting syringe. The purpose of this is to ensure that all areas between the plastic jacketed pins and the grains are covered with syrup. The grains are cured at this station.

After Turkey Basting and cure, the grains are transported to the bagging operation. Here the grains are placed in plastic bags to control moisture absorption during further processing. The grains are then transported to the Charge Weighing station where four

grains at a time are weighed on a "Shadow Graph" scale to ensure that they meet specification charge weight requirements.

The grains are finally transferred to the Motor Loading station where they are loaded into launch tubes. These launch tubes are then sent to shipping.

There is one saw, two machining stations available (only one is usually used), two pinning stations, one curing bay, one X-ray machine, one Turkey Basting station, one bagging station, one Charge Weighing station and one Motor Loading station. Some restrictions to material handling abilities are that the trucks cannot carry more than 500 pounds of propellant at once, and that the trucks cannot be less than 30 feet apart while in route.

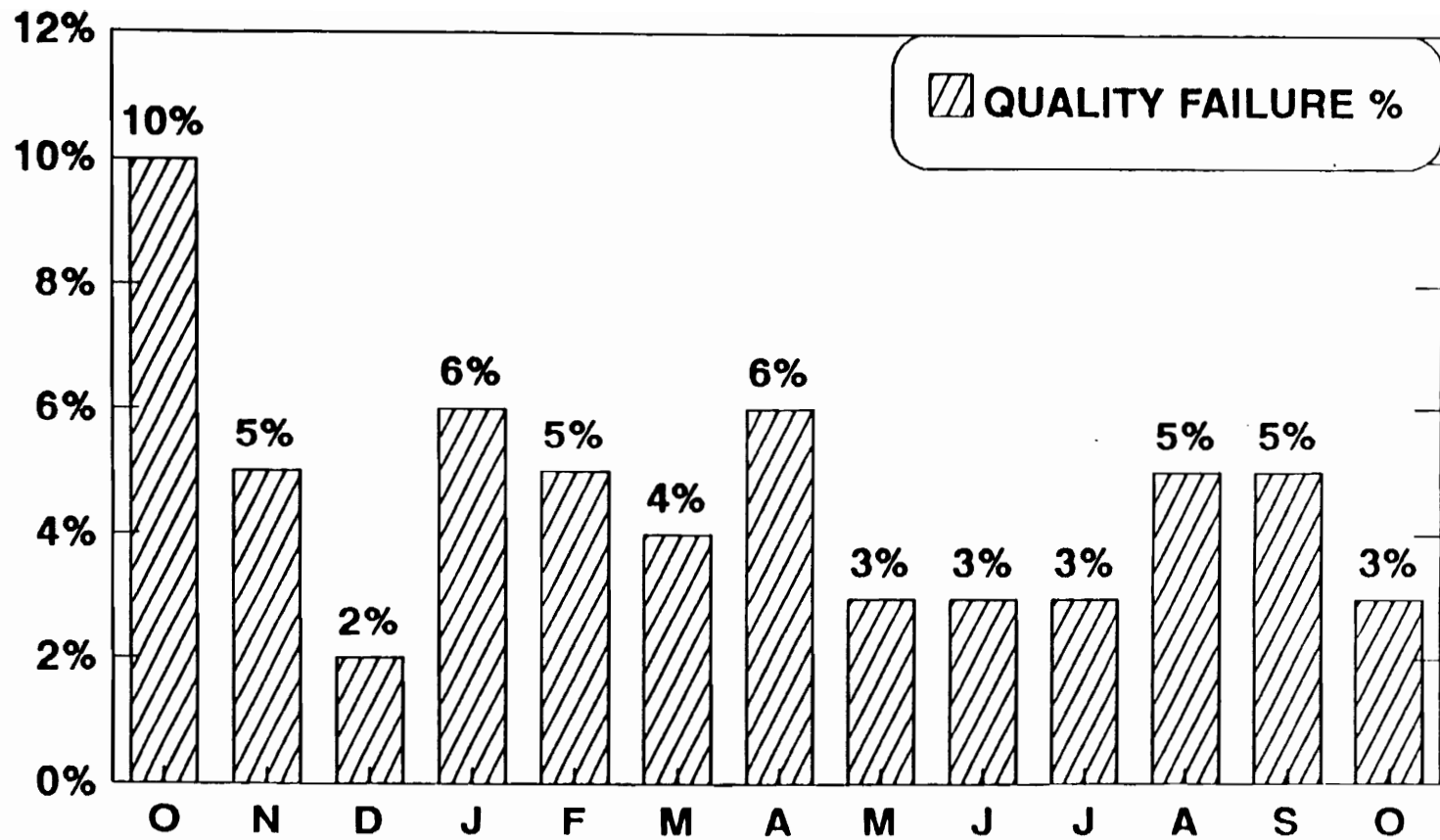
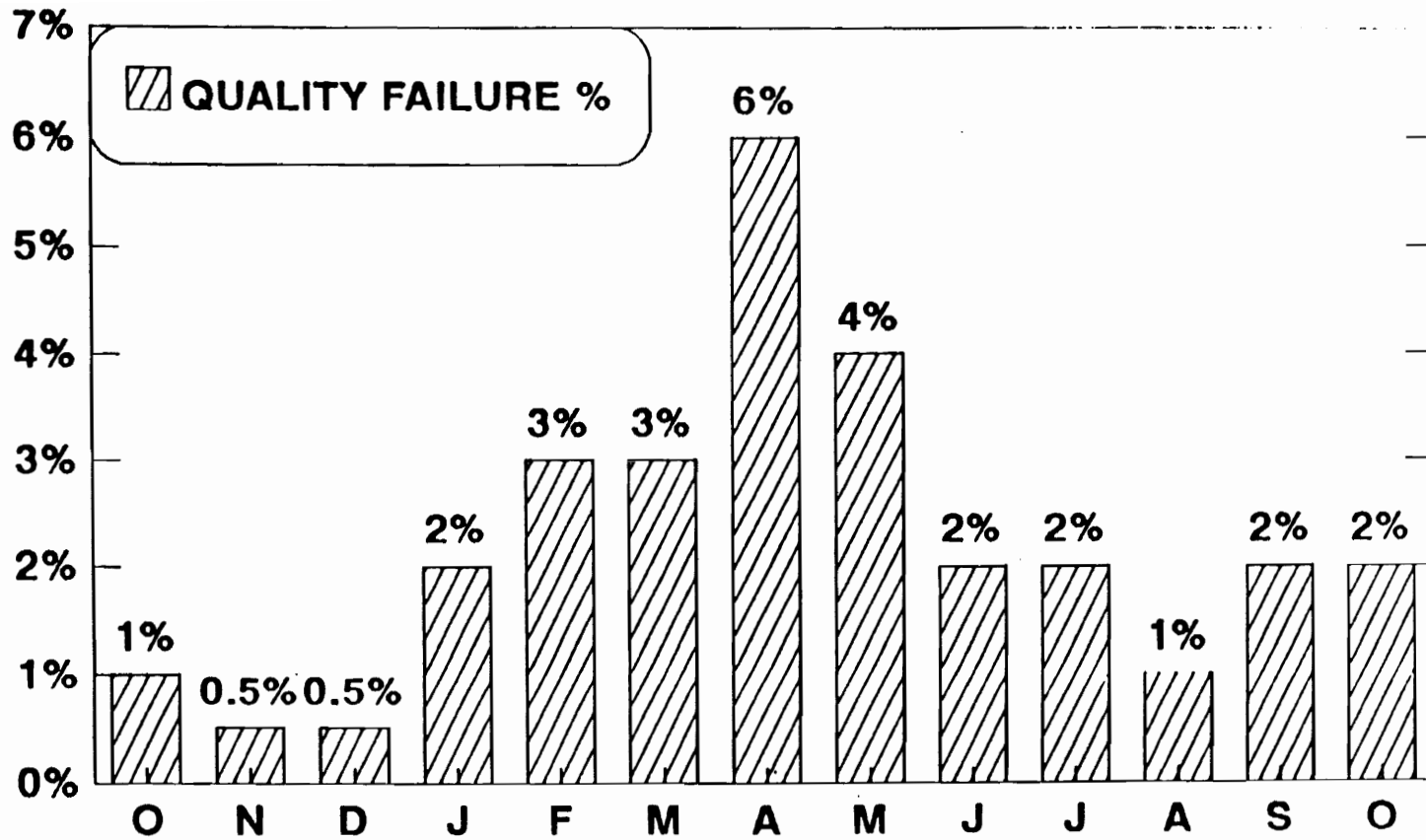


Figure 8: TOW Scrap - Sawing Operation

Rocket Manufacturing Area 1991 - 1992



**Figure 9: TOW Scrap - Machining Operation
Rocket Manufacturing Area 1991 - 1992**

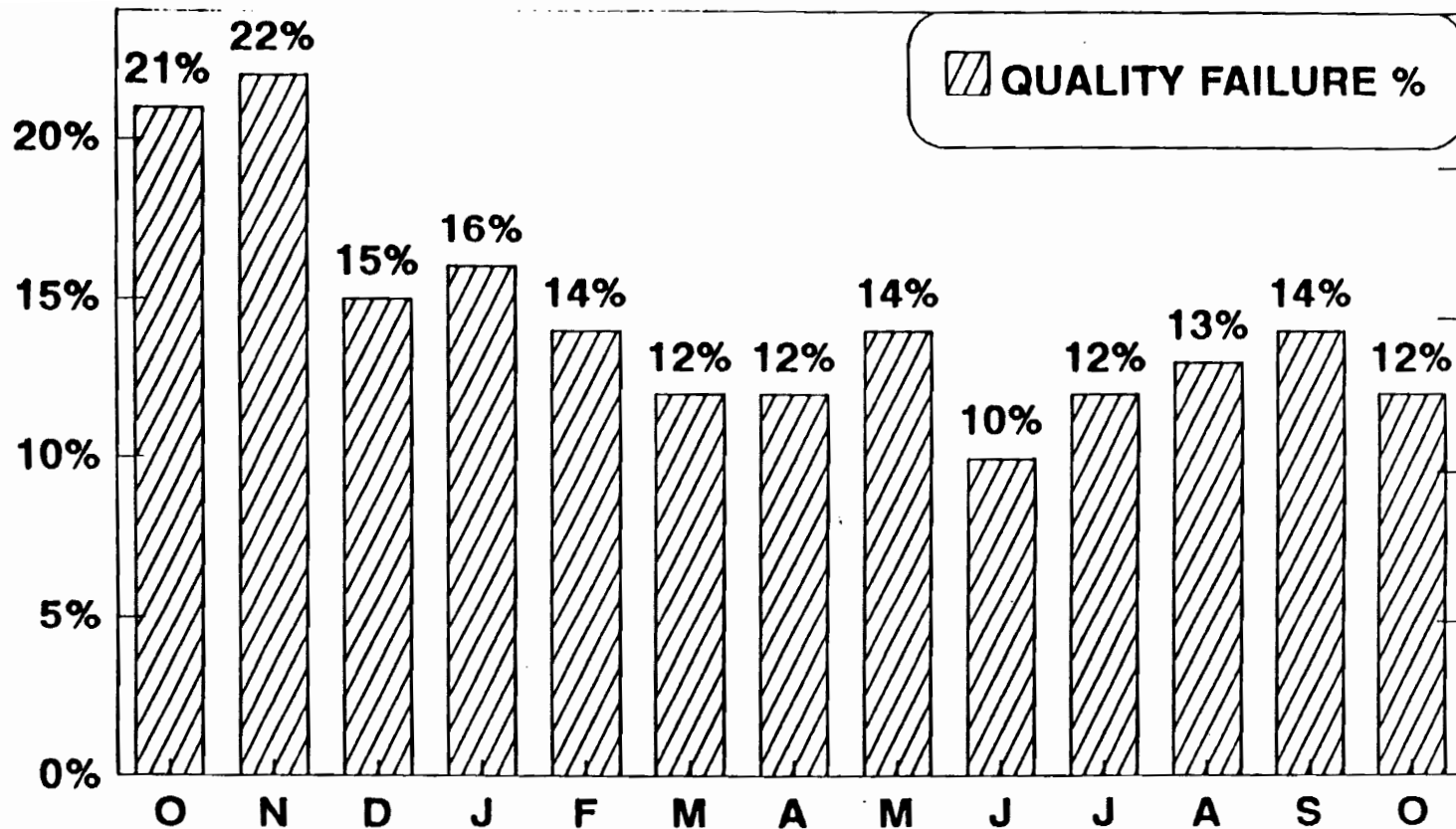
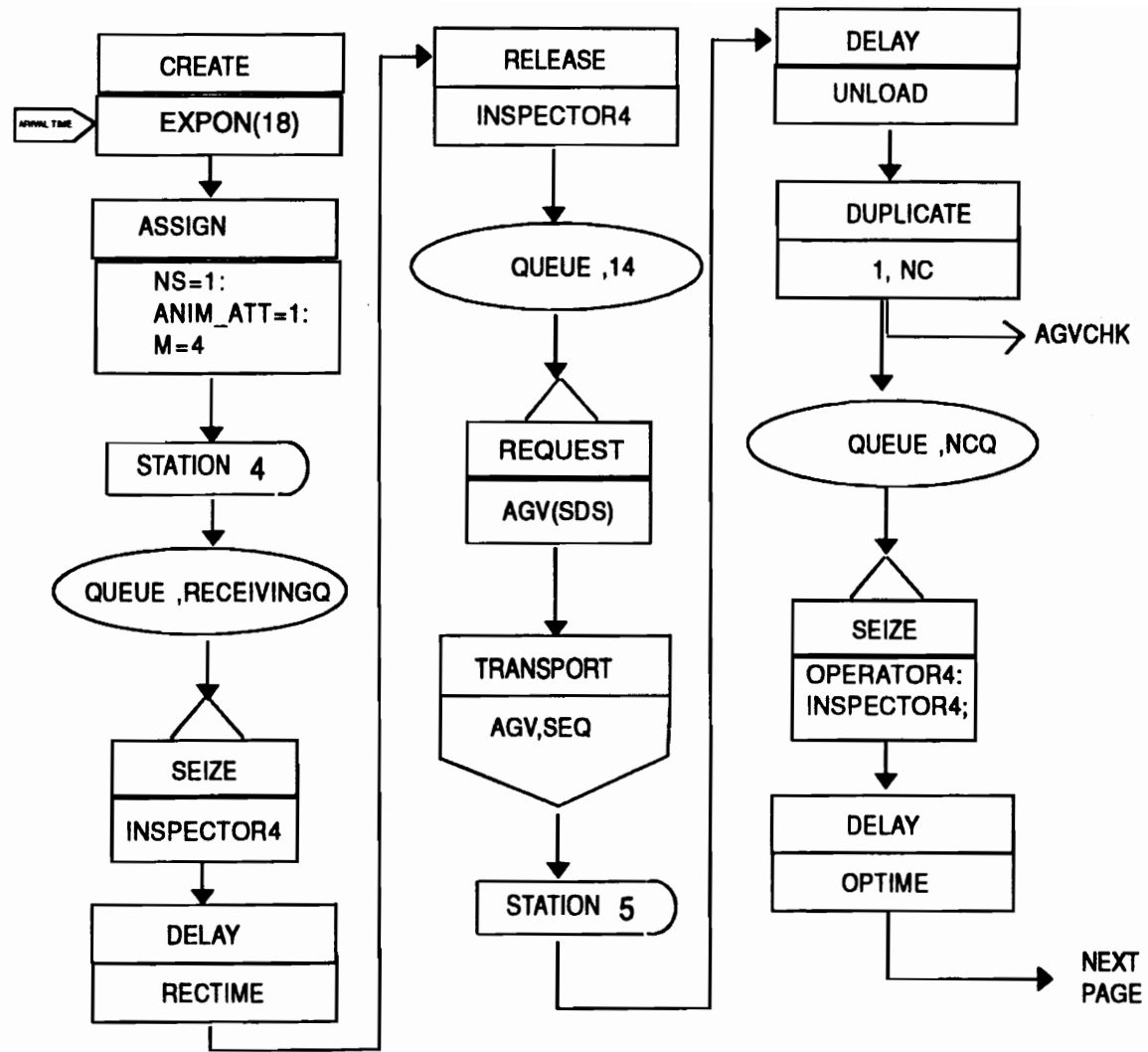


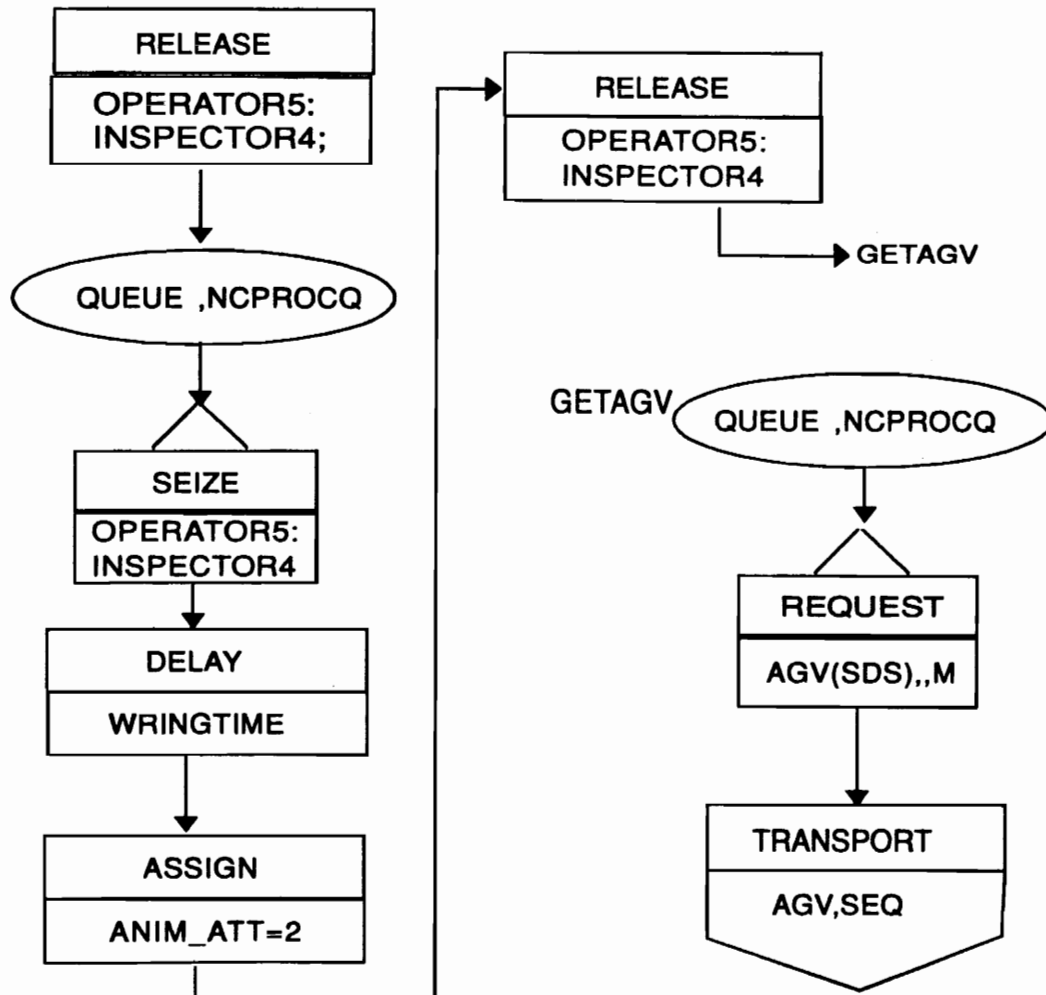
Figure 10: TOW Scrap - X-ray Operation

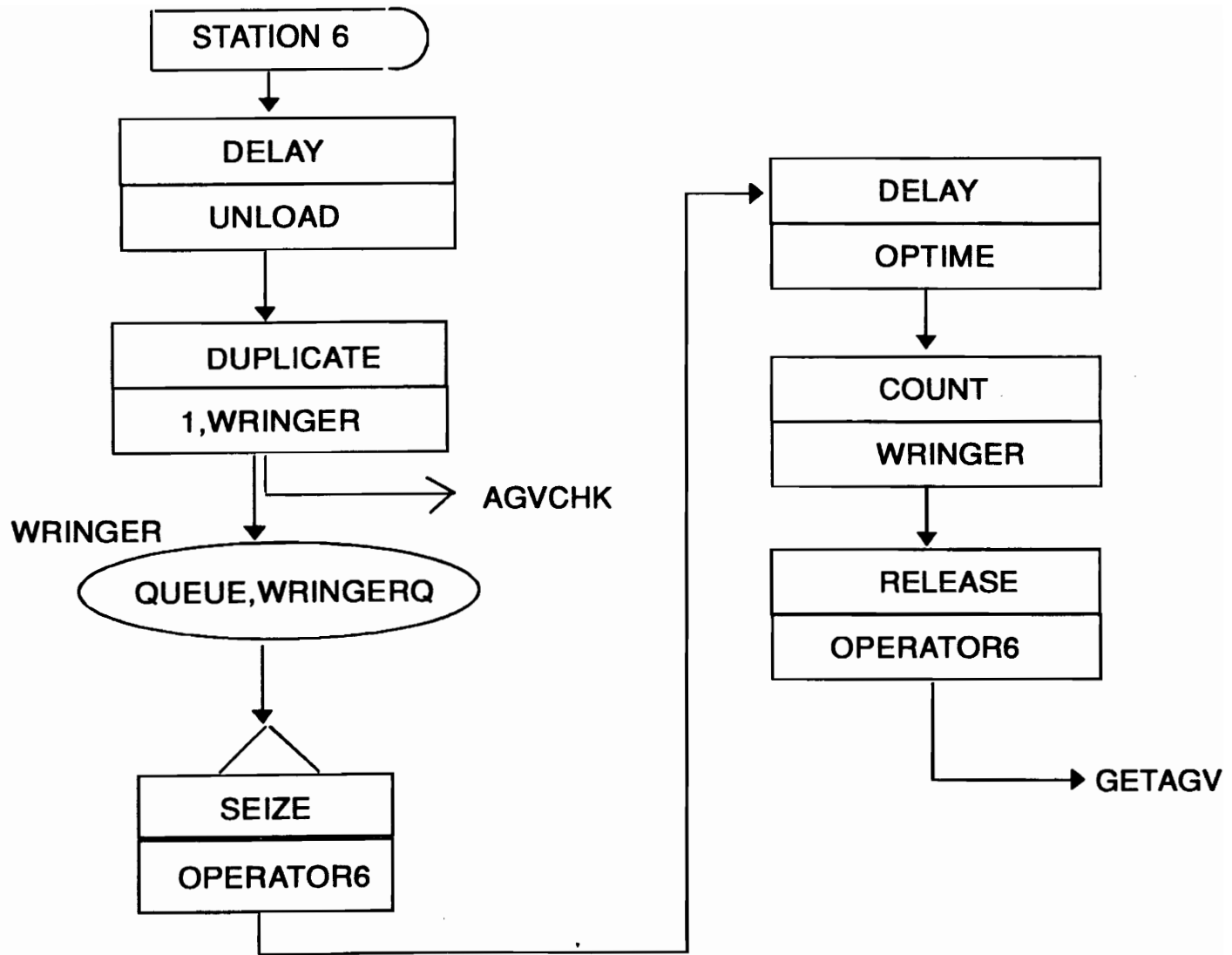
Rocket Manufacturing Area 1991 - 1992

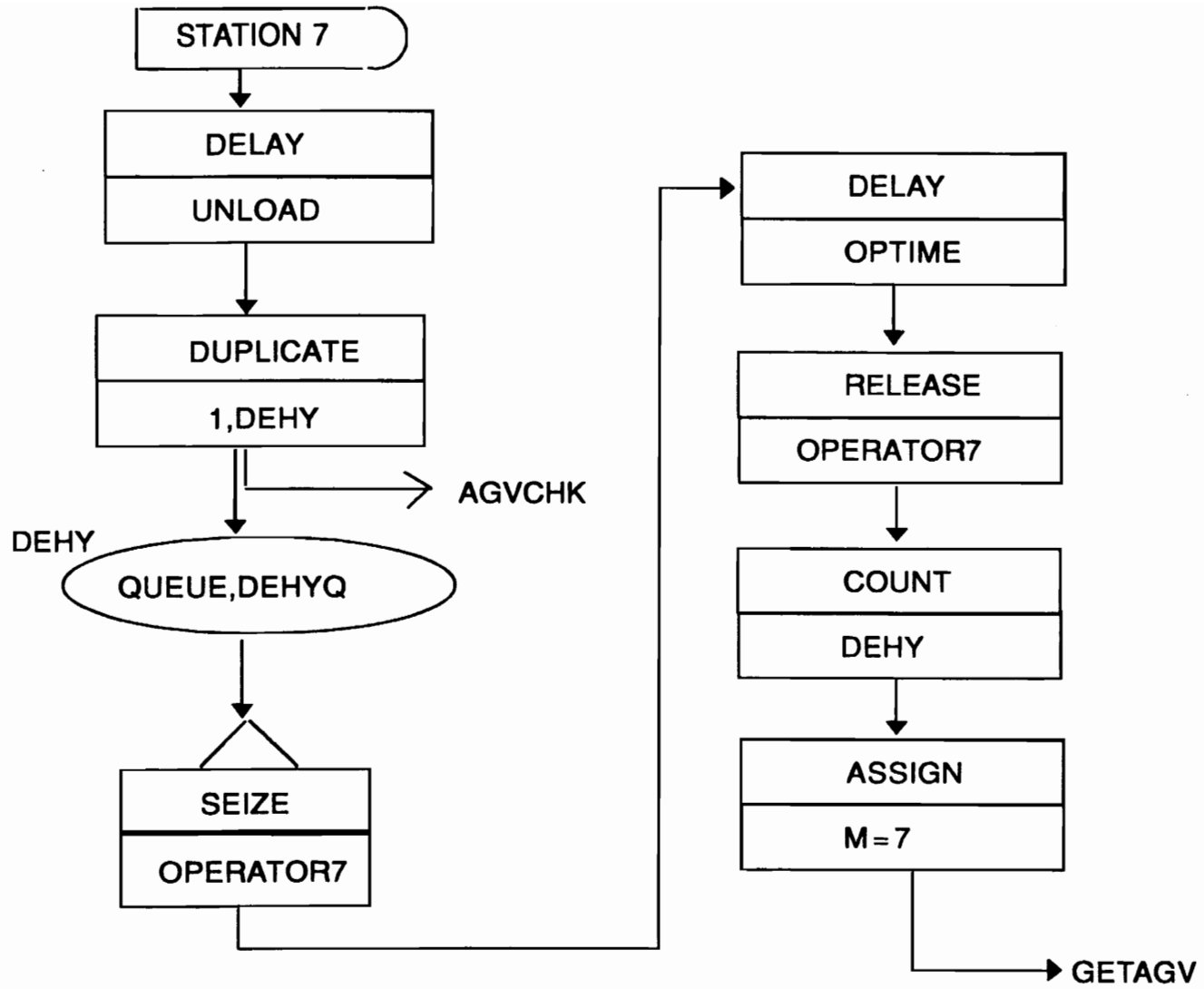
Appendix II

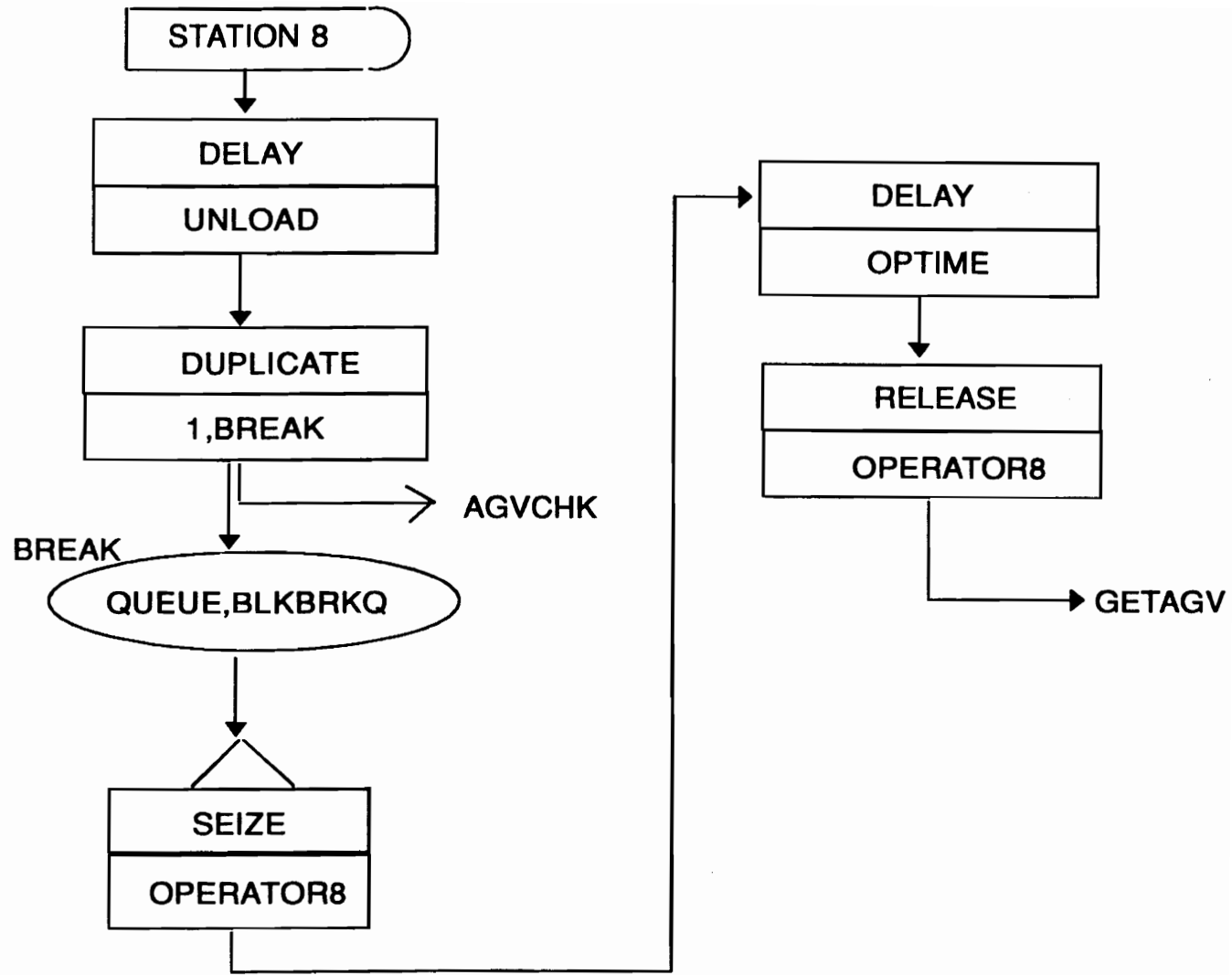
SIMAN Block Diagram For The Code

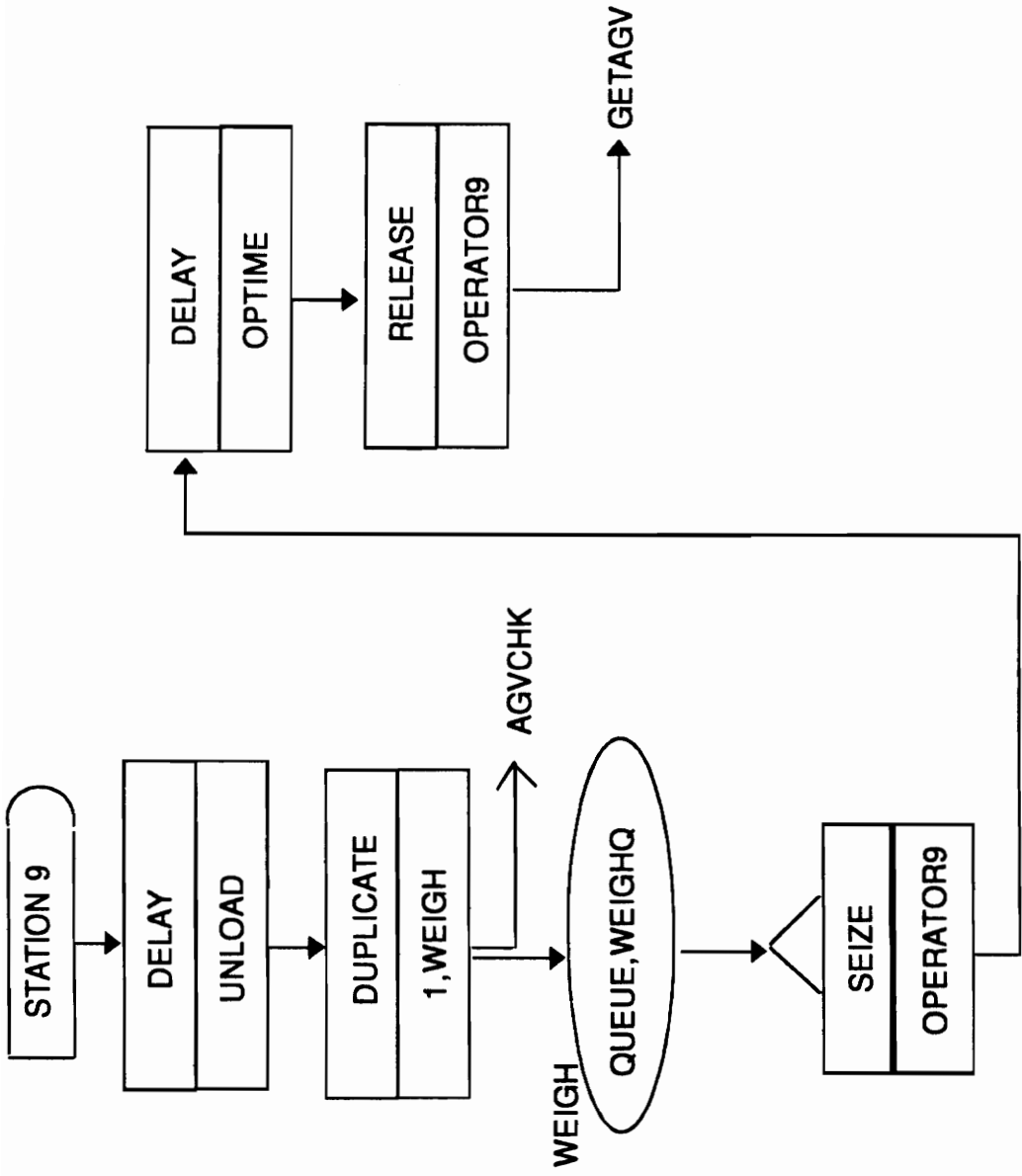


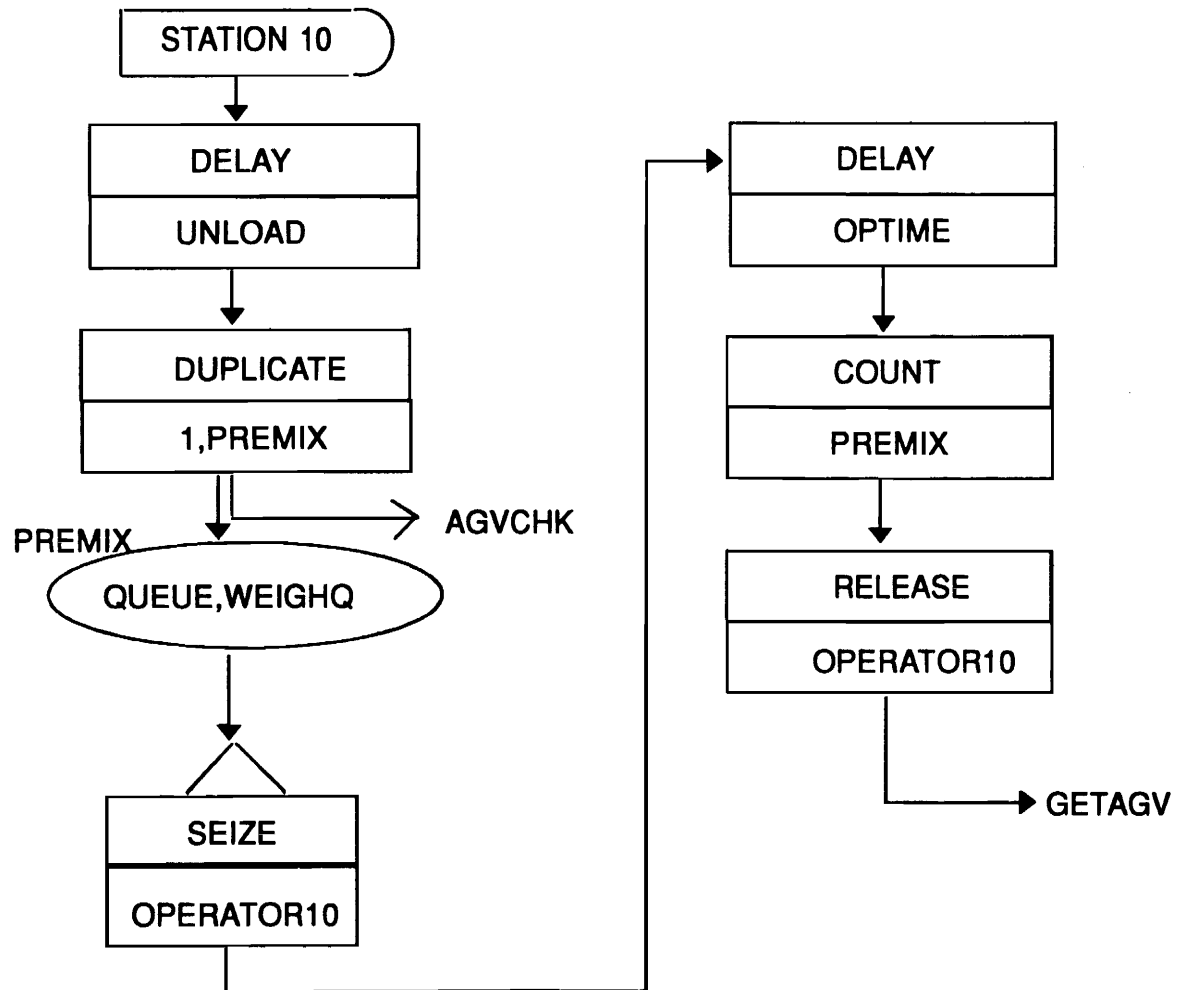


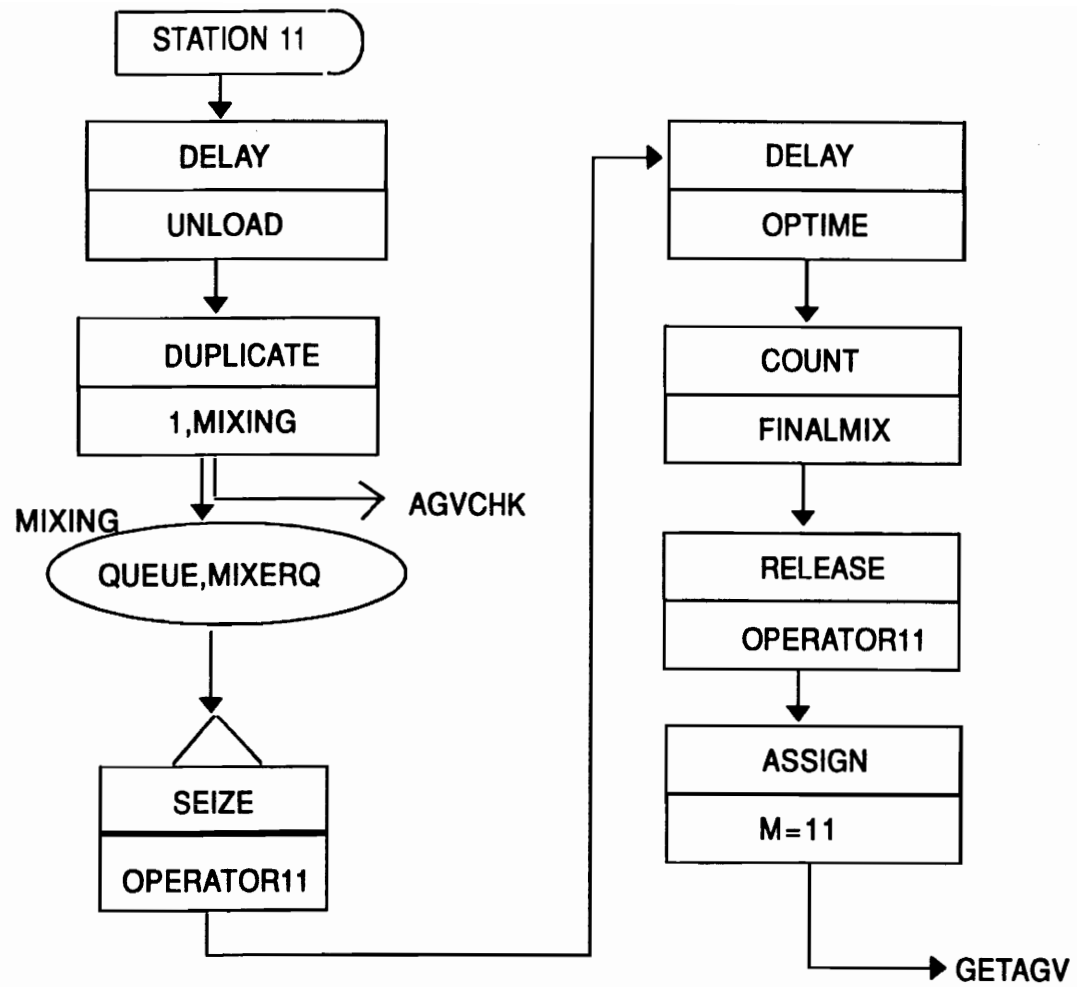


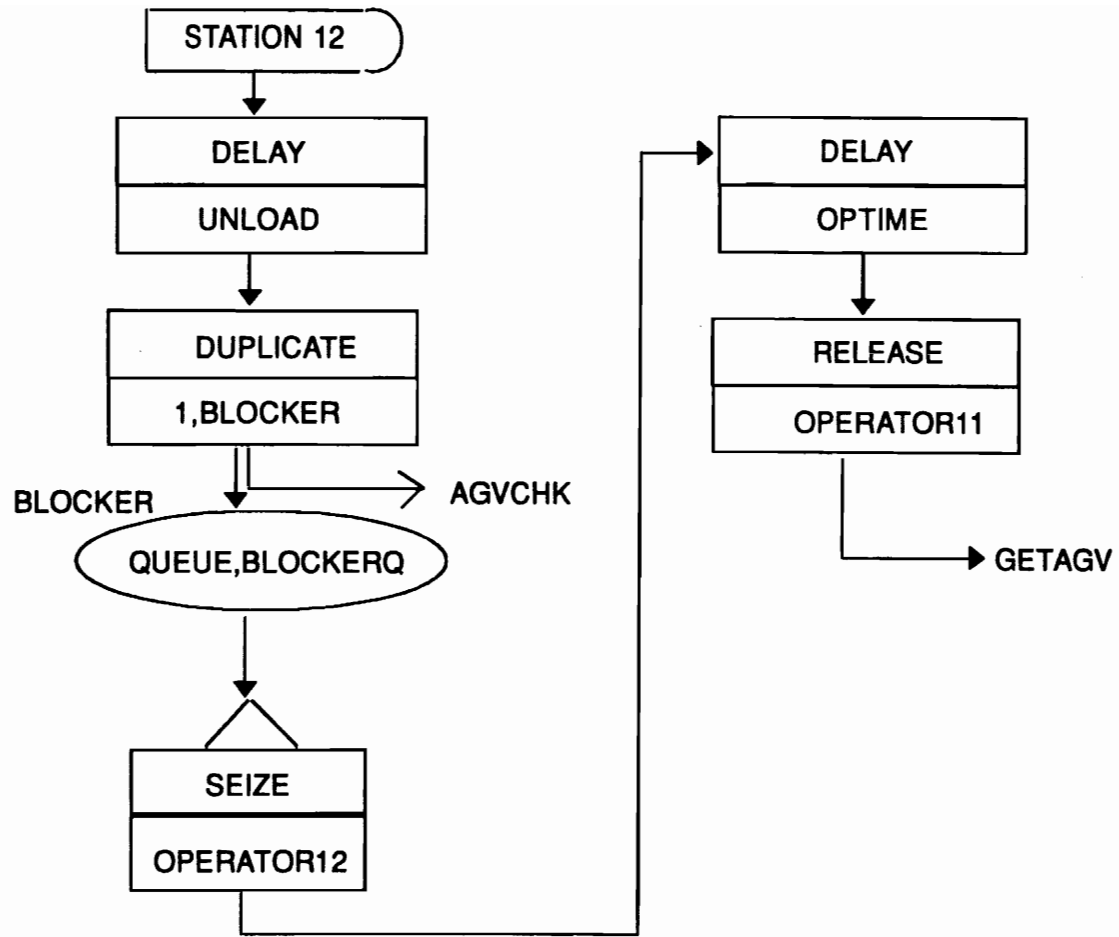


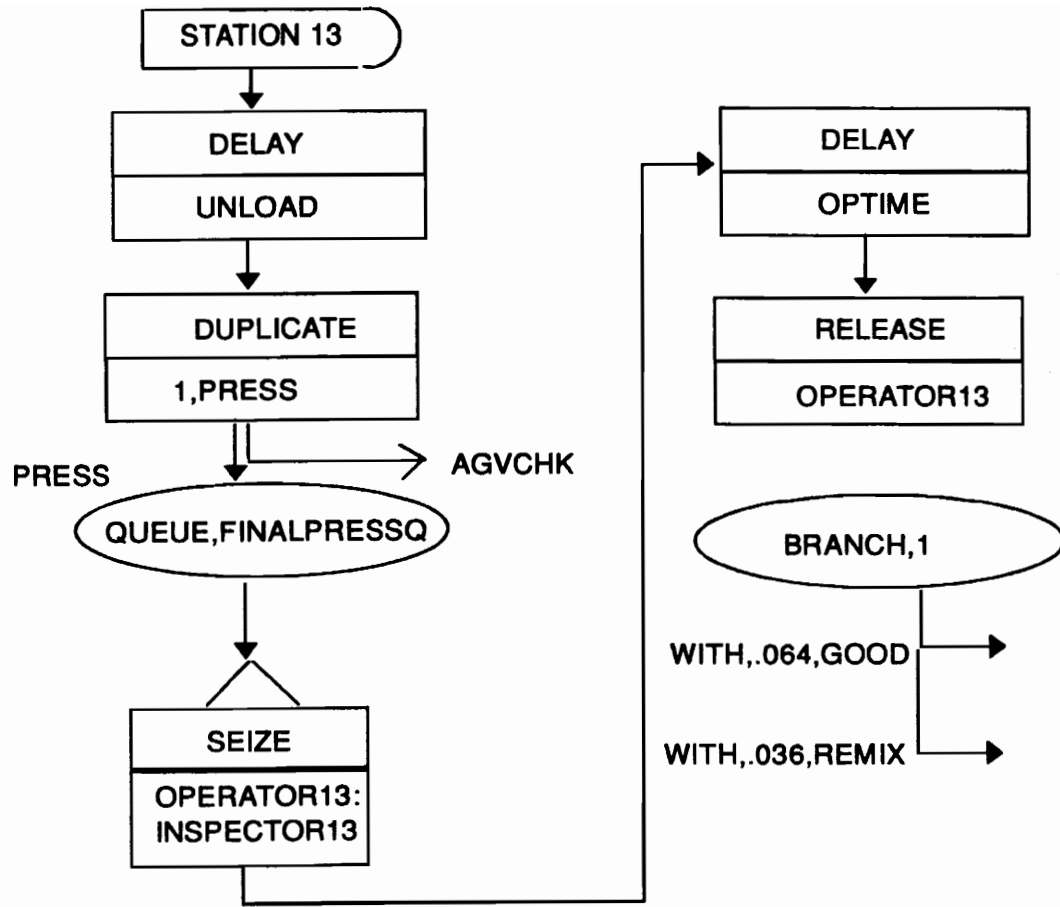


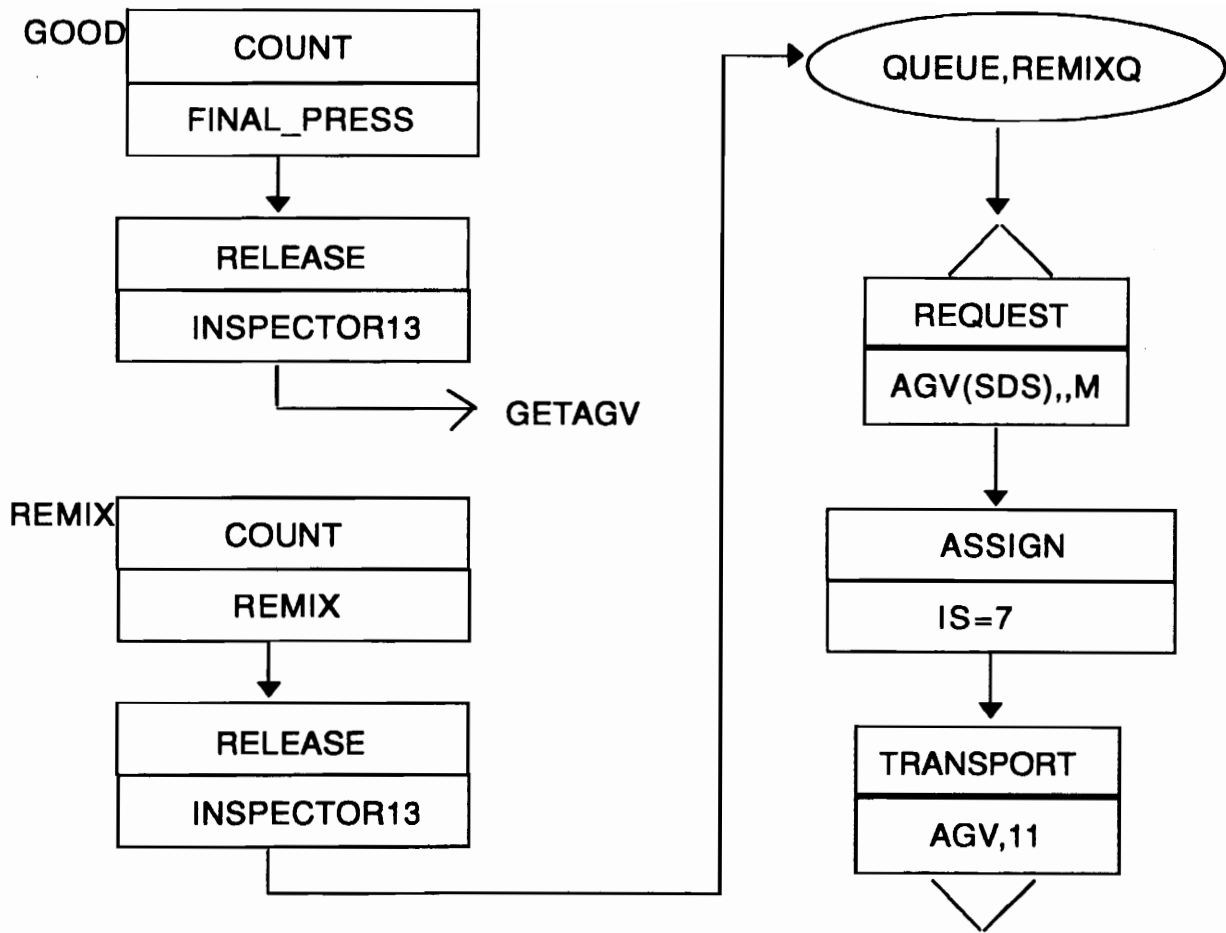


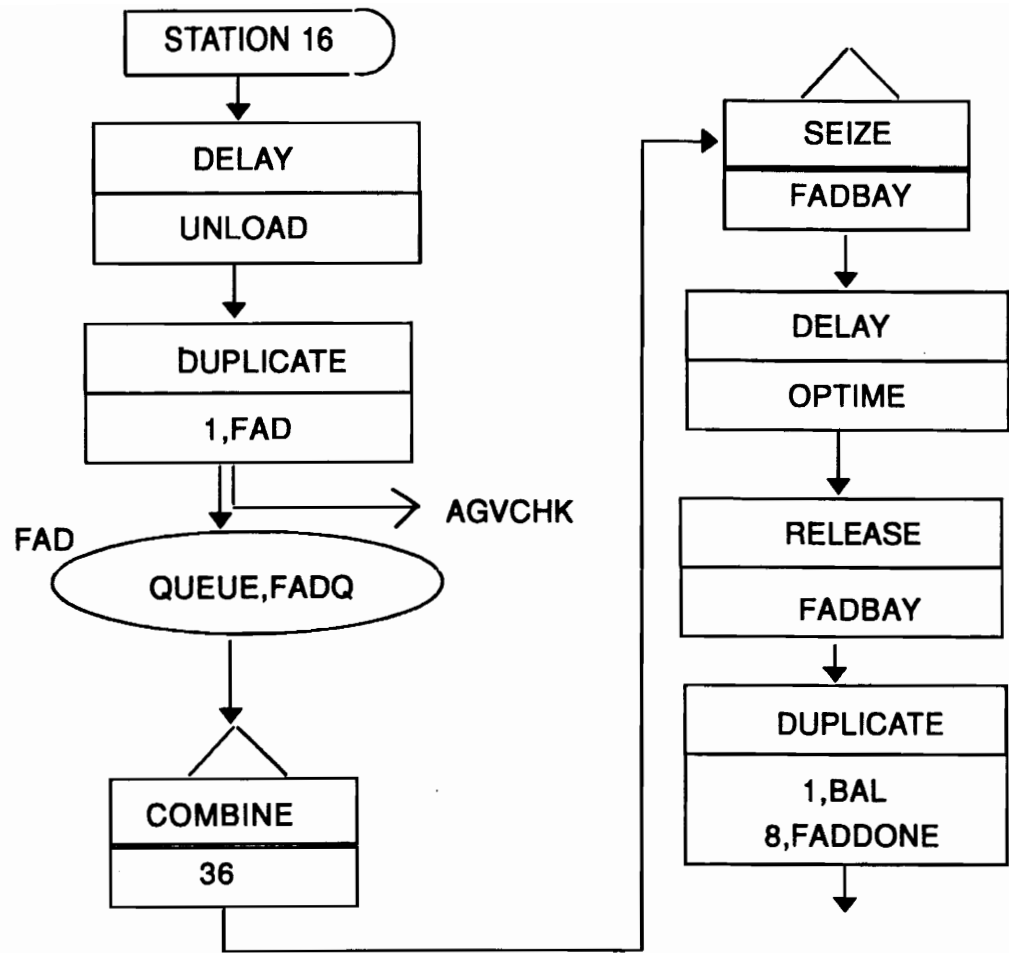


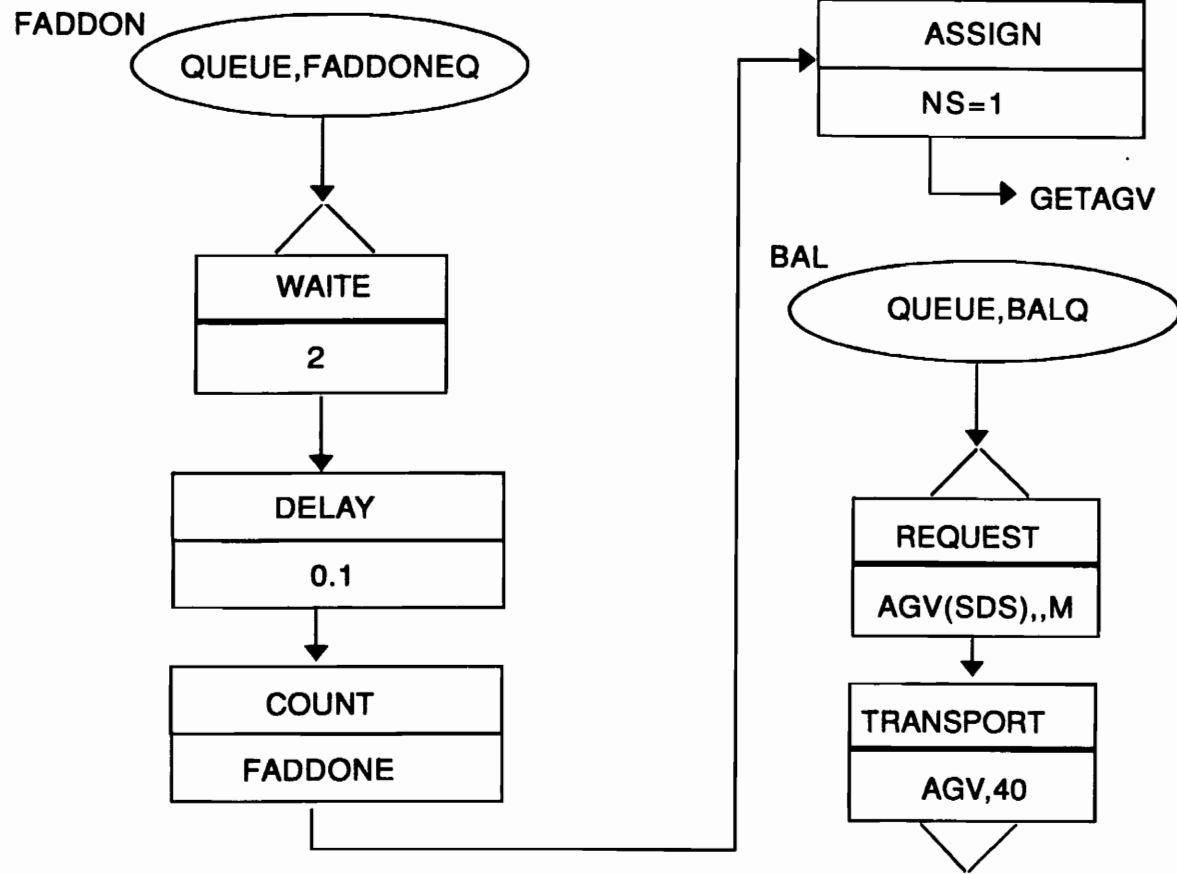


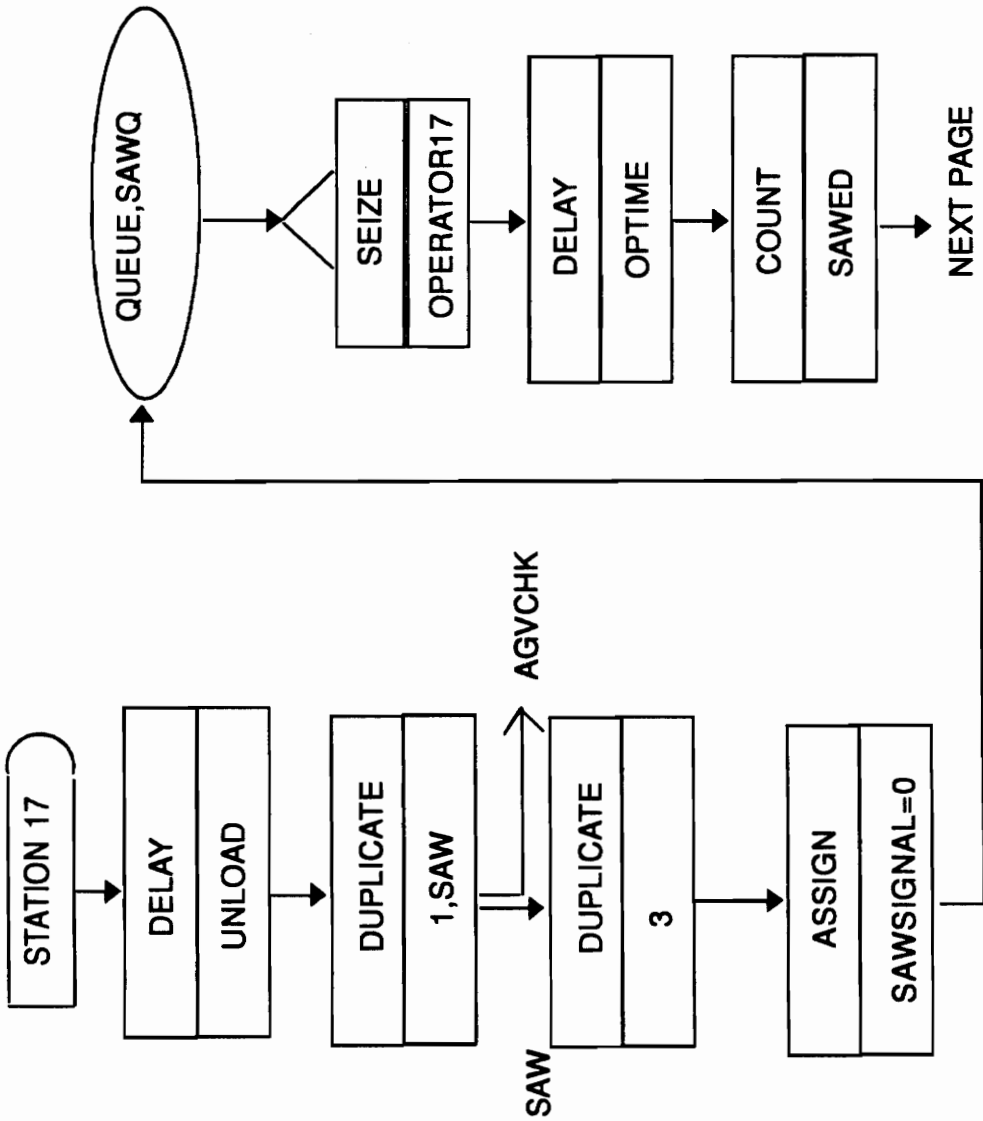


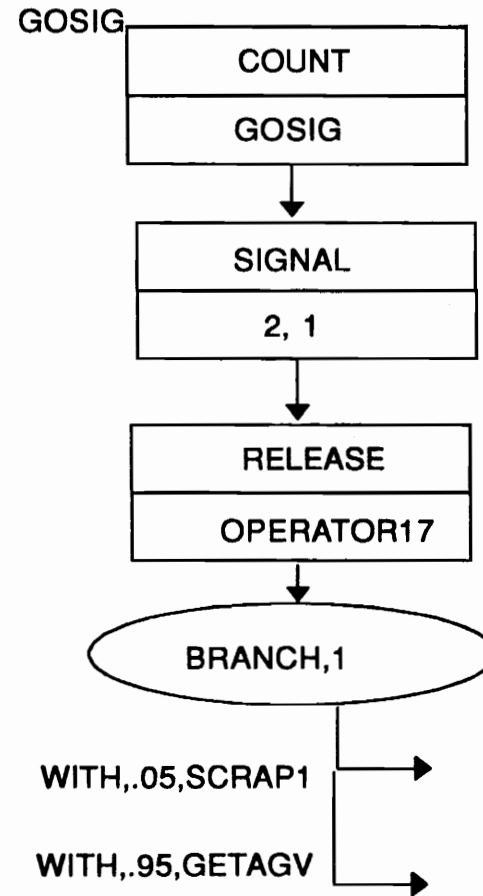
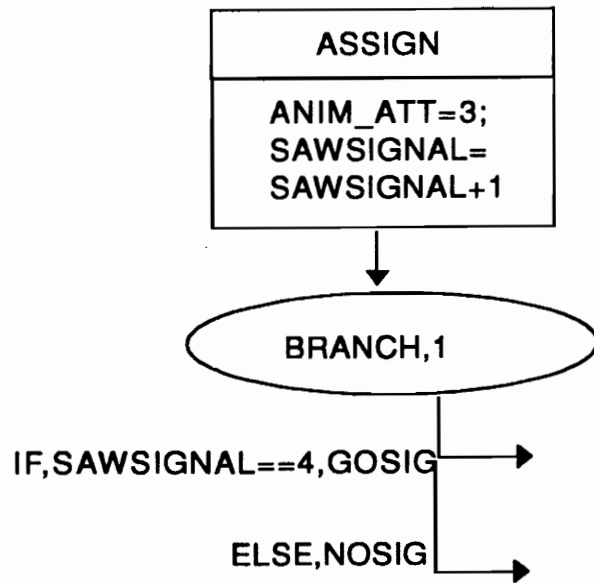


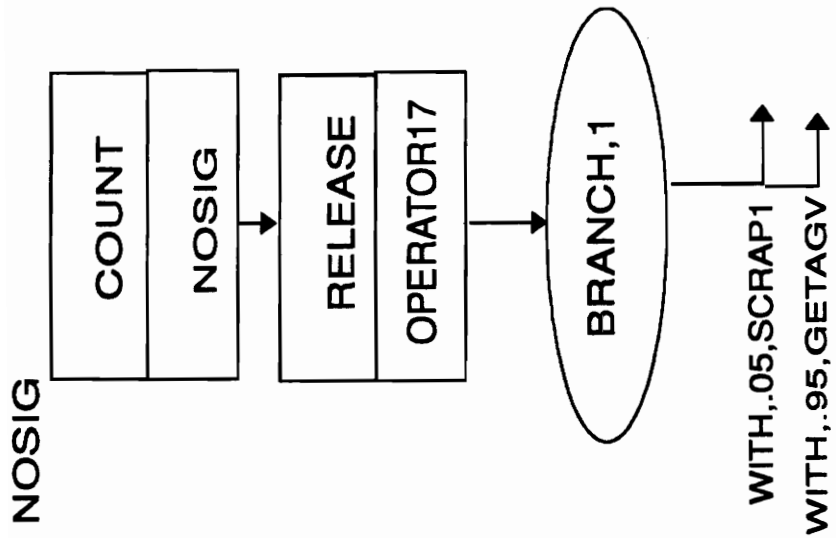




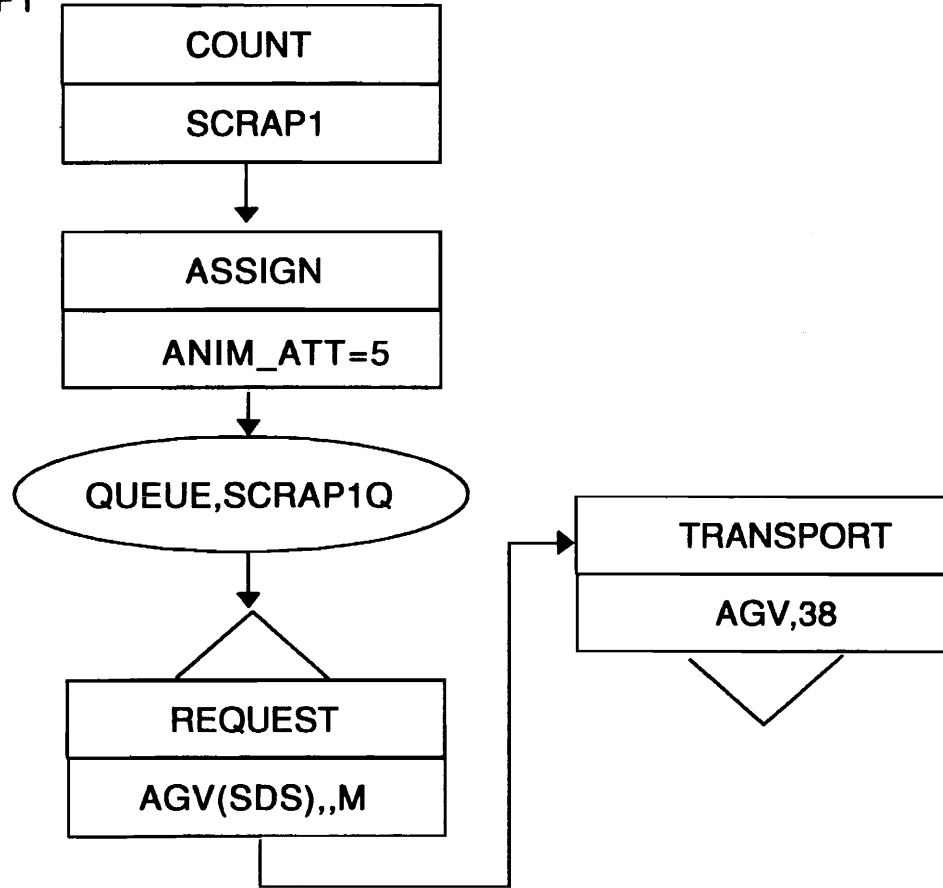


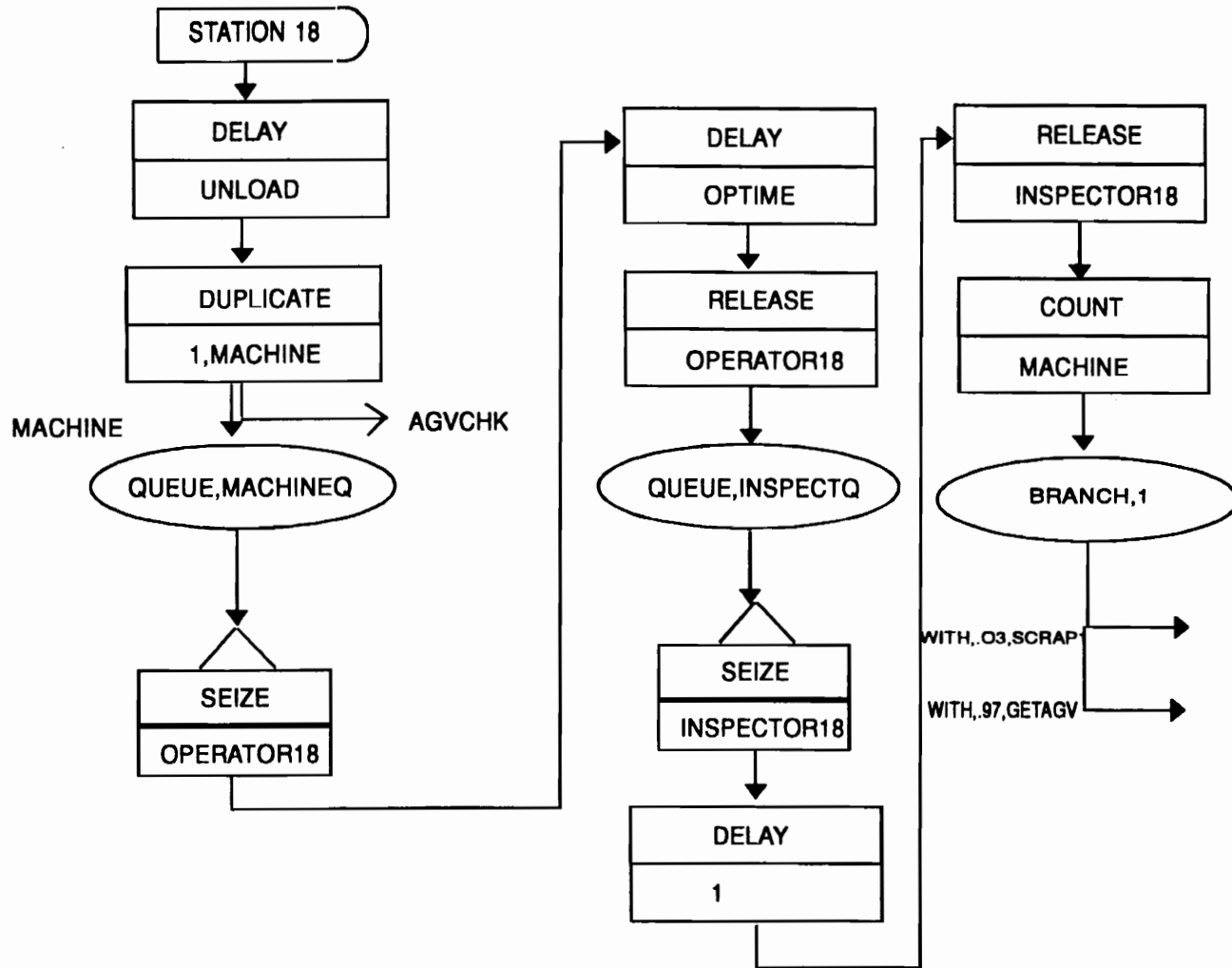




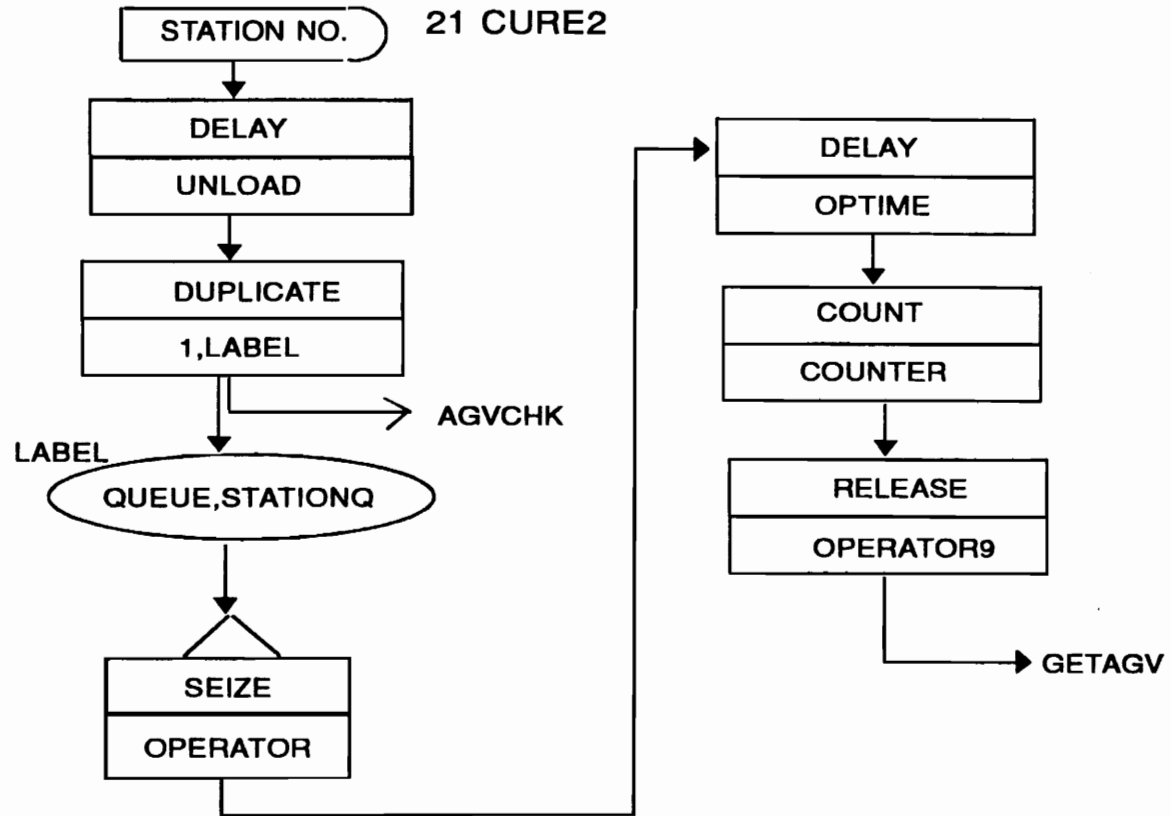


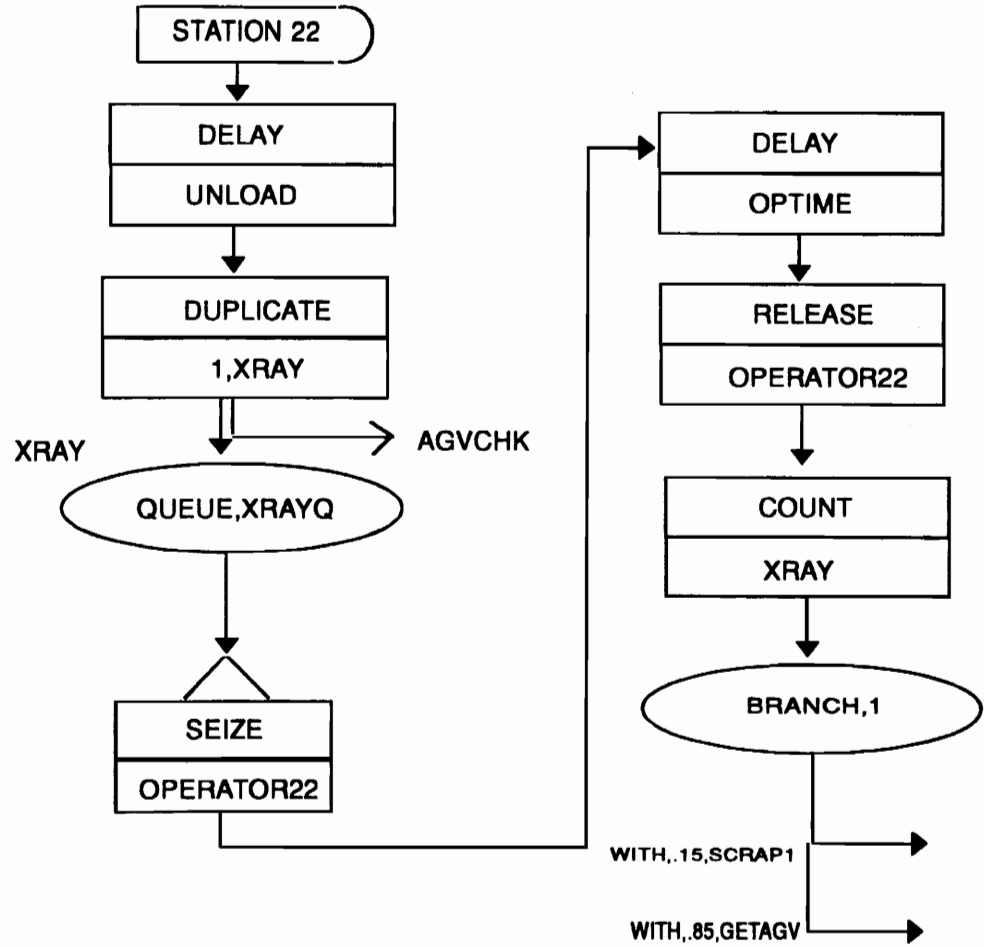
SCRAP1



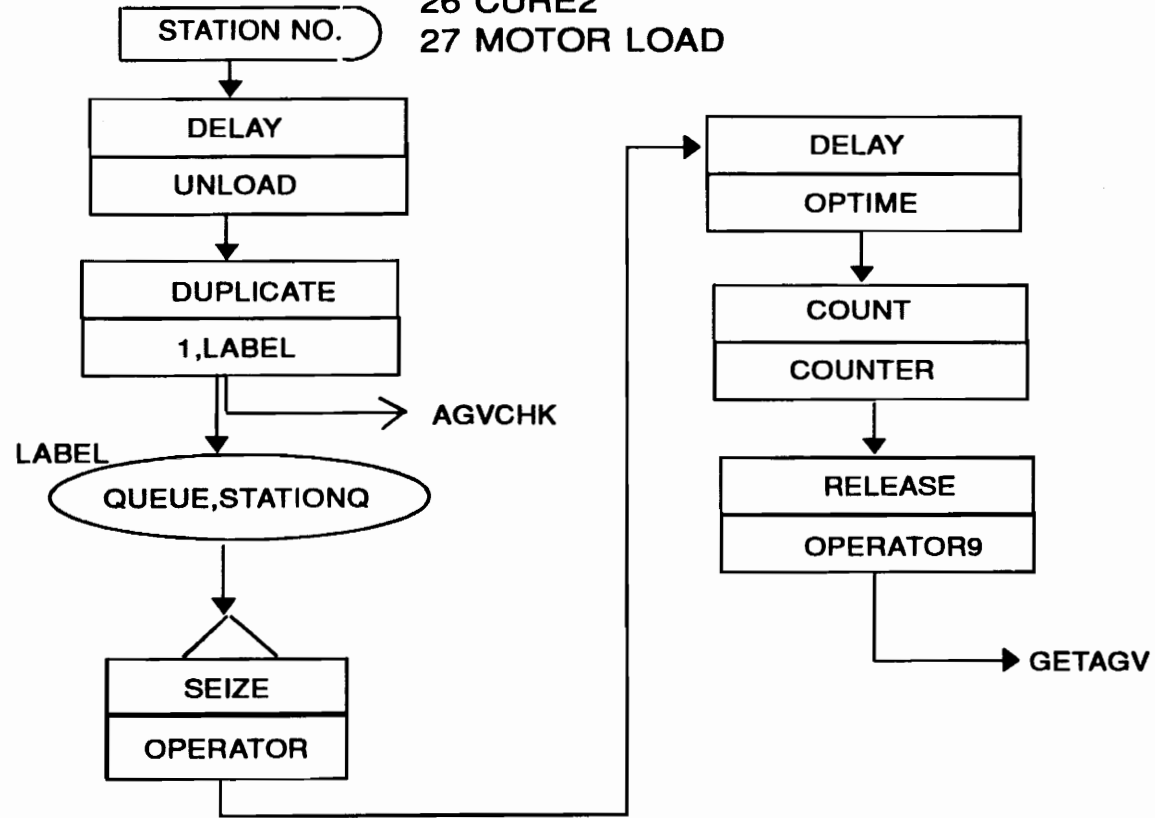


FOR NEXT 3 STATIONS:
19 GRAIN PREP
20 INSERT PIN
21 CURE2

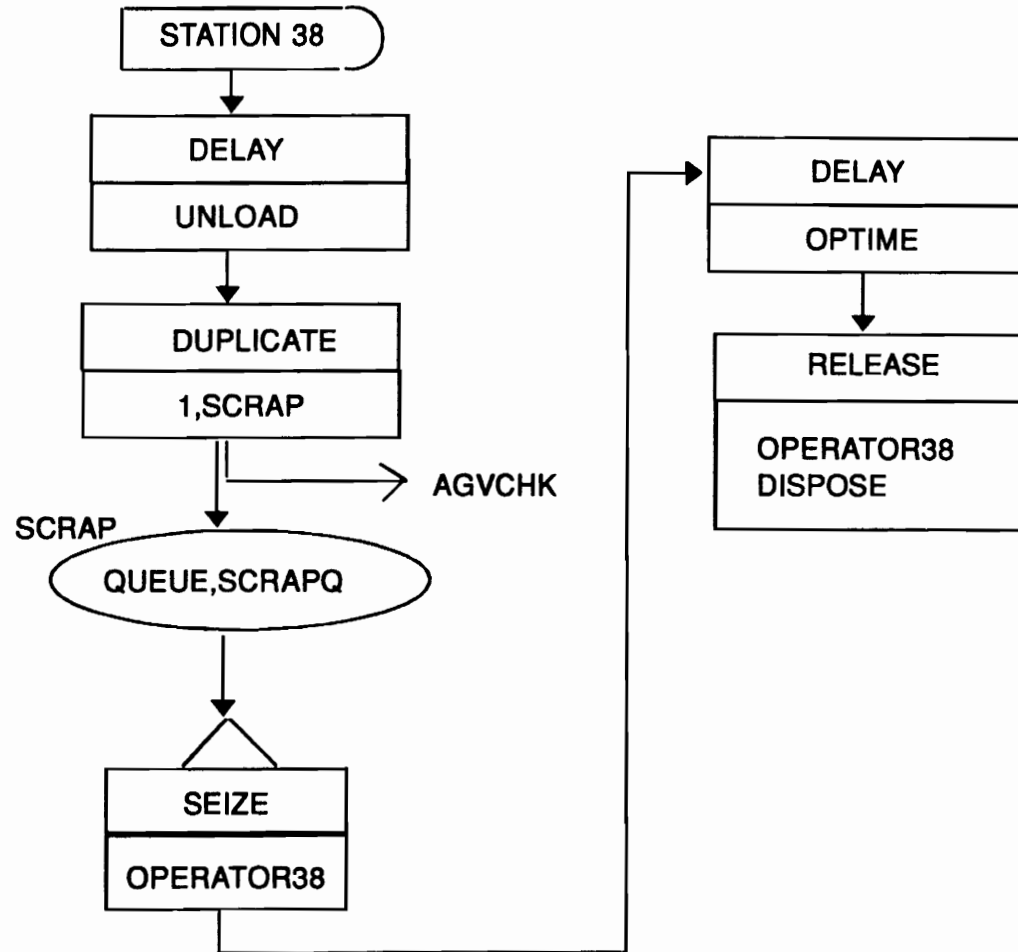


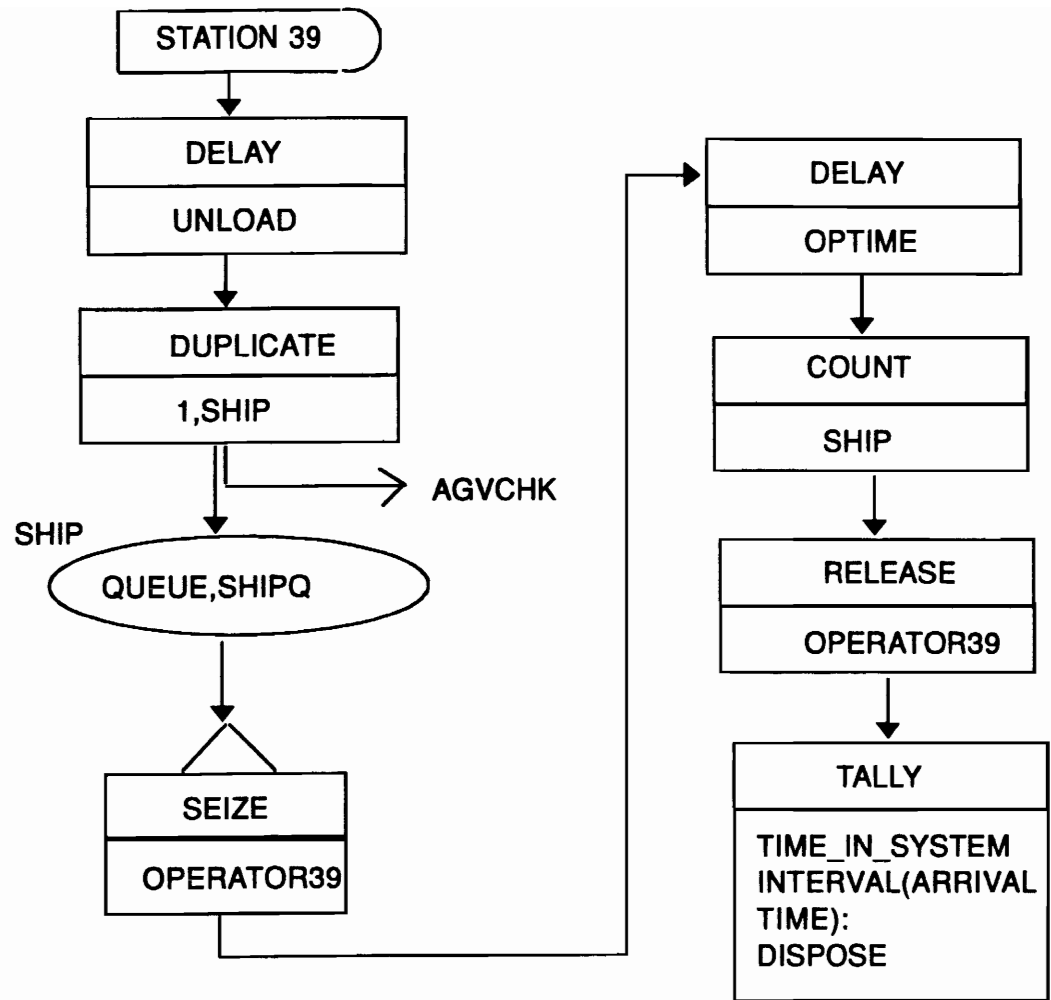


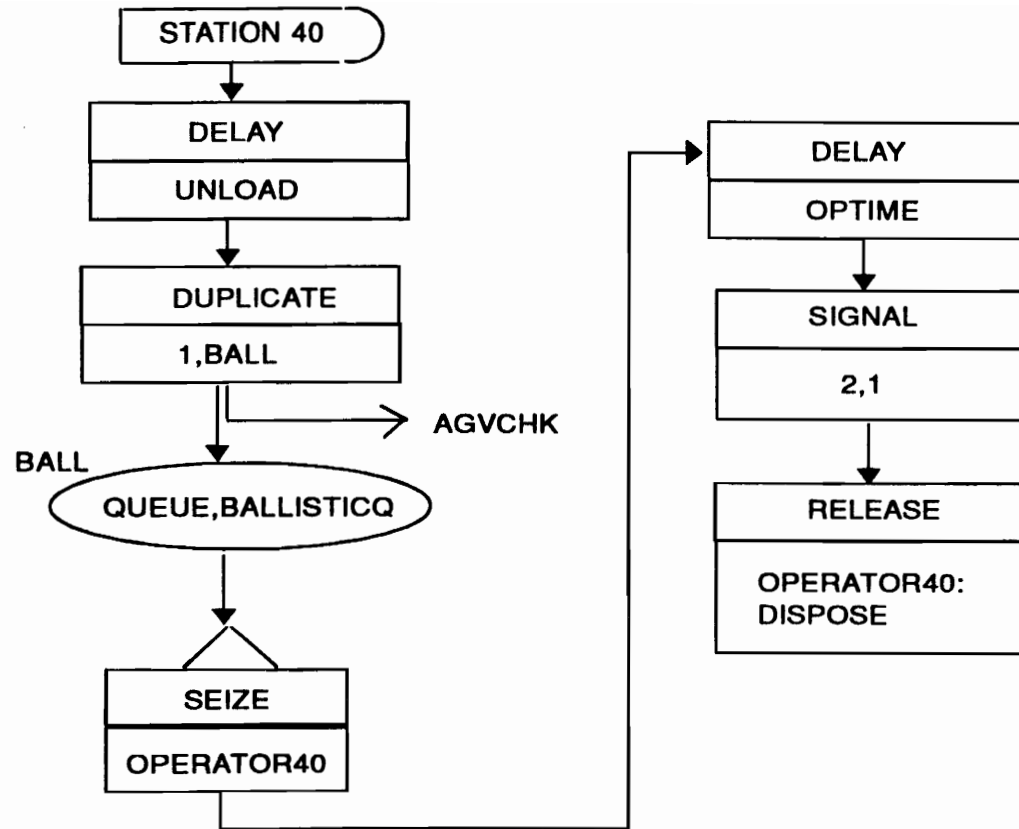
FOR NEXT 4 STATIONS:
23 TURKEY BASTE
25 BAGGING
26 CURE2
27 MOTOR LOAD



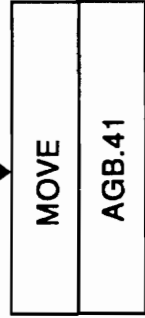
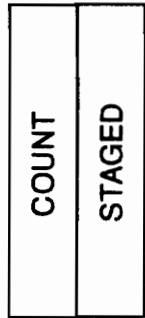
FOR STATION:
38 SCRAP



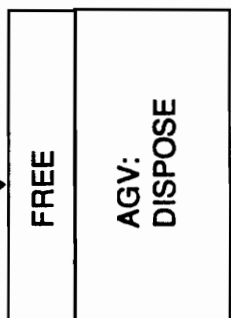




STAGE AGV



NOSTAGE



Appendix III

The Code:

The Model for the code

```
BEGIN,NO;
  CREATE,1,0:EXPO(18),36:
    MARK(ARRIVAL TIME);
  ASSIGN:  NS=1:
    Anim_Att = 1:
    M=4;
  STATION,  4;
  QUEUE,    RECEIVINGQ;
  SEIZE:    Inspector4;
  DELAY:    RECTIME;
  RELEASE:  Inspector4;

GetAGV  QUEUE,  14;
  REQUEST:  AGV(SDS),,M;
  TRANSPORT: AGV,SEQ;

;  Nitrocellulose submodel

  STATION,  5;          NC submodel
  DELAY:    UNLOAD;    Delay to unload
  DUPLICATE: 1,NC:
    NEXT(AGVCHK);
NC  QUEUE,  NCQ;      WIP at NC resource
  SEIZE:    Operator5:Inspector4;  Get NC operator
  DELAY:    Optime;      Delay for NC processing
  RELEASE:  Operator5:Inspector4;  Release NC-op resource
  QUEUE,  NCProcQ;
  SEIZE:    Operator5:Inspector4;
  DELAY:    WRINGTIME;
  ASSIGN:   Anim_att = 2;
  RELEASE:  Operator5:Inspector4:
    NEXT(GETAGV);

;  Wringer submodel

  STATION,  6;          Wringer submodel
  DELAY:    UNLOAD;    Delay to unload
  DUPLICATE: 1,WRINGER:
    NEXT(AGVCHK);
WRINGER QUEUE,  WringerQ;      Wip at Wringer
  SEIZE:    Operator6;      Get operator
  DELAY:    Optime;      Delay for Wringing
  count:    wringer;
  RELEASE:  Operator6:NEXT(GetAGV);  Release Wringer resource
```

; Dehy submodel

STATION, 7; Dehydration submodel
DELAY: UNLOAD; Delay to unload part
DUPLICATE: 1,DEHY:
NEXT(AGVCHK);
DEHY QUEUE, DehyQ; Wip at Dehy
SEIZE: Operator7; Get Dehy operator
DELAY: Optime; Delay for pumping of solvents
RELEASE: Operator7; Release Dehy operator
count: dehy;
ASSIGN: M=7:NEXT(GetAGV);

; Block Break Submodel

STATION, 8; Blkbrk submodel
DELAY: UNLOAD; Delay to unload part
DUPLICATE: 1,BREAK:
NEXT(AGVCHK);
BREAK QUEUE, BlkBrkQ; Inventory at BlkBrk
SEIZE: Operator8; Get BlkBrk operator
DELAY: Optime; Delay for BlkBrk
RELEASE: Operator8:NEXT(GetAGV); Release BlkBrk operator

; Cotton Weighing Submodel

STATION, 9; Weigh submodel
DELAY: UNLOAD; Delay to unload part
DUPLICATE: 1,WEIGH:
NEXT(AGVCHK);
WEIGH QUEUE, WeighQ; Inventory at Weigh
SEIZE: Operator9; Get Weigh operator
DELAY: Optime; Delay for weigh
RELEASE: Operator9:NEXT(GETAGV); Release weigh operator

; Premix Submodel

STATION, 10; Premix submodel
DELAY: UNLOAD;
DUPLICATE: 1,PREMIX:
NEXT(AGVCHK);
PREMIX QUEUE, PremixQ; Inventory at Premix
SEIZE: Operator10; :Inspector; Get Premix operators
DELAY: OPTIME; Delay for Premix
count: premix;
RELEASE: Operator10:NEXT(GETAGV);

; Final Mix Submodel

STATION, 11; FinalMix submodel
 DELAY: UNLOAD; Delay to unload part
 DUPLICATE: 1,MIXING:
 NEXT(AGVCHK);
 MIXING QUEUE, MIXERQ;
 SEIZE: Operator11; Get FinalMix operator
 DELAY: 4; Delay for FinalMix
 RELEASE: Operator11;
 count: finalmix;
 ASSIGN: M=11:NEXT(GetAGV); Release FinalMix operator

; Blocker Submodel

STATION, 12; Blocker submodel
 DELAY: UNLOAD; Delay to unload part
 DUPLICATE: 1,BLOCKER:
 NEXT(AGVCHK);
 BLOCKER QUEUE, BlockerQ; Inventory at Blocker
 SEIZE: Operator12; Get Blocker operator
 DELAY: 4; Delay for
 RELEASE: Operator12:NEXT(GetAGV); Release Blocker operator

; Final Press And Boarding Submodel

STATION, 13; Final submodel
 DELAY: UNLOAD; Delay to unload part
 DUPLICATE: 1,PRESS:
 NEXT(AGVCHK);
 PRESS QUEUE, FinalPressQ; Inventory at FinalPress
 SEIZE: Operator13:inspector13; Get FinalPress operator
 DELAY: optime; Delay for FinalPress
 RELEASE: Operator13;
 BRANCH,1:
 WITH,0.36,REMIX:
 WITH,0.64,GOOD; Separate remix from good
 GOOD count: final_press;
 RELEASE: Inspector13:NEXT(GETAGV);
 REMIX count: remix;
 RELEASE: Inspector13;
 QUEUE, REMIXQ;
 REQUEST: AGV(SDS),,M;
 ASSIGN: IS=7;
 TRANSPORT: AGV,11;

; Forced Air Dry Submodel

STATION, 16; FAD submodel
 DELAY: 2.0; Delay to unload part


```

    DUPLICATE: 1,FAD:
                NEXT(AGVCHK);
FAD  QUEUE,    FADQ;           Inventory at FAD
    COMBINE: 36;
    SEIZE:   FADbay;          FAD bay resource
    DELAY:   Optime;         Delay for
    RELEASE: FADbay;         Release FAD operator
    DUPLICATE: 1,BAL:8,FADDON;
FADDON QUEUE,    FADDONEQ;
    WAIT:    2;
    DELAY:   .1;
    count:   faddone;
    ASSIGN:  NS=1:NEXT(GetAGV);

BAL  QUEUE,    BALQ;
    REQUEST: AGV(SDS),,M;
    TRANSPORT: AGV,40;

;   Sawing Submodel

    STATION, 17;             Saw submodel
    DELAY:   2.0;           Delay to unload part
    DUPLICATE: 1,SAW:
                NEXT(AGVCHK);

SAW  DUPLICATE: 3;
    ASSIGN:   SawSignal=0;
    QUEUE,   SawQ;           Inventory at Saw
    SEIZE:   Operator17;     Get Saw operator
    DELAY:   Optime;         Delay for sawing
    COUNT:   SAWED;
    ASSIGN:  AnIm_Att = 3:
                SawSignal=SawSignal+1;
    BRANCH,1:
                IF,SawSignal==4,goSig:
                ELSE,noSig;
goSig count:   gosig;
    SIGNAL:   2,1;
    RELEASE: OPERATOR17;
    BRANCH,1: WITH,.05,SCRAP1:
                WITH,.95,GETAGV;

noSig count:   nosig;
    RELEASE:  Operator17;     Release Saw operator
    BRANCH,1:
                WITH,.05,SCRAP1:
                WITH,.95,GetAGV;

SCRAP1 count:  scrap1;

```

ASSIGN: Anim_Att=5;
QUEUE, SCRAP1Q;
REQUEST: AGV(SDS),,M;
TRANSPORT: AGV,38;

; Machine Submodel

STATION, 18;	Machine submodel
DELAY: 2.0;	Delay to unload part
DUPLICATE: 1,MACHINE:	
 NEXT(AGVCHK);	
MACHINE QUEUE, MachineQ;	Inventory at Machine
SEIZE: Operator18;	Get Machine operator
DELAY: Optime;	Delay for
RELEASE: Operator18;	Release Machine operator
QUEUE, INSPECT18Q;	
SEIZE: INSPECTOR18;	
DELAY: 1;	
RELEASE: INSPECTOR18;	
count: machine;	
BRANCH,1:	
 WITH,.03,SCRAP1:	
 WITH,.97,GetAGV;	

; Grain Preparation Submodel

STATION, 19;	Cure submodel
DELAY: 2.0;	Delay to unload part
DUPLICATE: 1,CURE:	
 NEXT(AGVCHK);	
CURE QUEUE, CureQ;	Inventory at Cure
SEIZE: Operator19;	Get Cure operator
DELAY: Optime;	Delay for Cure
count: cure;	
RELEASE: Operator19:NEXT(GetAGV);	Release Cure operator

; Insert Pin Submodel

STATION, 20;	InsertPin submodel
DELAY: 2.0;	Delay to unload part
DUPLICATE: 1,PINNIN:	
 NEXT(AGVCHK);	
PINNIN QUEUE, PINNINGQ;	Get InsertPin operator
SEIZE: Operator20;	Delay for InsertPin
DELAY: Optime;	
count: insertpin;	
RELEASE: Operator20:Next(GetAGV);	Release InsertPin operator

```

; Cure2 Submodel

    STATION, 21;                Cure2 submodel
    DELAY: .5;
    DUPLICATE: 1,CURE2:
        NEXT(AGVCHK);
CURE2 QUEUE, Cure2Q;
    SEIZE: Operator21;
    DELAY: 2.0;                Delay to unload part
    count: cure2;
    RELEASE: Operator21:NEXT(GetAGV); Release Cure2 operator

```

```

; X-ray Submodel

    STATION, 22;                Xray submodel
    DELAY: 2.0;                Delay to unload part
    DUPLICATE: 1,XRAY:
        NEXT(AGVCHK);
XRAY QUEUE, XrayQ;
    SEIZE: Operator22;
    DELAY: Optime;
    RELEASE: Operator22;
    count: xray;
    BRANCH,1:
        WITH,0.15,SCRAP1:
        WITH,0.85,GetAGV;
                                Inventory at Xray
                                Get Xray operator
                                Delay for Xray
                                Release Xray operator

```

```

; Turkey baste Submodel

    STATION, 23;                TurkeyBaste submodel
    DELAY: 2.0;                Delay to unload part
    DUPLICATE: 1,BASTE:
        NEXT(AGVCHK);
BASTE QUEUE, BASTEQ;
    SEIZE: Operator23;
    DELAY: Optime;
    count: turkeybaste;
    RELEASE: Operator23:NEXT(GetAGV); Release operator
                                Get Turkeybaste operator
                                Delay for TrkyBste and cure

```

```

; Bagging Submodel

    STATION, 25;                Bag submodel
    DELAY: 2.0;                Delay to unload part
    DUPLICATE: 1,BAG:
        NEXT(AGVCHK);
BAG QUEUE, BagQ;
    SEIZE: Operator25;
    DELAY: Optime;
    COUNT: BAGGING;
    RELEASE: Operator25:NEXT(GetAGV); Release operator
                                Inventory at Bag
                                Get Bag operator
                                Delay for Bag

```

; Charge Weigh Submodel

STATION, 26; ChargeWeigh submodel
DELAY: 2.0; Delay to unload part
DUPLICATE: 1,CHRGWGH:
NEXT(AGVCHK);
CHRGWGH QUEUE, ChargeWeighQ; Inventory at ChargeWeigh
SEIZE: Operator26; Get operator
DELAY: Optime; Delay for
COUNT: WEIGHING;
RELEASE: Operator26:NEXT(GetAGV); Release operator

; Motor Load Submodel

STATION, 27; MotorLoad submodel
DELAY: 2.0; Delay to unload part
DUPLICATE: 1,LOAD:
NEXT(AGVCHK);
LOAD QUEUE, MotorLoadQ; Inventory at Motorload
SEIZE: Operator27; Get operator
DELAY: Optime; Delay for
COUNT: LOADING;
RELEASE: Operator27:NEXT(GetAGV); Release operator

; Scrap Submodel

STATION, 38; Scrap submodel
DELAY: 2.0; Delay to unload part
DUPLICATE: 1,SCRAP:
NEXT(AGVCHK);
SCRAP QUEUE, ScrapQ; Inventory at
SEIZE: Operator38; Get operator
DELAY: 2; Delay for
RELEASE: Operator38:DISPOSE; Release operator

; Shlp Submodel

STATION, 39; Ship submodel
DELAY: 2.0; Delay to unload part
DUPLICATE: 1,SHIP:
NEXT(AGVCHK);
SHIP QUEUE, ShlpQ; Inventory at
SEIZE: Operator39; Get operator
DELAY: Optime; Delay for
COUNT: SHIP;
RELEASE: Operator39; Release operator
TALLY: Time In System,INTERVAL(
Arrival Time):

```

DISPOSE;

; Ballistic Submodel

STATION, 40;           Ballistic submodel
DELAY: 2.0;           Delay to unload part
DUPLICATE: 1,BALL:
NEXT(AGVCHK);
BALL QUEUE, BallisticQ;           Inventory at
SEIZE: Operator40;           Get operator
DELAY: 4;           Delay for
SIGNAL: 2,1;
RELEASE: Operator40:DISPOSE;           Release operator

; staging check
AGVCHK BRANCH, 1:
IF,NQ(14)==0,STAGEAGV:
ELSE,NOSTAGE;

STAGEAGV COUNT: STAGED;
MOVE: AGV,41;

STATION, 41;
NOSTAGE FREE: AGV: DISPOSE;

END;

```

Appendix IV

The experiment for the code

```
;SIMULATION OF THE TOW LAUNCH PROPELLANT MANUFACTURING PROCESS AT RAAP
;FINAL PROJECT
;DAN A. CREMER
BEGIN,no,no;
PROJECT,    TOW LAUNCH MFG PROCESS,DanC;
ATTRIBUTES:  Arrival Time:
              OpTime:
              Anim_Att:
              4;
```

```
VARIABLES:   SawSignal: COTTONSIZE,72:RECTIME,4.0:
              UNLOAD,1:WRINGTIME,6:
              BATCHSIZE,72:REWORK,0.20:HPCSIZE,72:
              SUBLOTS,3:SAWSCRAP,0.10:MACHSCRAP,0.05:
              XRAYSCRAP,0.20;
```

```
QUEUES:      4,RECEIVINGQ:5,NCQ:6,WRINGERQ:7,DEHYQ:8,BLKBRKQ:9,WEIGHQ:
              10,PREMIXQ:11,FINALMIXQ:12,BLOCKERQ:13,FINALPRESSQ:
              14,loadq:16,FADQ:17,SAWQ:18,MACHINEQ:
              19,CUREQ:20,INSERTPINQ:21,CURE2Q:22,XRAYQ:23,TURKEYBASTEQ:
              26,CHARGEWEIGHQ:27,MOTORLOADQ:28,IBLQ:
              29,PINSQ:30,COMPONENTPREPQ:31,IGNITERQ:32,FINALPACKQ:
              33,SYRUPPREPQ:34,SOLVENTSQ:35,NGQ:36,CHEMICALSQ:
              37,CHEMLABQ:38,SCRAPQ:39,SHIPQ:40,BALLISTICQ:
              COTTONQ:NEATNGQ:LABQ:POACHERQ:NCRESULTSQ:NCPRODQ:
              NCPROCQ:PREMIXPROCQ:LabOutQ:MIXINGQ:REMIXQ:SOLVENQ:
              MIXERQ:AGUQ:WRINGQ:DEHYDQ:DHDATAQ:DHDONEQ:CHEMSQ:
              FADDONEQ:BALQ:INSPECT18Q:CHEMDONEQ:SCRAP1Q:DHTRNQ:
              PinsReadyQ:SyrupreadyQ:Cure2done:BasteQ:PinningQ:
              BagQ:SYRUPREADY1Q;
```

```
RESOURCES:   Inspector(5):Inspector4(1):Inspector10(6):
              Inspector13(3):Inspector17(1):Inspector18(1):
              Inspector22(6):Inspector27(5):Inspector28(5):
              Inspector32(6):Inspector37(5):Inspector40(6):
              PRESS(8):
              Operator5(1):Operator6(1):Operator7(1):Operator8(1):
              Operator9(1):
              Operator10(2):Operator11(1):Operator12(1):
              Operator13(3):
              FADBay(2),74:Operator17(1):
              Operator18(1):
              Operator19(1):Operator20(1):Operator21(1):
              Operator22(1):
              Operator23(1):Operator25(1),6:
```

Operator26(1):
Operator27(1),4:Operator28(1):Operator29(1):
Operator30(1):
Operator31(1):Operator32(1):Operator33(1):
Operator34(1):
Operator35(5):Operator36(1):Operator37(1):
Operator38(1),4:
Operator39(1),4:Operator40(1);

STATIONS: 4,,1:5,,6:6,,9:7,,29:8,,2:9,,19:10,,45:11,,15:12,,16:
13,,5:15,,6:16,,47:17,,35:18,,40:19,,41:20,,42:21,,42:
22,,22:23,,42:25,,37:26,,43:27,,43:28,,23:29,,37:
30,,37:31,,37:32,,43:33,,42:34,,27:35,,45:36,,28:37,,26:
38,,31:39,,30:40,,46:41,stage,48:42,,15:43,,29:44,,11;

SEQUENCES: 1, 5,Optime=LOGN(4,.2) &
6,Optime=LOGN(4,.2) & 7,Optime=LOGN(4,.2) &
8,Optime=LOGN(4,.2) & 9,Optime=LOGN(5,.2) &
10,Optime=LOGN(4,.2) & 11,Optime=LOGN(4,.2) &
12,Optime=LOGN(3,.1) & 13,Optime=LOGN(5,.2) &
16,Optime=LOGN(10,.2) &
17,Optime=LOGN(4,.2) & 18,Optime=LOGN(8,.2) &
19,Optime=LOGN(8,.31) & 20,Optime=LOGN(2,.1) &
21,Optime=LOGN(4,.2) & 22,Optime=LOGN(2,.1) &
23,Optime=LOGN(8,.2) & 25,Optime=LOGN(3,.1) &
26,Optime=LOGN(2,.1) & 27,Optime=LOGN(2,.1) &
39,Optime=LOGN(2,.1);

STORAGES: FADSTR:
RECEIVING;

COUNTERS: WRINGER:DEHY:PREMIX:FINALMIX:FINAL_PRESS:REMIX:
FADDONE:GOSIG:NOSIG:SCRAP1:SAWED:MACHINE:CURE:INSERTPIN:
CURE2:XRAY:TURKEYBASTE:BAGGING:WEIGHING:
LOADING:SHIP:STAGED;

INTERSECTIONS: 1,,:2,,:3,,:4,,:5,,:6,,:7,,:9,,:11,,:13,,:15,,:16,,:17,,:18,,:
19,,:20,,:21,,:22,,:23,,:24,,:25,,:26,,:27,,:28,,:29,,:30,,:
31,,:32,,:33,,:34,,:35,,:36,,:37,,:38,,:39,,:40,,:41,,:42,,:
43,,:44,,:45,,:46,,:47,,:48,;

LINKS: 1,,3,1,10,10,Spur:
2,,3,6,8,10:3,,6,3,8,10:4,,3,13,5,10:5,,13,3,5,10:
6,,6,9,6,10:7,,9,6,6,10:8,,9,3,1,60:
9,,3,9,1,60:10,,9,29,1,50:11,,29,9,1,50:
12,,13,29,1,100:13,,29,13,3,100:
14,,29,28,2,35,SPUR:
15,,13,7,10,5:16,,7,13,10,5:17,,7,5,1,120:18,,5,7,1,120:
19,,5,27,7,10,SPUR:
20,,5,14,1,50:21,,14,5,1,50:22,,14,15,1,50:23,,15,14,1,50:

24,,15,11,1,50:25,,11,15,1,50:26,,11,16,1,60:
 27,,16,11,1,60:28,,16,17,1,50:29,,17,16,1,50:
 30,,4,17,1,10:31,,17,4,1,10:
 32,,4,2,3,3:
 33,,18,4,1,50:34,,4,18,1,50:
 35,,18,19,1,65:36,,19,18,1,65:
 37,,19,20,1,15:38,,20,19,1,15:
 39,,18,20,1,70:40,,20,18,1,70:
 41,,20,21,2,45:42,,21,20,2,45:
 43,,21,22,1,75,SPUR:
 44,,21,24,1,50:45,,24,21,1,50:
 46,,24,25,1,10:
 47,,25,26,1,70,SPUR:
 48,,25,23,2,45:
 49,,23,24,2,50:
 50,,18,32,10,50:51,,32,18,10,50:
 52,,32,30,2,5:
 53,,32,31,10,50:54,,31,32,10,50:
 55,,32,33,10,60:56,,33,32,10,60:
 57,,33,34,1,10:60,,34,33,1,10:
 61,,34,35,6,10:62,,35,34,6,10:
 63,,33,36,5,10:64,,36,33,5,10:
 65,,36,37,1,100,SPUR:
 66,,36,38,10,10:67,,38,36,10,10:
 68,,38,39,2,50:69,,39,38,2,50:
 70,,38,43,5,15:71,,43,38,5,15:
 72,,43,42,5,15:73,,42,43,5,15:
 74,,42,41,2,10:75,,41,42,2,10:
 76,,41,40,1,15:77,,40,41,1,15:
 78,,40,39,3,10:79,,39,40,3,10:
 80,,41,39,3,11:81,,39,41,3,11:
 82,,39,44,10,10:83,,44,39,10,10:
 84,,44,47,3,6:
 85,,44,45,10,10:86,,45,44,10,10:
 87,,45,46,15,10:88,,46,45,15,10:
 89,,46,44,15,10:90,,44,46,15,10:
 91,,24,48,15,5:
 92,LINK92,48,21,15,5:93,,17,14,1,50:
 94,,14,17,1,50:95,,2,4,3,3:96,,47,44,3,6:
 97,,30,32,2,5:98,,33,30,10,60;

NETWORKS: 1,AGV System,1-98;

TRANSPORTERS: 1,AGV,2,NETWORK(AGV System),
5380.0,LINK(92);

TALLIES: Time In System;

DSTATS: NQ(14),AGV QUEUE:

NQ(NCQ),NC QUEUE:
NQ(NCPROCQ):
NQ(wringerq),WRINGER QUEUE:
NQ(dehyq),DEHY QUEUE:
NQ(BLKBRKQ),BLOCK BREAK QUEUE:
NQ(WEIGHQ), WEIGH QUEUE:
NQ(PREMIXQ),PREMIX QUEUE:
NQ(FINALMIXQ),FINAL MIX QUEUE:
NQ(BLOCKERQ),BLOCKER QUEUE:
NQ(FINALPRESSQ),FINAL PRESS QUEUE:
NQ(REMIXQ),REMIX QUEUE:
NQ(FADQ),FAD QUEUE:NQ(FADDONEQ),FAD DONE QUEUE:
NQ(SAWQ):
NQ(MACHINEQ):NQ(INSPECT18Q),MACHINE INSP.Q:
NQ(CUREQ),GRAIN PREP QUEUE:
NQ(PINNINGQ):
NQ(CURE2Q):
NQ(CURE2DONE):
NQ(XRAYQ):
NQ(BASTEQ):NQ(BAGQ):NQ(CHARGEWEIGHQ):
NQ(MOTORLOADQ):NQ(SHIPQ):

IT(AGV,1),AGV 1 Time Active:
IT(AGV,2),AGV 2 Time Active:
;
IT(AGV,3),AGV 3 Time Active:
;
IT(AGV,4),AGV 4 Time Active:
;
IT(AGV,5),AGV 5 Time Active:

;
IT(AGV,6),AGV 6 Time Active:
;
IT(AGV,7),AGV 7 Time Active:

MAX(NT(1)-NL(LINK92),0)/5,AGV Actual Busy:

;
IT(AGV,8):
;
IT(AGV,9):
;
IT(AGV,10):
;
IT(AGV,11):
;
IT(AGV,12):
;
IT(AGV,13):
;
IT(AGV,14):
;
IT(AGV,15):

NR(INSPECTOR4),RECEIVING STATION:
NR(OPERATOR5),NITROCOTTON STATION:
NR(OPERATOR6),WRINGER STATION:
NR(OPERATOR7),DEHYS:
NR(OPERATOR8),BLOCKBREAKS:NR(OPERATOR9),WEIGHS:
NR(OPERATOR10),PREMIX STATION:
NR(OPERATOR11),FINAL MIX STATION:

NR(OPERATOR12),BLOCKERS:
NR(OPERATOR13),PRESS AND BOARD:
NR(FADBAY),FAD BAY:NR(OPERATOR17),SAW STATION:
NR(INSPECTOR17),SAW INSPECTION:
NR(OPERATOR18),MACHINING STATION:
NR(INSPECTOR18),MACHINING:
NR(OPERATOR19),GRAIN PREP:
NR(OPERATOR20),PINNING STATION:
NR(OPERATOR21),CURING BAY:NR(OPERATOR22),XRAY STATION:
NR(OPERATOR23),TURKEYBASTING:
NR(OPERATOR25),BAGGING STATION:
NR(OPERATOR26),CHRG WEIGHING:
NR(OPERATOR27),MOTOR LOADING:
NR(OPERATOR39),SHIPPING:
NR(OPERATOR38),BURNING GROUNDS;

LAYOUTS: "PROJ.LAY",AnIm_Att,.1;
REPLICATE, 2,0,2880,YES,YES,0.0;
END;

Appendix V

SIMAN IV - License #9110443
Virginia Tech.

Summary for Replication 1 of 20

Project: TOW LAUNCH MFG PROCESS
Analyst: DanC

Run execution date : 1/25/1993
Model revision date: 1/24/1993

Replication ended at time : 2880.0

TALLY VARIABLES

Identifier	Average	Variation	Minimum	Maximum	Observations
Time In System	345.18	.23632	186.41	464.83	25

DISCRETE-CHANGE VARIABLES

Identifier	Average	Variation	Minimum	Maximum	Final Value
AGV QUEUE	.04185	6.1169	.00000	4.0000	.00000
NC QUEUE	.09145	5.7636	.00000	6.0000	.00000
NQ(NCPROCQ)	.14054	4.5646	.00000	6.0000	.00000
WRINGER QUEUE	.00000	--	.00000	.00000	.00000
DEHY QUEUE	.91129E-06	1047.5	.00000	1.0000	.00000
BLOCK BREAK QUEUE	.24425E-03	63.978	.00000	1.0000	.00000
WEIGH QUEUE	.71466E-03	37.393	.00000	1.0000	.00000
PREMIX QUEUE	.00000	--	.00000	.00000	.00000
FINAL MIX QUEUE	.00000	--	.00000	.00000	.00000
BLOCKER QUEUE	.00134	27.286	.00000	1.0000	.00000
FINAL PRESS QUEUE	.54711E-03	42.741	.00000	1.0000	.00000
REMIX QUEUE	.22710E-03	66.351	.00000	1.0000	.00000
FAD QUEUE	3.2413	2.3193	.00000	36.000	.00000
FAD DONE QUEUE	.25202	4.7326	.00000	9.0000	.00000
NQ(SAWQ)	.07619	5.4429	.00000	3.0000	.00000
NQ(MACHINEQ)	.64215	3.6250	.00000	14.000	.00000
MACHINE INSP.Q	.00000	--	.00000	.00000	.00000
GRAIN PREP QUEUE	.00933	10.302	.00000	1.0000	.00000
NQ(PINNINGQ)	.00000	--	.00000	.00000	.00000
NQ(CURE2Q)	.00000	--	.00000	.00000	.00000
NQ(CURE2DONE)	.00000	--	.00000	.00000	.00000
NQ(XRAYQ)	.00000	--	.00000	.00000	.00000
NQ(BASTEQ)	.00297	18.327	.00000	1.0000	.00000
NQ(BAGQ)	.00000	--	.00000	.00000	.00000
NQ(CHARGEWEIGHQ)	.00000	--	.00000	.00000	.00000
NQ(MOTORLOADQ)	.00000	--	.00000	.00000	.00000
NQ(SHIPQ)	.00000	--	.00000	.00000	.00000
AGV 1 Time Active	.90185	.32989	.00000	1.0000	1.0000
AGV 2 Time Active	.26415	1.6690	.00000	1.0000	.00000
AGV 3 Time Active	.91039	.31373	.00000	1.0000	1.0000
AGV Actual Busy	.41421	.16169	.00000	.60000	.40000
RECEIVING STATION	.17456	2.1745	.00000	1.0000	.00000
NITROCOTTON STATION	.12456	2.6511	.00000	1.0000	.00000
WRINGER STATION	.04974	4.3707	.00000	1.0000	.00000
DEHYS	.04975	4.3706	.00000	1.0000	.00000
BLOCKBREAKS	.04995	4.3612	.00000	1.0000	.00000
WEIGHS	.06246	3.8744	.00000	1.0000	.00000
PREMIX STATION	.04952	4.3809	.00000	1.0000	.00000
FINAL MIX STATION	.08750	3.2293	.00000	1.0000	.00000
BLOCKERS	.08750	3.2293	.00000	1.0000	.00000
PRESS AND BOARD	.08830	3.2133	.00000	1.0000	.00000
FAD BAY	.00353	16.793	.00000	1.0000	.00000
SAW STATION	.05079	4.3229	.00000	1.0000	.00000
SAW INSPECTION	.00000	--	.00000	.00000	.00000
MACHINING STATION	.09725	3.0468	.00000	1.0000	.00000
MACHINING	.01215	9.0159	.00000	1.0000	.00000
GRAIN PREP	.08818	3.2156	.00000	1.0000	.00000
PINNING STATION	.02236	6.6117	.00000	1.0000	.00000

CURING BAY	.02222	6.6333	.00000	1.0000	.00000
KRAY STATION	.02225	6.6294	.00000	1.0000	.00000
TURKEYBASTING	.06963	3.6553	.00000	1.0000	.00000
BAGGING STATION	.02609	6.1100	.00000	1.0000	.00000
CHRG WEIGHING	.01732	7.5314	.00000	1.0000	.00000
MOTOR LOADING	.01755	7.4822	.00000	1.0000	.00000
SHIPPING	.01736	7.5238	.00000	1.0000	.00000
BURNING GROUNDS	.00764	11.398	.00000	1.0000	.00000

COUNTERS

Identifier	Count	Limit
WRINGER	36	Infinite
DEHY	36	Infinite
PREMIX	36	Infinite
FINALMIX	63	Infinite
FINAL_PRESS	36	Infinite
REMIX	27	Infinite
FADDONE	9	Infinite
GOSIG	9	Infinite
NOSIG	27	Infinite
SCRAP1	11	Infinite
SAWED	36	Infinite
MACHINE	35	Infinite
CURE	32	Infinite
INSERTPIN	32	Infinite
CURE2	32	Infinite
KRAY	32	Infinite
TURKEYBASTE	25	Infinite
SHIP	25	Infinite
STAGED	576	Infinite

VITA

Dan A. Cremer was born on May 9, 1960 in Saigon, South Vietnam. He immigrated to the United States when he was nine years old. He attended Clarkson University, Potsdam, New York and received his Bachelors of Science degree with a major in Industrial Distribution in May of 1982.

After graduation, he worked for Texas Instruments for two years as a Manufacturing Engineer for the F4 Radar Display Program. Then he worked for Simmonds Precision for three years as the Manufacturing Engineer for the B1B Fuel Management System. For the last five years he has been working at the Radford Army Ammunition Plant as a Quality Engineer.

Mr. Cremer began his graduate work in Industrial and Systems Engineering at Virginia Polytechnic Institute and State University in January of 1991. He plans to start a career with Michelin Corporation February of 1993.